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CROP SCIENCE

Influence Of Hulling And Storage Conditions On Maintaining Coffee Quality

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Abstract: Storage is important in the coffee post-harvest. Determining the maximum period that coffee can remain storaged is important aiming to reduce losses in quality and, consequently, allow the producer to achieve maximum profitability. The aim was to determine the suitable storage period for natural and fully washed coffees, under different conditions. Beans were dried to 11% moisture content after dry processing (natural coffee, dry cherry coffee) and wet processing (parchment coffee, fully washed). Before storage, part of the coffee was hulled and part was not. The coffee was stored under refrigerated air (10ºC and 50% relative humidity) or in an environment at 25ºC. In the periods of 0, 3, 6, and 12 months, samples were taken for sensory, electrical conductivity and tetrazolium evaluation. Refrigerated environment favors conservation of sensory and physiological quality of the natural hulled coffee beans and fully washed coffee. Hulled beans of natural and fully washed coffee stored under refrigerated conditions have the initial quality conserved for up to 12 months and in non-controlled environmental, for up to 3 months. Mechanical damage caused by hulling, associated with the lack of tissue fruit parts, contributes to reduction hulled coffee quality in storage, regardless of the processing.

Key words: *Coffea arabica* L., deterioration, mechanical damage, sensory analysis.

INTRODUCTION

In the coffee production process, there are two periods in which the coffee is stored. The first is after drying, for it is recommended that the product remain in a resting period in the dry cherry form or as parchment coffee for at least 30 days. In this period, the coffee is stored in a storage barn or shed on the farm property. Then, the coffee is hulled, after which it may be taken to cooperatives or to a general storehouse where it is stored in a conventional system without control of ambient conditions and placed in jute bags or “big-bags”, both of which are permeable. The storage of unroasted/green coffee beans placed in permeable packaging allows interaction of moisture content of the beans with ambient air, which may lead to greater reduction in initial quality (Borém et al. 2008, 2013, Nobre et al. 2007, Ribeiro et al. 2011, Rigueira et al. 2009). Another possibility is directing the hulled coffee lots to the domestic or foreign consumer market. In both cases, the time of coffee bean transport is considered a storage period, in which the coffee is subject to deterioration.

The dry cherry coffee and the parchment coffee are hulled before being stored in the cooperatives and storehouses or directed to the consumer market. The aim of the hulling operation is to reduce the amount of product transported, reducing freight costs and increasing the static capacity of storehouses, due to the greater amount of green coffee beans stored per volume of the storehouse. However, after coffee is hulled, there may be a more accelerated reduction in product quality, probably as a result of mechanical damages that the hulling machines cause to the endosperms of the coffee beans (Clemente et al. 2015).

In addition, the presence of the husk (exocarp) on the dry cherry coffee or the parchment (endocarp) on the fully washed coffee is important for conservation of sensory quality, as noted by Rendón et al. 2014, Selmar et al. 2008. These authors reported a direct relationship between loss of coffee bean viability and a decline in sensory quality. Rendón et al. (2014) observed in their study that after hulling of coffee, performed at 3 months of storage, coffee bean viability decreased rapidly up to total loss in the ninth month, together with a decline in sensory quality. Selmar et al. (2008) found total loss of viability of hulled coffee seeds after 6 months of storage. In that study, the parchment coffees remained viable for 12 months.

In spite of these results, it is not clear in the literature if the reduction in the quality of hulled coffee is caused by the absence of husk or parchment, which protect the endosperm against oxidations of organic compounds, or because of the mechanical damages caused to the endosperm by hulling equipment. It is known that mechanical damages in coffee beans during the production process are perceived in storage after a certain period of time (Neves et al. 2016, Pinto et al. 2012).

Reduction in quality caused by hulling of coffee, associated with effects of storage conditions in a conventional system, i.e., a system without control of temperature and relative humidity, intensify even more deterioration of coffee beans. With a view toward ensuring a longer period of conservation of quality, especially for specialty coffees, the use of packaging with a high barrier to exchanges of water vapor and gases for green coffee beans have been investigated (Borém et al. 2013, Ribeiro et al. 2011). However, in spite of advances in this area, there is no commercial package able to maintain the initial quality of the coffee beans and, in practice, most coffee beans are kept in permeable packaging.

The technique of refrigeration for conservation of foods is used mainly in the post-harvest chain of fruits and vegetables, which are products of higher added value compared to grains and seeds (Silva et al. 2009). However, studies have shown the beneficial effects of refrigeration of ambient air on conservation of the quality of seeds and grains of various species during storage . The technique favors reduction in seed metabolism, controlling progression of the deterioration process and conserving the chemical constituents of the green coffee beans, precursors of coffee flavor and aroma, for a longer time (Abreu et al. 2015 and 2017). Although production of specialty coffees is more labor intensive, they are products with higher sale value compared to commodity coffees, which justifies additional costs for preservation of quality.

In spite of the complexity of the problem and of the importance of the specialty coffee market in the world, there are few studies that evaluate the effects of the form of packing coffee and of the ambient conditions during storage, as well as the interaction of these factors, on conservation of coffee quality either in dry processing or wet processing. Knowing the suitable period of time of storage of coffee beans can lead to benefits in management and control of coffee lots by the coffee grower and other agents of the green coffee bean industry. Thus, it will be possible to determine the maximum time a coffee lot can remain in storage without compromising the initial quality and its market price.

To understand the phenomenon, sensitive analyses associated with traditional evaluation of coffee quality, such as sensory analysis used by the market to evaluate, establish price, and direct the coffee to different markets, are necessary. Physiological analyses are more sensitive than sensory analysis, with potential for identifying changes in quality caused by damage to endosperms even before the sensory quality of the coffee bean is affected (Abreu et al. 2015, 2017, Clemente et al. 2015, Saath et al. 2014, Taveira et al. 2012, Zonta et al. 2009).

In light of the above, the aim of this study was to evaluate conservation of the quality of both dry processed and wet processed coffee, which was stored in dry cherry form or parchment coffee form and hulled form, and then stored under different ambient conditions. An additional aim was to determine the most suitable storage period for each condition that did not lead to reduction in quality compared to the initial quality.

MATERIALS AND METHODS

Obtaining fruit, processing, and hulling

Coffee beans of *Coffea arabica* L. 'Catuaí Amarelo' were used, obtained from production fields of the Fundação Procafé experimental farm, at 940 m AMSL in the municipality of Varginha, MG, Brazil. The coffee fruit was harvested in the cherry maturation stage through selective harvest and then passed through a mechanical coffee washer for separation of floaters, poorly formed fruit, fruit injured by coffee borers, and impurities before passing through either wet processing or dry processing. Part of the selected fruit was immediately dried, obtaining natural coffee, and the other part was mechanically pulped, followed by fermentation of the coffee beans in water for 24 hours before drying, obtaining what is known as "fully washed" coffee.

The coffees were dried to the half way point on polyethylene screens with a 1.00 mm^2 mesh that were mounted on wooden supports in a suspended manner. The coffee was uniformly distributed on the screens and was turned over 12 times a day during the drying period up to the half-dry stage (natural coffee with 30% w.b. and fully washed coffee with 25% w.b.).

At the half-dry stage, the coffees were transferred to fixed bed mechanical dryers. During drying, the temperature of the coffee bean mass was kept at 35°C and constantly monitored by a thermostat at the entry of the drying air and by a mercury thermometer inserted in the coffee mass until the beans reached 11% moisture content (wet basis).

After drying, part of the coffee was mechanically hulled for removal of the exocarp (husk) in natural coffee and removal of the endocarp (parchment) in the fully washed coffee, and the other part was stored in the dry cherry form (for natural coffee) or as parchment coffee (for fully washed coffee). Mechanical hulling was performed in a machine similar to machines used by producers in coffee hulling operations.

Coffee beans were packed in Jutex® polypropylene bags, with permeability similar to jute bags, though manufactured in synthetic fiber, and stored in two environments. The first environment was with refrigerated air in cold dry storage, with a temperature of 10°C and relative humidity of 50%. The second storage location was in an environment with constant temperature of 25°C, without control of relative humidity. Sensory and physiological quality were determined after each storage period of the coffees (0, 3, 6, and 12 months). For evaluation in each storage period, the coffees that were stored in the dry cherry form and as parchment coffee were hulled manually to prevent mechanical damage.

Sensory quality

Sensory quality of the coffees was evaluated through sensory analysis carried out by cuppers certified by the Specialty Coffee Association (SCA) through the use of the SCA protocol, according to the methodology proposed by Lingle (2011) for sensory evaluation of specialty coffees. In this method, scores are attributed for fragrance/aroma, acidity, body, flavor, aftertaste, sweetness, uniformity, clean cup, balance, and overall impression.

A quantity of 100 g of coffee beans of at least grade 16 sieve size were roasted moderately lightly, and temperature was monitored so that roasting time was not less than 8 minutes or greater than 12 minutes. To standardize the roasting and keep it from influencing evaluation by the cuppers, a standard sample of roasting from the first period was used in the other periods of evaluation. Al the samples were roasted at least 12 hours prior to cupping. The final results of sensory evaluation were composed of the sum of all the sensory attributes.

In each storage period, roasted samples of the best coffees from each treatment were placed in Falcon tubes and stored in a deep freezer (-80°C). These samples were cupped at the times of the following evaluations for the cuppers to be able to recover the sensory experience regarding the previous evaluation.

Physiological quality

The physiological quality of the coffee was evaluated by the electrical conductivity and tetrazolium tests. For the electrical conductivity test, an adapted method proposed by Malta et al. (2005) was carried out. The result of electrical conductivity was expressed in $\mu S.cm^{-1}.g^{-1}$ of coffee beans.

The tetrazolium test was performed with four replications of 25 coffee beans placed in containers with distilled water for soaking for a period of 48 hours at 30°C (Clemente et al. 2011). After this period, the embryos were removed from the coffee beans with the aid of a scalpel to avoid damaging them. The embryos were stained in 0.5% tetrazolium solution in the absence of light for a period of 3 hours at 30ºC. After evaluation of viability, the results were expressed in percentage of viable embryos.

Experimental design and statistical analysis

Statistical analysis was carried out separately for natural coffee and for fully washed coffee. A completely randomized experimental design was used in each study in a 2 x 2 x 4 factorial arrangement, with three replications, consisting of two forms of the coffee bean in storage [hulled or non-hulled coffee (parchment coffee or dry cherry coffee), two conditions of the air in the storage environment (10°C and 50% RH, and 25°C without control of RH), and four storage periods (0, 3, 6, and 12 months).

In each type of coffee processing (natural and fully washed), analysis of variance was used on the data, as well as the Scott-Knott test of mean comparison at the level of 5% probability. Analysis of regression was performed to study storage time. Statistical analyses were conducted with the assistance of the statistical program SISVAR (Ferreira 2014).

RESULTS AND DISCUSSION

Results for natural coffee

Sensory analysis

No significant effect was found for interaction among the factors of form of the coffee bean in storage, ambient air conditions, and storage period on the sensory quality of natural coffee. The form of the coffee bean in storage (dry cherry or hulled coffee) influenced the sensory quality of the natural coffee, as can be seen in Table I.

Coffee under natural processing and stored in dry cherry form better preserved its sensory characteristics compared to coffee stored in hulled form. The protective effect of the remaining parts of the fruit tissue (pericarp) probably contributed to improved quality. In addition, the hulled coffee passed through a mechanical huller at the beginning of storage, which may have contributed to lower quality because of mechanical damage caused to the endosperms of the coffee beans. For affirmations with a greater degree of confidence, information from more sensitive analyses are necessary, such as the physiological evaluations soon to be presented.

Wet processed coffees and dry processed coffees have distinct sensory characteristics. Natural coffees give rise to fuller bodied, sweeter, and lower acidity beverages, which is an essential ingredient for expresso coffee blends. The literature includes studies that associate wet processed coffees with superior beverages, compared to dry processed coffees (Borém et al. 2008). Nevertheless, the lower quality observed in natural coffees is often related to a lack of care during the steps of harvest, processing, and drying.

According to the data in in Table II and Figure 1, there was interaction between the ambient air conditions and storage period factors regarding the sensory quality of natural coffee.

The environment cooled to 10°C and relative humidity of 50% provided for better conservation of the sensory quality of natural coffee under storage. These results corroborate the results of other studies that showed that cooling of ambient air to below 15°C is beneficial for preservation of coffee bean quality, lengthening the possible storage period and reducing the speed of deterioration (Rigueira et al. 2009, Rosa et al. 2013). Rigueira et al. (2009) observed better conservation of the initial quality characteristics of the coffee beans stored at 15°C compared to coffee beans stored at 25°C. Rosa et al. (2013) found that cooling of the air is an effective method for prolonging the period of coffee bean conservation and preservation of the initial quality characteristics.

Table I. **Result of sensory analysis of natural coffee stored as dry cherry coffee or hulled coffee.**

Coffee storage	Sensory analysis (Final Score)
Dry cherry coffee	79.65 a
Hulled coffee	78.70 b

Mean values followed by the same lowercase letter in the column do not differ from each other by the Scott-Knott test at 5% probability.

Table II. **Result of sensory analysis of natural coffee stored under refrigerated and non-refrigerated conditions for 12 months.**

Storage period (months)	Ambient air conditions	
	Refrigerated air (10°C; 50% RH)	Non-refrigerated air (25°C, RH not controlled)
0	81.08 Aa	80.54 Aa
3	80.54 Aa	80.46 Aa
6	79.77 Aa	76.16 Bb
12	79.73 Aa	75.14 Bb

Mean values followed by the same uppercase letter in the row and lowercase letter in the column do not differ from each other by the Scott-Knott test at 5% probability.

In Brazil, most coffee is stored in conventional storehouses without control of temperature and relative humidity and without refrigeration. Coffee beans are kept in jute bags, allowing variation of the moisture content of the beans and interaction with ambient air, which leads to a decline from initial quality (Borém et al. 2013)

Currently, the use of refrigerated air in storage for conservation of coffee is contested due to the high cost of the technique. However, the specialty coffee market has required more alternatives that preserve the initial qualitative characteristics of the coffee for a longer period of time. In the case of specialty coffees, which have

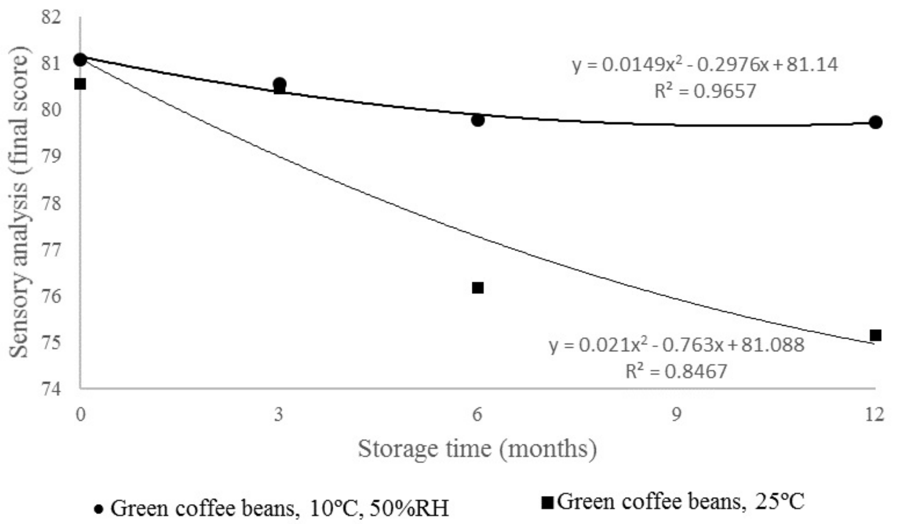

Figure 1. Results of sensory analysis of hulled natural coffee stored in refrigerated air (10°C, 50% RH) and non-refrigerated air (25°C, RH not controlled) for 12 months.

high added value, additional costs are justifiable because this investment is often lower than the cost of depreciation in the value of the coffee due to reduced quality during storage.

In relation to storage in ambient air conditions (25°C and without control of RH), there was greater reduction in coffee quality; at 6 months of storage, sensory quality is lower compared to quality at the beginning of storage. From 6 months of storage on, the natural coffee no longer has specialty coffee classification. Reduction in sensory quality, which led to demotion from the category of specialty coffee, is related to reduction in beverage complexity, with penalties in the attributes of flavor, aroma, acidity, and aftertaste. The main sensory scores used by cuppers to describe natural coffees after 6 months of storage were paper, cardboard, jute, and wood. These characteristics are normally used in the coffee market to describe old coffees.

A hypothesis for the flavors that characterize old coffee perceived by the cuppers is that a large part of the coffee endosperm is constituted of hemicellulose, lignin, and cellulose (Farah 2012). Ambient conditions that provide for greater metabolic activity and greater respiration rate of the coffee bean and the use of permeable packaging in a non-climate-controlled environment lead to greater oxidation of carbohydrates, lipids, and proteins (Andrade 2017, Ribeiro 2013). The organic compounds readily available for respiration of the coffee beans are the carbohydrates of low molecular weight, such as sugars (glucose, fructose, sucrose). These compounds are precursors of the flavor and aroma of the beverage. Without their presence, other disagreeable flavors are perceived, probably precursors of the high molecular weight carbohydrates (hemicellulose, cellulose, and lignin (Andrade 2017). For that reason, the sensory descriptors of old coffee are related to paper and wood.

Physiological quality

To evaluate the physiological quality of the coffees, tests of electrical conductivity of the coffee beans and the tetrazolium test were used. The results of physiological analyses indicate significant interaction among the factors studied (type of coffee processing, ambient air conditions, and storage period). The results of the electrical conductivity and tetrazolium tests of the coffee beans stored in dry cherry form and in hulled form under different conditions of ambient air in storage are shown in Figure 2.

According to the results of the physiological tests of the coffee beans, all the coffees had a reduction in physiological quality during the storage period, shown by the increase in the values of electrical conductivity of the beans and reduction in the percentage of viable embryos. This indicates disorganization of the cell membranes during storage and corroborates the results found in other studies (Nobre et al. 2007, Rigueira et al. 2009, Saath et al. 2012).

The beans with poorly structured and damaged membranes leach a greater amount of solutes and have higher values of electrical conductivity and leaching of potassium (Malta et al. 2005), indicating loss of quality.

Nevertheless, the initial physiological quality and the reduction in this variable during storage were different, in accordance with the factors studied. The physiological quality of the coffee beans at the beginning of storage is lower for the hulled coffee beans compared to the physiological quality of the dry cherry coffee. These results indicate deterioration due to mechanical damage caused by the hulling equipment since the hulled beans that were stored were mechanically pulped, but the dry cherry coffee was hulled manually for determination of quality in each storage period.

During storage, a greater effect of the storage conditions on the physiological quality of the hulled coffee beans is observed compared to the dry cherry coffee. Hulled coffee beans stored under ambient conditions (25°C, without control of relative humidity) have greater reduction in physiological quality. Mechanical damage of coffee beans caused by the hulling machine may have compromised the cell structures of the endosperm at the beginning of storage (0 month period), making the mechanically hulled coffee more susceptible to the effects of ambient air compared to the dry cherry coffee that was manually hulled, leading to a reduction in physiological quality when in the environment without refrigeration. In addition to the mechanical damage brought about by the hulling machine, the absence of protection of the fruit (pericarp) in storage likely contributed to greater sensitivity of the hulled coffee. Other studies have already confirmed the protective effect of parts of the fruit tissues present in unhulled natural coffees in conservation of physical, chemical, and sensory characteristics of coffee (Rendón et al. 2014).

Results for fully washed coffee

Sensory analysis

Just as in natural coffee, no significant effect of the interactions among the factors of form of the coffee bean in storage, characteristics of the ambient air, and period of storage was found on the sensory quality of the fully washed coffee that was stored. Nevertheless, there was interaction between the form of the coffee bean in storage and characteristics of the storage environment (Table III).

The refrigerated air environment ensured conditions for conservation of the quality of fully washed coffee in storage, regardless of the form of the coffee in storage (parchment coffee or hulled coffee). These results emphasize the beneficial effect of refrigeration of the ambient air on conservation of coffee beans (Abreu et al. 2015, 2017, Rigueira et al. 2009). Under non-controllled ambient conditions, the hulled fully washed coffee has lower quality compared to the parchment coffee.

Conservation of the quality of parchment coffee is not affected by conditions of the air in the storage environment. However, hulled coffee has a reduction in quality in the environment

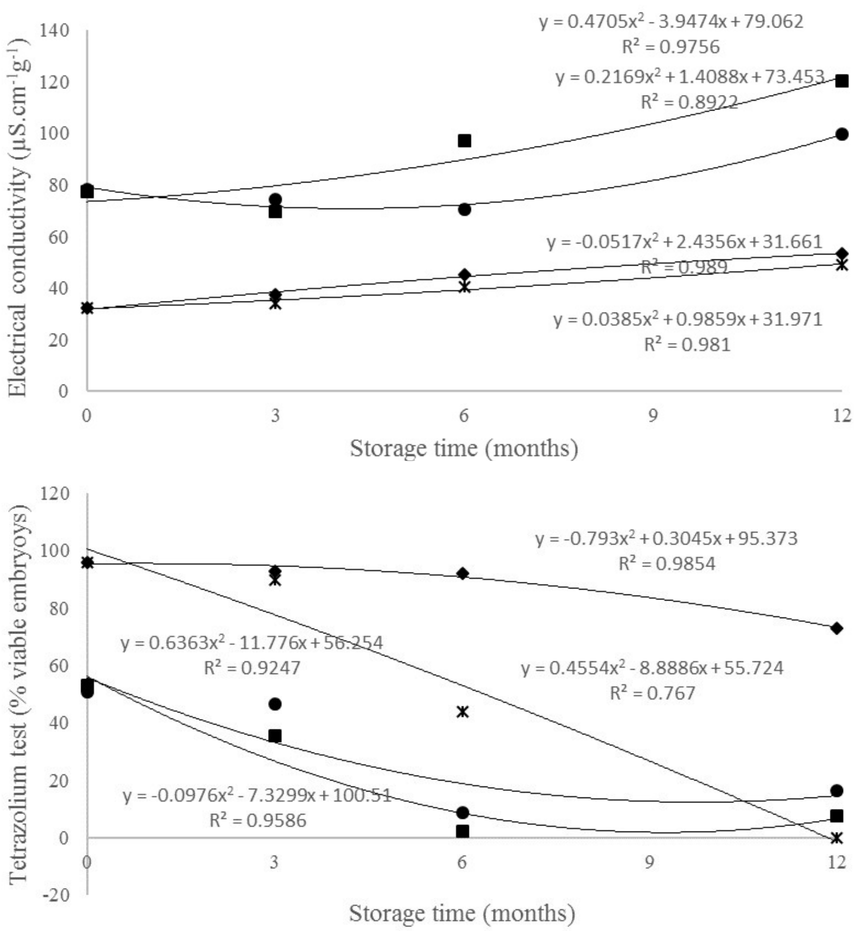

Figure 2. **Results of the physiological tests of electrical conductivity (a) and viable embryos in the tetrazolium test (b) of unhulled natural coffee (dry cherry coffee) and hulled coffee, stored in refrigerated air (10°C, 50% RH) and non-refrigerated air (25°C, without control of RH) for 12 months.**

Table III. **Result of sensory analysis of fully washed coffee stored as parchment coffee or hulled coffee under refrigerated condition (10°C, 50% RH) and non-refrigerated condition (25°C, without control of RH).**

Form of coffee bean in storage	Characteristic of the storage environment	
	Refrigerated air (10°C; 50% RH)	Non-refrigerated air (25°C, without control of RH)
Parchment coffee	79.53 Aa	79.58 Aa
Hulled coffee	79.18 Aa	77.31 Bb

Mean values followed by the same uppercase letter in the row and lowercase letter in the column do not differ from each other by the Scott-Knott test at 5% probability

with a temperature of 25°C, compared to the refrigerated environment. This indicates that the characteristics of the ambient air in storage have a greater effect on hulled fully washed coffee compared to parchment coffee.

Just as discussed above for natural coffee, the mechanical damage caused by the hulling equipment, associated with the lack of protection offered by parts of the fruit tissue, may have contributed to greater sensitivity of the hulled coffee under non-refrigerated conditions, as shown by the final score of sensory analysis.

The results expressed in Table IV and Figure 3 show a significant effect between the characteristics of the storage environment and the storage period on the sensory quality of

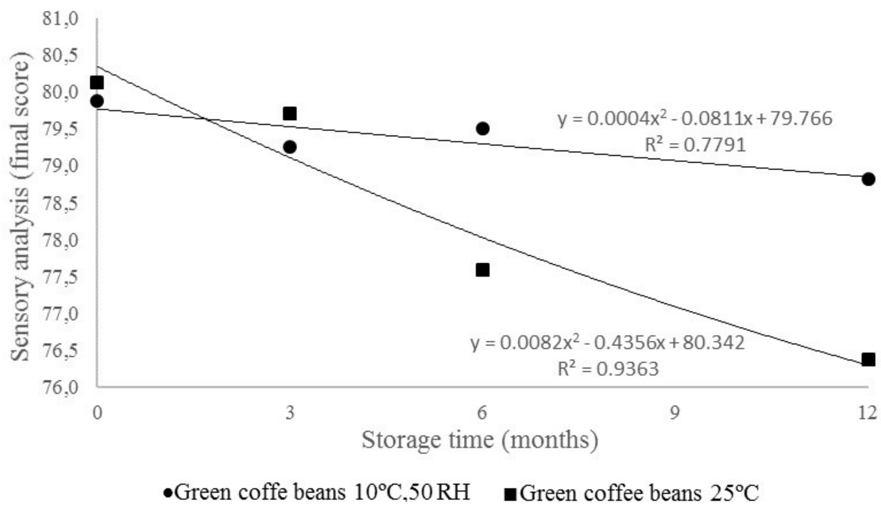

Figure 3. Results of sensory analysis of fully washed coffee stored under refrigerated (10° C, 50% RH) and non-refrigerated (25° C, without control of RH) conditions for 12 months.

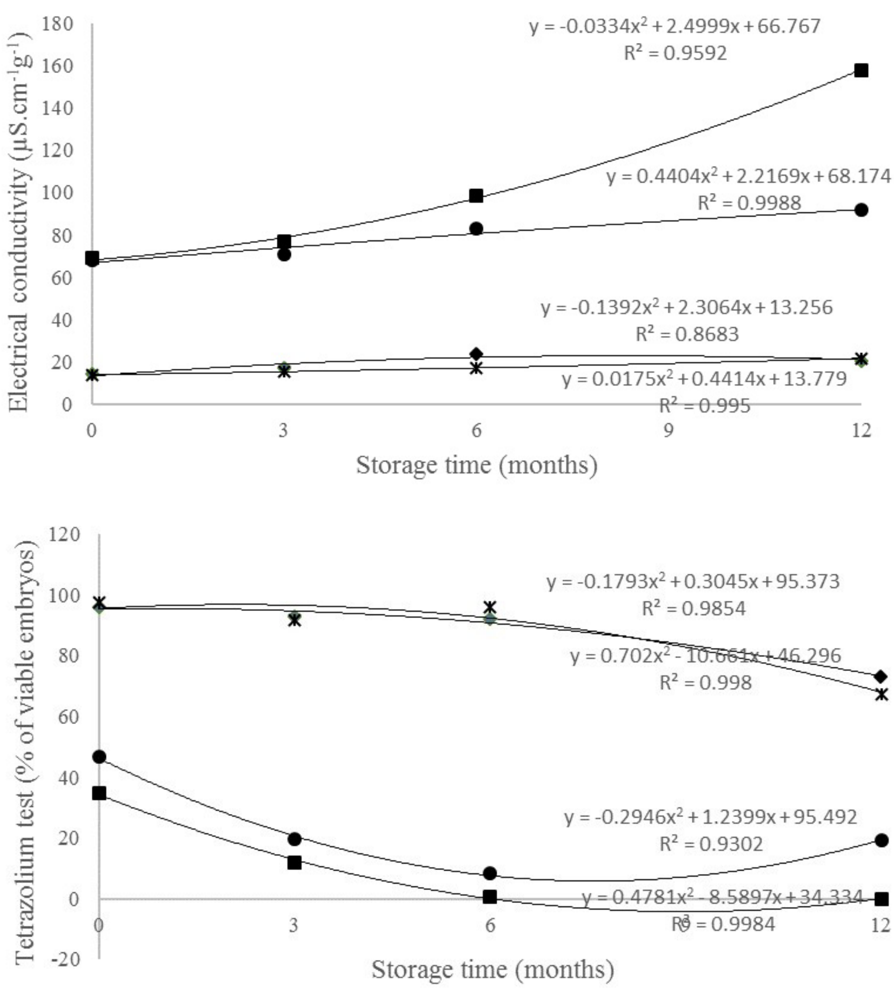

Figure 4. Results of physiological tests of electrical conductivity (a) and viable embryos by the tetrazolium test (b) of fully washed coffee beans stored as parchment coffee or hulled coffee under refrigerated (10° C, 50% RH) and non-refrigerated (25° C, without control of RN) conditions for 12 months.

Table IV. Result of sensory analysis of the fully washed coffee stored under refrigerated and non-refrigerated conditions for 12 months.

Storage period (months)	Ambient air conditions	
	Refrigerated air (10°C; 50% RH)	Non-refrigerated air (25°C, without control of RH)
0	79.87 Aa	80.12 Aa
3	79.25 Aa	79.71 Aa
6	79.50 Aa	77.58 Bb
12	78.81 Aa	76.38 Bb

Mean values followed by the same uppercase letter in the row and lowercase letter in the column do not differ from each other by the Scott-Knott test at 5% probability.

fully washed coffee. In relation to storage under ambient conditions (25°C, without control of RH), there was reduction in the quality of fully washed coffee, just as observed for natural coffee; at 6 months of storage, the sensory quality is lower compared to the quality at the beginning of storage.

Physiological analyses

There was significant interaction among the factors studied of form of the coffee bean in storage, characteristics of the storage environment, and storage period, both for results of electrical conductivity of the coffee beans and for the tetrazolium test. The results of the electrical conductivity and tetrazolium tests of the fully washed coffee beans stored as parchment coffee and hulled coffee are shown in Figure 4.

The results of the physiological tests of the fully washed coffee are similar to the results of natural coffee. Thus, as already discussed above, the physiological quality of the coffee at the beginning of storage is lower in hulled coffee beans compared to the physiological quality of parchment coffee. During storage, a greater effect of storage conditions on the hulled coffee bean is observed compared to the parchment coffee. Hulled coffee beans stored in an environment at 25°C and without control of relative humidity have a higher rate of reduction in physiological quality.

These results confirm the deterioration arising from mechanical damage to the endosperm of mechanically hulled coffee beans caused by the hulling equipment, associated with the lack of protection from parts of the fruit tissue during storage.

CONCLUSIONS

The refrigerated environment (10°C, 50% RH) favors maintenance of sensory and physiological quality of coffee beans, both natural and fully washed, stored in hulled form for up to 12 months.

Natural and fully washed coffee beans stored in hulled form and in an environment without refrigeration have initial quality preserved for up to 3 months.

The association between mechanical damage caused by hulling equipment, associated with the lack of parts of the fruit tissue in natural coffee and of the parchment in fully washed coffee, contributes to reduction in hulled coffee quality during storage.

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GFA performed the experiment and wrote the manuscript; SDVFR coordinated and supervised the experimente and co-worked the manuscript; SVBC, CCP, TBF and ALV co-worked the experiment; MRM co-worked the statistical analyses; GFA, SDVFR and SVBC reviewed and approved the final version of the work.