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Storage of green coffee in hermetic packaging injected with CO_2

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ABSTRACT

The objective of this study was to evaluate the physical, chemical, and sensory qualities of green coffee beans (*Coffea arabica* L.) during storage in different types of packaging. Coffee was stored from October 2008 to September 2009 in a warehouse of the Agriculture Society Ltda. (SAAG) in Santana da Vargem, southern Minas Gerais State, Brazil. The treatments in the factorial design consisted of two types of packaging (hermetic big bags with the injection of up to 60% CO_2 in a controlled atmosphere; similar bags but without the injection of CO_2 in a modified atmosphere) and three sampling positions in the bags (high, medium, and low). At 3-month intervals during a 12-month period, grains were analyzed to determine their water content, color, electrical conductivity, potassium lixiviation, and content of sugars. Sensory analysis was also conducted at these sampling times. The storage of green coffee beans in hermetic big bags on a commercial scale under modified and controlled atmospheric conditions is viable over a 12-month period. The coffee packed in big bags maintained its quality and exhibited an intensification of the green coloration of the grains during storage. Sensory analysis of coffee beans stored in a controlled atmosphere showed that the medium sampling position yielded the best ratings. The results of this analysis demonstrated that this storage technique can potentially increase the effectiveness of methods used to preserve the sensory quality of coffee beans.

1. Introduction

Coffee is an agricultural product with a quality-based price. The value of coffee increases significantly with improvements in quality, which are necessary to obtain new markets. During roasting, the taste and aroma of coffee develop from ingredients originally present in raw beans. Taste and aroma are the principal factors affecting beverage quality. The presence and development of the taste and aroma precursors in raw coffee beans depend on genetic, environmental, and technological factors (Alpizar and Bertrand, 2004; Farah et al., 2006). Sensory analysis of coffee is subjective, however various research projects are being conducted to relate coffee's sensory characteristics with its chemical and physiochemical properties to complement and assist the interpretation of results obtained through the sensory analysis (Nobre et al., 2007; Reinato et al., 2007; Coradi et al., 2008; Marques et al., 2008).

According to Jham et al. (2008) lipids are known to play an important role in the quality of several crops such as soybeans, cacao, nuts, etc. Despite speculation of involvement of lipids (TAGs) in coffee quality, found no evidence to support this in relation to storage time.The preservation of the desirable sensory attributes of coffee essentially depends on the storage of the product. Storage is one of the stages following production that strongly influences the commercialization of coffee beans. Storage is therefore considered one of the most important factors for maintaining final product quality, meeting between-harvest demand, and securing the best market price for the producer.

Traditionally, green coffee beans have been stored in jute sacks. Jute is most frequently used because it is readily adaptable to small-scale commerce and because it is easily sampled for lot inspections. Elevated operational costs that result from the need for manual handling represent one disadvantage of storage in jute sacks. Another disadvantage is rapid deterioration in quality when the beans are stored in warehouses without ambient air control. Containers called "big bags" represent another form of storage used in Brazilian warehouses. The ease of mechanized handling, along with operational economies of scale, represent the principal

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advantages offered by this method of storage. However, big bags, like jute sacks, have the disadvantage of being permeable to water vapor and to gases present in ambient air (Borém et al., 2008a).

One of the challenges facing coffee bean exportation is maritime transport over long distances for prolonged periods. Such transport poses a challenge because the quality of the product is degraded by the time the beans arrive at their destination (Harris and Miller, 2008). During shipping, prolonged storage under inadequate conditions in traditional jute sacks exposes beans to potentially harmful variations in ambient conditions, including fluctuations in temperature and relative humidity. Volatile chemical products that are near the coffee containers during shipping may also alter the quality of the coffee, primarily by affecting the color and the organoleptic properties of the beans. Borém et al. (2008b) and Nobre et al. (2007) have stated that storage in hermetically sealed systems that permit atmospheric modification or control represents a viable alternative for preserving coffee bean quality. Certain additional costs are acceptable for the preservation of quality in select coffees of higher value. Plastic sacks impermeable to CO_2 have recently entered the market in response to the growing demand for new methods of storage for coffee beans. These bags, sold under the name GrainPro, are used to line jute sacks in which green coffee is stored (Trubey et al., 2005).Some Brazilian companies working in the production and exportation of coffee are already using vacuum bagging successfully for the preservation of coffee bean quality. However, because of its elevated cost, this method has not been viable for many producers (Borém et al., 2008b).

Better understanding of storage factors and the advent of new forms of bagging permit extension of coffee storage times. These developments are of immense importance for preserving product quality. Preservation of product quality over longer periods of storage secures a longer sales period for growers and guarantees better prices. To achieve these goals, the present study proposes and evaluates a new storage system that preserves the physical, chemical, and sensory qualities of stored green coffee beans on a commercial scale using hermetic big bags under modified atmospheric conditions and using hermetic big bags into which CO_2 is injected to produce a controlled atmosphere.

2. Materials and methods

2.1. Sample preparation and experimental procedures

The experiment was conducted in a warehouse of the Agriculture Society Ltda. (SAAG) in Santana da Vargem, southern Minas Gerais State, Brazil. The coffee used in the experiment was obtained from a lot taken from the 2008 (*Coffea arabica* L.) crop and passed through 17 and 18 screens. The beverage made from this lot had a minimum score of 80 points, classifying it as good-quality coffee on the Specialty Coffee Association of America (SCAA) scale.

Coffee was bagged in 60-kg quantities in conventional jute sacks and in hermetic plastic sacks (GrainPro). Coffee was also bagged in 840-kg quantities in big bags. The hermetic big bags were constructed of the same material used in commercial silo bags. The big bags, consisting of two layers of high-density polyethylene and a layer of PVC, were constructed according to the specifications of patent PI 0903676-8 filed with the INPI (National Institute of Industrial Protection). A bag with this structure is impermeable to water and gases including carbon dioxide (CO_2), oxygen (O_2), and nitrogen (N_2). Bags measuring 1.0 m $\times$ 1.10 m $\times$ 1.30 m were fitted with an interior system of valves for the injection, distribution, monitoring, and repositioning of CO_2. An exterior nylon wrap placed over the hermetic big bags made them resistant to mechanical stress. Thus, the bags were protected both from atmospheric influences and from mechanical damage.

CO_2 was injected into the bottoms of the big bags. The injected gas progressively displaced the intergranular air until the CO_2 reached the desired 60% level. The level of CO_2 was measured using an Anagas-CD98 instrument. CO_2 concentrations in the containers were monitored biweekly. We reintroduced gas when a reduction below the desired level was detected. This procedure served to maintain a constant concentration of CO_2 inside the bags.Ambient temperature and humidity levels were recorded daily using a thermohygrograph located inside the warehouse near the experimental area.

2.2. Analytical procedures

The coffee samples were randomly collected using a grain sampler in the jute sacks and GrainPro. However, in the hermetic big bags, the sampling was done at three depths: 0.30 m (high), 0.60 m (medium) and 1.00 m (low). For all package, 500 g of coffee beans were collected at 3-months intervals at 0, 3, 6, 9 and 12 months of storage. The samples were analyzed to determine water content, color, electrical conductivity, potassium lixiviation, and content of sugars. Sensory analysis was also performed at these sampling times. The analyses were performed at the Laboratory of Storage and Processing of Agricultural Products, Department of Engineering, Universidade Federal de Lavras.

All analyses were made using bean samples passed through 17 and 18 screens to guarantee uniformity during roasting. Besides, defective beans like poorly formed, badly filled, unripe, shell, shell-crumb, broken beans and insect-bored were discarded to avoid external effects that might interfere with the treatments used. In this study, only the insect-bored beans by *Hypothenemus hampei*, an insect borer from the field (Jaramillo et al., 2006), were removed.

Water content was determined by oven-heating at 105 °C $\pm$ 1 °C for 16 h $\pm$ 0.50 h, according to the standard ISO method 6673 (ISO, 2003). Bean color was determined on a Minolta model CR300 colorimeter by direct reading of the coordinates (L), (a), (b) and according to the method described by Nobre (2005). The sugars were extracted by the Lane-Enyon method cited by the AOAC (1990) and determined by means of the Somogy technique adopted by Nelson (1994). The methodology proposed by Vieira et al. (2001) for the determination of electrical conductivity was used for four replications of 50 grains each. The determination of the quantity of potassium ions in the leachate was made using a Digimed NK-2002 photometer. This analysis was performed after the grain had been subjected to imbibition for 5 h at 25 °C, using the methodology recommended by Prete (1992). Sensory analysis was done by cupping judges certified by Specialty Coffee Association of America (SCAA), according methodology proposed by Lingle (2011). In this evaluation, grades on a scale of zero to ten were awarded for the following attributes: aroma, uniformity, clean cup, sweetness, flavor, acidity, body, aftertast, balance and overall. The grains were roasted in a Probat roaster, model “Probatino”, having a capacity of 150 g.

2.3. Statistical analysis

The experiment used a completely randomized design with three replications in parcels subdivided by time (0, 3, 6, 9 and 12 months). A 2 $\times$ 3 factorial design was used. In this design, the factors were the two packaging methods (hermetic big bags with and without the CO_2 injection) and the three sampling positions (high (0.30 m), medium (0.60 m) and low (1.00 m)). In addition to the treatments included in the factorial design, two additional treatments were used: storage in GrainPro sacks and conventional

Table 1
Analysis of variance for both experiments.

Source of variation	DF
Packing (Pa)	1
Position (Po)	2
Pa × Po	2
Factorial × Additional	1
Time (T)	4
Pa × T	4
Po × T	8
Pa × Po × T	8
(Factorial × Additional) × T	4
Error	(104)

storage in jute sacks. Two ANOVAs were conducted for each variable studied, using the factorial scheme (2 × 3) + 1 for each additional treatment (Table 1). If statistically significant differences ($P < 0.05$) were detected by ANOVA, individual comparisons were made using the Tukey test ($P < 0.05$). For the comparison of hermetic big bags with and without CO_2, the F test analysis for variation was sufficient ($P < 0.05$), because this factor has only two levels. Regression analyses were performed to determine the relationship between each quality parameter and the storage time.

3. Results

3.1. Variation in temperature and relative humidity

The coffee beans were stored under natural conditions without any control over ambient air characteristics. In the first 150 days of storage (October 2008 to April 2009), the average ambient temperature oscillated between 22° and 30 °C, and relative humidity ranged from 60% to 85%. During the subsequent period, between 150 and 270 days of storage, the average ambient temperature was less than 20 °C, and relative humidity varied between 60% and 80%. In September 2009, during the last 30 days of the experiment, ambient conditions returned to the values observed at the beginning of storage (Fig. 1).

3.2. Variation in water content

Coffee beans in jute sacks showed an elevated water content until the sixth month of storage. The value of water content increased, on average, between 9.80% and 11.40%. The water content remained in equilibrium with the temperature and the humidity, relative to the ambient air. The water content in the impermeable packaging remained stable at approximately 10% throughout the storage period (Fig. 2).

3.3. Chemical analysis

The increase in the average electrical conductivity of the samples in the hermetic big bags during the entire storage period did not depend on the use of CO_2 (Fig. 3a). After the sixth month of storage, the average values increased significantly in comparison with the initial values. However, the electrical conductivity of the coffee contained in the jute sacks differed significantly from that found in the GrainPro sacks and in the hermetic big bags. The most noticeable differences began to appear during the sixth month of storage (Fig. 3b). At the beginning of storage, the coffee beans in all the treatments exhibited electrical conductivity values of approximately 110 μS $cm^{-1}.g^1$. After 12 months of storage, however, the electrical conductivity of the samples in the impermeable packaging was nearly 160 μS cm^{-1} g^1, whereas it exceeded 220 μS cm^{-1} g^1 in the jute sack samples.

Increased levels of lixiviation were observed in all types of bagging from the third month onwards (Fig. 4). Potassium lixiviation in coffee in hermetic big bags increased independently of CO_2 use and exhibited a quadratic trend during storage. The maximum value of potassium lixiviation was observed at 12 months (Fig. 4a). The highest levels of potassium lixiviation occurred during the final period of the study in coffee stored in jute sacks (Fig. 4b). These

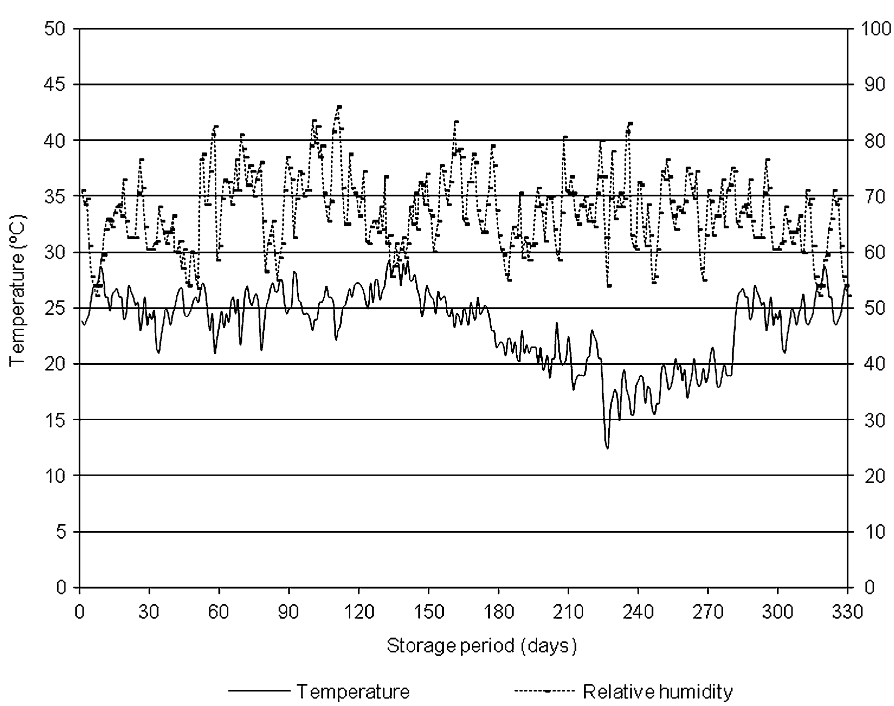

Fig. 1. Average daily temperature and humidity values in the experimental study area of the storage warehouse (October 2008 to September 2009).

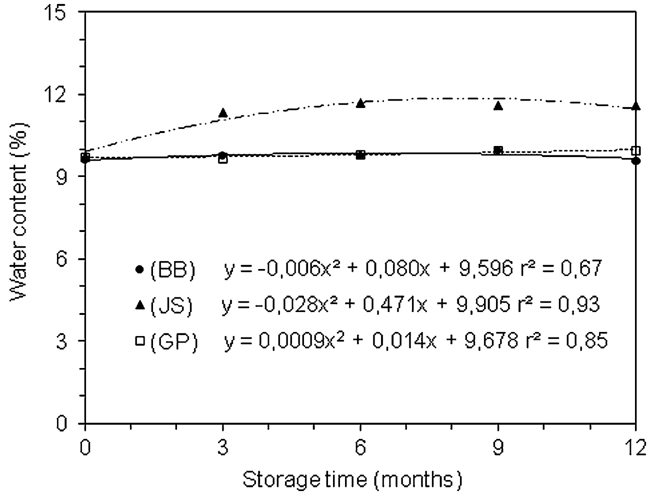

Fig. 2. Average values of water content for storage of green coffee. Experimental treatments: hermetic big bags (BB); controls: jute sacks (JS) and GrainPro (GP).

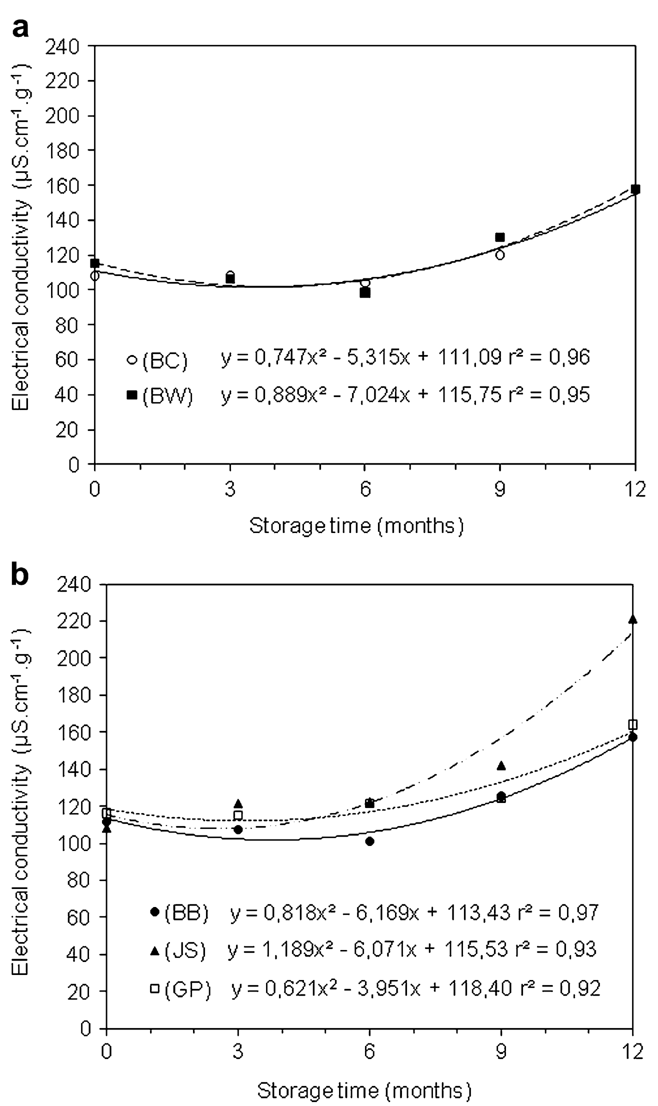

Fig. 3. Average values of electrical conductivity for storage green coffee. Experimental treatments: big bags with injection of up to 60% CO_2 (BC) and without the injection of CO_2 (BW) (a); hermetic big bags (BB), controls: jute sacks (JS) and GrainPro (GP) (b).

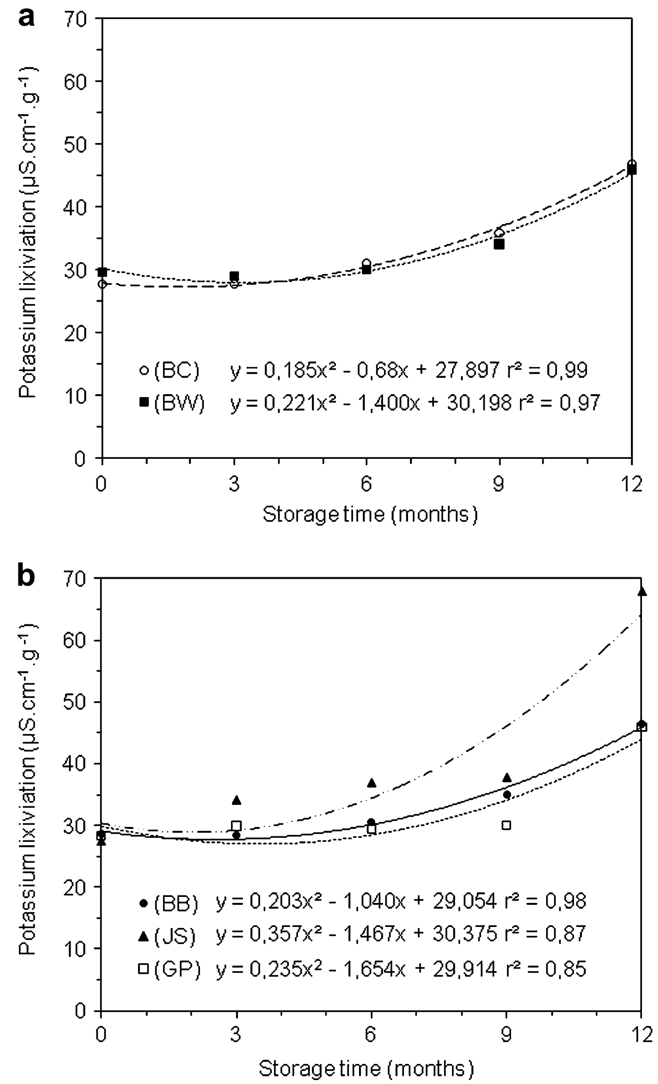

Fig. 4. Average values of potassium lixiviation for storage green coffee. Experimental treatments: big bags with injection of up to 60% CO_2 (BC) and without the injection of CO_2 (BW) (a); hermetic big bags (BB), controls: jute sacks (JS) and GrainPro (GP) (b).

results were similar to the results of the electrical conductivity tests.

The factorial treatments and their interaction with the additional treatments had no significant effect on the levels of total sugars, nonreducing sugars or reducing sugars for the grains stored in hermetic big bags, in jute sacks and in GrainPro. The total sugar and nonreducing sugar levels showed small oscillations over the storage period. However, no associations were found between the increases or decreases in the values of these variables and the storage method (Fig. 5a and b). These values were within the normal range of variation, between 5% and 10% for total sugars (Prete, 1992; Leite et al., 1996; Njoroge, 1987), and between 1.9% and 10% for nonreducing sugars (Abraham, 1992; Tressl et al., 1982). The average levels of reducing sugars decreased gradually and sequentially from the sixth month to the end of storage (Fig. 5c).

3.4. Color analysis

The results of the quantitative evaluation of bean color were expressed in terms of the coordinates (L), (a), and (b). Luminosity (L) did not differ significantly between treatments. Coffee beans

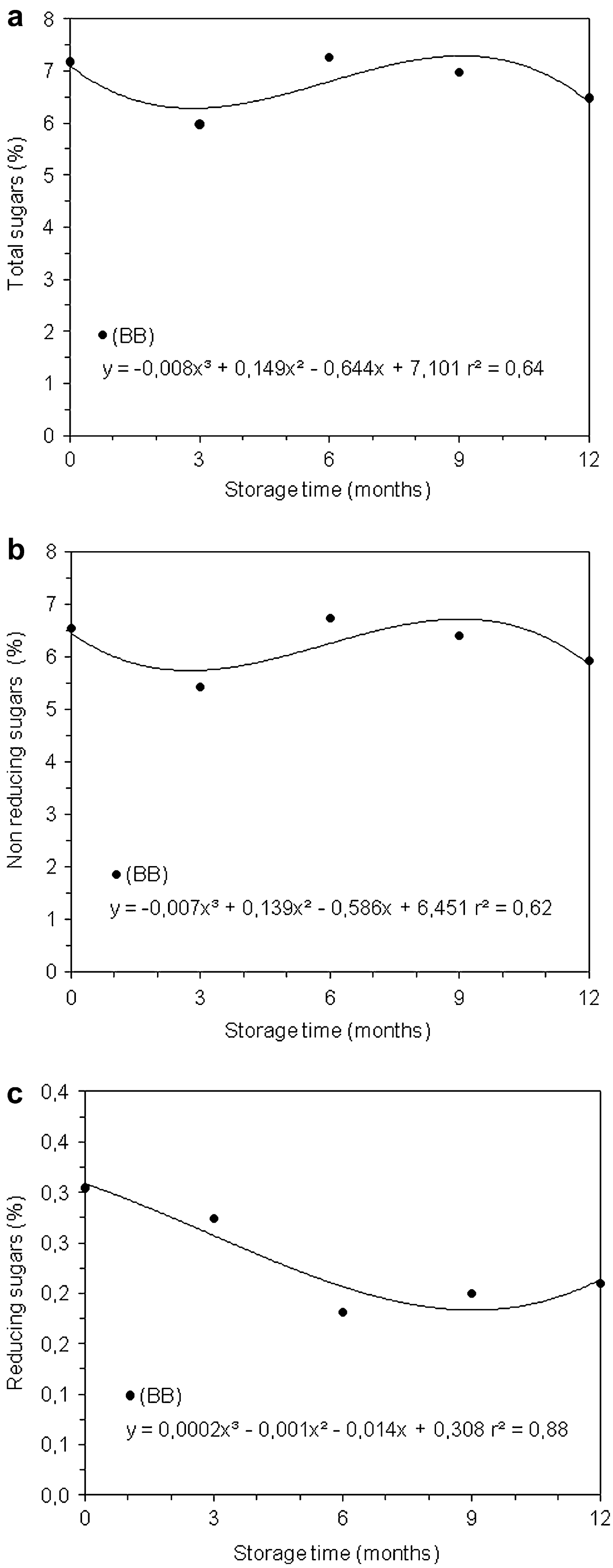

Fig. 5. Average values of total sugars (a), nonreducing sugars (b) and reducing sugars (c) for green coffee storage experiments using hermetic big bags (BB).

packed in big bags showed small color variations during storage (Fig. 6). Beans stored in big bags without CO_2 exhibited a small increase in the value of coordinate (a) at the beginning of storage and, starting in the third month, a reduction in the value of this coordinate that continued throughout the remainder of the storage period. Big bags injected with CO_2 exhibited a downwards linear tendency in the value of coordinate (a) throughout the storage period (Fig. 7). Despite a significant difference ($P < 0.05$) in the initial values of this coordinate between coffee stored with and without CO_2, by 12 months no differences remained between these two conditions (Table 2). The values of coordinate (b) for samples stored in hermetic big bags varied between 12.0 and 13.5 during storage. Samples stored in jute sacks exhibited larger oscillations during this period. In general, beans stored in GrainPro showed a reduction in values during the first six months. This decrease was followed by an increase that continued until the twelfth month (Fig. 8).

3.5. Sensory analysis

The results of the sensory analysis of coffee beans sampled from different positions in big bags injected with CO_2 (Fig. 9a) indicated a significant difference between the middle and lower positions at 12 months of storage (Table 3). At the beginning of storage, sensory note scores for all three positions were above 80 points. According to the SCAA, scores in this range signify very good or “specialty” coffee. After 12 months of storage, only the beans sampled from the middle position continued to score above 80 points. However, the sensory analysis scores for the high and low positions during the 12-month study period were approximately 78 points, a value that indicates good-quality coffee but that is not high enough to signify specialty coffee.

The values of the sensory note scores for coffee stored in big bags without CO_2 exhibited small variations (Fig. 9b). Values for the three different positions varied between 79 and 77 points over the 12-month storage period. After 12 months of storage, these values continued to indicate that the coffee was of good quality (normal coffee). Coffees stored in impermeable packaging exhibited small score variations but maintained their good-quality coffee classification during the storage period (Fig. 10). However, the scores for coffee stored in jute sacks exhibited a linear decrease over the

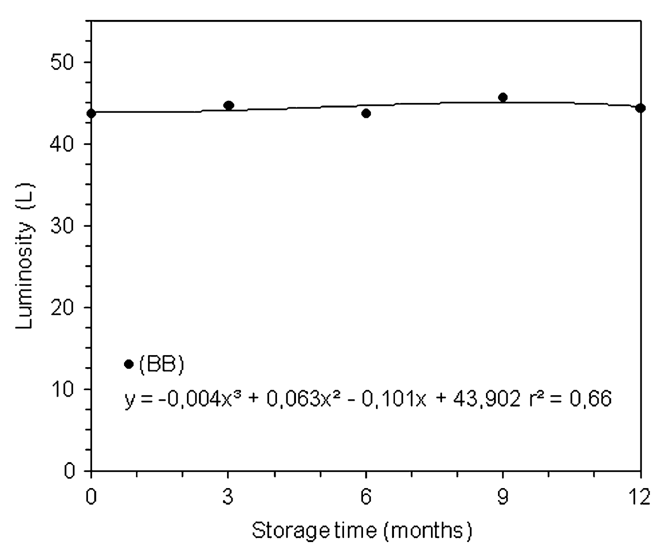

Fig. 6. Average values of luminosity coordinate (L) for green coffee storage experiments using hermetic big bags (BB).

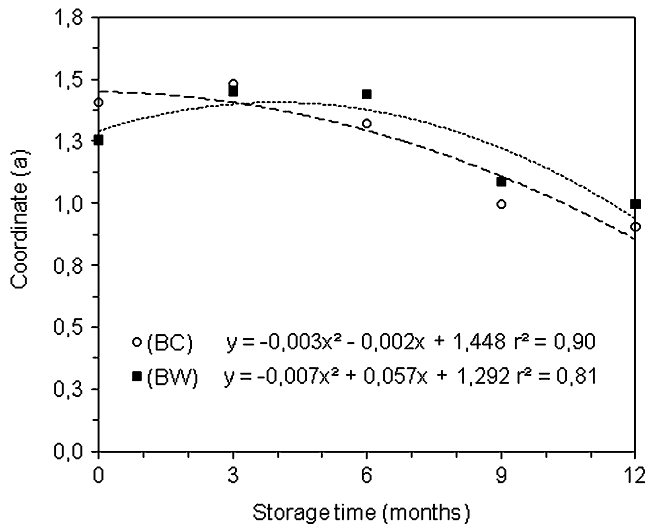

Fig. 7. Average values of coordinate (a) for green coffee storage experiments using hermetic big bags (BB).

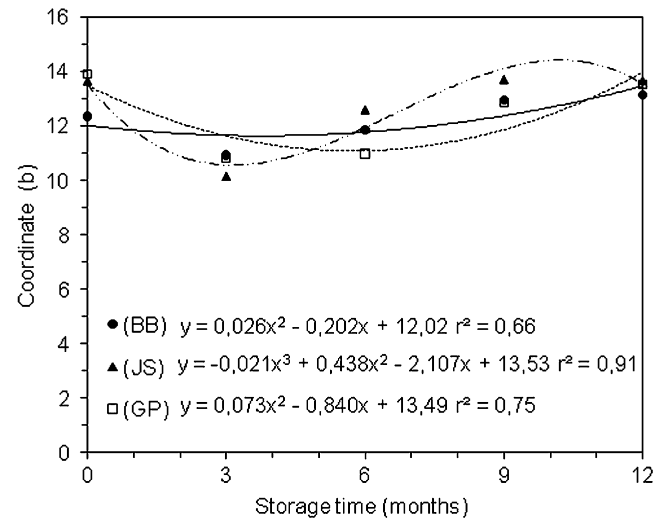

Fig. 8. Average values of coordinate (b) for green coffee storage experiments using hermetic big bags. Experimental treatments: big bags (BB); controls: jute sacks (JS) and GrainPro (GP).

course of storage. From an initial score of 79.5 at zero time, these values fell to 74 points after 12 months of storage. Thus, after 12 months the coffee stored in jute sacks was classified as weak and of medium quality according to SCAA standards.

4. Discussion

According to Harris and Miller (2008) the water content required for secure storage is between 10% and 11%. These authors have verified that coffee beans stored in GrainPro effectively maintained a stable water content level for four months. The results of the present study demonstrate that a stable water content level can be maintained in hermetic big bags or GrainPro for 12 months. An elevation of water content in processed beans in jute sacks can compromise quality. According to Vilela et al. (2000), the increase in water content in the green coffee during storage produces undesirable changes in the physical-chemical composition of the beans.

Tests for the lixiviation of potassium and electrical conductivity indicate possible injury to the cellular membrane system (Prete, 1992). The observed increase in the values of the test results indicates evident cellular membrane disorganization. Such disorganization, accompanied by a subsequent loss of permeability control and by the leakage of solutes, characterizes coffee deterioration and quality loss (Malta et al., 2005). Permeable bagging permits the absorption of water by the beans and results in increased metabolic activity levels. Consequently, higher potassium lixiviation and higher electrical conductivity can be produced (Coelho et al., 2001; Nobre et al., 2007).

Table 2
Coordinate (a) of green coffee stored in hermetic big bags with and without CO_2 and control treatments.

Packaging big bags	Storage time (months)				
	0	3	6	9	12
with CO_2	1.40 ± 0.1a	1.48 ± 0.2a	1.32 ± 0.1a	0.99 ± 0.1a	0.90 ± 0.1a
without CO_2	1.25 ± 0.3b	1.45 ± 0.2a	1.43 ± 0.1a	1.08 ± 0.1a	0.99 ± 0.1a
Control treatments					
Jute sack	1.25 ± 0.2	1.52 ± 0.2	1.30 ± 0.1	1.15 ± 0.1	0.82 ± 0.2
GrainPro	1.30 ± 0.1	1.46 ± 0.3	1.43 ± 0.1	1.23 ± 0.1	0.98 ± 0.1

Values presented as the mean ± standard deviation. Means followed by same letter in same column do not differ significantly (F test, $P < 0.05$).

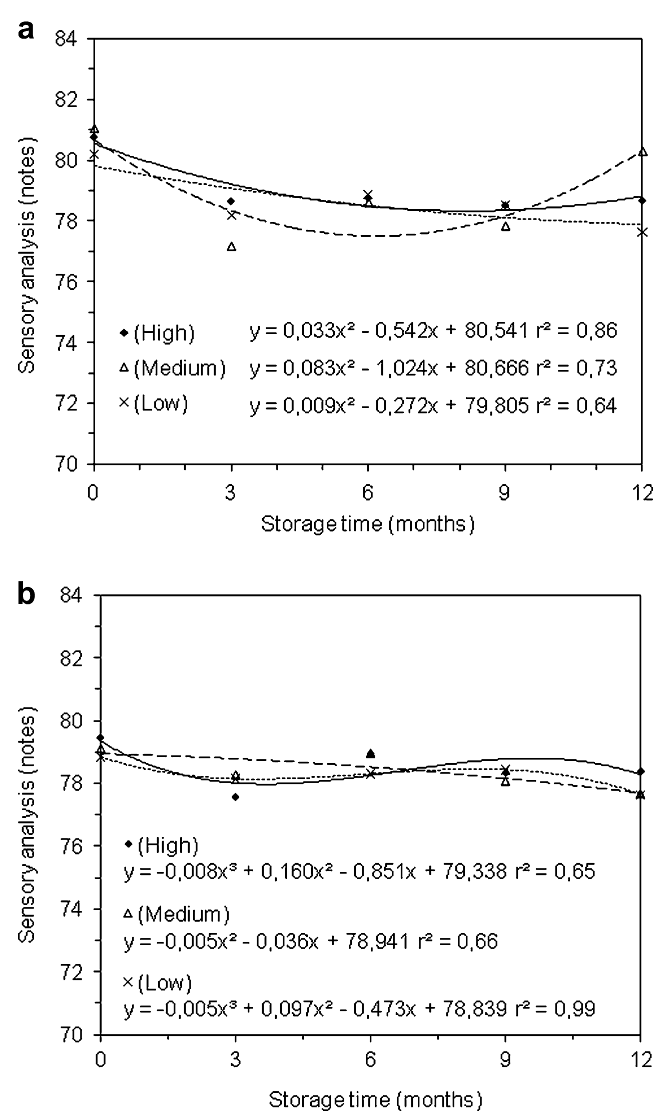

Fig. 9. Average values of sensory analysis notes for green coffee storage in hermetic big bags. Big bags with CO_2 (a) and big bags without CO_2 (b).

Table 3
Sensory analysis of green coffee stored in hermetic big bags with and without CO_2 at different sampling positions of high, medium, low.

Time	Big bags	Position		
		High	Medium	Low
0	with CO_2	80.77 ± 0.7 aA	81.06 ± 0.5 aA	80.19 ± 0.1 aA
	without CO_2	79.45 ± 1.1 aA	79.12 ± 0.4 aA	78.84 ± 0.4 aA
3	with CO_2	78.66 ± 0.4 aA	77.18 ± 0.6 aA	78.18 ± 1.2 aA
	without CO_2	77.56 ± 0.4 aA	78.27 ± 0.5 aA	78.14 ± 0.1 aA
6	with CO_2	78.77 ± 0.3 aA	78.62 ± 0.3 aA	78.87 ± 1.5 aA
	without CO_2	78.93 ± 0.5 aA	78.97 ± 0.7 aA	78.31 ± 1.0 aA
9	with CO_2	78.52 ± 1.4 aA	77.85 ± 1.1 aA	78.52 ± 0.3 aA
	without CO_2	78.33 ± 1.3 aA	78.06 ± 1.2 aA	78.43 ± 0.6 aA
12	with CO_2	78.68 ± 0.5 aA	80.31 ± 1.1 aA	77.62 ± 1.1 aB
	without CO_2	78.38 ± 0.7 aA	77.66 ± 0.4 aA	77.64 ± 1.5 aA

Values presented as the average ± standard deviation. Means followed by same lower-case letter in same column or same upper-case letter in same row, do not differ significantly (Tukey test and F test, respectively, $P < 0.05$).

Results similar to those of this study have been observed by Nobre et al. (2007), who reported lower levels of conductivity in green coffee beans stored in impermeable packaging. Variation in electrical conductivity was similar for samples of coffee stored in hermetic big bags and in GrainPro; however, hermetic big bags offer certain advantages. These advantages include the capacity to store 1.200 kg of beans in one sack and the reduction in operational costs that results from the sack's greater resistance to mechanical stress. This increase in durability facilitates mechanized handling and reduces the use of manual labor in the warehouse.

The level of reducing sugars is directly related to the respiratory activity of the beans during storage. The reduction in sugar levels observed in this study confirms previous results that have explained the effects of elevated electrical conductivity and potassium lixiviation. Lopes et al. (2000) have stated that sugars, amino acids, proteins, and various volatile compounds in roasted coffee are associated with quality. However, according to Selmar et al. (2008), the progressive loss of coffee aroma during prolonged storage can result from viability by the beans, not from changes in sugar levels or amino acid content.

The phenomenon of whitening is understood to occur during the storage of green coffee beans. Whitening is measured by the increase in coordinate (L) (Bacchi, 1962). According to some authors (Godinho et al., 2000; Lopes et al., 2000; Afonso Júnior and Corrêa, 2003; Nobre, 2005), when coffee is stored in the dried pod as "natural coffee", this phenomenon does not occur because the fruit's external covering helps to protect it from possible environmental effects. Storage of coffee beans in their unprocessed form, however, is not a method adopted commercially by cooperatives and warehouses. The reduction in coordinate (a) values found by the present study indicates that storage in hermetic big bags encouraged an increase in the color intensity of green coffee beans over the course of storage. Maintenance or intensification of the green color of coffee beans during storage is extremely important because visual characteristics often determine commercial acceptance. The observed increase in the value of coordinate (b) indicates a loss of bluish color (Afonso Júnior and Corrêa, 2003), undesirable in terms of the quality of the coffee. The variations observed in coordinates (a) and (b) during coffee storage in jute sacks and storage in hermetic big bags indicate that the coffee stored in the big bags exhibited more green color and more bluish color at the end of 12 months. According to Godinho et al. (2000), color change occurs principally because of cell membrane destruction. The study show that coffee stored in jute sacks exhibited the highest solute leakage. The highest loss of blue coloration at the end of the storage period occurred in jute sacks, compared with other treatments. Research conducted with maize grains showed that the hermetic storage prevents deterioration of the grain while maintaining product quality during 150 days of storage (Santos et al., 2010).

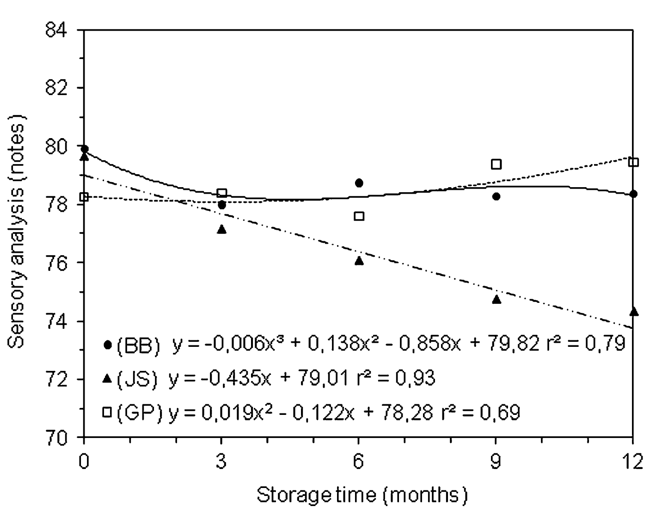

Fig. 10. Average values of final sensory analysis notes for green coffee storage experiments using hermetic big bags. Experimental treatments: big bags (BB); controls: jute sack (JS) and GrainPro (GP).

The results of this experiment agree with the findings of various authors who have described the reduction in sensory quality of coffee stored in jute sacks (Corrêa et al., 2003; Borém et al., 2008b; Rigueira et al., 2009). The present study, however, shows that coffee stored in hermetic big bags and GrainPro preserved its beverage quality for 12 months. Storage in an atmosphere without CO_2 injection is more uniform from the sensory point of view, because no differences were found among the grades of sensory quality measured at high, medium, and low sampling positions. The injection of CO_2 produced differences in the grades found at the three different positions. The highest grades occurred at the medium level. The grades measured at the different positions for coffee stored without CO_2 were lower than the grade found at the medium level in the CO_2-injected bags. Thus, the injection of CO_2 demonstrates potential value for the preservation of sensory quality in coffee. Borém et al. (2008b) have reported similar results in coffee beans stored in impermeable containers on a laboratory scale. The research reported here, however, involved experiments conducted on a commercial scale. The results of these experiments confirm the technical feasibility of the use of hermetically sealed containers such as hermetic big bags to maintain coffee quality over a prolonged storage period. Economic feasibility must be considered in the light of the organization, logistics, and market opportunities of each warehousing facility.

Acknowledgments

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