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Research Article

Effect of Edible Coatings Based on Oxidized Cassava Starch on Color and Textural Properties of Minimally Processed Yam

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Abstract: The effect of the edible coating of oxidized cassava starch along with two packaging conditions on color and textural properties of minimally processed yam was evaluated. The coating suspensions were formulated with an oxidized cassava starch (3 and 5%), ascorbic acid (0.5 and 1%), carnauba wax (0.1 and 0.2%), glycerol (1%), Tween 80 (0.1%) and applied to yam cubes. Samples were packaged in two different conditions (vacuum and non-vacuum). Changes in color and texture properties were measured during 42 days storage at 25°C. A non-vacuum packaging and low wax concentrations increased browning index (61.6%), while the vacuum packaging and this same wax concentration decreased browning index (47.2%). Low acid and high wax concentrations increased 1.52% lightness. A non-vacuum packing and a decrease in wax concentration produces a decrease in hardness (6.37%) of yam while a vacuum packing this same change in wax concentration causes an increase in the hardness (1.51%). In synthesis, a vacuum packing and coatings with 5% of oxidized cassava starch, 0.1% wax and 0.5% of acid maintains the color and hardness of minimally processed yam during storage.

Keywords: Browning index, coating solutions, color, hardness, modified starch, tubers

INTRODUCTION

The cultivation of roots and tubers that comprise mainly potato, cassava, yam, sweet potato, among others, occupy the second place worldwide in sown area and volume of production after cereals. The countries of Latin America and the Caribbean contribute 8% of this production, Colombia is the third largest producer of Cassava in South America with 50,000 ton. And first in production of Yam with 363,036 ton (FAO, 2014). The Hawthorn variety (*D. Rotundata*) is the preferred in the Colombian Caribbean region, its pulp is firm and white, it is marketed fresh in markets and supermarkets and its consumption is usually in cooked form, soups, fried, sweets and other homemade preparations (González Vega, 2012).

Yam is a food with a good source of carbohydrates, mineral salts and vitamins. It also contains riboflavin, niacin, ascorbic acid, pyridoxine and carotene. Its tubers possess most of the essential amino acids, it has low levels of fat, it is good an appetite stimulant and excellent blood purifier (Balogun, 2009). Its high moisture content (50-80% wet basis) makes it a very perishable product, which is reflected in the post-harvest losses, estimated at about 30 to 40%, this being one of the main problems it faces, making it difficult to use, commercialization and export (Andrade *et al*., 2012a; Oyelade *et al*., 2008).

Despite their nutritional benefits, the evidence of processing of this tuber is reduced. In Colombia, 78% of the production is directed to the market in fresh and no technological transformations are known that allow to provide favorable conditions for its conservation. This indicates that the agro-industry of yam has not yet been developed, since only in Africa flour preparation is traditional and does not rule out the existence of small home-type industries dedicated to canning production (Akissoe *et al*., 2011).

Population changes have led to new food trends, generating a growing concern in the world population for the consumption of ready-to-prepare foods (minimally processed) (Rico *et al*., 2007). Research indicates that products such as mangos, sweet potatoes, yams, among others, submitted to the minimum processing (Dussan-Sarria *et al*., 2014; Ojeda *et al*., 2014), become highly perishable, because they lose the protection of the pericarp, modifying their properties. Studies report losses of 25% firmness in potatoes (variety *Desiree*) minimally processed after the first day of storage and constant behavior during the

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remaining days of storage (Rocha *et al*., 2003). In mangos, 59% loss of firmness is evident after 12 days of storage (Navarro *et al*., 2012).

An alternative for the conservation of minimally processed fruits and vegetables are the edible coatings, which arise as an option capable of extending the lifespan of a product, as they act as a semi-permeable barrier to moisture loss, gas exchange and oxidative reactions; They can also serve as a carrier of active ingredients (Chiumarelli and Hubinger, 2014). On the other hand, this alternative has been growing due to the need to reduce and replace the use of synthetic polymers, with the aim to protect the environment, maintain the quality of the products, generate added value and direct them to meet the needs and preferences of the consumer (Elsabee and Abdou, 2013).

Edible coatings can be made from proteins, lipids or polysaccharides (Andrade *et al*., 2012b; Cerqueira *et al*., 2012; Pereda *et al*., 2014). The latter include starch, cellulose derivatives, alginate, pectin, chitosan and various gums (Galus *et al*., 2013; Galus and Kadzińska, 2015). Several studies show that the application of edible coatings in fruits and vegetables improves the retention of the components of color, taste and odor during storage, retards the loss of moisture, firmness and senescence of the product (Ciolacu *et al*., 2014; Dhall, 2013). Freshly cut apples Golden Delicious coated with gellan rubber (0.5% w/v) stored for 14 days, showed a decrease of 2.71% in lightness (L*), compared with uncoated slices (Moreira *et al*., 2015). Also, the firmness of fresh-cut apple coated with rubber gellan remained throughout the storage (Moreira *et al*., 2015).

Starch coatings present good permeability properties to gases (CO_2 and O_2). However, the water vapor permeability property is high. The native starch of cassava has some limitations as a form of coatings, mainly it has a high permeability to the vapor of water because it is highly hydrophilic (Pérez-Gago *et al*., 2003). An alternative to improve this property is the oxidation of starch, which confers low viscosity, clarity of pasta, high stability, binding properties and lower temperature of gelatinization (Sangseethong *et al*., 2010; Ascencio *et al*., 2016).The objective of this study was to evaluate the effect of the application of a coating of oxidized cassava starch in the color and textural properties of the minimally processed yam packaged in vacuum.

MATERIALS AND METHODS

Materials: Fresh tubers of yam (*Dioscorea rotundata*), with uniform size, without any mechanical and pathological injuries, were obtained from a local farm (Sucre, Colombia). The native starch of cassava was used from starches of Sucre S.A.S. (Sincelejo, Sucre).

Modification of starch: The oxidation of starch was carried out at 35°C with sodium hypochlorite (NaOCl), following the methodology proposed by Rivas-González *et al*. (2008) and Wang and Wang (2003).

Preparation of the coating solutions: The suspensions of coatings were prepared by mixing oxidized cassava starch (3 and 5%), ascorbic acid (0.5 and 1%), carnauba wax (0.1 and 0.2%), glycerol (1%) and Tween 80 (0.1%). This suspension was heated with constant stirring at 80°C for 30 min to ensure starch gelatinization. It was left to cool down and then it was applied.

Yams coating: Yams were shelled and were cut up in cubes with an edge of 3 cm, were immersed in sodium hypochlorite solution (0.0001%) and then in ascorbic acid solution (0.0003%). Subsequently, the yam cubes were dipped into coating solutions for 30s. The residual solution was allowed to drip off for 1 min and yam cubes allowed to air-dried for 5 min at 25°C. Next, nine yam cubes were packaged into polyethylene film in atmospheric and vacuum-packaging conditions and heat-sealed using a chamber machine for vacuum packaging (M-300T, Barbi). All samples were stored at 25±1°C until their analyses after storage for 0, 7, 14, 21, 28, 35 and 42 days. Three replicates were set up for each treatment.

Determination of hardness: Yams hardness evaluation was performed using a TA-XT Plus Texture Analyzer (Stable Micro Systems Ltd., England, UK) by measuring the maximum penetration force required for a 6.35 mm diameter probe to penetrate into a yam cube (edge of 3 cm) at a rate of 1 mm/s.

Determination of color: Minimally processed yam surface color was directly measured with a Colorflex EZ 45 (HunterLab) colorimeter. The color was measured using the CIE L*, a*, b* coordinates. Illuminant D65 and 10° observer angle were used. L* value indicates lightness of the color, which range from 0 (black) to 100 (white). The positive value of a* indicates red color, while the negative value of a* indicates green color. The positive value of b* indicates yellow color, while the negative value of b* indicates blue color.

Determination of browning index: Browning index was determined by measuring the extent of the total brown area on each coated yam surface using the following scale: 1:no browning, 2: <20% of the surface, 3: 20-40% of the surface, 4: 40-60% of the surface and, 5: >60% of the surface, according to Luo *et al*. (2015). The flesh browning index was calculated according to the following equation:

$$BI = \frac{\sum \begin{array}{c}\text{browning level x number of pieces}\\ \text{with that browning level}\end{array}}{\text{total number of pieces}}$$

Table 1: Treatments applied to minimally processed yams

Treatment	Concentration of starch (%)	Wax concentration (%)	Acid concentration (%)	Packaging system
T1	3	0.2	0.5	Vacuum
T2	5	0.2	0.5	Non-vacuum
T3	3	0.2	1	Non-vacuum
T4	3	0.1	0.5	Non-vacuum
T5	3	0.1	1	Vacuum
T6	3	0.1	0.5	Vacuum
T7	5	0.1	0.5	Vacuum
T8	3	0.2	0.5	Non-vacuum
T9	3	0.1	1	Non-vacuum
T10	5	0.1	1	Non-vacuum
T11	5	0.1	1	Vacuum
T12	3	0.2	1	Vacuum
T13	5	0.2	0.5	Vacuum
T14	5	0.1	0.5	Non-vacuum
T15	5	0.2	1	Non-vacuum
T16	5	0.2	1	Non-vacuum

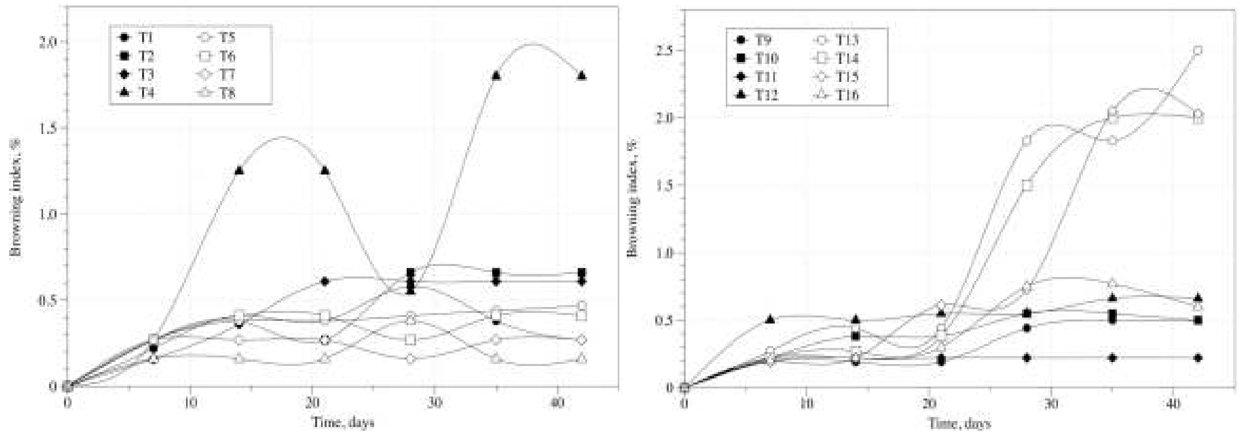

Fig. 1: Browning index changes of coated yam pieces during storage

Statistical analysis: The experiment was studied under a completely randomized design with 2^4 factorial arrangement and variables tested were concentration of oxidized starch (3% and 5%), concentration of carnauba wax (0.1% and 0.2%), concentration of ascorbic acid (0.5% and 1%) and packing system (vacuum of 99% and non-vacuum) (Table 1). The variables responses were browning index, color and hardness. The analysis of variance was performed at a level of 95% confidence ($p \leq 0.05$) and to compare the mean values, the Tukey multiple range test was used. The data were processed by the Statgraphics software Centurion XVI.I.

RESULTS AND DISCUSSION

Browning index in coated yam: The mean values of the percentage of the browning index of minimally processed yams coated with oxidized cassava starch during the storage time were in an average range of 0.23 to 0.76%. In Fig. 1 is observed that all the treatments presented an increase in the browning index at the end of the storage time. Similar behavior was found in fresh-cut Chinese yam to nano-packaging, which showed an increase of 1.55% during 5 days of storage at 10°C, but 33% lower than the uncoated samples (Luo *et al*., 2015). Also, Ojeda *et al*. (2014) reports that sweet potatoes variety CV. *Blanca correntina* minimally processed coated with cassava starch and ascorbic acid showed increments of 0.15% in the browning index after 16 days of storage.

The ANOVA shows that all the factors studied and the interactions concentration of oxidized starch * carnauba wax (p = 0.00), concentration of carnauba wax*ascorbic acid (p = 0.00), carnauba wax concentration*packing system (p = 0.00), oxidized starch concentration*packing system (p = 0.00) and packing system*storage time (p = 0.015) significantly affected the browning index (%).

With a lesser storage time, the vacuum packed and greater concentration levels of ascorbic acid in the edible coating reduction is generated in the browning rate of the yam. This reduction was also present in Chinese-packed yams in modified atmospheres, lychees coated with chitosan and salicylic acid for 6 days, sweet potatoes coated with cassava starch and ascorbic acid for 16 days (Luo *et al*., 2015; Ojeda *et al*., 2014). The incidence of storage time in the browning rate is explained considering that after peeling and cutting the vegetables, the compartmentalization of the cells disappears and enzymes such as polyphenoloxidase can act on phenol substrates, which results in darkening reactions, which become greater as time increases (Olivas *et al*., 2007). It is noteworthy that ascorbic acid is one of the most effective substances to inhibit enzymatic browning, as it acts by lowering the pH and functions as an inhibitor of the reaction by converting quinone into phenols (Lee, 2007). Besides, the effectiveness of vacuum packaging is because it acts as a barrier to the oxygen of the medium, which delays the processes of browning of fruits and vegetables.

On the other hand, the interactions concentration of ascorbic acid*carnauba wax and packing system* carnauba wax concentration presented the highest coefficients, which represents a greater effect on the variable response compared with the other interactions. The Tukey test showed differences in the browning index for the levels of the wax concentration factor in the high level of ascorbic acid. At low concentrations of ascorbic acid (0.5%), an increase in the concentration of carnauba wax results in a decrease of 19% in the Browning index, while high concentrations of ascorbic acid, this same increase in wax, increases the browning index by 81.2%. The combined effect wax-acid is associated in that the wax can act as a barrier to the water and the acid acts as inhibitor of the enzyme responsible for the browning (Hu *et al*., 2007), but this barrier is greater in low concentrations of wax, while it decreases at high concentrations (Chiumarelli and Hubinger, 2014) which affects the antioxidant action of ascorbic acid.

For the interaction of the packaging system*carnauba wax concentration, the Tukey test shows that there are differences in the browning index for the levels of the packing system factor in the low level of carnauba wax concentration. When non-vacuum packaged conditions at low wax concentrations (0.1%), an increase of 61.6% is generated, while a vacuum packaged at this same concentration of wax causes a decrease of 47.2%. This decrease can be due to the elimination of oxygen inside the package that is generated with vacuum packaging, which allows to reinforce the barrier that forms the wax at low concentrations (Chiumarelli and Hubinger, 2014) converting this combination into a barrier to the passage of oxygen, which is not present in a packaged atmosphere, where the air contained in the packaging and the weak barrier formed at high concentrations of wax allow an increase in the Yam browning.

Color parameters of coated yam: The average lightness (L*) values obtained for minimally processed yams coated with oxidized cassava starch in the storage time (0 to 42 days) ranged from 75.32 to 83.77. In Fig. 2 is observed that the treatments showed decreases of approximately 10% at the end of the storage. This coincides with similar studies in minimally processed potatoes treated with ascorbic acid and ozone that report 14.9% decreases in lightness at 28 days of storage (Calder *et al*., 2011). Decreases of 16.2% in lightness after 17 days of storage in pieces of sweet potatoes coated with cassava starch added with ascorbic acid (Ojeda *et al*., 2014) were also reported.

The ANOVA shows that all the factors studied and interactions concentration of ascorbic acid*carnauba wax (p = 0.0042), oxidized starch concentration*storage time (p = 0.0004), storage time*packing system (p = 0.0049) significantly affected the lightness (L*). The coefficients of all the significant factors presented negative values. This indicates that at the final time of storage when the yam is vacuum packed and the coating contains the highest levels of concentration of oxidized starch and

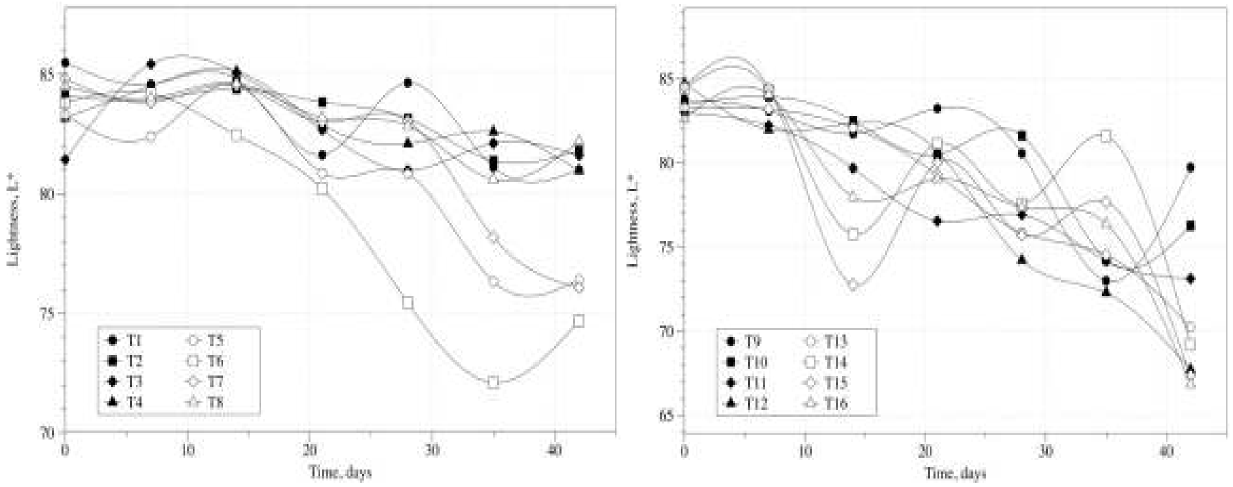

Fig. 2: Behavior of lightness (L*) of coated yam pieces with storage time

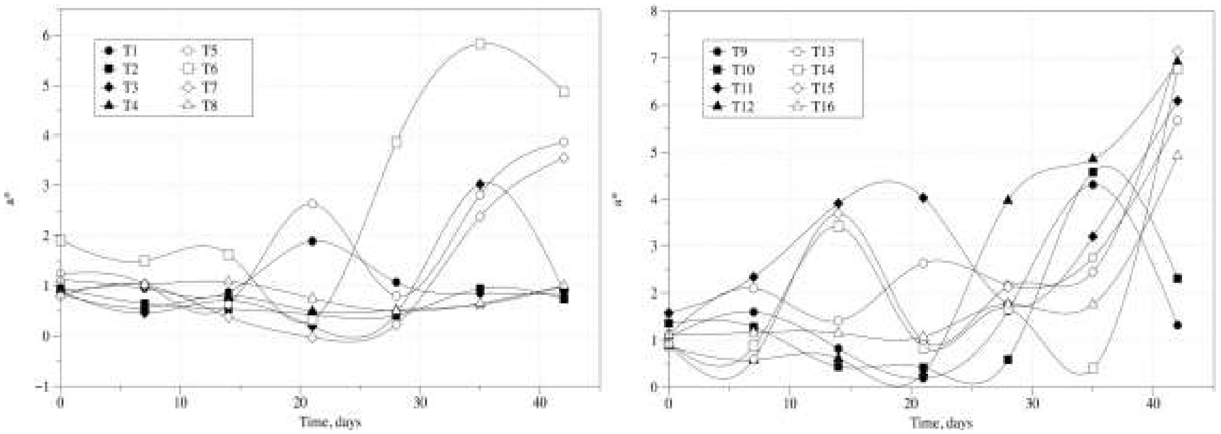

Fig. 3: Behavior of a* of coated yam pieces with storage time

ascorbic acid, the lowest values of lightness are present. It is worth mentioning that the storage time has a greater effect on the lightness, to present this factor the greater value of the coefficient. This decrease in lightness is similar to that found in minimally processed products such as potatoes stored for 28 days (Calder *et al*., 2011), sweet potatoes stored for 17 days (Ojeda *et al*., 2014) and apples stored for 15 days (Moreira *et al*., 2015). This behavior is associated with the minimally processed foods. By including operations that alter the integrity of the product tissue, once the fruit is cut and peeled, the underlying tissue is exposed to the environment and when contact is made with oxygen, the enzyme polyphenoloxidase acts generating browning whose effect increases as the time elapses, taking into account that the value of L* is used as an indicator of browning (Villacorta and Vásquez, 2013).

The concentration interaction of ascorbic acid*carnauba wax according to the Tukey test presented differences in the lightness of high and low levels of the factors. Low level of wax (0.1%), an increase in the acid concentration effect a significant change in the lightness (1.52%), meanwhile high concentrations of wax (0.2%) the same level of acid increase produced a reduction of 3.76%. This reduction in lightness indicates the trend towards a dark (black) color of the sample, which can be associated with the increase in wax concentration, the barrier to the water exchange around the food is made weak, which results in a greater exposure to oxygen of the medium, thus reducing the antioxidant action of the ascorbic acid (Pérez-Gago *et al*., 2003; Calder *et al*., 2011).

The average values of a* obtained for minimally processed yams coated with oxidized starch of yucca packed in the atmosphere and vacuum during the storage time were in an approximate range of 1.09 to 3.61. In Fig. 3, the behavior of the parameter a* is represented for all the treatments during the storage time, which showed a tendency to red hues (a*) and an increase of 229% at the end of the storage time (42 days). Other studies report increases at the end of storage (14 days) of 143% in minimally processed yams coated with cassava starch and ascorbic acid and 200% in potato chunks treated with ozone and ascorbic acid (Calder *et al*., 2011; Ojeda *et al*., 2014).

The ANOVA shows that the ascorbic acid concentration factors (p=0.0156), packing system (p = 0.0004), storage time (p = 0.0000) and the concentration interaction of the starch*storage time (p = 0.0305), significantly affected the values of the a*. The vacuum-packed yam, high levels of ascorbic acid and a greater storage time presented greater values of the parameter a*. This could be associated with the enzymatic browning, which results in colors closer to red hues. This behavior was also reported in minimally processed potatoes at the end of the 28-day storage period (Calder *et al*., 2011), In sweet potatoes treated with ascorbic acid (5%) stored for 17 days (Ojeda *et al*., 2014) and in potatoes stored for 15 days vacuum packed and treated with ozone. However, the minimal processing next to a vacuum package causes less color changes in light-colored fruits, sensitive to enzymatic browning, since with the reduction of oxygen in the interior of the product the oxygen concentration in the fruit tissue, therefore, the oxidation reaction speed slows down and results in a good color to the final product (Zhao and Xie, 2004).

According to the Tukey test there exists significant differences in parameter a*, there are significant differences in parameter a* for high starch level at the high level of storage day. At low levels of oxidized starch (3%) an increase in storage time produces decreases of 22.72% in the values of a *, while, at high levels of oxidized starch, this same increase in storage time generates increments of 324.6%, indicating the presence of shades close to the red color, which may be related to the enzymatic browning that is present in the cut fruits. This may be associated with that although polysaccharide coatings such as starch generate a high barrier to gases and their use in many cases decreases

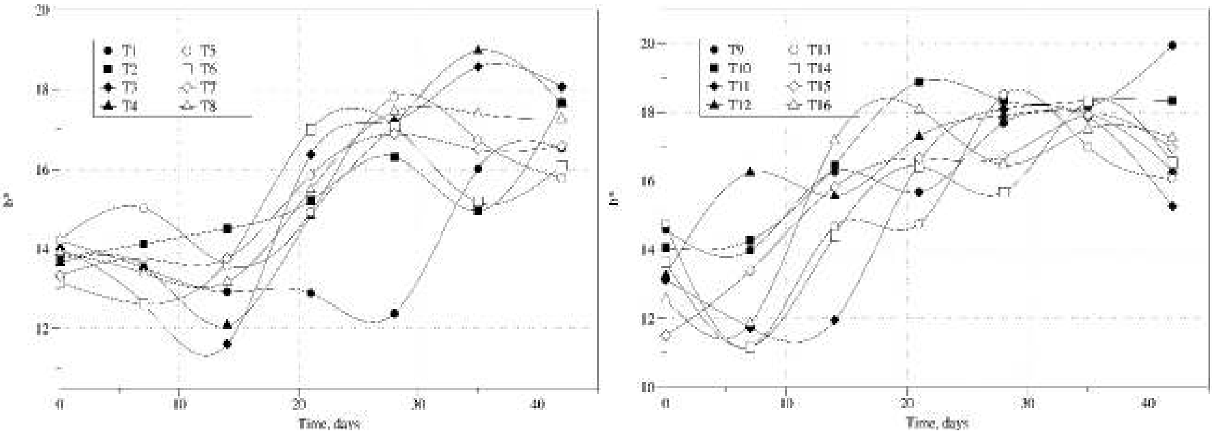

Fig. 4: Behavior of b* of coated yam pieces with storage time

respiration and metabolic activities allowing a delay in browning, as time passes, this barrier becomes weak (Dussan-Sarria *et al*., 2014; Chiumarelli *et al*., 2011), bearing in mind that this type of oxidized starch has in its functional characteristics a greater solubility percentage than that of native starch, proving that a greater starch concentration in time represents a poor barrier to water vapor, which consequently results in an increase in the browning.

The average values of the b* parameter obtained in minimally processed yams coated with oxidized cassava starch are in the range of 13.57 to 16.92. In Fig. 4 the behavior of the b* values are shown during storage time. All the treatments presented positive values (shades close to yellow) and most obtained an average increase of 24.6% as the storage time increased. Studies in minimally processed apples treated with citric acid showed increases of 25% in the values of b* for the day 20 of storage (Augusto *et al*., 2016). Likewise, Calder *et al*. (2011) report increases of 29.2% in the values of b* in minimally processed potatoes treated with ozone, ascorbic acid and citric acid for 28 days of storage.

The ANOVA shows that the factors concentration of ascorbic acid ($p = 0.011$), storage time ($p = 0.00$) and the interaction starch concentration*storage time ($p = 0.0072$) significantly affected the color parameter b*. As the concentration of ascorbic acid in the coating and the storage time increases, an increase in the values of b* is produced. This behavior is similar to that found in potatoes stored for 28 days (Calder *et al*., 2011), sweet potatoes treated with ascorbic acid (5%) stored for 17 days (Ojeda *et al*., 2014) and apples stored for 15 days (Moreira *et al*., 2015). This increase in parameter b* indicates that the pieces of yam change from green to yellow hue, which may be related to decreased concentration in pigments that absorb the green color on the yam surface.

For the interaction oxidized starch concentration* storage time Tukey's test shed significant differences for the high and low levels of the factors. High levels of storage time (42 days) and an increase in starch concentration produces 24% increments in b* values, while at low storage time (0 days), this same increase in starch concentration generates 16.8% decreases. This behavior is associated with the edible coatings based on polysaccharides, such as starch delay browning in fresh-cut products (Chiumarelli *et al*., 2011).These same authors report that coatings of cassava starch, citric acid and glycerol offer an effective maintenance of the characteristics of color in samples of mango cut, but that to the extent that increases the storage time the action of the enzyme polyphenoloxidase generates browning on the surface of the cut.

Texture of minimally processed yam coated with cassava starch: The mean values of hardness obtained for minimally processed yams coated with oxidized cassava starch at a storage time of 42 days ranged in an average range of 3939.16 to 8020.66 g_f. Figure 5 shows that all the treatments showed a decrease of 50.8% at the end of the storage time. This behavior coincides with the decrease in hardness (67.2%) reported in plantains coated with cassava starch and N-acetyl-cysteine after 32 days of storage (Palacín Beltrán, 2012).

The ANOVA shows that all the factors studied and interactions concentration of ascorbic acid * carnauba wax ($p = 0.0006$), concentration of ascorbic acid * time storage ($P = 0$), oxidized starch * time storage ($P = 0$) and carnauba wax * Packing system ($P = 0$) significantly affected the hardness. High levels of starch concentration and ascorbic acid in the coating and a longer storage time produces decreases in the hardness of the yam. The effect of the concentration of starch and acid can be associated with the internal fermentation that can be generated in the fruit when these concentrations are high, which can generate loss of the cellular structure. Japanese cucumbers coated with cassava starch at 4% showed greater loss in hardness (12.25%) with respect to the coatings with

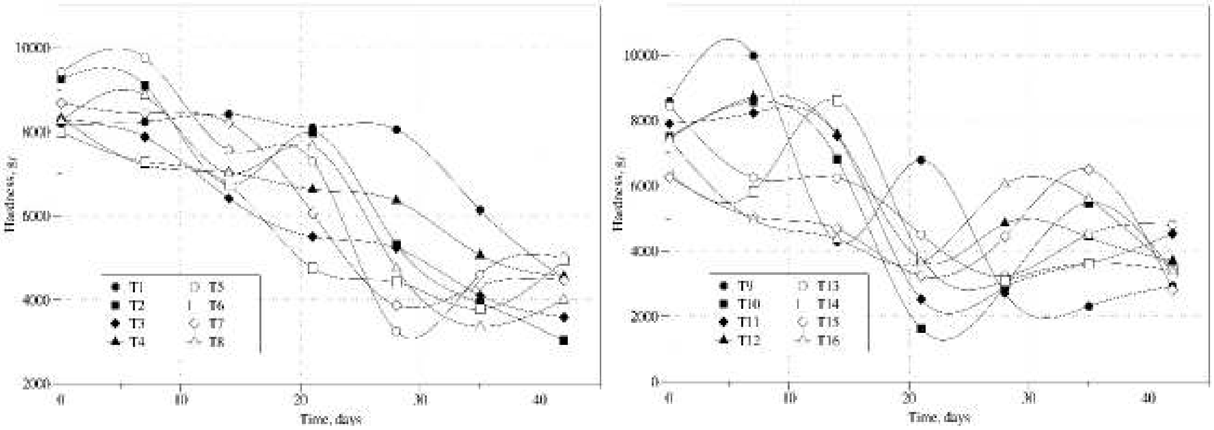

Fig. 5: Hardness changes of coated yam pieces during storage

suspensions of 2% and 3% of starch (0.79% and 1.89%) (Dos Reis *et al*., 2006). The effect of storage time on the loss of hardness of yam pieces, is similar to the loss of hardness (57.1%) found in mango minimally processed after 8 days of storage (Sothornvit and Rodsamran, 2008), which can be attributed to water losses, cellular decomposition and biochemical activities that occur and increase as time elapses after peeling and cutting the fruits (Singh *et al*., 2016).

With a vacuum package you get the greatest hardness of the yam. This behavior coincides with the reported by Dussan-Sarria *et al*. (2014) in vacuum-packed, minimally processed handles, which preserved a greater hardness after 24 days of storage with respect to non-packaging. This can be attributed to the effective modified atmosphere caused by the container, taking into account that a low oxygen atmosphere can prevent water losses and degradation of the superficial fruit membrane (Dussan-Sarria *et al*., 2014).

The Tukey test for interaction packaging system * cera carnauba shows significant differences in hardness for the packaging system factor at low wax concentration level. When packaged to atmospheric conditions and a decrease in the concentration of wax causes decreases of 6.37% in the hardness of the yam, while the vacuum packed and this same decrease in wax generates increases of 1.51%. This increase in hardness is associated with the use of wax at low concentrations generates a more resistant barrier (Chiumarelli and Hubinger, 2014) which, together with a vacuum pack provides a stronger barrier and therefore a greater retention in the hardness of the fruits that they cover, because they reduce the rate of dehydration (Pérez-Villarreal and Báez, 2003).

CONCLUSION

The application of edible coating based on oxidized cassava starch with an addition of 0.5% ascorbic acid and 0.1% of carnauba wax maintains the browning index and lightness of the minimally processed yam. The use of oxidized cassava starch in concentrations of 5% maintains the hardness of yam pieces vacuum packing for 42 days of storage. However, a storage time of more than 35 days causes a decrease in lightness and colors close to red and yellow hues in the yam pieces.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this study.

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