Postharvest conservation of minimally processed cassava roots subjected to different packaging systems

Conservação pós-colheita de raízes de mandioca minimamente processadas submetidas a diferentes sistemas de embalagem

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Abstract

Cassava (*Manihot esculenta* Crantz) is one of the main energy sources in human food, being largely consumed and produced in Brazil. However, it is not easy to prepare and has a high deterioration degree after harvest. As an alternative, producers and agribusinesses are extensively using vacuum packaging for the storage of minimally processed cassava roots. This study evaluates the postharvest conservation of minimally processed cassava roots packed in 130 µm, 200 µm, and 300 µm LDPE packages with and without vacuum, stored at 3 °C and 90% relative humidity. Samples were evaluated every seven days for a period of 28 days for pH, titratable acidity, soluble solids, SS/TA ratio, texture, fresh weight loss, moisture, dry matter, cooking time, color (L*, a*, b*, increase in browning, chroma, and hue angle), and microbiology (counting mesophilic aerobes, psychrotrophic aerobes, molds and yeasts, total and thermotolerant coliforms). Minimally processed cassava roots packed in LDPE packages with higher thickness (200 µm and 300 µm) show greater stability in physicochemical and microbiological components. For packages 200 µm vacuum LDPE and 300 µm LDPE in the two atmosphere conditions, stored at 3 ºC and 90% relative humidity, the shelf life of minimally processed cassava roots was 14 days. The recommended storage period for the remaining treatments is seven days.

Additional keywords: *Manihot esculenta* Crantz; minimal processing; storage; vacuum packaging; conservation.

Resumo

A mandioca (*Manihot esculenta* Crantz) é uma das principais fontes mundiais de energia na alimentação humana, grandemente consumida e produzida no Brasil; entretanto, não apresenta facilidade no preparo e tem um alto grau de deterioração após a colheita. Como alternativa, o processo de embalagem a vácuo para o acondicionamento de raízes de mandioca minimamente processadas tem sido utilizado consideravelmente pelos produtores e pelas agroindústrias. Assim, o objetivo deste trabalho foi avaliar a conservação pós-colheita de raízes de mandioca de mesa minimamente processadas e acondicionadas em embalagens PEBD 130 µm, 200 µm e 300 µm, com e sem vácuo, armazenadas na temperatura de 3 ºC e 90% de umidade relativa. As amostras foram avaliadas a cada sete dias, por um período de 28 dias, quanto ao pH, acidez titulável, sólidos solúveis, Ratio, textura, perda de massa fresca, umidade, matéria seca, tempo de cocção, cor (L*, a*, b*, incremento no escurecimento, croma e ângulo hue) e microbiologia para a contagem de aeróbios mesófilos, aeróbios psicrotróficos, bolores e leveduras, coliformes totais e termotolerantes. Raízes de mandioca minimamente processadas acondicionadas nas embalagens de PEBD com maior espessura (200 µm e 300 µm), apresentam maior estabilidade nos componentes físicos-químicos e microbiológicos. Na embalagem PEBD 200 µm com vácuo e PEBD 300 µm nas duas condições de atmosfera e armazenamento na temperatura de 3 ºC e 90% de umidade relativa, a vida útil das raízes de mandioca minimamente processada foi de 14 dias. Nos demais tratamentos, o período de armazenamento recomendado foi de sete dias.

Palavras-chave adicionais: *Manihot esculenta* Crantz; processamento mínimo; armazenamento; acondicionamento a vácuo; conservação.

Introduction

Brazil is the fourth largest producer of cassava in the world, after Nigeria, Thailand, and Indonesia, whose climatic conditions are the main factors regulating production (Moreto et al., 2018). This crop is fundamental for the Brazilian socioeconomic scenario, with cultivation in both small and large farms. Moreover, cassava is versatile, with potential to be planted in all regions of Brazil (Santiago et al., 2018).

In the green belt of large and medium-sized Brazilian cities, cassava is mainly grown for culinary consumption (precooked, cooked, fried, chips, cassava stick, among others) of its reserve roots (Vieira et al., 2018). The crop is one of the preferred by the producers because of its high profitability and adaptation to crop rotation and/or succession with other vegetables.

Physiological deterioration of roots represents one of the great difficulties of the cassava market. The deterioration process begins in the first 48 hours after harvest, limiting its storage and hindering commercialization (Ramos et al., 2013).

Minimally processed cassava is an alternative to add value to the raw material and to meet the needs of consumers looking for easy-to-prepare products (Vieites et al., 2012). Farmers, wholesalers, and supermarkets are increasingly using processed cassava, since today's consumers consider the practicality of minimally processed products over their prices (Andrade et al., 2016).

Among the different techniques and methods of food preservation, the study of packaging has stood out due to the need to preserve physicochemical and sensory characteristics. In addition to the package definition, the use of vacuum can result in a longer shelf life due to reduced microorganism development, oxidation, and discoloration (Ricciardi, 2008). According to Cenci (2011), the use of vacuum in packaging promotes the suppression of oxygen, which tends to increase the shelf life of the food because it slows respiration, maturation, aging, moisture loss, texture change, enzymatic browning, and the development of microorganisms. The use of vacuum packaging is efficient in the preservation of meat, pasta, eggs, and grains (Lima et al., 2014). When evaluating the quality of minimally processed cassava subjected to gamma radiation, Vieites et al. (2012) packed minimally processed cassava roots (IAC-576-70) in two different situations. The first situation consisted of expanded polystyrene packages coated with low density polyethylene (LDPE) plastic film subjected to different irradiation rates. The second situation included minimally processed roots packed only in nylon + polyethylene packaging with vacuum application, stored under refrigeration at 5 ºC for 12 days. The authors concluded that the vacuum treatment associated with refrigeration allowed a slight superiority compared to the other treatments.

Despite being widely used by producers and agribusinesses, there is insufficient scientific information on physicochemical and microbiological characteristics of minimally processed cassava roots packaged and marketed in vacuum packages of different thicknesses, as well as on the shelf life of this product. Thus, this study evaluates the postharvest conservation of minimally processed cassava roots packed in 130 μm, 200 μm, and 300 μm PEBD packages with and without vacuum, stored at 3 °C and 90% relative humidity.

Materials and methods

The work was developed in the Laboratory of Food Science and Technology of Embrapa Cerrados, located in Planaltina - DF. Cassava cultivar IAC 576-70 was used, popularly known in the Cerrado region as "Japonesinha", with cream root pulp.

Twelve months after planting, the roots were harvested, transported to the laboratory, washed in running water, and cooled in a cold room (10 ± 1 ºC and 90% relative humidity) for 12 hours. Minimal processing consisted of manually peeling the roots and discarding the tips; washing under running water; and cutting the median part of roots into cylinders (10 cm long). Moreover, the following procedures were performed: immersion (10 minutes) in sanitizing solution of sodium hypochlorite with 150 mg.L^{-1} active chlorine; rinsing (5 minutes) in 5 mg.L^{-1} solution of the same sanitizer; and root draining for five minutes in a stainless steel drainer similar to those used in semi-industrial restaurants. The temperature of the running, sanitizing, and rinsing water was maintained at 5 ± 2 °C. The processing area was previously sanitized, as well as all utensils kept inside. Room temperature was maintained at 15 ± 3 ºC, and individual protective equipment (IPE) was used.

Minimally processed cassava roots were packed in LDPE plastic bags with 130μm, 200μm, and 300 μm. All studied packages were closed with and without vacuum, consisting of the following treatments: 130 μm nonvacuum LDPE, 130 μm vacuum LDPE, 200 μm nonvacuum LDPE, 200 μm vacuum LDPE, 300 μm nonvacuum LDPE, 300 μm vacuum LDPE. All packages containing minimally processed cassava roots were stored in a cold room at 3 °C and 90% relative humidity.

After minimal processing and at 7, 14, 21, and 28 days of storage, the product was analyzed for pH, titratable acidity, soluble solids, SS/TA ratio, moisture, and dry matter content according to Carvalho et al. (1990). Texture analysis was based on the perforation resistance test (normal test) using the Brookfield texture Analyzer, model CT3 4500. The following configuration was set: trigger (strength) at 10 g, deformation at 10 mm, and speed at 10 mm/s, using TA 17 tips with a 30 mm D cone, 40°, and TA 15/1000 tips with a 30 mm D cone, 45°. The results were expressed in Newton. Fresh weight loss during storage was determined by the difference between the initial weight and the weight at the time of evaluation. Cooking time was evaluated according to Butarelo et al. (2004). Color (L^*, a^*, b^*) was determined using a MiniScan® EZ spectrophotometer (brand HunterLab). L^* defines luminosity (L^* = 0 black and L^* = 100 white); a^* and b^* define chromaticity (+a^* red and -a^* green; +b^* yellow and -b^* blue). The values of L^*, a^*, and b^* made it possible to calculate the chroma (color saturation or intensity: 0 - impure color; 60 - pure color) and the hue angle (0° red, 90° yellow, 180° green, 270° blue, and 360° black). As recommended by Hunterlab (2008), the following formulas were used:

chroma [$(a^2 + b^2)^{1/2}$] and hue angle [tangent arc (b/a)]. Microbiological analysis was performed according to Silva et al. (2010) for the counting of mesophilic aerobes, psychrotrophic aerobes, molds and yeasts, total and thermotolerant coliforms.

Experimental design and statistical analysis

The experimental design was completely randomized with three replicates for each analysis. Each replicate consisted of approximately 500 g of minimally processed cassava roots. For color and texture analysis, three readings were performed in each 10-cm-long cylinder of minimally processed cassava roots. The data were submitted to analysis of variance, and means were compared by the Tukey test at 1% probability, using the Assistat software (Silva, 2015).

Results and discussion

pH, titratable acidity, and soluble solids

The pH values did not vary significantly during storage, ranging between 5.96 and 6.32, with an initial value of 6.04 (Table 1). Low oscillation in pH values during storage may be related to the association between storage temperature and adequate packaging, resulting in efficient respiration control (Freire et al., 2014).

Table 1 - Mean values of pH, titratable acidity and soluble solids in minimally processed cassava roots submitted to different treatments.

Packages	Days of storage				
	0	7	14	21	28
	pH				
LDPE 130 μm without vacuum	6.04 aA	6.16 aA	6.20 aA	6.21 aA	6.18 aA
LDPE 130 μm with vacuum	6.04 aA	6.11 aA	6.16 aA	6.16 aA	6.03 aA
LDPE 200 μm without vacuum	6.04 aA	6.16 aA	5.96 aA	6.31 aA	6.08 aA
LDPE 200 μm with vacuum	6.04 aA	6.18 aA	6.24 aA	6.31 aA	6.30 aA
LDPE 300 μm without vacuum	6.04 aA	6.12 aA	6.00 aA	6.20 aA	6.11 aA
LDPE 300 μm with vacuum	6.04 aA	6.16 aA	6.14 aA	6.32 aA	6.27 aA
	Titratable acidity (g anhydrous citric acid/100 g)				
LDPE 130 μm without vacuum	0.11 aB	0.06 cC	0.11 aB	0.13 aA	0.04 cD
LDPE 130 μm with vacuum	0.11 aA	0.07 bcB	0.08 bB	0.12 aA	0.11 aA
LDPE 200 μm without vacuum	0.11 aA	0.08 bcB	0.09 abA	0.09 bA	0.11 aA
LDPE 200 μm with vacuum	0.11 aA	0.10 aA	0.08 bB	0.12 aA	0.09 bB
LDPE 300 μm without vacuum	0.11 aA	0.08 bcB	0.09 abB	0.11 abA	0.11 aA
LDPE 300 μm with vacuum	0.11 aA	0.07 bcC	0.09 abB	0.11 abA	0.09 bB
	Soluble solids (°Brix)				
LDPE 130 μm without vacuum	7.00aA	7.87 aA	8.10 aA	7.40 aA	7.27 aA
LDPE 130 μm with vacuum	7.00 aA	7.60 aA	7.13 aA	8.50 aA	9.57 aA
LDPE 200 μm without vacuum	7.00 aA	7.63 aA	7.20 aA	7.03 aA	7.83 aA
LDPE 200 μm with vacuum	7.00 aA	7.47 aA	7.77 aA	7.07 aA	7.07 aA
LDPE 300 μm without vacuum	7.00 aA	8.63 aA	7.97 aA	7.93 aA	8.63 aA
LDPE 300 μm with vacuum	7.00 aA	7.17 aA	7.83 aA	7.33 aA	6.87 aA

Means followed by different lowercase and uppercase letters in the same column and row, respectively, differ from each other at 1% probability by the Tukey test.

There is a relationship between increased pH and decreased titratable acidity in stored products due to the consumption of organic acids as substrates in the respiratory process (Chitarra & Chitarra, 2005). Rinaldi et al. (2015a) observed a significant increase in pH values of minimally processed cassava roots conditioned with and without vacuum and stored under refrigeration and freezing (without vacuum) for cultivars IAC 576-70, BRS 400, and BRS 399, differing from that observed in this study. The pH value determines the enzymatic activity, the deterioration degree, the texture variation, the degree of maturation of fruits and vegetables, and the choice of the most appropriate packaging and storage conditions (Chitarra & Chitarra, 2005). Foods with low acidity (pH > 4.5) are more susceptible to microbial, pathogenic, or deteriorating development (Franco & Landgraf, 2005). In this context, the pH observed in all treatments is favorable to the development of these microorganisms, which may cause a decrease in root storage time (Teixeira et al., 2017). Thus, the storage condition and temperature must be well defined for maintaining postharvest quality of minimally processed cassava roots.

Titratable acidity values varied significantly throughout the storage, with fluctuation in practically all treatments. The initial value was 0.11 g anhydrous citric acid per 100 g, and the lowest value (0.04) was observed at 28 days of storage for roots packed in 130 μm nonvacuum LDPE (Table 1). With the exception of the 200 μm vacuum LDPE package, all treatments decreased titratable acidity values during the first seven days of storage. This indicates that the main

metabolic changes occurred at this stage for roots subjected to these treatments. Titratable acidity values tend to decrease during storage of refrigerated products due to the use of acids in the respiratory process (Rinaldi et al., 2015b). In the study by Vieites et al. (2012), minimally processed cassava only vacuum-packaged had higher values of titratable acidity when compared to the other treatments subjected to different irradiation rates, which did not occur in the present study, in which titratable acidity values oscillated and decreased during storage.

Soluble solids content did not vary significantly during storage probably due to the low metabolism of roots, the packages used, and mainly the low storage temperature (3 °C) (Table 1). Although not statistically significant, the highest soluble solids content was obtained for minimally processed cassava roots kept in the 130 µm vacuum LDPE package, at 28 days of storage. The lowest value was also obtained at 28 days for roots packed in the 300 µm vacuum LDPE package.

Throughout the storage period, the soluble solids content ranged from 6.87 °Brix to 9.57 °Brix, with an initial value of 7.00 °Brix (Table 1). The variation in soluble solids contents during storage is influenced by intrinsic characteristics of the sample, by metabolic reactions that may occur during the storage period, using sugar as a substrate, and by microbial activity in the product kept under refrigeration (Rinaldi et al., 2015a). Thus, we can affirm that the processing, packaging, and storage conditions were adequate for the maintenance of this variable. Soluble solids represent an important variable in postharvest evaluation, since they allow to infer about the flavor of the vegetable (Castricini et al., 2014). This characteristic can influence the final quality of cassava products such as cakes, ice cream, biscuits, purees, and others. In addition, higher levels of soluble solids tend to provide more sweetness and better taste, meeting consumers' preference (Teixeira et al., 2017).

SS/TA ratio, texture, and fresh weight loss

The SS/TA ratio values correspond to the ratio between soluble solids and titratable acidity, basically defining root flavor and maturity stage. In general, with the exception of products subjected to the 130 µm non-vacuum LDPE package and the 200µm vacuum LDPE package, the highest SS/TA ratio was observed at seven days of storage (Table 2). The packages also varied significantly for this variable from 7 to 28 days of storage. The SS/TA ratio values ranged between 58.39 (200µm vacuum LDPE at 21 days of storage) and 162.94 (130µm nonvacuum LDPE at 28 days). These values tend to increase during plant maturation due to increased sugars and decreased acids (Cavalini et al., 2006). In the present study, the values of this variable oscillated as a function of the values of soluble solids and titratable acidity (Table 1). The soluble solids/titratable acidity ratio is generally a good indicator of flavor, in which the balance between these two components is a good outcome (Fernandes et al., 2010).

Table 2 - Mean values of ratio, texture and loss of fresh mass in minimally processed cassava roots submitted to different treatments.

Packages	Days of storage				
	0	7	14	21	28
	Ratio				
LDPE 130 µm without vacuum	64.12 aD	133.50 aB	76.18 cC	58.73 cD	162.94 aA
LDPE 130 µm with vacuum	64.12 aC	111.70 bA	92.78 aB	65.26 bC	94.31 bB
LDPE 200 µm without vacuum	64.12 aD	102.16 cA	80.87 bcB	78.01 aB	71.52 dC
LDPE 200 µm with vacuum	64.12 aC	79.85 dB	92.61 abA	58.39 cC	82.22 cB
LDPE 300 µm without vacuum	64.12 aD	113.59 bA	87.80 bB	72.30 abC	76.33 dC
LDPE 300 µm with vacuum	64.12 aC	99.83 cA	85.52 bB	68.45 bC	82.02 cB
	Texture (N)				
LDPE 130 µm without vacuum	30.0 aA	24.23 aA	24.67 aA	22.03 aA	21.96 aA
LDPE 130 µm with vacuum	30.0 aA	25.80 aA	24.97 aA	22.73 aA	20.20 aA
LDPE 200 µm without vacuum	30.0 aA	21.80 aA	24.50 aA	26.10 aA	23.27 aA
LDPE 200 µm with vacuum	30.0 aA	23.03 aA	25.57 aA	23.77 aA	23.53 aA
LDPE 300 µm without vacuum	30.0 aA	22.73 aA	24.77 aA	24.50 aA	20.20 aA
LDPE 300 µm with vacuum	30.0 aA	22.07 aA	24.23 aA	25.03 aA	24.93 aA
	Loss of fresh mass (%)				
LDPE 130 µm without vacuum	0.00 aA	0.00 aA	0.02 aA	0.02 aA	0.07 aA
LDPE 130 µm with vacuum	0.00 aA	0.03 aA	0.09 aA	0.11 aA	0.12 aA
LDPE 200 µm without vacuum	0.00 aA	0.00 aA	0.01 aA	0.07 aA	0.08 aA
LDPE 200 µm with vacuum	0.00 aA	0.01 aA	0.01 aA	0.02 aA	0.09 aA
LDPE 300 µm without vacuum	0.00 aA	0.00 aA	0.01 aA	0.03 aA	0.06 aA
LDPE 300 µm with vacuum	0.00 aB	0.03 aAB	0.01 aAB	0.01 aAB	0.10 aA

Means followed by different lowercase and uppercase letters in the same column and row, respectively, differ from each other at 1% probability by the Tukey test.

Texture did not differ significantly between packages and between storage periods; as expected, it had only a gradual but not expressive decrease. Although there was no significant difference in texture data during storage, all treatments had a more pronounced reduction during the first seven days of storage (Table 2). Rinaldi et al. (2017b) also did not observe a significant difference in the texture of cassava roots of the same cultivar. The roots were immersed in water with different concentrations of citric acid after minimal processing, with texture values ranging between 39.66 N and 16.71 N. The storage temperature was set at 30 °C for 35 days. In turn, Teixeira et al. (2017) obtained the average texture value of 22.66 N after harvesting cassava roots of the variety IAC 576-70, which is a lower value than that obtained for the same variety in the present study. The textural properties of minimally processed foods indicate their quality, in which packaging is fundamental to maintain the conservation of these products (Fernandes et al., 2016). In the present study, there was no significant effect of packaging on the texture of the product.

There was no significant increase in fresh weight loss in all treatments during storage, with a loss of 0% to 0.12%, which did not influence product quality (Table 2). Freire et al. (2014) also did not observe a significant increase of fresh weight loss in minimally processed cassava roots stored at 5 ± 20 °C for 11 days. According to these authors, low fresh weight loss in minimally processed cassava roots may be due to lignification, which can act as a natural barrier to water loss, resulting in less susceptibility to dehydration. Weight loss occurs mainly due to the loss of moisture by transpiration (Freitas et al., 2017).

Color

Table 3 shows the color values, expressed in L*, a*, b*. Samples packaged in 200 μm vacuum LDPE and 300 μm nonvacuum LDPE showed higher stability in L* values, with no significant variation during the 28 days of storage. The lower the L* values, the darker the samples. The highest L* value (89.06) was obtained at the beginning of storage, and the lowest value (66.48) occurred in the samples of minimally processed roots conditioned in the 200 μm nonvacuum LDPE package, at 28 days of storage.

Table 3 - Mean values of L *, a * and b * in minimally processed cassava roots submitted to different treatments.

Packages	Days of storage				
	0	7	14	21	28
			L*		
LDPE 130 μm without vacuum	89.06 aA	86.28 aA	75.86 bB	85.02 aA	76.96 bB
LDPE 130 μm with vacuum	89.06 aA	86.66 aAB	80.91 abB	87.76 aA	88.29 aA
LDPE 200 μm without vacuum	89.06 aA	85.33 aAB	80.52 abB	85.84 aAB	66.48 cC
LDPE 200 μm with vacuum	89.06 aA	86.14 aA	85.32 aA	87.04 aA	84.53 aA
LDPE 300 μm without vacuum	89.06 aA	86.37 aA	85.21 aA	87.42 aA	86.87 aA
LDPE 300 μm with vacuum	89.06 aA	86.21 aAB	84.98 aAB	82.23 aB	86.53 aAB
			a*		
LDPE 130 μm without vacuum	4.77 aA	3.32 aB	2.60 abBC	2.90 aB	2.05 bC
LDPE 130 μm with vacuum	4.77 aA	3.26 aB	2.06 bC	3.04 aB	3.01 aB
LDPE 200 μm without vacuum	4.77 aA	2.80 abB	2.98 aB	3.08 aB	2.73 abB
LDPE 200 μm with vacuum	4.77 aA	3.09 abB	2.86 aB	2.70 aB	3.45 aB
LDPE 300 μm without vacuum	4.77 aA	2.31 bC	2.60 abBC	3.22 aB	3.30 aB
LDPE 300 μm with vacuum	4.77 aA	3.11 aBC	2.88 aBC	2.75 aC	3.53 aB
			b*		
LDPE 130 μm without vacuum	24.97 aA	21.43 aB	21.36 aB	22.49 aAB	21.23 aB
LDPE 130 μm with vacuum	24.97 aA	21.93 aB	17.56 bC	21.51 aB	22.26 aAB
LDPE 200 μm without vacuum	24.97 aA	21.35 aB	21.51 aB	21.26 aB	21.11 aB
LDPE 200 μm with vacuum	24.97 aA	22.01 aB	21.22 aB	21.91 aB	23.12 aAB
LDPE 300 μm without vacuum	24.97 aA	21.15 aB	21.03 aB	22.74 aAB	23.39 aAB
LDPE 300 μm with vacuum	24.97 aA	21.46 aB	23.48 aAB	20.23 aC	22.02 aABC

Means followed by different lowercase and uppercase letters in the same column and row, respectively, differ from each other at 1% probability by the Tukey test.

In turn, a* values decreased significantly in all treatments until seven days of storage. The values varied significantly for roots in the 300 μm nonvacuum LDPE package at seven days of storage. At 14 days, only the 130 μm vacuum LDPE package showed significant variation. Moreover, at 28 days, the same occurred for the 130 μm nonvacuum LDPE package.

After seven days, only the product subjected to the 200 μm LDPE package with and without vacuum did not show significant variation in a* values until the end of storage. These values are responsible for regulating chlorophyll degradation: when a* is positive, the product has a reddish color; when a* is negative, the product is green (Rinaldi et al., 2017b).

Similarly, b* values varied significantly during storage except for the product in the 200 µm nonvacuum LDPE package after seven days of storage. However, only the product subjected to the 130 µm vacuum LDPE package showed a significant reduction in the values of this variable, at 14 days of storage. It is known that b* values represent the yellowing of the vegetable: when b* is positive, the product is yellow; when b* is negative, the product is blue. The values were positive for all days of analysis, corresponding to the characteristic color of the studied cultivar. It is then possible to affirm that there was no significant variation in the color of minimally processed cassava roots subjected to the different treatments during the whole experiment.

Increase in browning, chroma, and hue angle

The increase in browning determines the browning presented by roots during the storage period (Table 4). The highest value (23.50) occurred for roots in the 200 µm nonvacuum LDPE package, on the twenty-eighth day of storage, corresponding to the lowest L* value (66.48) obtained throughout the experiment (Table 3). When the product was packed in the same package but subjected to the vacuum process, it showed a low increase in browning throughout the storage period. The product subjected to the 300 µm LDPE package with and without vacuum also showed low increase in browning during the 28 days of storage, proving that this packaging is suitable for maintaining low levels of browning in minimally processed cassava roots stored under refrigeration at 3 °C.

Table 4 - Mean values of increment in browning, chroma and hue angle in minimally processed cassava roots submitted to different treatments.

Packages	Days of storage				
	0	7	14	21	28
	Browning				
LDPE 130 µm without vacuum	0.00 aC	5.90 aB	14.70 aA	6.95 aB	13.40 bA
LDPE 130 µm with vacuum	0.00 aC	5.64 aB	13.88 aA	6.08 aB	5.17 cB
LDPE 200 µm without vacuum	0.00 aC	7.84 aB	10.87 abB	7.25 aB	23.50 aA
LDPE 200 µm with vacuum	0.00 aB	5.81 aA	6.30 bA	5.30 aA	7.42 cA
LDPE 300 µm without vacuum	0.00 aB	6.80 aA	7.32 bA	6.21 aA	6.76 cA
LDPE 300 µm with vacuum	0.00 aB	6.17 aA	7.16 bA	8.69 aA	6.27 cA
	Chroma				
LDPE 130 µm without vacuum	25.44 aA	21.71 aB	21.53 aB	22.69 aAB	21.47 aB
LDPE 130 µm with vacuum	25.44 aA	22.19 aB	17.70 bC	21.74 aB	22.88 aAB
LDPE 200 µm without vacuum	25.44 aA	21.54 aB	22.20 aB	21.50 aB	21.36 aB
LDPE 200 µm with vacuum	25.44 aA	22.24 aB	21.43 aB	22.08 aB	23.63 aAB
LDPE 300 µm without vacuum	25.44 aA	21.30 aB	21.21 aB	22.99 aAB	23.98 aAB
LDPE 300 µm with vacuum	25.44 aA	21.70 aBC	23.67 aAB	19.86 aC	22.73 aABC
	Hue angle				
LDPE 130 µm without vacuum	79.24 aA	81.39 aA	83.16 aA	82.58 aA	84.17 aA
LDPE 130 µm with vacuum	79.24 aA	81.60 aA	83.41 aA	82.12 aA	82.93 aA
LDPE 200 µm without vacuum	79.24 aA	82.64 aA	82.24 aA	81.80 aA	82.77 aA
LDPE 200 µm with vacuum	79.24 aA	81.89 aA	82.45 aA	83.14 aA	81.63 aA
LDPE 300 µm without vacuum	79.24 aA	83.79 aA	83.08 aA	82.09 aA	82.21 aA
LDPE 300 µm with vacuum	79.24 aA	81.93 aA	82.63 aA	78.07 aA	81.38 aA

Means followed by different lowercase and uppercase letters in the same column and row, respectively, differ from each other at 1% probability by the Tukey test.

The increase in browning is measured to assess the browning of the product during storage. In general, for plant products, when values regarding this increase are higher than 10, the degree of browning is considered high (Rinaldi et al., 2017c). In the present study, the values ranged from 0 to 23.50, and the products packed in 200 µm vacuum LDPE and 300 µm LDPE with and without vacuum showed values below the maximum limit during the 28 days of storage. Hence, these treatments are considered effective in the browning control of minimally processed cassava roots. As for the variability obtained during the experiment, a factor that can interfere with the calorimetry analysis of cassava is the samples being destructive, that is, a new sample is used for each time of evaluation. The cassava must be removed from the package for analysis, and repackaging is not advisable due to the modification of the atmosphere around the product (Henrique et al., 2015).

Chroma values ranged from 17.70 to 25.44, corresponding to faint colors, of low intensity, tending to white (Table 4). Chroma values define color intensity, where values close to zero correspond to neutral colors, and values close to sixty account for stronger colors (Tunick, 2000). Chroma is a variable related to the degree of purity of the color, which delimits the saturation level by the black or white scale that contains it (Reis et al., 2017).

The chroma values obtained during the storage period did not differ significantly between packages, except for the product subjected to the 130 μm with vacuum LDPE package, at 14 days of storage, with the lowest chroma (17.70) of the whole experiment (Table 4). It is not possible to state that the packages had any effect on the chroma values of minimally processed cassava roots during the 28 days of storage.

Moreover, hue angle values also did not vary significantly during the 28 days of storage of minimally processed cassava roots conditioned in the different packaging systems. The hue angle (h) of roots in the different treatments ranged between 78.07 and 84.17 throughout the storage period, corresponding to the yellow color (Table 4). The hue angle characterizes different color shades every 90°, as follows: 0° red, 90°

yellow, 180° green, and 270° blue (Silva et al., 2015).

Moisture, dry matter, and cooking time

Moisture values ranged from 56.97% to 63.06%, with an overall mean of 60.94% during the 28 days of storage. The moisture content of roots subjected to the 130 μm vacuum LDPE package and the 300 μm LDPE package in the two atmosphere conditions did not vary significantly throughout the storage period. The other treatments showed oscillation in moisture values during storage (Table 5). In general, the moisture values of minimally processed cassava roots agree with the data obtained by Rinaldi et al. (2015a, b) and Rinaldi et al. (2017a).

Table 5 - Mean values of moisture, dry matter and cooking time in minimally processed cassava roots submitted to different treatments.

Packages	Days of storage				
	0	7	14	21	28
	Moisture (%)				
LDPE 130 μm without vacuum	61.61 aA	62.08 aA	60.64 aA	61.43 abA	60.14 aA
LDPE 130 μm with vacuum	61.61 aAB	62.90 aA	60.76 aAB	59.87 bcB	60.67 aAB
LDPE 200 μm without vacuum	61.61 aA	60.96 abAB	58.65 aBC	56.97 cC	60.94 aAB
LDPE 200 μm with vacuum	61.61 aAB	59.08 bB	60.68 aAB	63.06 aA	60.48 aAB
LDPE 300 μm without vacuum	61.61 aA	60.14 abA	61.19 aA	61.04 abA	62.38 aA
LDPE 300 μm with vacuum	61.61 aA	61.49 abA	61.53 aA	61.95 abA	59.45 aA
	Dry matter (%)				
LDPE 130 μm without vacuum	38.39 aA	37.92 abA	39.36 aA	38.57 bcA	39.85 aA
LDPE 130 μm with vacuum	38.39 aAB	37.10 bB	39.24 aAB	40.13 abA	39.33 aAB
LDPE 200μm without vacuum	38.39 aC	39.04 abBC	41.35 aAB	43.04 aA	39.06 aBC
LDPE 200μm with vacuum	38.39 aAB	40.92 aA	39.32 aAB	36.95 cB	39.51 aAB
LDPE 300μm without vacuum	38.39 aA	39.86 abA	38.81 aA	38.96 bcA	37.62 aA
LDPE 300μm with vacuum	38.39 aA	38.51 abA	38.47 aA	38.05 bcA	40.55 aA
	Cooking time (minutes)				
LDPE 130 μm without vacuum	24 aB	25 aB	24 bB	30 aA	30 aA
LDPE 130 μm with vacuum	24 aB	25 aB	30 aA	30 aA	30 aA
LDPE 200μm without vacuum	24 aB	23 abB	24 bB	29 aA	28 aA
LDPE 200μm with vacuum	24 aB	22 bB	30 aA	30 aA	30 aA
LDPE 300μm without vacuum	24 aB	25 aB	24 bB	29 aA	30 aA
LDPE 300μm with vacuum	24 aB	22 bB	24 bB	24 bB	29 aA

Means followed by different lowercase and uppercase letters in the same column and row, respectively, differ from each other at 1% probability by the Tukey test.

The moisture results obtained in this work also agree with those presented by TACO (Unicamp, 2011) in raw cassava roots (61.80%). Bezerra et al. (2002) highlight the importance of maintaining the moisture of cassava roots during storage, since a decrease implies favoring enzymatic reactions that culminate in vascular discoloration. According to the same authors, increased moisture values due to packaging, inadequate centrifugation, and other storage problems can facilitate the multiplication of microorganisms present in the product, decreasing its shelf life.

Dry matter values ranged from 36.95 to 43.04, with an overall mean of 39.06. The roots subjected to the 200 μm vacuum LDPE package showed the highest dry matter content, while the 200 μm nonvacuum LDPE package accounted for the lowest value (Table

5). The dry matter percentage of roots packed in the 130 μm nonvacuum LDPE package and in the 300 μm LDPE package with and without vacuum did not vary significantly during the 28 days of storage, proving that these packages were more stable in maintaining the dry matter content of minimally processed cassava roots. Root dry matter values are highly related to starch content, depending on the variety, crop location, age, and harvesting time (Fukuda et al., 2006).

The cooking time of cassava roots ranged between 22 and 30 minutes. It is noteworthy that 30 minutes is the maximum acceptable time for commercialization of cassava roots for culinary purposes (Fukuda et al., 2002; Vieira et al., 2018) (Table 5). The lower the cooking time, the better the mass quality (Talma et al., 2013). In addition, low cooking time leads

to energy and time savings, which is desired by the final consumer (Moreto & Neubert, 2014). Rapid cooking of cassava roots is also associated with soft texture and crispness of fried cassava (Schallenberger et al., 2016).

The cooking time of roots subjected to the 130 μm vacuum LDPE and 200μm vacuum LDPE packages increased significantly from 14 days of storage, these values being maintained until the end of the experiment. For the other treatments, with the exception of the 300 μm vacuum LDPE package, the cooking time increased significantly after 21 days of storage. However, this variable also increased at 28 days for roots in the 300 μm vacuum LDPE package, reaching 29 minutes. Furthermore, Bezerra et al. (2002) observed significant differences in root cooking time as a function of storage periods, with a reduced amplitude, ranging from 24.85 to 27.70 minutes and increasing during storage. Freire et al. (2014) also observed increased root cooking time for cassava cultivar Mossoró minimally processed into different formats ("minitolete" and "rubiene").

The increase in root cooking time in the described periods is probably due to the characteristics of the raw material. It is not possible to affirm that the thickness of the package and the vacuum process had a significant influence on this variable. Regarding cassava roots, samples from the same root or cultivar may differ in cooking quality. A sample may show proper cooking as opposite to the other, even with the same characteristics of cultivation, harvest, and other factors such as climate, soil, postharvest handling, and storage management.

The cooking time considered adequate for cassava roots is 11 to 20 minutes (Pereira et al., 1985). Cereda et al. (1990) reported a cooking time of 13.5 minutes for cultivar 279. The cooking time and culinary parameters of cassava roots may vary between roots of the same plant, between plants of the same variety, between different genetic materials, and depending on the physiological status of plants, soil and climate conditions, and harvesting times (Fialho et al., 2009). Plants harvested earlier have shorter cooking time (Oliveira & Moraes, 2009). Cooking time is thus the main feature related to culinary quality. Teixeira et al. (2017) state that cassava consumers are demanding about root cooking time, which must be as short as possible to be considered of good quality. These authors obtained a cooking time of 14 minutes for the same variety of this study.

However, since the cooking time was less than 30 minutes for all treatments, it is possible to affirm that all were efficient in maintaining the culinary qualities of cassava roots.

There was no presence of mesophilic aerobes, psychrotrophic aerobes, molds and yeasts, total and thermotolerant coliforms after minimal processing of roots (day zero), proving that the raw material was in good microbiological conditions and that minimal processing was performed adequately (Table 6).

The total count of mesophilic aerobes ranged from < 10 (est.) in the raw material to 2.2×10^5 CFU g^{-1} in the treatment of 130 μm nonvacuum LDPE at 28 days of storage. The lowest counts of mesophilic aerobes during storage were obtained for the treatments 200μm vacuum LDPE and 300μm vacuum LDPE. Therefore, when allied to the vacuum process, these packages are effective in reducing mesophilic aerobes in minimally processed cassava roots. In these treatments, the count reached a maximum of 10^3 up to 28 days of storage. The presence of a large number of mesophilic microorganisms in food may be indicative of product maintenance under improper conditions (Franco & Landgraf, 2005). When allied to the vacuum process, the packages with greater thickness in the present study showed a lower count of these microorganisms. Although mesophilic aerobes do not have a maximum tolerance established in Brazil, the APHA (American Public Health Association) establishes the limit of 1.4×10^3 CFU g^{-1} (Doores et al., 2013) for safety in the commercialization and consumption of the product.

The total psychrotrophic count ranged from < 10 (est.) in the roots immediately after processing to 1.5×10^5 CFU g^{-1} in the treatment of 130 μm nonvacuum LDPE at 21 days of storage (Table 6). In Brazilian legislation, there is no standard for these microorganisms in foods, but high amounts (> 10^5 CFU g^{-1}) are completely undesirable. At these levels, food may be inadequate for consumption, with actual or potential loss of sensory qualities, impaired appearance, and presence of pathogenic and/or deteriorating microorganisms (Caruso & Camargo, 1984). In the present study, only the roots subjected to 130 μm LDPE treatments with and without vacuum showed counts reaching 10^5, from 21 days of storage. The roots subjected to the other treatments did not reach the limit for the commercialization of products, being in acceptable conditions regarding these microorganisms until the end of storage. Positively, the lowest values of psychrotrophic aerobes were observed in the 200 and 300 μm vacuum LDPE treatments, again proving the efficiency of these treatments in the microbial control of minimally processed cassava roots.

For molds and yeasts, the treatments showed a count ranging from < 10 (est.) to 8.5×10^4 CFU g^{-1} during storage, with higher values in 130 μm LDPE treatments with and without vacuum. Once again, products subjected to the 200 μm vacuum LDPE and 300 μm vacuum LDPE packages showed less microbial contamination. Resolution RDC Nº. 12 of January 2, 2001 (Brasil, 2001) sets a limit value only for Salmonella and thermotolerant coliforms in refrigerated and frozen vegetables. However, in general, the lower the amount of mold and yeast in a food, the longer its shelf life and consumer safety.

The thermotolerant coliform count was also low, with maximum value of < 3 MPN g^{-1}, meeting the requirements of the legislation (Brasil, 2001). Resolution RDC Nº. 12 of January 2, 2001 regulates microbi-

ological standards for fresh and prepared vegetables, defining as a limit the coliform content of 10^2 MPN g^{-1} at 45 °C (Passos et al., 2017). Thus, minimally processed cassava roots were adequate regarding thermotolerant coliforms in all treatments.

Alves et al. (2005) report that minimally processed cassava roots stored in a styrofoam tray wrapped in polyvinyl chloride film (uninformed thickness) showed physiological, microbiological, and sensory deterioration from the 7th day of storage. In contrast, those stored in a vacuum-sealed multilayer package showed the same deterioration only on the 24th day of storage. The proliferation of microorganisms during storage is evident in foods with pH higher than 4.5 (Nutrição e Saúde, 2018). The pH of cassava roots is higher than this value, justifying the results obtained in the count of the microorganisms evaluated in the experiment.

Table 6 - Mean values of total counts of mesophilic aerobes, psychrotrophic aerobes, molds and yeasts, total and thermotolerant coliforms in minimally processed cassava roots submitted to different treatments.

Packages	Days of storage				
	0	07	14	21	28
Total counts of mesophilic aerobes (*CFU g^{-1})					
LDPE 130 μm without vacuum	< 10 est*	3.3×10^2	1.5×10^4	8.0×10^4	2.2×10^5
LDPE 130 μm with vacuum	< 10 est	1.5×10^2 est	5.9×10^3	6.6×10^4	1.7×10^5
LDPE 200 μm without vacuum	< 10 est	3.0×10^2	1.7×10^3	5.7×10^4	3.1×10^5
LDPE 200 μm with vacuum	< 10 est	1.2×10^2 est	2.9×10^2	4.6×10^3	1.7×10^3
LDPE 300 μm without vacuum	< 10 est	3.3×10^2	7.6×10^4	7.3×10^3	1.0×10^4
LDPE 300 μm with vacuum	< 10 est	2.6×10^2	1.6×10^2 est	1.3×10^3	3.2×10^3
Total counts of psychrotrophic aerobes (CFU g^{-1})					
LDPE 130 μm without vacuum	< 10 est	4.8×10^3	4.9×10^4	1.5×10^5	6.9×10^5
LDPE 130 μm with vacuum	< 10 est	8.6×10^2	8.5×10^3	1.3×10^5	6.8×10^5
LDPE 200 μm without vacuum	< 10 est	3.3×10^2	5.9×10^3	8.1×10^4	5.5×10^3
LDPE 200 μm with vacuum	< 10 est	< 10 est	1.4×10^2 est	4.5×10^3	4.3×10^3
LDPE 300 μm without vacuum	< 10 est	4.5×10^2	3.4×10^2	1.1×10^4	3.1×10^4
LDPE 300 μm with vacuum	< 10 est	< 10 est	1.3×10^2 est	3.6×10^2	2.8×10^3
Total counts of molds and yeasts (CFU g^{-1})					
LDPE 130 μm without vacuum	< 10 est	< 10 est	8.6×10^3	9.7×10^2	8.5×10^4
LDPE 130 μm with vacuum	< 10 est	< 10 est	1.4×10^3	4.0×10^2	7.6×10^4
LDPE 200 μm without vacuum	< 10 est	< 10 est	1.8×10^3	3.8×10^2	8.5×10^2
LDPE 200 μm with vacuum	< 10 est	< 10 est	< 10 est	2.6×10^2	5.0×10^2
LDPE 300 μm without vacuum	< 10 est	< 10 est	7.2×10^2	2.2×10^2	1.3×10^3
LDPE 300 μm with vacuum	< 10 est	< 10 est	< 10 est	1.9×10^2	4.6×10^2
Total coliforms (*MPN g^{-1})					
LDPE 130 μm without vacuum	< 3	1.1×10^2	1.1×10^2	6.4×10^4	1.1×10^5
LDPE 130 μm with vacuum	< 3	1.1×10^2	1.1×10^2	3.6×10^1	1.1×10^5
LDPE 200 μm without vacuum	< 3	< 3	1.1×10^2	2.1×10^3	2.4×10^4
LDPE 200 μm with vacuum	< 3	< 3	1.1×10^2	1.1×10^5	1.1×10^5
LDPE 300 μm without vacuum	< 3	2.3×10^3	3.0×10^1	4.3×10^3	1.1×10^5
LDPE 300 μm with vacuum	< 3	< 3	< 3	< 3	1.1×10^5
Thermotolerant coliforms (MPN g^{-1})					
LDPE 130 μm without vacuum	< 3	< 3	< 3	< 3	< 3
LDPE 130 μm with vacuum	< 3	< 3	< 3	< 3	< 3
LDPE 200 μm without vacuum	< 3	< 3	< 3	< 3	< 3
LDPE 200 μm with vacuum	< 3	< 3	< 3	< 3	< 3
LDPE 300 μm without vacuum	< 3	< 3	< 3	< 3	< 3
LDPE 300 μm with vacuum	< 3	< 3	< 3	< 3	< 3

*CFU: Colony forming units; *est: estimated; *MPN: Most probable number.

Conclusions

Minimally processed cassava roots packed in LDPE packages with greater thickness (200 µm and 300 µm) show greater stability in physicochemical and microbiological components.

When using the 200µm vacuum LDPE package and the 300µm LDPE package in the two atmosphere conditions, with storage at a temperature of 3 ºC and 90% relative humidity, the shelf life of minimally processed cassava roots is 14 days. For the other treatments, the recommended storage period is seven days.

Acknowledgements

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