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Research Article

Effect of Edible Coatings Based on Oxidized Cassava Starch and Vacuum Packaging on Physicochemical Properties of Minimally Processed Yam

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Abstract: This research studied the effect of edible coatings based on oxidized cassava starch and two conditions of packaging (vacuum and non-vacuum) on physicochemical properties of minimally processed yam. A factorial arrangement of 2^4 was applied to the following factors: oxidized starch of yucca (3 and 5%), ascorbic acid (0.5 and 1%), carnauba wax (0.1 and 0.2%), determining the physicochemical properties of minimally processed yam for 42 days. High concentrations of acid and wax decreased the pH and the acidity of yam by 10.2 and 5.25%, respectively. A vacuum packaging and high levels of wax increased the acidity by 10.8% and a non-vacuum packaging with the same level of wax deceased it by 5.76%. The moisture content increased by 3.24% and the total solids decreased by 2.48% in a vacuum packaging in low concentrations of wax, due to the weak barrier caused by wax at low concentrations. Weight loss increased with the time of storage, as a cut produces cells breakage which in turn, results in a greater moisture loss. Finally, 0.5% of acid and 0.1% of wax in the coating maintain the physicochemical properties of yam.

Keywords: Acidity, *Dioscorea rotundata*, moisture content, pH, weight loss

INTRODUCTION

Yam is a tuber originally from Asia, belonging to the breed *Dioscorea ceae*, it is cultivated in Africa, Asia y America and it is consumed as a food with energetic and nutritional contents by the people in much of the world (González Vega, 2012; Reina Aranza, 2012). In Colombia, one of its most important species both in terms of area sown and its demand is the “Hawthorne” yam (*Dioscorea rotundata*), which is an export product. However, many problems exist that are reflected in the wastages during post-harvest and its marketing (30-40%) owing to the fact that there is a lack of adequate conservation, packaging and logistical systems failing hence to provide favorable conditions for the product’s durability before it reaches its final destination (Andrade *et al*., 2012a), thereby hampering its utilization, marketing and export.

In addition, the general trend is to consume foods that could be made simply and easily such as the minimally processed products (Qi *et al*., 2011). Nevertheless, the application of these processes reduces the durability of the product, as they trigger physiological and biochemical changes due to the alteration caused in the tissues by shelling and cutting (Chiumarelli *et al*., 2011). Studies indicate that products such as mango, sweet potato yam, amongst others, when processed minimally (Dussan-Sarria *et al*., 2014; Ojeda *et al*., 2014; Andrade *et al*., 2012b), turn out to be highly perishable, since they lose the protection provided by pericarp, thus changing their physicochemical properties due to the metabolic disorders caused by the cut (Tovar *et al*., 2001).

Currently there are many conservation mechanisms that are employed for fruits and vegetables in order to conserve their best quality, to extend their shelf life and to give added value (Ojeda *et al*., 2014), these include the controlled and modified atmosphere treatments, vacuum packaging and edible coatings (Vargas *et al*., 2006; Andrade *et al*., 2012b).

Edible coatings are fine layers of edible material placed on food surfaces to increase product quality, extend the shelf-life or improve food safety. This strategy could reduce both moisture loss and gas exchange and could act as carrier of additives (antimicrobials, biologically controlled microorganisms, antioxidants, flavoring, coloring, etc.) and could control hence the undesired reactions helping to maintain the structural integrity of the product wrapped (Andrade *et al*., 2013b; Baldwin *et al*., 1995).

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When applied to the fruits and vegetables, they help in controlling respiration and senescence, working just like the modified atmosphere treatments, by creating a barrier from the gases and by reducing the transpiration and deterioration caused in the physiological process (Baldwin, 1999).

Edible coatings could be developed from proteins, lipids or polysaccharides or from a combination of these (Chiumarelli and Hubinger, 2014; Cerqueira *et al*., 2012; Pereda *et al*., 2014). The latest ones include starch, derived from cellulose, alginate, pectin, chitosan and various other forms, these are the most used components in the formation of edible coatings available in the market (Rojas-Grau *et al*., 2008; Pérez-Gago *et al*., 1999; Chiumarelli and Hubinger, 2012; Galus and Kadzinska, 2015). Besides, many formulas also contain a plasticizer to provide flexibility and resistance to the coating; for this purpose, among other options, glycerol, sorbitol, glucose, are most commonly used (Sung *et al*., 2013; Chiumarelli and Hubinger, 2014).

Edible coatings are applied to different food products; e.g., apples (Chiumarelli and Hubinger, 2012), mangoes (Dussan-Sarria *et al*., 2014) and guavas (Achipiz *et al*., 2013). Studies report an increase in the durability of the minimally processed fruits when edible coatings based on native cassava starch are applied upon them, for example: 25% in tamarillo stored at 18°C, coated with 4% starch (Andrade *et al*., 2013a), 171% in mangoes stored at a room temperature (29°C) applying 3% de starch in formulation (Júnior *et al*., 2007), 300% en apples stored at 25°C applying 3% de starch (Chiumarelli and Hubinger, 2012, 2014), y 533% en sweet potatoes applying 2.5% de starch (Ojeda *et al*., 2014).

However, the native cassava starch is a highly hygroscopic material, which absorbs moisture of the environmental and the surface of product, thus presenting a poor water vapor barrier (Pérez-Gago *et al*., 2003; Lu *et al*., 2009). This property can be improved by a modification of starch (Ascencio *et al*., 2016). Amongst the modified starches that are used for coating applications, oxidized starch is essentially important, because it has lower viscosity, high stability and transparency of the paste (Zhang *et al*., 2009; García-Tejeda *et al*., 2013; Fonseca *et al*., 2015; Ascencio *et al*., 2016).

The purpose of this research was to investigate the effect of edible coatings based on oxidized cassava starch and vacuum packaging on physicochemical properties of minimally processed yam.

MATERIALS AND METHODS

This experimental development was carried out in the facility of the University of Sucre's Pilot Plant of Unitary Operations (Granja Los Pericos Branch). Native cassava starch coming from Starch from Sucre S.A.S. (Sincelejo-Sucre) was used.

Yam (*Dioscorea rotundata*), with uniform size, without any mechanical and pathological injuries, were obtained from a local farm (Sucre, Colombia). The experiment was conducted under a completely randomized factorial arrangement of 2^4. The factors and levels studies were:concentration of oxidized cassava starch (3% and 5%), concentration of carnauba wax (0.1% and 0.2%), concentration de ascorbic acid (0.5% and 1%), packaging system (vacuum (99%) and non-vacuum).

Yams were cut up in cubes with an edge of 3 cm, were immersed in a solution of sodium hypochlorite (0.0001%) and ascorbic acid (0.0003%). Coatings suspensions were formed by a matrix (oxidized cassava starch), a plasticizer (glycerol), an antioxidant (ascorbic acid), a lipid compound (carnauba wax) and an emulsifier (Tween 80). 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. 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. In each one of the treatments (Table 1) the following analyses were conducted in triplicate, in accordance with the official methods laid down by AOAC (2012): titratable acidity (method 942.15), pH (method 981,12), total solids (method 932.12), moisture (method 925.10) and weight loss. An analysis of variance was performed at a 95% level of confidence ($p \leq 0.05$) and to compare the average values, Tukey's Multiple Range Test was utilized. The data was processed by the software Statgraphics Centurion XVI.I.

RESULTS AND DISCUSSION

The average values for pH of minimally processed yam coated with oxidized cassava starch during different stages of storage showed a decrease in the pH value of the yam, at the end of the storage period of all the treatments, by an average range approximately from 6.0 to 4.46.

In Fig. 1, it is observed that the treatmentsT1, T2, T5, T8 y T9 showed increase in the pH value by del 16.4%, 13.09%, 19.96%, 12.16% and 10.55%, respectively untill the 28th day, followed by a period of decrease untill the 42nd day of storage, this increase is constant with an increase in production of fermentation sub-products such as acetic acid (Pushkala *et al*., 2012). On the other hand, in other treatments, a decrease

Table 1: Treatments applied to the minimally processed yam

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

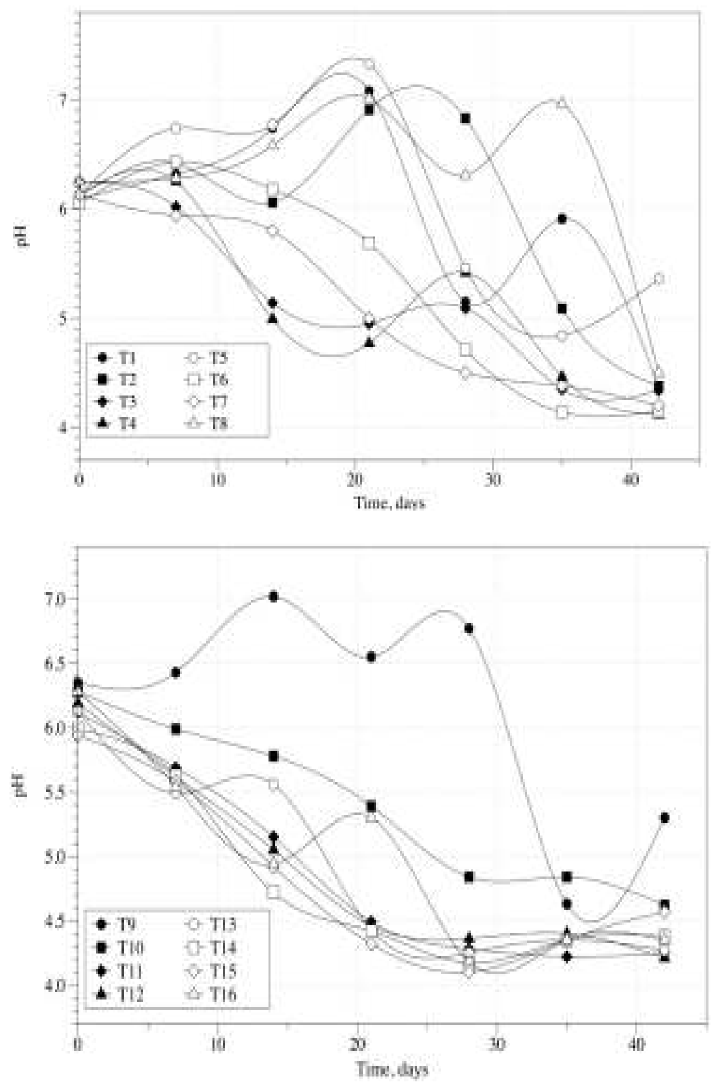

Fig. 1: Behavior of pH value in minimally processed yam during the storage period

between 69 to 73% in the pH in regards to their initial value was registered during the storage period, showing the pH value of 4.46±0.36 at the end of this period. This behavior is in accordance with the findings of Mendoza and Janny (2014) in boiled sweet potato pieces coated with chitosan and ascorbic acid for 30 days at 4°C, whose pH decreased by 72%. Likewise, potato pieces treated with ozone and ascorbic acid stored for 28 days showed a decrease in pH by 47% (Calder *et al*., 2012).

ANOVA shows that the factors: concentration of oxidized cassava starch (p = 0.000), concentration of ascorbic acid (p = 0.0147), packaging system (p = 0.0016), storage period (p = 0.0000) and their interactions concentration of carnauba wax* ascorbic acid (p = 0.000) and packaging system* concentration of carnauba wax (p = 0.0032) significantly affected the pH value.

The coefficients of all the significant factors showed negative values, which shows that when the yam is vacuum packaged and the coating has high levels of concentration of starch and ascorbic acid and the storage period is long, then pH values decrease. In minimally processed mangoes coated with cassava starch and vacuum packaged, decrease by 14.6% in pH value is registered by the 20^{th} of the storage period (Dussan-Sarria *et al*., 2014). Similarly, mango slices immersed in a solution of malic acid showed a decrease by 12.3% in the pH value during the storage period (14^{th} day) (Salinas-Roca *et al*., 2016). This decrease in the pH value of yam could be attributed to the anti-microbial activity produced by ascorbic acid decreasing intercellular pH value by ionization of the disassociated acid molecules (Salinas-Roca *et al*., 2016), the similarly decrease in the pH value could be explained by acidification of the cytoplasm caused by the emission of CO_2, which gets partially dissolved in the moist of cellular tissues with the subsequent decrease of the average pH value (Rodríguez Sauceda, 2011). It is important to note that, in terms of the stability of food products, the most adequate thing for the product is have low pH values during its conservation, possibly lower than 4.5, as this condition forbids the growth of pathogenic microorganisms particularly the bacteria *Clostridium botulinum* (Dussan-Sarria *et al*., 2014).

In the interaction concentration of carnauba wax* ascorbic acid, in accordance with the tests run by Tukey, it is clear that there appear clear significant differences in the pH value for every level of concentration of wax and ascorbic acid. At lower levels of ascorbic acid (0.5%) an increase in the concentration of wax causes an increase by 11.1% in the pH value of yam, whereas at higher concentrations of ascorbic acid (1%) this very increase of wax produces a decrease by 10.2% in the pH value. Likewise, in accordance with the tests run by Tukey for the interaction with packaging system*concentration of carnauba wax, the levels of packaging system showed significant difference in the pH value only at high levels of concentration of wax. A packaging in atmospheric conditions and an increase in the concentration of carnauba wax leads to an increase by 2.78% in the pH, while, in a vacuum packaging, this very increase causes a decrease by 2.79%. In the same way, Andean raspberry coated with carnauba wax added with citric acid showed an increase by 12.5% in the pH value in 12 days of the storage period (Quiñones Guarnizo *et al*., 2014). Whereas the decrease registered in the pH value may be because the edible coating layer with a high concentration of carnauba wax promotes a deceleration of metabolic and respiratory activity, thus avoiding the use of organic acids particularly the citric acid (Pérez-Gago *et al*., 1999).

All the treatments indicated an increase in acidity levels of citric acid untill the 42^{nd} day of storage, these values varied in an average range from 0.05% to 0.43%. In the Fig. 2 it is seen that the treatments T2, T7 y T8 showed lower levels of acidity (0.07% citric acid) untill the 28th day of storage, while the other treatments maintained the average acidity level of citric acid 0.29% until this time. At the end of the storage period (day 42), average increase by 760% in the acidity levels was registered in all the treatments.

This behavior is similar to what was reported by Palacín (2012) in bananas coated with cassava starch, ascorbic acid and N-acetylcysteine; they showed an increase by 250% in their acidity levels. However, Luo *et al*. (2015) reporteda decrease by 19.2% in the acidity levels of Chinese yam cut and packaged in nano-$CaCO_3$-LDPEpacking.

ANOVA shows that concentration of starch (p = 0.0068) and the interaction of the factors concentration of carnauba wax*ascorbic acid (p = 0.0068) and concentration of carnauba wax*packaging systems (p = 0.0068) significantly affected the acidity of the minimally processed yams. The increase in the concentration of oxidized cassava starch causes a decrease in the acidity of minimally processed yams. This shows that an increase in the concentration of starch was not effective in creating a barrier, well, the acidity reflects the level of organic acids in the fruit tissues, particularly the citric acid and these acids are substrate for the respiratory cycle and an increase in the respiration would lead to a decrease in their levels (Lurie and Klein, 1990).

In accordance with tests performed by Tukey, the interaction concentration of carnauba wax*ascorbic acid shows differences in the acidity of the concentration levels of wax for a low level of ascorbic acid (0.5%). At this level of ascorbic acid, an increase in the concentration of carnauba wax leads to an increase by 11.53% in the acidity levels, whereas at high concentrations of ascorbic acid (1%) this very increase in the concentration levels of carnauba wax causes a decrease by 5.25%. It must be kept in account, that the ascorbic acid acidifies the medium through which it is added, preserving thus its sensory and microbiological qualities (Özdemir and Gökmen, 2017) and the carnauba wax at high concentrations may form weak barriers, thereby allowing the insoluble polysaccharides to be hydrolyzed by mono-and

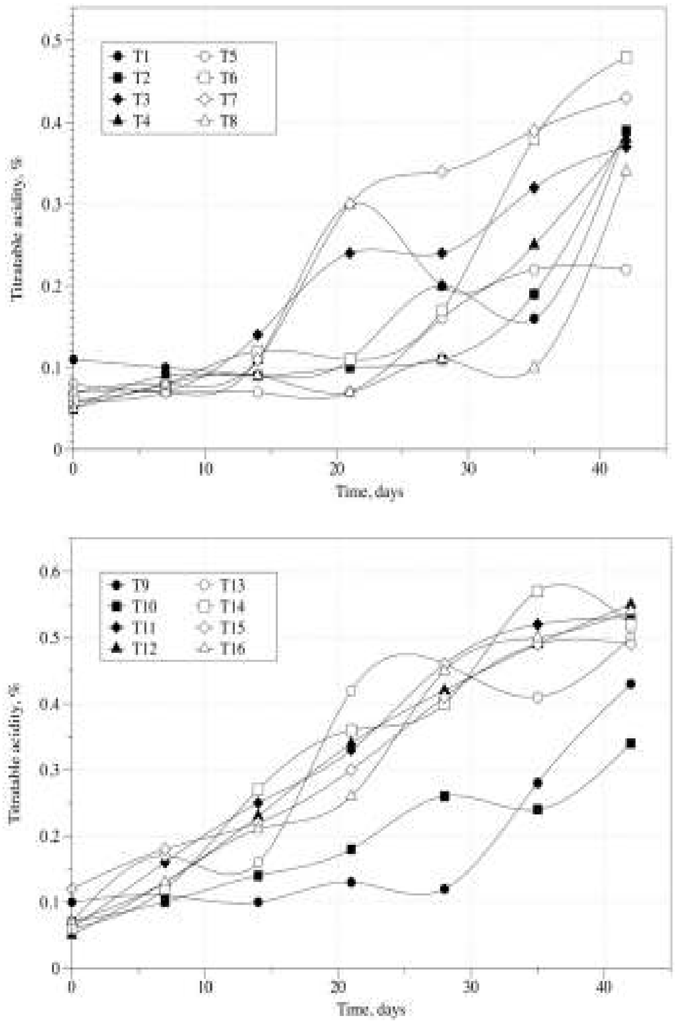

Fig. 2: Behavior of acidity of minimally processed yam during the storage period

disaccharide and leading also to consumption of citric acid for the metabolism during the storage period (Jha *et al*., 2012; Chiumarelli and Hubinger, 2014). In addition, as the time passes, starch availability decreases and the sugar content present in the fruit increases causing its acidity to decrease too (Jha *et al*., 2012). Studies done with apples and tomarillo coated with carnauba wax in concentrations of 2% and acid ascorbic show decrease by 50.9% by the 30th day of storage period and 16.6% by the 60th day, whereas tomatoes and strawberries coated with a suspension of rice starch with lipid and antioxidant indicate increase by 9.3% by the 8th day of storage and 25% till the 15th day, respectively, highlighting the effect of these two components in delaying of the fruit's ripening process (Jha *et al*., 2012; Das *et al*., 2013).

For the interaction packaging system* concentration of carnauba wax, the test done by Tukey shows differences in acidity in the levels of the packaging system for a high level of wax. A packaging at the normal atmospheric conditions and an increase in levels of carnauba wax causes a decrease by 5.76% in acidity of yam, whereas in vacuum packaged yam, this very increase in wax concentration causes an increase by 10.8%. This increase in the acidity of yam is low when compared to the findings of vacuum packaged carrot straps (18.1%) for a storage period of 10 days (Pushkala *et al*., 2012). This could be due to the fact that an increase in the lipid content does not enhance the resistance to the water vapor. Farris *et al*. (2009), leading to the production of CO_2inside the package, which after coming in contact with the tissues' moisture produces acidification (Rocha *et al*., 2013).

The average moisture level (%) in minimally processed yams coated with oxidized cassava starch during the storage period showed an average range of values between 37.2 a 41.4%. It is noted that when the storage time is prolonged, the moisture decreases in most of the treatments. In the Fig. 3 it is seen that the treatments T3, T4 y T11 maintain an almost constant behavior till the 28th day of storage, the other treatments suffered decrease by around 10.1% by the 42nd day of

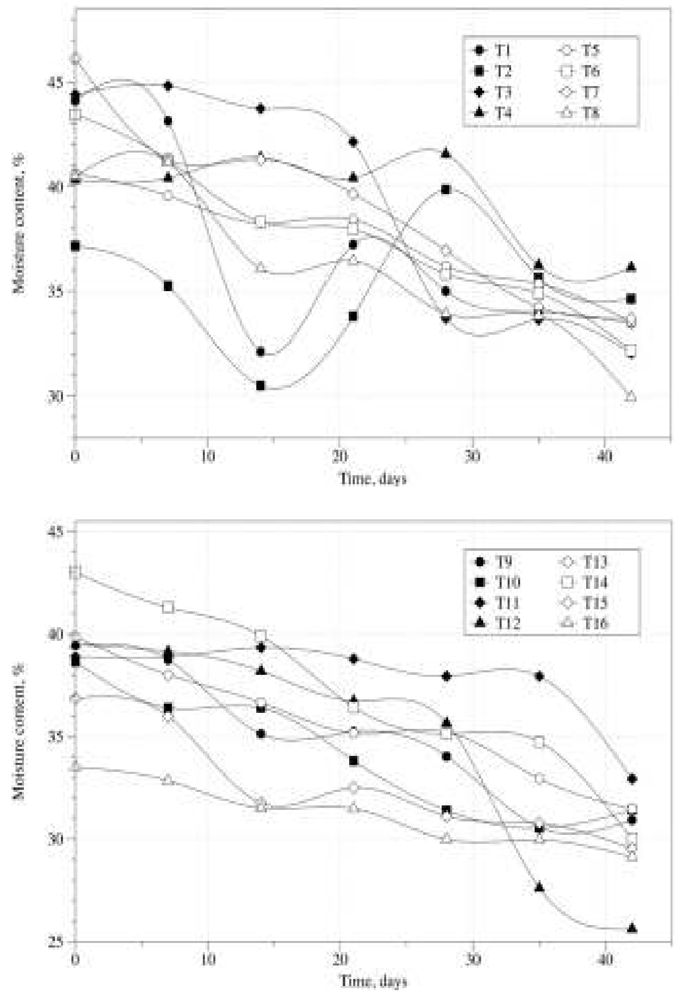

Fig. 3: Behavior of moisture percentage in minimally processed yam during the storage period

storage. Similar studies done on grated carrots coated with chitosan and packaged in low-density polyethylene indicate the decrease in moisture by 2.8% by the 10th day of storage (Pushkala *et al*., 2012). In the same way, apples stored for 20 days and treated with citric acid showed the decrease by 2.6% at the end of the storage period (Augusto *et al*., 2016). A high percentage of decrease in moisture shown in this study could be related to the period of its storage.

ANOVA shows that concentration of oxidized cassava starch ($p = 0.000$), concentration of carnauba wax ($p = 0.000$), concentration of ascorbic acid ($p = 0.000$), storage period ($p = 0.000$) and interactions with the factors oxidized cassava starch*carnauba wax ($p = 0.0002$), oxidized cassava starch *packaging system ($p = 0.0105$), oxidized cassava starch *storage period ($p = 0.0485$) and carnauba wax*packaging system ($p = 0.0001$) significantly affected the moisture of yam.

High levels of oxidized cassava starch, ascorbic acid and carnauba wax concentrations and a greater storage period cause decrease in the humidity of yam. As the concentration of carnauba wax impacted the moisture most, it appears as the major coefficient value of this variable. This behavior agrees with the findings by Chiumarelli and Hubinger (2014) who studied other kinds of edible coatings where carnauba wax was utilized. This water loss could be associated to the fact that an increase in the concentrations of lipids does not guarantee a barrier to the passage of water molecules towards the outer side of the fruit coated by it (Chiumarelli and Hubinger, 2014).

Amongst the significant interactions, the combination of carnauba wax*packaging system produced the highest value of the coefficient, meaning that it produces the highest effect on moisture. In accordance with the tests done by Tukey, the moisture percentage is different according to the concentration levels of carnauba wax in high level packaging system (vacuum packaging). This interaction shows that at lower concentrations of wax in a vacuum packaging leads to an increase by 3.24%, whereas at higher concentrations of wax in a vacuum causes a decrease in moisture by 4.33%. This increase, according to Kamper and Fennema (1984) is due to the barrier formed by

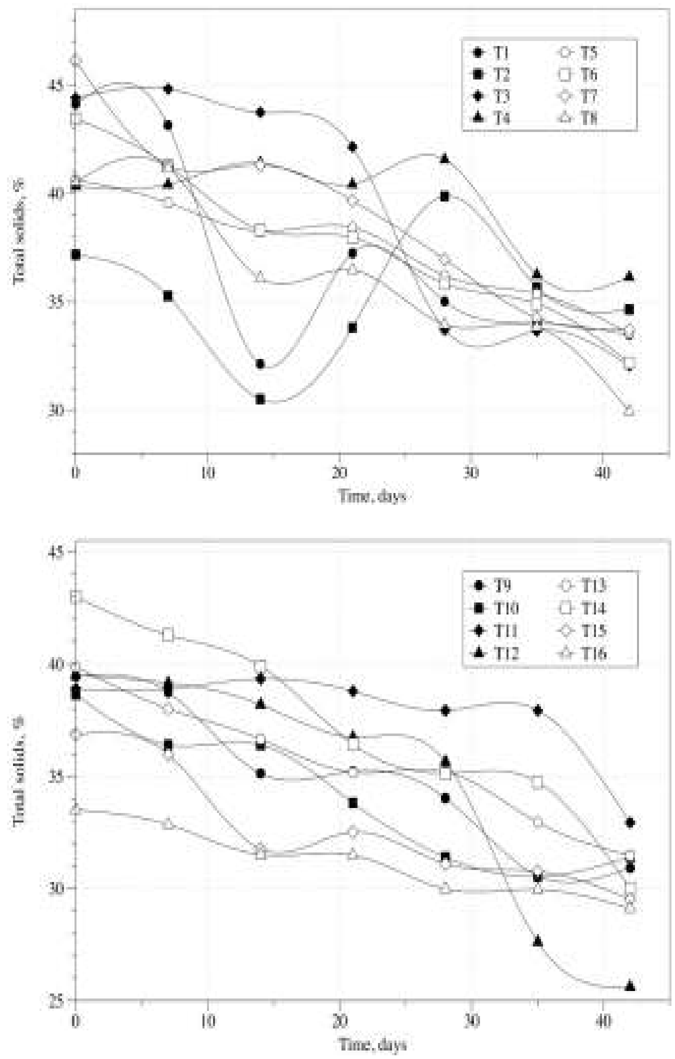

Fig. 4: Behavior of total solid contents of minimally processed yam over a storage period

wax at higher concentrations in a vacuum packaging, providing thus a strong resistance to the passage of water vapor.

The values for total solids (%) of minimally processed yam coated with oxidized starch for a storage period, fluctuated between an average range from 59.59 to 68.3%. In the Fig. 4 the evolution of total solids percentage in minimally processed yam processed for a certain storage period is shown, where a marginal increase (14.6%) is registered over the time of storage. This behavior agrees with the findings in guavas coated with 1.0 and 2.0% of chitosan, they show a slight increase (8.8%) in the solid content stored for 12 days at 11°C (Hong *et al*., 2012). However, Martiñon *et al*. (2014) did not note significant differences in the solid content in melons coated with cassava starch and stored for 15 days at 4°C.

ANOVA shows that concentration of oxidized cassava starch ($p = 0.000$), concentration of carnauba wax ($p = 0.000$), concentration of ascorbic acid ($p = 0.000$), storage period ($p = 0.000$) and the interactions of the factors oxidized cassava starch* carnauba wax ($p = 0.0002$), oxidized cassava starch* ascorbic acid ($p = 0.0097$), oxidized cassava starch*packaging system ($p = 0.015$), oxidized cassava starch*storage period ($p = 0.0485$) significantly affected the total solid contents of yam.

All the coefficients of these significant factors indicated positive values, this shows that when the coating has higher levels of concentration of oxidized cassava starch, ascorbic acid and carnauba wax and is stored for a longer period, total solids percentage increases. Keeping in mind the fact that the concentration of carnauba wax causes the highest coefficient value, it is possible to note this is the factor that has the highest influence over the total solid content of minimally processed yam.

On the other hand, the combination of packaging system*carnauba wax showed the highest coefficient value and in accordance with the tests done by Tukey,

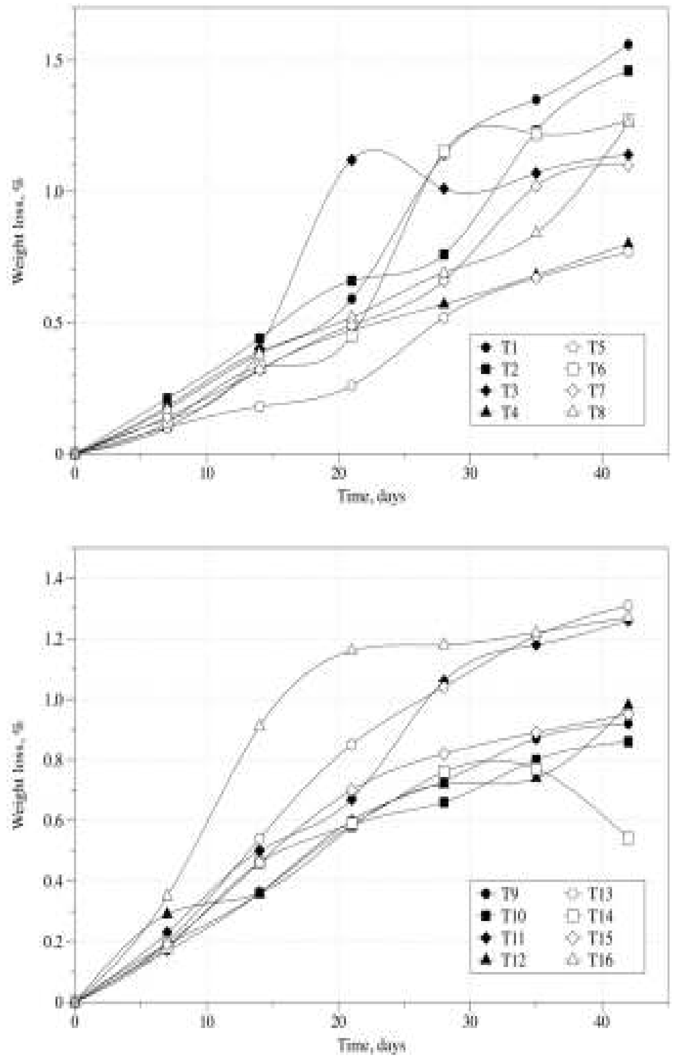

Fig. 5: Behavior of weight loss (%) of minimally processed yam during the storage period

the total solids percentage is different for different levels of factors of concentration of carnauba wax in a high level packaging system (vacuum packaging). At high concentration levels of wax (0.2%) and a vacuum packaging results in an increase by 1.80%, whereas low concentrations of wax (0.1%) with the same packaging system cause a decrease by 2.48%. This reduction in the total solids is due to the rate of decrease in respiration and the metabolic activity of the coated fruit (Ali *et al*., 2011; Gol *et al*., 2013). Studies have shown that the properties of the coating barriers depend on the kind of lipids and their concentration (Martin-Polo *et al*., 1992; Gontard *et al*., 1994). Therefore, a reduction in the total solids could be associated with the properties of wax barrier, which along with a modification in the internal atmosphere of the product (reduction in O_2) leads to a lower production of ethylene (Dong *et al*., 2004), resulting in a reduction in respiration rate hence allowing the synthesis and the use of metabolites to be less, which results in lesser solids content owing to the fact that the hydrolysis of carbohydrates to sugar happens very slowly (Rohani *et al*., 1997).

The weight loss percentage of minimally processed yam coated with oxidized cassava starch during the storage period was recorded in a range from 0.16 to 1.09%. Figure 5 shows the evolution of the weight loss (%) of yam, where it is observed that all the treatments showed an increase in weight loss at the end of the storage period (day 42).

It is worth mentioning that the treatments T4, T5, T10 y T14 recorded the lowest percentages of weight loss being around 30% less than the other treatments at the end of storage period. This behavior is similar to the findings with sweet potatoes coated with cassava starch added with ascorbic acid that indicated weight loss up to 2% (Ojeda *et al*., 2014). However, in other food products higher weight loss has been recorded; for example, in carrots coated with chitosan, 6.3% at the end of the 10th day of storage (Pushkala *et al*., 2012), in sapotas coated with extracts of pullulan a weight loss of 14% was registered by the 9th day of storage (Shah *et al*., 2016) and in pieces of guava coated with cashew gum and carboxymethyl cellulose weight loss of 20% by the 13th day of storage (Forato *et al*., 2015).

On the other hand, high concentration levels of carnauba wax also caused a higher percentage of weight loss (28.84%), in contrast with the findings of Vázquez-Celestino *et al*. (2016) who report that the application of wax reduced the weight percentage by 133% in mangoes in comparison with the unwaxed mangoes. Same as found by Jeong *et al*. (2003), lower weight loss than control was observed in avocado treated with carnauba wax. However, Chiumarelli and Hubinger (2014) point out that carnauba wax concentrations below than 0.38% cause a greater resistance to the water vapor, highlighting the fact that an increase in lipids content does not enhance its resistance, this could explain the behavior recorded in this study.

CONCLUSION

An addition of 0.5% of acid ascorbic and 0.1% of carnauba wax in the matrix of the oxidized cassava starch coating maintains the characteristics of pH and acidity, of minimally processed yam. A storage period higher than 35 days causes greater weight loss and moisture content and a vacuum packaging reduces the weight loss percentage during the storage period.

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CONFLICT OF INTEREST

The authors of this study do not have conflict of interest to report.

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