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Shelf life of minimally processed cassava roots submitted to different conservation methods

Vida útil de raízes de mandioca minimamente processadas submetidas a diferentes métodos de conservação

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Abstract

The useful life of minimally processed cassava roots submitted to different conservation methods was evaluated. Cassava roots *in natura* were physically characterized, minimally processed and stored after submission to treatments in different packaging types. During storage period, the product was submitted to physicochemical, sensorial and microbiological analyzes. Storage time and treatment influenced on minimally processed cassava roots quality. When only the sensorial analysis is considered, the useful life of minimally processed cassava roots was of 28 days for all treatments, except for the roots submitted to the CONTROL and CA treatments, which had a 24-day shelf life. However, at 14 days of storage, CONTROL, VAC, CA, and H_2O treatments showed high psychotrophic count. Mold and yeast counts were also high for CONTROL and VAC treatments at 14 days of storage. At 28 days of storage, psychrotrophs, molds and yeasts count was high for all treatments. In general, the most recommended treatments, due to having a longer shelf life, were CA and H_2O reaching a maximum period of 14 days of storage. Considering the cooking time and the other physicochemical analyzes, the 2.5% H_2O+CA treatment is not recommended for the commercialization of minimally processed cassava roots.

Additional keywords: *Manihot esculenta* Crantz; minimal processing; packaging; postharvest conservation; temperature

Resumo

Avaliou-se a vida útil de raízes de mandioca minimamente processadas submetidas a diferentes métodos de conservação. As raízes de mandioca *in natura* foram caracterizadas fisicamente, minimamente processadas e armazenadas, após serem submetidas aos tratamentos em diferentes tipos de acondicionamentos. Durante o período de armazenamento o produto foi submetido a análises físico-químicas, sensoriais e microbiológicas. O tempo de armazenamento e o tratamento tiveram influência na qualidade das raízes de mandioca minimamente processadas. Considerando-se apenas a análise sensorial, a vida útil das raízes de mandioca minimamente processadas foi de 28 dias para todos os tratamentos, com exceção das raízes submetidas aos tratamentos TEST e AC que apresentaram vida útil de 24 dias. No entanto aos 14 dias de armazenamento, os tratamentos TEST, VAC, AC, e H_2O apresentaram contagem alta de psicotróficos. A contagem de bolores e leveduras também foi alta para os tratamentos TEST e VAC aos 14 dias de armazenamento. Aos 28 dias de armazenamento a contagem de psicrotróficos e bolores e leveduras foi alta para todos os tratamentos. De maneira geral os tratamentos mais recomendado por apresentar maiores vida útil foi o AC e H_2O chegando a um período máximo de 14 dias de armazenamento. Considerando o tempo para a cocção e as demais análises físico-químicas realizadas, o tratamento H_2O+AC a 2,5 % não é recomendado para a comercialização de raízes de mandioca minimamente processadas.

Palavras-chave adicionais: conservação pós-colheita; embalagem; *Manihot esculenta* Crant;, processamento mínimo; temperatura.

Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most traditional Brazilian crops, cultivated practically in the entire territory (Silva et al., 2013), especially due to the use of its tuberous roots, rich in starch. The Brazilian *Cerrado* region is one of the main cassava dispersion centers (El-Sharkawy, 2012). It is one of the most suitable crops for the region due to its great rusticity, and this biome is an

alternative for the diversification of Brazil's cassava production areas (Vieira et al., 2015). In the Federal District region, the currently most planted cassava cultivar is IAC 576-70. It is popularly known in the region as *Japonesinha* (Rinaldi et al., 2015b).

Cassava production is becoming more professionalized, since the consumer market is increasing, profitability is high and many producers traditionally cultivate it (Aguiar et al., 2013). Commercialization of roots for use in human food *in natura* form is becoming less frequent in markets and supermarkets from large cities. Besides the unattractive visual appearance and the lack of product information, the roots are perishable after harvest, which limits their period of commercialization and consumer acceptability (Rinaldi et al., 2015a).

In the Federal District, consumers of higher purchasing power classes would consume more cassava roots and would pay a higher price if it was ensured that they were buying a product with higher culinary and sanitary characteristics (Aguiar et al., 2013), which highlights cassava potential and the need for investments in final product quality. From the consumer point of view, demand for *in natura* roots is decreasing, which decreases their supply in supermarkets and hypermarkets from large consumer centers (Rinaldi et al., 2015a). However, maintenance of fresh roots for several days after harvest is one of the major problems of *in natura* and processed roots commercialization (Ramos et al., 2013).

Minimally processed cassava production has been proposed as an alternative to increase supply periods and to provide a more practical and ready-to--use food to consumers. Minimally processed foods emerged to respond to a new consumption trend and have been increasingly accepted in world markets (Santos & Oliveira, 2012). However, one of the major problems of minimally processed products is their rapid deterioration. The mechanical damage caused by peeling, cutting and slicing increase respiratory activity and ethylene production, especially in the first hours after processing. Injured cells presence and cellular component loss during processing operations favor microorganism development (Arruda et al., 2011).

Therefore, objective of this study was to determine the shelf life of minimally processed cassava roots produced in the Federal District, Brazil, submitted to different treatments and stored under refrigeration.

Material and methods

Cassava roots of IAC 576-70 variety, popularly known in the Cerrado region as *Japonesinha*, were used. In the Cerrado Cassava Germplasm Bank (BGMC), this variety is identified as BGMC 753 and is indicated for cultivation in the region (Fialho et al., 2009). Root harvest was conducted twelve months after planting. In the laboratory, roots were characterized by weight, length and circumference. Afterwards, roots were washed in running water and cooled in a cold room (10 ± 1 °C and 95% relative humidity) for 12 hours. Minimum processing consisted of manually peeling the roots and discarding the tips; washing under running water; cutting the root middle part into cylinders (10 cm long); and cutting these cylinders longitudinally into four parts. Afterwards, roots were immersed (10 minutes) in a sanitizing solution of sodium hypochlorite with 150 mg L^{-1} active chlorine and rinsed (5 minutes) in a 5 mg L^{-1} solution of the same solution. Then, roots were drained for 5 minutes.

Washing, sanitization and rinse waters temperature was kept at 5 ± 2 °C, which was controlled through the addition of ice. Good manufacturing practices were adopted. The processing area and all utensils were previously sanitized. Ambient temperature was kept at 15 ± 3 ºC, and personal protective equipment (PPE) was used.

Minimally processed roots were submitted to the following treatments: 1) packaging in 100-µm thick low-density polyethylene (LDPE) and submission to the vacuum process (VAC); 2) treatment with 2.5% citric acid (5 minutes) and packaging in 100-µm thick LDPE (CA); 3) Packaging in 100-µm thick LDPE (control treatment) (CONTROL); 4); Packaging in polyethylene boxes with lid and water addition, keeping the product submerged (H_2O); 5) packaging in polyethylene boxes with lid and water addition, keeping the product submerged with the addition of 2.5% citric acid (H_2O + CA). All treatments were stored in a cold room at 3 °C and 95% relative humidity for 28 days.

After minimum processing (day zero) and at 3, 7, 11, 14, 17, 21, 24 and 28 days of storage, the product was submitted to moisture analysis based on water evaporation and non-volatilized residue weighting. The pH was measured using a pH meter and titratable acidity was measured by titration with sodium hydroxide solution, using a pH meter until pH reached the value of 8.1. Soluble solids were measured through refractometric reading, ascorbic acid was measured based on 2,6-dichlorophenolindophenol sodium (DCPIP) reduction by ascorbic acid, through manual titration, and SS/TA ratio and total solids were measured by gravimetric method, as described by Carvalho et al. (1990). Cooking time was evaluated at 0, 3, 14, 24 and 28 days, according to Butarelo et al. (2004), and sensory analysis was conducted at 0, 3, 7, 14, 21, 24 and 28 days of storage. For sensorial analysis, the methodology classified as Affective Quantitative Method, according to Ferreira (2000), with 60 untrained judges (cassava consumers) was conducted. General appearance, color, texture and aroma were evaluated through an acceptability test using a nine-point hedonic scale. Scores ≤ 5.0 were considered unsuitable for product acceptability to the market and were eliminated from analysis.

The product was only characterized in relation to ethereal extract after minimal processing (Campos et al., 2004), with modification due to the use of ANKOM^{XT10} extractor, XT10L model. Protein was measured according to AOAC (1975). Conversion of

nitrogen to protein was performed by N x 6.25. Ashes were measured according to Campos et al., (2004). Dietary fiber was measured according to the 985.29 enzyme-gravimetric method by AOAC (2005). Carbohydrates were obtained by difference (Nifext fraction).

Microbiological analyzes for the total count of psychrotrophs, mold, yeasts, coliforms and thermotolerant coliforms were carried out in the raw material and in minimally processed cassava roots at 0, 14 and 28 days of storage, according to Silva et al. (2010). For the raw material, aerobic mesophiles analysis was also carried out.

The experimental design was completely randomized, with three repetitions for each treatment, where each repetition consisted of a package containing 500 g of minimally processed cassava roots. In the product submitted to H_2O and H_2O+CA treatments, 10 units were considered per repetition. Data were submitted to analysis of variance using the F test and means were grouped by Scott and Knott's test, with 5% error probability. All statistical analyzes were performed with the aid of Genes statistical software (Cruz, 2001). In the cooking time analysis, the H_2O+CA treatment did not cook the roots and was characterized in the repetitions with the abbreviation NC (not cooked). However, cooking times of 39 or 40 minutes were adopted for the three repetitions in this treatment, in order to be computed in the statistical analysis.

Results and discussions

Raw Material Physical Characterization and Centesimal Composition

Cassava roots showed mean weight values of 0.602 kg, mean length of 34.89 cm and mean circumference of 15.18 cm. Cassava roots centesimal composition consisted of 60.00% moisture, 0.30% ethereal extract, 0.68% protein, 5.17% dietary fiber (4.50% insoluble and 0.67% soluble), 0.92% ashes and 32.93% carbohydrates. Results found by Taco (2011) in raw cassava roots were very close to those obtained in this study for moisture, ethereal extract, ashes and carbohydrates, differing from protein (1.10%) and dietary fiber (1.90%) variables.

Soluble and insoluble fiber values close to those found in this study were obtained in 10 different cassava cultivars (Maieves, 2010). However, higher ash values (1.27% to 2.72%) were observed in 8 cassava varieties (Oliveira et al., 2007).

Moisture ranged from 56.26% to 65.96% (values not shown), with mean value of 60.85% (Table 1), and no significant effects between treatments and storage periods were observed in this variable. Oliveira et al. (2003) observed similar moisture values (63.60% to 65.54%) for minimally processed cassava stored for 28 days. The minimally processed *Baianinha* cultivar had mean moisture value of 57.01% during storage (Bezerra et al., 2002). Mean moisture values of 57% were obtained in fresh, *in natura* cassava roots, bleached and stored under refrigeration at 5 °C for 28 days (Alves et al., 2005).

Total solids ranged between 34.04% and 43.74% (values not shown), with mean value of 39.15% (Table 1), although without significant differences between treatments and storage periods. Dry matter content in IAC 576-70 cassava cultivar was 43.58% (Mezette et al., 2009), which was similar to some values found in this study. A lower value of 40.90% for the *Pioneira* cultivar and 42.30% for the *Catarina Amarela* cultivar were found by Pereira & Beléia (2004), which were in the total solids range observed in this study.

Physicochemical Analysis - pH and Titratable Acidity

The H_2O+CA treatment had the lowest pH values during the storage period (Table 3), differing from the other treatments evaluated in the same day of analysis from the third day of storage. Significant decrease in roots pH value was caused by the addition of 2.5% citric acid in the water where they were kept during storage.

Table 1 - Summary of analysis of variance with indication of degrees of freedom (DF), mean squares (MS) and coefficients of variation (CV) of humidity, in percentage (HU), total solids, in percentage (TS), pH, titratable acidity, in g of citric acid in 100 grams of fresh matter (TA), soluble solids, in ºBrix (SS), SS/TA ratio and ascorbic acid, in milligrams per 100 grams of fresh matter (AA) evaluated in minimally processed cassava roots submitted to control, vacuum, citric acid, water plus citric acid and water in relation to storage days.

Souces of variation	DF	MS						
		HU	TS	pH	TA	SS	SS/TA	AA
Treatments (T)	4	26.37	26.47	31.56*	3.89*	10.43*	1263*	2479*
Storage (S)	8	12.16	12.20	0.84*	0.08*	8.39*	171*	2292*
T x S	32	6.36	6.34	0.61*	0.08*	1.49*	75.82*	96.14*
Residue	90	14.21	14.22	0.22	0.002	0.73	18.38	18.80
CV (%)	-	6.20	9.63	2.68	11.28	15.76	25.27	7.64
Mean	-	60.85	39.15	5.56	0.47	5.44	16.97	56.72

*Significant at 5% error probability by F test

Table 2 - Summary of analysis of variance with indication of degrees of freedom (DF), mean squares (MS) and coefficients of variation (CV) of cooking time, in minutes (CT), general appearance (GA), color (COR), texture (TX) and aroma (AR) evaluated in minimally processed cassava roots submitted to CONTROL, vacuum, citric acid, water plus citric acid and water in relation to storage days

Souces of variation	DF	MS	DF	MS			
		CT		GA	COR	TX	AR
Treatments (T)	4	873*	4	12.80*	8.71*	2.01	11.27*
Storage (S)	4	109*	6	50.42*	17.35*	31.34*	29.13*
T x S	16	66.56*	24	16.09*	12.07*	6.97*	7.04*
Residue	50	2.80	1015	2.51	2.66	2.94	3.50
CV (%)	-	7.83	-	22.45	23.09	24.59	27.90
Mean	-	21.35	-	7.06	7.06	6.97	6.71

*Significant at 5% error probability by F test

Table 3 - Mean comparison of pH and titratable acidity (TA) of minimally processed cassava roots submitted to the control (CONTROL), vacuum (VAC), citric acid (CA), water plus citric acid (H_2O+CA) and water (H_2O) treatments in relation to days of storage (DS).

DS	pH in function of the treatment					TA (g citric acid 100 g^{-1} fresh mass) in function of the treatment				
	CONTROL	VAC	CA	H_2O+CA	H_2O	CONTROL	VAC	CA	H_2O+CA	H_2O
0	6.14 Aa	6.13 Aa	6.14 Aa	6.13 Aa	6.13 Aa	0.30 Aa	0.31 Ba	0.30 Aa	0.31 Ea	0.31 Aa
3	6.17 Aa	5.97 Aa	5.59 Bb	4.00 Bc	6.15 Aa	0.35 Ab	0.27 Bb	0.36 Ab	1.10 Da	0.31 Ab
7	6.16 Aa	6.12 Aa	6.02 Aa	3.72 Cb	6.35 Aa	0.25 Bc	0.37 Ab	0.34 Ab	1.19 Ca	0.33 Ab
11	5.98 Ab	6.21 Aa	5.91 Ab	3.30 Dc	5.98 Bb	0.17 Bc	0.22 Bc	0.42 Ab	1.11 Da	0.35 Ab
14	6.05 Aa	6.08 Aa	5.70 Bb	3.44 Dc	5.65 Cb	0.25 Bc	0.37 Ab	0.37Ab	1.26 Ca	0.29 Ac
17	6.21 Aa	6.15 Aa	5.73 Bb	3.04 Ec	6.03 Ba	0.35 Ab	0.25 Bc	0.36 Ab	1.18 Ca	0.25 Bc
21	5.96 Ab	6.25 Aa	5.78 Bb	3.08 Ec	6.13 Aa	0.30 Ac	0.23 Bc	0.38 Ab	1.36 Ba	0.27 Bc
24	6.28 Aa	6.25 Aa	5.86 Ab	2.95 Ec	6.32 Aa	0.24 Bc	0.39 Ab	0.40 Ab	1.59 Aa	0.24 Bc
28	6.07 Aa	6.12 Aa	5.69 Bb	3.08 Ec	5.91 Ba	0.20 Bc	0.27 Bb	0.33 Ab	1.23 Ca	0.21 Bc

Means followed by the same uppercase letters in the columns and lowercase letters in the lines do not differ from each other, at 5% error probability, by the Scott and Knott's test

CA treatment pH values were not as low as those of H_2O+CA treatment. This was because minimally processed cassava roots were immersed in the antioxidant solution for only 5 minutes in the CA treatment, with the excess solution being drained from the roots soon afterwards, forming only a surface treatment. Cassava pieces packed in polyethylene + EVOH bags stored at temperatures of 4 °C for 28 days had a mean pH value of 6.89 (Oliveira et al., 2003).

Titratable acidity values ranged from 0.17 to 1.59 g citric acid per 100 g^{-1} of fresh matter (Table 3), with mean value of 0.47 g citric acid per 100 g^{-1} of fresh matter (Table 1). The H_2O+CA treatment had the highest acidity values over the storage period, corresponding to low pH values (Table 3). Acidity of cassava roots of the same cultivar *in natura* was of 1.57%, while acidity ranged between 1.39% and 3.44% for minimally processed cassava treated with 5% citric acid solution (Oliveira et al., 2003), being significantly higher than the CA treatment in this study. Difference may be due to a lower antioxidant solution concentration (2.5%). However, the H_2O+CA treatment showed almost identical values (1.59%) to those obtained by the authors.

Soluble Solids and SS/TA Ratio

Soluble solids oscillated over the storage period in all treatments. The largest reduction occurred in the product stored in H_2O+CA and only in H_2O (Table 4). Possibly, storage with liquid immersion may have leached minimally processed cassava roots soluble solid contents. Soluble solid contents reduced until the third day of storage for CA, H_2O+CA and H_2O treatments. For CONTROL and VAC treatments, reduction lasted until the seventh day. Although soluble solids content varied between treatments, values were ranged between 3.53 °Brix to 6.97 °Brix, with mean value of 5.44 ° Brix (Table 1), close to the variation between 4.0 °Brix at 6.0 °Brix verified by Silva et al. (2003). Soluble solids content decrease occurs after plant harvesting due to internal reactions, which are not only catabolic (destruction), but also anabolic (synthesis), leading to energy expenditures that decrease soluble solids (Oliveira & Cereda, 1999). Soluble solids increase in some periods and treatments may have occurred due to normal variations in the raw material of cassava samples used in the study.

Table 4 – Mean comparison of soluble solids (SS) and SS/TA ratio of minimally processed cassava roots submitted to the control (CONTROL), vacuum (VAC), citric acid (CA), water plus citric acid (H_2O+CA) and water (H_2O) treatments in relation to days of storage (DS).

DS	SS (ºBrix) in function of the treatment					SS/TA Ratio in function of the treatment				
	CONTROL	VAC	CA	H_2O+CA	H_2O	CONTROL	VAC	CA	H_2O+CA	H_2O
0	6.97 Aa	6.97 Aa	6.97 Aa	6.97 Aa	6.97 Aa	22.95 Aa	22.92 Ba	22.95 Aa	22.92 Aa	22.92 Aa
3	4.93 Ba	4.33 Ca	4.60 Ba	4.93 Ba	4.80 Ba	14.42 Ba	17.69 Ca	12.86 Ba	4.42 Bb	16.65 Ba
7	4.87 Ba	4.10 Ca	5.53 Ba	5.00 Ba	4.90 Ba	19.24 Ba	11.16 Ca	16.24 Ba	4.21 Bb	14.88 Ba
11	5.07 Bb	6.67 Aa	5.70 Ba	5.20 Bb	4.33 Bb	29.17 Aa	34.10 Aa	13.52 Bb	4.62 Bc	12.42 Bb
14	6.47 Aa	5.60 Ba	5.70 Ba	4.17 Cb	4.50 Bb	26.52 Aa	14.82 Cb	15.60 Bb	3.29 Bc	15.28 Bb
17	6.30 Aa	6.50 Aa	7.23 Aa	5.23 Bb	5.57 Ab	18.03 Ba	26.40 Ba	20.28 Aa	4.43 Bb	22.29 Aa
21	6.40 Aa	6.47 Aa	6.47 Aa	4.50 Bb	4.30 Bb	23.87 Ab	31.14 Aa	17.35 Bc	3.28 Bd	16.18 Bc
24	5.83 Aa	5.37 Ba	4.67 Ba	3.53 Cb	3.57 Bb	24.10 Aa	14.03 Cb	12.33 Bb	2.22 Bc	15.46 Bb
28	6.00 Aa	6.67 Aa	6.83 Aa	3.60 Cb	3.70 Bb	29.57 Aa	25.58 Ba	20.66 Ab	2.93 Bc	17.61 Bb

Means followed by the same uppercase letters in the columns and lowercase letters in the lines do not differ from each other, at 5% error probability, by the Scott and Knott's test

SS/TA ratio oscillated from 2.22 to 34.10 throughout the storage period (Table 4), with mean value of 16.97 (Table 1). The lowest values were found in the H_2O+CA treatment due to soluble solid contents decrease and titratable acidity increase during storage. Ratio values tend to increase during plant maturation due to sugar content increase and acid content decrease. In general, this behavior occurred for CONTROL and VAC treatments, which had higher values at the end of storage than those obtained at day zero. The SS/TA ratio that indicates sensory balance is between 12 and 18 (Carvalho et al., 1990). In all treatments, SS/TA ratio values were above or below the balance range in most days of analysis. No values were found in the literature that could classify cassava through this variable. SS/TA ratio values are generally a good flavor indicator, giving an idea of balance between the two components (Fernandes et al., 2010).

Ascorbic Acid and Cooking Time

Ascorbic acid values ranged from 19.64 to 76.23 mg ascorbic acid per 100 g^{-1} fresh matter (Table 5), with mean value of 56.72 mg ascorbic acid per 100 g^{-1} fresh matter (Table 1). The highest value was found in the VAC treatment, on the 3rd day of storage, and the lowest value was found in the H_2O+CA treatment, on the 28th day of storage. Vitamin C is soluble in water. In addition, very low pH, as the one found for this treatment (Table 3), facilitates the oxidation of this acid. However, contrary to what occurred in this study, Sebastiany et al. (2008) stated that vitamin C is more stable in acidic medium and low temperatures.

Table 5 - Mean comparison of ascorbic acid (AA) and cooking time of minimally processed cassava roots submitted to control (CONTROL), vacuum (VAC), citric acid (CA), water plus citric acid (H_2O+CA) and water (H_2O) treatments in relation to days of storage (DS).

DS	AA (mg 100 g^{-1}) in function of the treatment					Time for cooking (in minutes) in function of the treatment				
	CONTROL	VAC	CA	H_2O+CA	H_2O	CONTROL	VAC	CA	H_2O+CA	H_2O
0	75.79 Aa	75.76 Aa	75.79 Aa	75.76 Aa	75.76 Aa	16.67 Ba	16.67 Ba	16.83 Ba	16.83 Ba	16.83 Aa
3	72.78 Aa	76.23 Aa	74.22 Aa	57.31 Bc	65.43 Bb	18.33 Ac	14.67 Bd	25.33 Ab	NC Aa	18.33 Ac
7	66.27 Aa	73.64 Aa	67.23 Ba	51.51 Cb	68.14 Ba	NA	NA	NA	NA	NA
11	71.81 Aa	72.41 Aa	66.83 Ba	46.69 Cb	73.42 Aa	NA	NA	NA	NA	NA
14	52.48 Ba	52.85 Ca	50.91 Ca	34.02 Db	46.05 Ca	20.00 Ab	20.33 Ab	18.00 Bb	39.33 Aa	18.00 Ab
17	56.40 Bb	49.73 Cb	54.82 Cb	31.08 Dc	64.29 Ba	NA	NA	NA	NA	NA
21	52.03 Bb	61.22 Ba	49.32 Cb	19.87 Ec	53.29 Cb	NA	NA	NA	NA	NA
24	56.69 Ba	54.54 Ca	47.38 Cb	22.34 Ec	50.79 Cb	16.00 Bc	17.33 Bc	19.67 Bb	NC Aa	19.97 Ab
28	49.03 Ba	50.49 Ca	41.50 Db	19.64 Ec	48.70 Ca	14.97 Bc	16.00 Bc	16.33 Bc	NC Aa	19.00 Ab

Means followed by the same uppercase letters in the columns and lowercase letters in the lines do not differ from each other, at 5% error probability, by the Scott and Knott's test. NA = not analyzed. NC = not cooked

Minimally processed cassava roots of *Baianinha* cultivar showed mean ascorbic acid content of 38.90 mg per 100 g^{-1} of fresh pulp after 18 days of storage (Bezerra et al., 2002), which was lower than data obtained in this study, except for the H_2O+CA treatment after 14 days of storage. In general, there was ascorbic acid content reduction in all treatments during storage. Ascorbic acid usually decreases during storage of minimally processed products (Rinaldi et al., 2009). Damage from cutting and enzyme interaction may lead to ascorbic acid loss (Klein, 1987). However, there was ascorbic acid content increase during the

storage period of minimally processed cassava of *Pernambucana* cultivar, with lower initial value (32.02 mg 100 g^{-1}) (Silva, 2009).

Minimally processed cassava roots submitted to H_2O+CA treatment were the only ones that did not cook (Table 5). The acid medium may have caused cell wall changes in the product, not allowing the starch to gel. Cooking time is of great importance in cassava market for food (Moreto & Neubert, 2014). In this study, cooking time increase or reduction in samples of treatments that were cooked may be due to intrinsic features of the sample. Bezerra et al. (2002) observed significant differences in cooking time of minimally processed cassava roots in relation to storage periods, even with reduced value amplitude, ranging from 24.85 to 27.70 minutes. Variation was within the time range obtained in this study (14.67 to 25.33 minutes), which is within the acceptable limit to market cassava for food, 30 minutes (Fukuda et al., 2002). However, Talma et al. (2013) stated that the lower the cooking time, the better the mass quality, considering between 15 and 25 minutes as the optimal time.

Sensory Analyzes - General Appearance and Color

The highest score (8.00) attributed by the judges to the overall appearance was given to the raw material at day zero (Table 6). On the third day of storage, minimally processed cassava submitted to the VAC treatment received a significantly lower score (6,17) than the other treatments, remaining practically constant until the seventh day of storage, when, along with the H_2O treatment, it obtained the lowest score.

On the 28th day, CONTROL and CA treatments obtained the lowest values for this attribute during the storage period, which were considered unsuitable for commercialization (mean score ≤ 5.0). Negative appearance, according to the majority of the judges, was due to the high incidence of visible mold in the roots, which was confirmed by results obtained in the microbiological analysis (Table 8). Therefore, it was confirmed that these two treatments were not very efficient in the maintenance of sensorial quality and microbiology of minimally processed cassava roots.

Table 6 – Mean comparison of general appearance and color of minimally processed cassava roots submitted to control (CONTROL), vacuum (VAC), citric acid (CA), water plus citric acid (H_2O+CA) and water (H_2O) treatments in relation to days of storage (DS).

DS	General appearance in function of the treatment					Color in function of the treatment				
	CONTROL	VAC	CA	H_2O+CA	H_2O	CONTROL	VAC	CA	H_2O+CA	H_2O
0	8.00 Aa	8.00 Aa	8.00 Aa	8.00 Aa	8.00 Aa	7.50 Aa	7.50 Aa	7.50 Aa	7.50 Aa	7.50 Aa
3	7.60 Aa	6.17 Bb	7.47 Aa	7.60 Aa	7.13 Aa	7.53 Aa	6.30 Bb	7.47 Aa	7.40 Aa	7.23 Aa
7	7.73 Aa	6.23 Bb	7.30 Ba	7.13 Aa	6.17 Bb	7.80 Aa	6.60 Bb	7.40 Aa	7.33 Aa	6.17 Bb
14	7.73 Aa	7.50 Aa	7.70 Aa	7.67 Aa	7.30 Aa	7.47 Aa	7.50 Aa	7.57 Aa	7.37 Aa	7.37 Aa
21	6.50 Ba	6.70 Ba	6.63 Ba	6.80 Aa	7.33 Aa	6.50 Ba	6.27 Ba	6.53 Ba	6.83 Aa	7.37 Aa
24	5.83 Bb	6.97 Ba	7.13 Ba	7.37 Aa	6.03 Bb	6.20 Bb	7.03 Aa	7.53 Aa	7.57 Aa	5.97 Bb
28	5.00 Cc	6.27 Bb	4.63 Cc	7.67 Aa	7.87 Aa	5.83 Bc	6.67 Bb	5.27 Cc	7.73 Aa	7.80 Aa

Means followed by the same uppercase letters in the columns and lowercase letters in the lines do not differ from each other, at 5% error probability, by the Scott and Knott's test

For the color attribute, scores ranged from 7.80 to 5.27 (Table 6). The highest score was obtained by the CONTROL treatments on the seventh day and by H_2O on the twenty-eighth day of storage. The lowest score was obtained for the CA treatment on the 28th day of storage. In general, there was little storage time influence on color attribute for minimally processed cassava roots. Until the end of the storage, none of the treatments scored equally or below the standard for commercialization.

Texture and Aroma

Most of treatment scores oscillated for the texture attribute (Table 7). The highest score for this attribute was 7.70, on the seventh day of storage, for the H_2O+CA treatment, which was statistically equal to all other treatments (Table 7). According to the judges, minimally processed cassava roots had the typical cooked cassava aroma, justifying the good acceptability of the product. According to the results obtained in relation to the cooking time of roots submitted to this treatment (Table 5), roots only cooked after minimum processing (day zero). From the third day of storage, treatment may have influenced sample aroma.

The storage was only significant for the aroma attribute for CONTROL, VAC and CA treatments (Table 7). Besides being rejected by the judges on the 28th day of storage due to the general appearance attribute (Table 6), the CA treatment was also rejected by the aroma attribute, with scores of 4.57 on the same day of analysis. The judges described the aroma of the minimally processed cassava roots submitted to these treatments as roots that had mold smell, which was confirmed by the high incidence of molds and yeasts observed visually, and by microbiological analysis results (Table 8).

Microbiological Analysis

Total count of mesophilic aerobes in the raw material was of 4.9 x 10^2 CFU/g, which was considerably low for a soil product.

Total psychrotrophic count increased in CONTROL, VAC, CA and H_2O treatments on the 14th and 28th days of storage (Table 8). At 28 days of storage, the H_2O+CA treatment also showed high psychrotrophic count, confirming that refrigeration temperature may not provide sufficient safety for minimally processed cassava (Verzeletti et al., 2010). Thus, psychrotrophs may eventually overcome temperature, showing the need for additional barriers in storage systems, in order to ensure product safety. In the Brazilian legislation, there is no standard for total psychrotrophic counts in foods, although products with high psychrotrophic counts should not be recommended for commercialization and consumption.

Table 7 - Mean comparison of texture and aroma of minimally processed cassava roots submitted to control (CONTROL), vacuum (VAC), citric acid (CA), water plus citric acid (H_2O+AC) and water (H_2O) treatments in relation to days of storage (DS).

DS	Texture in function of the treatment					Aroma in function of the treatment				
	CONTROL	VAC	CA	H_2O+CA	H_2O	CONTROL	VAC	CA	H_2O+CA	H_2O
0	7.80 Aa	7.80 Aa	7.80 Aa	7.80 Aa	7.80 Aa	6.83 Aa	6.83 Aa	6.83 Aa	6.83 Aa	6.83 Aa
3	7.17 Aa	6.63 Aa	7.03 Aa	7.10 Aa	6.77 Ba	7.23 Aa	6.43 Aa	6.97 Aa	6.80 Aa	6.80 Aa
7	7.63 Aa	7.03 Aa	7.10 Aa	7.20 Aa	6.20 Bb	7.20 Aa	6.97 Aa	7.10 Aa	7.70 Aa	6.87 Aa
14	7.13 Aa	7.17 Aa	7.10 Aa	7.37 Aa	7.40 Aa	6.97 Aa	6.63 Aa	7.20 Aa	7.40 Aa	7.27 Aa
21	6.50 Ba	6.80 Aa	7.00 Aa	6.57 Aa	7.23 Aa	5.77 Bb	6.40 Ab	6.70 Aa	7.17 Aa	7.23 Aa
24	5.77 Bb	6.77 Aa	7.00 Aa	6.90 Aa	6.10 Bb	5.87 Ba	6.83 Aa	6.93 Aa	6.50 Aa	6.43 Aa
28	5.93 Bc	6.63 Ab	5.37 Bc	6.80 Ab	7.60 Aa	5.03 Bb	6.37 Aa	4.57 Bb	6.63 Aa	6.67 Aa

Means followed by the same uppercase letters in the columns and lowercase letters in the lines do not differ from each other, at 5% error probability, by the Scott and Knott's test

Table 8 - Mean values of microbiological analysis of minimally processed cassava roots submitted to control (CONTROL), vacuum (VAC), citric acid (CA), water plus citric acid (H2O+AC) and water (H_2O) treatments in relation to days of storage (DS).

Treatment	Total psychrotrophs count (CFU/g)	Total molds and yeasts count(CFU/g)	Total coliforms (MPN/g)	Thermotolerant coliforms (MPN/g)
		Zero day		
Matéria-prima	<2.5 x 10^1 est	2.6 x 10^3	0.36 x 10^1	<3
MMP	<2.5 x 10^1 est	4.0 x 10^2 est	<3	<3
		14th day		
CONTROL	2.4 x 10^6	1.3 x 10^6	0.36 x 10^1	<3
VAC	1.2 x 10^6	3.8 x 10^5	0.74 x 10^1	<3
CA	1.6 x 10^5	7.3 x 10^3	2.1 x 10^1	<3
H_2O+CA	1.5 x 10^2 est	2.3 x 10^2 est	<3	<3
H_2O	1.1 x 10^5	6.0 x 10^3	<3	<3
		28th day		
CONTROL	7.7 x 10^5	5.0 x 10^6 est	<3	<3
VAC	5.2 x 10^6 est	3.9 x 10^6 est	<3	<3
CA	3.0 x 10^5	8.5 x 10^4	<3	<3
H_2O+CA	4.9 x 10^5	3.1 x 10^3	<3	<3
H_2O	4.6 x 10^6 est	5.5 x 10^6 est	<3	<3

MPC: Minimally Processed Cassava; est .: Estimated count.

CONTROL and VAC treatments, on all days in which they were evaluated, as well as the H_2O and CA treatments on the 28th day, had high yeast and mold count. Although there is no standard in the Brazilian legislation for mold and yeast counting on minimally processed products, the RDC Resolution No. 12 of January 2, 2001 (Brasil, 2001) provides the limit of 10^3 CFU/g for food safety. Mold and yeast counts ranging from 1.0 x 10^1 CFU/g on the first day of storage to 8.0 x 10^5 CFU/g on the 24th day of storage were obtained in minimally processed cassava (Alves et al., 2005).

The results obtained for total coliform counts showed low values, ranging from <3 to 2.1 x 10^1 MPN/g for both raw material and minimally processed cassava roots. These values show that roots were in good hygienic condition. In thermotolerant coliform counts, there was also low contamination, with maximum value of <3MPN/g, meeting the requirements of RDC Resolution No. 12 of January 2, 2001 (Brasil, 2001). A similar result was obtained in minimally processed cassava roots (Rinaldi et al., 2015ab). Coliform analysis and total aerobe, mold and yeast counts indicated hygienic-sanitary quality and the shelf life of minimally processed cassava (Santos et al., 2010).

With the exception of total psychrotrophic counts, roots submitted to the H_2O+CA treatment had lower microorganism counts, confirming the affirmation by Brito et al. (2015) that pH is related to microorgan-

ism development capacity in the food, i.e., foods with low pH are less susceptible to microorganisms development.

Conclusion

Cassava roots submitted to CA and H_2O treatments had longer shelf life, reaching up to 14 days of storage. The 2.5% H_2O+CA treatment is not recommended for the commercialization of minimally processed cassava roots. New studies should be carried out with the objective of defining the adequate citric acid concentration to be used in minimally processed cassava immersed in water intended for the food market.

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