Innovative Food Science and Emerging Technologies 12 (2011) 381–387

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Fresh cut 'Tommy Atkins' mango pre-treated with citric acid and coated with cassava (*Manihot esculenta* Crantz) starch or sodium alginate

Marcela Chiumarelli [a,*], Cristhiane C. Ferrari [a], Claire I.G.L. Sarantópoulos [b], Miriam D. Hubinger [a]

[a] Dept. of Food Engineering, Faculty of Food Engineering, University of Campinas (UNICAMP), P.O. Box 6121, Campinas/SP, 13083-862, Brazil
[b] Packaging Technology Centre, Institute of Food Technology (ITAL), Av. Brasil 2880, Campinas/SP 13070-178, Brazil

ARTICLE INFO

Article history:
Received 23 November 2010
Accepted 19 February 2011

Keywords:
Cassava starch
Minimally processed
Mango
Citric acid
Sodium alginate
Respiration rate
Edible coating

ABSTRACT

This work aimed to evaluate quality parameters of 'Tommy Atkins' mango slices pre-treated with citric acid and cassava starch or sodium alginate edible coatings, with or without glycerol. Samples only treated with citric acid were also evaluated. Mango slices dipped in sanitising solution were used as control. Colour parameters, mechanical properties, weight loss and respiration rate were analysed during 15 days at 5 °C. Cassava starch coating, with or without glycerol, provided higher stress at failure and lightness values than control sample throughout storage ($p \leq 0.05$). The citric acid promoted colour preservation, but increased significantly samples weight loss during storage. Sodium alginate coatings did not maintain quality characteristics, showing stress at failure and lightness values lower than control after 15 days. All coatings reduced respiration rate, but citric acid dipping and cassava starch coating without glycerol treatments were more effective, reaching values around 41% lower, when compared to control sample.

Industrial relevance: Fresh-cut mangoes are appreciated world-wide for its exotic flavour and nutritional composition. However, their shelf life is limited by changes in colour, texture, appearance and microbial growth. The edible coatings act as gas and water vapour barrier, extending the storage time of fresh-cut fruit and vegetables. Thus, cassava starch and alginate are alternatives to preserve minimally processed mangoes, maintaining the quality parameters of fresh fruit. This work is useful for the minimal processing industry in order to increase shelf life of fresh-cut mangoes, which can be considered an alternative to fast food and other ready-to-eat products, attending the demand for healthy and convenient foodstuffs.

1. Introduction

Mango is one of the most popular fruits in the world, mainly because of its pleasant flavour and nutritional value. Brazil is the sixth greatest producer and the third greatest exporter of mango, specially the 'Tommy Atkins' variety (FAO, 2009). 'Tommy Atkins' mangoes are large fruits (400–600 g),with bright red peel, pleasant taste and great potential for minimal processing industry, as they are resistant to handle and their pulp is orange-yellow, not fibrous and with a high content of vitamins A, B and C (Cunha, Sampaio, Nascimento, Santos Filho, & Medina, 1994).

The fresh-cut products demand has increased, because people are looking for ready to eat and healthy food. Fruits comprise 21% of fresh cut retail in USA, totalling US$ 787.4 million in 2008 (Agriculture and Agri-Food Canada, 2010). However, quality and shelf life of fresh-cut fruits are reduced by water loss, senescence processes, microbial growth, colour and texture changes, due to the tissue injuries caused by peeling, slicing and cutting. Thus, in spite of their convenience, fresh-cut mangoes may show browning and undesirable texture changes during storage (Beaulieu & Lea, 2003; Rodrigues, Pereira, Ferrari, Sarantópoulos, & Hubinger, 2008).

Several treatments have been studied in order to maintain quality and to extend the shelf life of fresh-cut products (Beaulieu & Lea, 2003; Fontes, Sarmento, Spoto, & Dias, 2008; Rocculi et al., 2007; Rodrigues et al., 2008; Rojas-Graü, Tapia, & Martin-Belloso, 2008; Soliva-Fortuny & Martín-Belloso, 2003). The use of edible coatings on minimally processed products creates a semipermeable barrier to external elements, promoting a similar effect to the storage under modified atmosphere. Therefore, the edible coatings can reduce moisture loss, solutes migration, respiration and oxidative reaction rates (Colla, Sobral, & Menegalli, 2006; Rojas-Graü et al., 2008). However, there is little information available in literature about the application of edible coatings on fresh-cut mango (González-Aguilar et al., 2008; Sothornvit & Rodsamran, 2010).

Edible coatings can be formulated with polysaccharides, such as starch and alginate. Cassava (*Manihot esculenta* Crantz) is the cheapest material for starch production in Brazil, costing approximately US$ 0.85/kg. Cassava starch edible coating is tasteless, odourless, colourless, non-toxic, biodegradable and safe, and shows low permeability to oxygen (Pareta & Edirisinghe, 2006). Despite its

* Corresponding author. Tel.: +55 19 3521 4036; fax: +55 19 3521 4027.
E-mail address: march@fea.unicamp.br (M. Chiumarelli).

1466-8564/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ifset.2011.02.006

advantages, there are few studies related to the use of this coating on fresh-cut products (Fontes et al., 2008; Garcia, Pereira, Sarantópoulos, & Hubinger, 2010; Vieira, Vieites, & Evangelista, 2000). Alginate, a linear polymer of 1,4-linked-β-D-mannuronic and α-L-guluronic acids extracted from brown algae, is employed in the food industry as a texturing and gelling agent (Mancini & McHugh, 2000). Some studies showed that sodium alginate coatings can preserve the quality parameters of fresh-cut papaya, apple and melon, increasing their shelf life (Oms-Oliu, Soliva-Fortuny, & Martin-Belloso, 2008a; Rojas-Graü et al., 2008; Tapia et al., 2008).

Edible coatings can also minimise colour changes of fresh cut products, but the use of anti-browning agents reduce the enzymatic browning more efficiently. Colour is an important attribute for fresh-cut fruits and the enzymatic browning can imply in appearance loss of these products, which makes them less attractive to consumers (Garcia & Barrett, 2002). Few studies have suggested that the use of citric acid can avoid enzymatic browning of plant tissue, thereby reducing the product appearance loss, without changing its minimally processed condition (Andrés, Giannuzzi, & Zaritzky, 2002; Brennan, Le Port, & GormLey, 2000; Moda, Spoto, Horii, & Zocchi, 2005).

In this context, the objective of this study was to evaluate the quality parameters of 'Tommy Atkins' mango slices treated with citric acid, coated with cassava starch or sodium alginate, containing glycerol or not, throughout the storage of 15 days at 5 °C, by analysing their mechanical properties, weight loss, colour parameters and respiration rate.

2. Materials and methods

2.1. Material

Mangoes (*Mangifera indica* cv 'Tommy Atkins') were obtained from the local market (Ceasa, Campinas, Brazil). A lot of 84 mangoes (six boxes of 6 kg each) was bought and the fruits of uniform size (563.9 ± 45.7 g), maturity stage (based on internal colour and firmness) with no physical damage and soluble solids between 13 and 14 °Brix were selected to the experiments. Standards for mango fruit described by the Brazilian Program for Horticulture Modernization were used to determine the ripening stage and fruits from the mono-embryonic group, class 350, sub-class 'yellow' and category extra were chosen (CEAGESP, 2004).

Peracetic acid (Tsunami 100®, ECOLAB, São Paulo, Brazil) was used as sanitising agent. Cassava starch (17% amylose content, Tapioca Starch, National Starch, São Paulo, Brazil), sodium alginate (Manugel DMB, ISP do Brasil Ltda, Cabreúva, Brazil) and glycerol as plasticiser agent (ECIBRA, São Paulo, Brazil) were used for coating formulation. Citric acid (ECIBRA, São Paulo, Brazil) was used as anti-browning agent.

The packaging system was composed by expanded polystyrene (EPS) trays (110 mm × 110 mm × 30 mm) wrapped with polyvinyl chloride (PVC) stretch film (Goodyear, São Paulo, Brazil) with a thickness of 20 μm, O_2TR of 8200 cm³ (SPT) m^{-2} d^{-1} (at 25 °C and 101.3 kPa) and WVTR of 262 g m^{-2} d^{-1} (at 38 °C and 90% RH). Each tray contained approximately 80 g of the product, corresponding to 7 or 8 mango slices. The packaging system was only used for samples protection.

2.2. Methods

2.2.1. Sample preparation

Six groups were chosen for experimental treatments. They were named Control: non-treated fresh-cut mango; CA: fresh cut mango only treated with citric acid (5 g/L); CS: fresh-cut mango treated with citric acid (5 g/L) and coated with cassava starch (10 g/L); CSG: fresh-cut mango treated with citric acid (5 g/L) and coated with cassava starch (10 g/L) and glycerol (10 g/L); SA: fresh-cut mango treated with citric acid (5 g/L) and coated with sodium alginate (20 g/L); and SAG: fresh-cut mango treated with citric acid (5 g/L) and coated with sodium alginate (20 g/L) and glycerol (10 g/L). The citric acid and cassava starch concentration were obtained from previous tests (Chiumarelli, Pereira, Ferrari, Sarantópoulos, & Hubinger, 2010). The sodium alginate and glycerol concentrations were established according to literature (Rojas-Graü, Tapia, Rodríguez, Carmona, & Martin-Belloso, 2007; Rojas-Graü et al., 2008; Tapia et al., 2008).

Cassava starch suspensions and alginate solutions with or without the addition of 10 g/L of glycerol were prepared at 70 °C with constant stirring, and then cooled to room temperature. The alginate solutions were stored during 24 h at room temperature (25 °C) to eliminate trapped air.

Whole mangoes were dipped in a peracetic acid solution (0.08 g/L) for 3 min. Fruits were manually peeled and cut into 9 mm thick slices with an acrylic form and a sharp knife. Mango slices were dipped into the peracetic acid solution (0.08 g/L) once more for 3 min, dipped in citric acid solution (5 g/L) for 3 min, immersed in coating suspensions, with or without glycerol, for 2 min and finally drained at room temperature (15 °C and 80% RH) for 30 min in order to dry the coating material. All samples were packaged in EPS trays with PVC stretch film and stored in a chamber (BOD TE 391, Tecnal Equipamentos Ltda, Piracicaba, Brazil) at 5 °C and 80% RH for 15 days. For each treatment, around 204 slices were obtained from 12 fruits, which were randomly distributed in 26 trays (approximately 8 slices/tray).

2.2.2. Analysis

2.2.2.1. Gas composition. The concentration of O_2 and CO_2 in the headspace of packaging were analysed using an O_2/CO_2 Dual Space Analyzer (model PAC CHECK 325, Mocon, Minneapolis, USA). The gas concentration was measured by inserting the equipment needle through a silicon septum attached to the packaging surface. Three trays per treatment were analysed after 1, 3, 6, 9, 13 and 15 days of storage.

Gas concentration in the packages was analysed in order to verify if the packaging system, only used for samples protection, modified the atmosphere around the product.

2.2.2.2. Respiration rate. The respiration rate of mango slices was determined in a static system. The samples (approximately 50 g) were placed in sealed 180 mL glass jars with silicon septum. A 0.3 mL aliquot of gas was removed from the headspace with a hermetic syringe after 1 h of closing the jars, which were kept at 5 °C and 101.3 kPa. CO_2 production and O_2 consumption were measured using a gas chromatograph (Shimadzu, model CG514A, São Paulo, Brazil; column Porapak N, 50 °C; injector, 70 °C; detector, 150 °C; Argon as carrier gas at flow rate of 30 mL/min, limit detection 0.1% CO_2 and 10% O_2). The respiration determinations were performed in triplicate after processing (Day 0).

2.2.2.3. Weight loss. Five trays per treatment were weighed immediately after the processing and after 3, 6, 9, 13 and 15 days of storage. The results were expressed as percentage loss of initial weight.

2.2.2.4. Mechanical properties. The mechanical properties of mango slices were evaluated by uniaxial compression test, using a Universal Testing Machine (model TA-TX plus, Stable Micro Systems, Surrey, UK). In this test there is no interference of the sample fibres, as can be observed in the puncture test. Stress and strain at failure values were determined with a 60 mm diameter lubricated acrylic cylindrical plate at a compression speed of 1 mm s^{-1} until 80% sample deformation. Samples of 20 × 20 mm taken from the center of mango were used. The force and height values obtained from this test were converted into Hencky's stress (σ_H) and strain (ε_H), considering a constant sample volume during compression, according to Eqs. (1) and (2). The stress and strain at failure were determined from the peak of the stress–strain curve (Bierhals, Chiumarelli, & Hubinger, 2011; Ferrari, Carmello-Guerreiro, Bolini, & Hubinger, 2010; Fontes et al., 2008; Ito, Tonon, Park, & Hubinger, 2007). Mechanical properties were evaluated after 1, 3, 6, 9, 13 and 15 days of storage, using seven slices per treatment taken from different trays.

$$\sigma_H = \frac{F(t)}{A(t)} \tag{1}$$

$$\varepsilon_H = -\ln\left(\frac{H(t)}{H_o}\right) \tag{2}$$

where: $F(t)$ = Force [N] at time t [s]; $A(t)$ = Area [m²] at time t [s]; H_0 = Initial height of the sample [m]; $H(t)$ = Height of the sample [m] at time t [s].

2.2.2.5. Colour parameters. The surface colour of mango slices was measured using a Hunter Lab colorimeter (model Color Quest II, Reston, USA), with reflectance mode (RSIN), CIELab scale (L*, a* and b*), D65 as illuminant and a 10° observer angle as a reference system. The colour measurements were expressed in terms of lightness L* (L* = 0 for black and L* = 100 for white), and the chromaticity parameters a* (green [−] to red [+]) and b* (blue [−] to yellow [+]). From these parameters, the cylindrical coordinates C* (chroma) and H* (hue) were calculated according to Eqs. (3) and (4), respectively. The measurements were made in triplicate (three slices per treatment taken from different trays) and each sample was scanned at four different regions after 1, 6, 9 and 15 days of storage.

$$C^* = \left(a^{*^2} + b^{*^2}\right)^{1/2} \tag{3}$$

$$H^* = \arctan\left(\frac{b^*}{a^*}\right) \tag{4}$$

2.3. Statistical analysis

The results were analysed statistically by the analysis of variance (ANOVA) using the software Statistica® 5.5 (StatSoft, Inc., Tulsa, USA). Mean separation was determined using the Tukey test at $p \leq 0.05$.

3. Results and discussion

3.1. Respiration rate

The respiration of vegetal tissues continues after the harvest and implies undesirable physiological, chemical/biochemical and physical changes in fruits. The use of edible coatings can reduce the respiration rate, which provides a decrease on metabolic activities, delaying the product deterioration and increasing its shelf life (Qi, Hu, Jiang, & Tian, 2010; Rojas-Graü et al., 2008).

Table 1 shows the respiration rates of control samples and slices pre-treated with citric acid and coated with cassava starch or sodium alginate, with or without added glycerol. Higher CO_2 production was verified for control sample, which can be related to tissue stress caused by minimal processing operations, such as trimming, peeling and cutting. Similar behaviour was also noticed by Ribeiro, Vicente, Teixeira, and Miranda (2007) and Fontes et al. (2008) in their works with strawberries and apple slices, respectively.

The citric acid and coatings reduced the respiration rates of mango slices, proving that treatments were efficient to control the product metabolism. Samples treated with CA and CS showed the lowest respiration rates, reaching values 41% lower than control samples. A different behaviour was reported by Fontes et al. (2008). According to them, fresh-cut apples coated with sodium alginate without glycerol showed lower respiration rates than samples coated with cassava starch, probably due to the formation of cracks on surface of cassava starch coating, which facilitated the gas exchange.

Table 1
Respiration rate of fresh-cut mangoes subjected to different treatments.

Treatment	Respiration rate × 10^{-3} [ml CO_2 kg^{-1} s^{-1}]
Control	2.41 ± 0.12 [a]
CA	1.42 ± 0.01 [b]
CS	1.41 ± 0.15 [b]
CSG	2.08 ± 0.03 [c]
SA	1.68 ± 0.03 [d]
SAG	1.85 ± 0.14 [d]

Control = fresh-cut mangoes untreated; CA = only citric acid dipping; CS = citric acid + cassava starch coating; CSG = citric + cassava starch coating with glycerol; SA = citric acid + alginate coating; SAG = citric + alginate coating with glycerol.
Values with the same letter within the column are not significantly different $p \leq 0.05$.

SA and SAG treatments did not show significant differences ($p > 0.05$), but presented a reduction on 26% in respiration rate of mango slices when compared to control samples. However, CSG treatment promoted higher and statistically significant respiration rates than the other treatments, but 14% lower in comparison to the values for control sample.

Glycerol addition increased coatings permeability, resulting in an increase of samples CO_2 content. Thus, the respiration rate of fruits coated with CSG was significantly higher than the values obtained for treatment without the plasticiser. In accordance with Krochta (2002), plasticisers, like glycerol, disrupt inter- and intra-molecular hydrogen bonds, increasing the distance between polymer molecules. Even though the glycerol fills the empty spaces in the polymer matrix, it can facilitate the gases exchange, increasing samples respiration rates in comparison to the coatings with no plasticiser (Chiumarelli et al., 2010; Ribeiro et al., 2007).

3.2. Gas composition

Changes on the gas composition of packaging did not promote modified atmosphere (Fig. 1 a and b). The internal atmosphere of packaging systems was close to that of air, with CO_2 concentration lower than 1.5% and O_2 concentration around 20% in all trays throughout the storage. The packaging system (EPS trays wrapped with PVC stretch film) did not interact with the product, only acting as display packaging for mango slices. Moreover, the reduction of coated fresh-cut mangoes respiration rate could also avoid the modified atmosphere inside the packaging.

According to some researches, edible coatings may create a modification of internal atmosphere, as a result of formation of a semi permeable film in the product surface, which reduce the oxygen available to vegetal tissue and decrease the respiration rate of fresh-cut fruits (Oms-Oliu, Soliva-Fortuny, & Martin-Belloso, 2008b; Rojas-Graü et al., 2008). However, no modifications on the packaging atmosphere used to wrap mango slices was observed in the present work, behavior also reported by Chiumarelli et al. (2010).

3.3. Weight loss

Weight loss of control and treated samples all along the storage is presented in Fig. 2. The use of cassava starch and alginate edible coatings contributed to the significant reduction ($p \leq 0.05$) of fresh-cut mango weight loss from the 6th day on, reaching values around 6% in the end of storage. The weight loss of all samples increased throughout the storage time, due to the moisture loss of coatings and

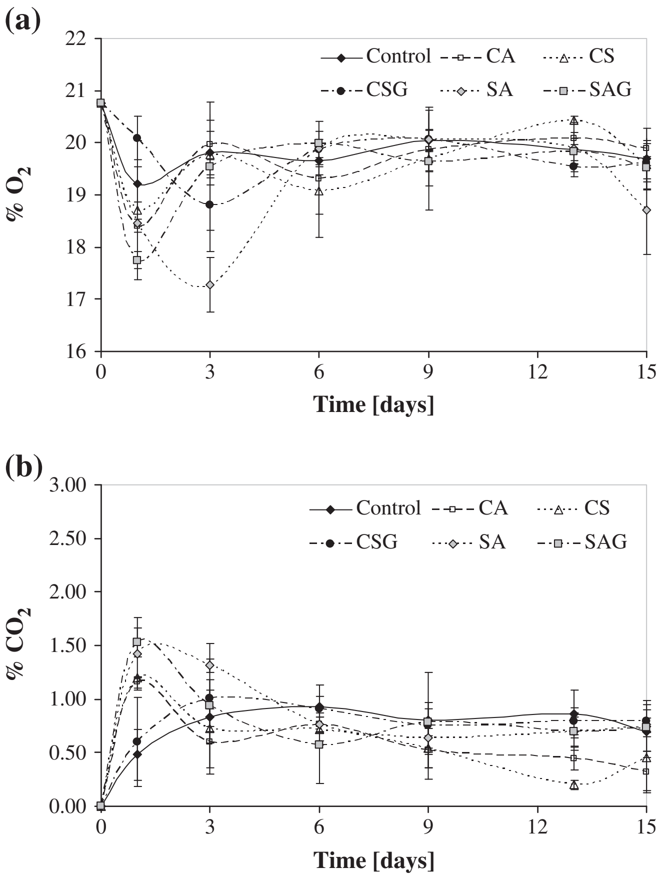

Fig. 1. Change of O_2 (a) and CO_2 (b) of fresh-cut mango subjected to different treatments during storage at 5 °C: untreated (control), only citric acid dipping (CA), citric acid + cassava starch coating (CS), citric acid + cassava starch coating with glycerol (CSG), citric acid + alginate coating (SA) and citric acid + alginate coating with glycerol (SAG). Error bar shows standard deviation.

the ripening process. The addition of glycerol to the coating formulations showed no significant effect on fruits weight loss, since the results for coated samples with or without the plasticiser addition did not differ significantly ($p > 0.05$). This behaviour could be a consequence of the high hygroscopicity of glycerol, which dissolved in contact with the fruit surface.

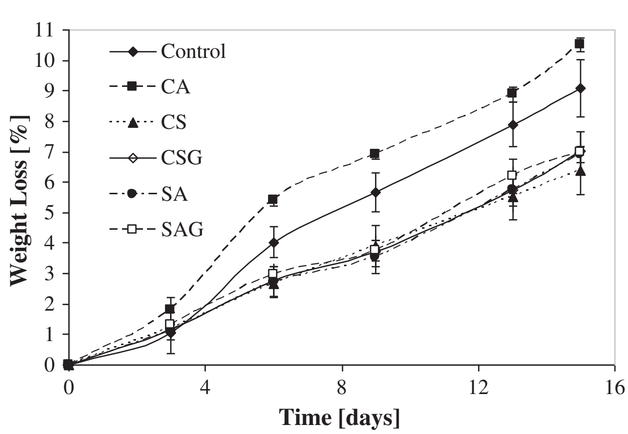

Fig. 2. Effect of citric acid (CA) and edible coatings (cassava starch without (CS) and with glycerol (CSG), and sodium alginate coating without (SA) and with glycerol (SAG)) on weight loss of fresh-cut mango during storage at 5 °C. Error bar shows standard deviation.

CA samples presented higher weight loss than control fruit ($p \leq 0.05$) during storage. The weight loss of samples subjected to citric acid dipping (CA treatment) was about 11% after 15 days of storage, while control samples weight loss was approximately 9% at the same time. As observed by Rocculi et al. (2007), the use of citric acid increases the weight loss of fresh-cut products, causing a partial dehydration of the vegetable tissue. However, in the present work the use of cassava starch and alginate coatings was able to hinder this undesirable effect of citric acid, presenting a lower weight loss of coated samples (CS, CSG, SA and SAG) in the end of storage.

According to Raybaudi-Massilia, Rojas-Graü, Mosqueda-Melgar, and Martin-Belloso (2008), edible coatings can reduce weight loss, because they help to decrease water loss of fresh-cut products, which was also observed by Chien, Sheu, and Yang (2007) in mango slices with chitosan coatings during seven days of storage at 6 °C. Vegetal tissues tend to lose water and, consequently, lose weight when relative humidity is below 99% and Bico, Raposo, Morais, and Morais (2009) verified the efficacy of carrageenan edible coating against weight loss of fresh-cut bananas during 5 days of storage at 5 °C and 55% RH. This behavior was also reported by Maftoonazad, Ramaswamy, and Marcotte (2008) in peaches recovered with sodium alginate or methyl cellulose coatings throughout the storage of 24 days at 15 °C. According to authors, control samples showed moisture loss until three times higher than methyl cellulose and sodium alginate coated peaches.

3.4. Mechanical properties

Fig. 3 shows the stress and strain at failure of mango slices during the storage at 5 °C. The heterogeneity amongst the fruits and a lack of internal structure uniformity in biological materials probably promoted relatively large deviations in stress and strain at failure measurements. The mechanical properties of a biological material depend on its structure and cell wall constituents, process conditions, ripeness levels and harvest time. Pereira et al. (2004) and Ferrari and Hubinger (2008) also observed considerable variability in the raw materials in their studies with guavas slices and melons cubes, respectively.

The stress and strain at failure values decreased throughout storage for all treatments (Fig. 3), possibly due to the senescence process and the action of polygalacturonase on the solubilisation and depolymerisation of pectic substrates (Toivonen & Brummell, 2008). According to Varanyanond, Naohara, Wongkrajang, and Manabe (1999), water soluble pectin content in 'Kaew' mango changed from 106.8 mg/100 g in ripe stage to 283.3 mg/100 g when the fruit was overripe, attesting the softness of the vegetal tissues during ripeness.

CA samples showed higher stress at failure than other samples from the 6th day on, probably due to the dehydration of mango slices (Fig. 3a) and lower respiration rate (Table 1) that reduced the senescence process. CS and CSG samples showed a better maintenance of mechanical properties, with stress at failure values slightly higher than control mango in the end of storage time ($p \leq 0.05$), while the alginate coatings (SA and SAG) resulted in higher decrease of stress at failure after 3 days of storage. Samples recovered with alginate containing or not glycerol showed the lowest stress at failure values in the end of storage when compared to the other treatments and higher strain at failure, indicating a firmness loss of these mango slices. CS samples presented low respiratory activity (Table 1), which implied in slower deterioration and consequently on the maintenance of mechanical properties.

According to Maftoonazad et al. (2008), the pectin-esterase and polygalacturonase activities cause the degradation of components responsible for structural rigidity of the fruit. The activity of these enzymes is reduced when the product is stored with lower O_2 content, implying in retention of fruits and vegetables firmness. This behavior was observed in CS and CSG samples, which presented lower

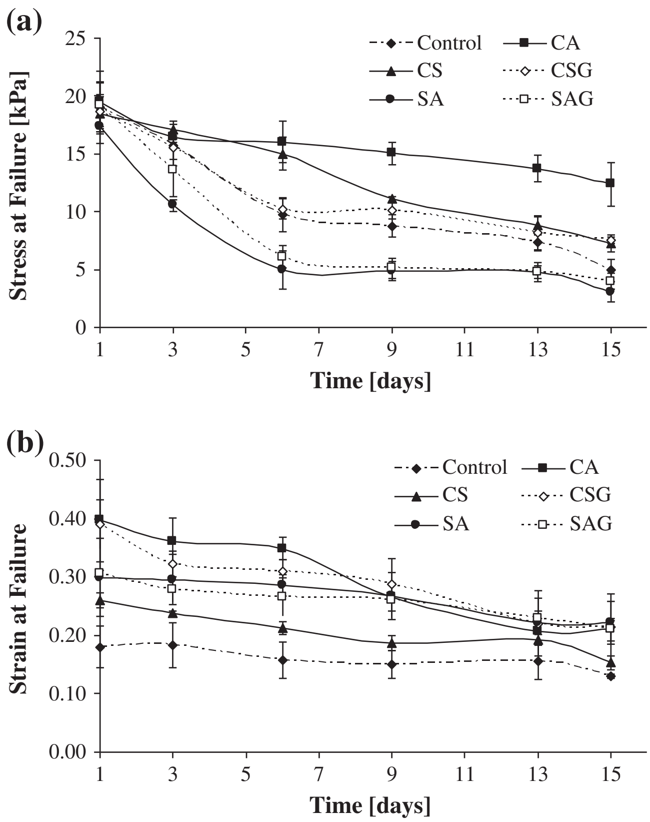

Fig. 3. Stress (a) and strain (b) at failure of fresh-cut mango subjected to different treatments during storage at 5 °C: untreated (control), only citric acid dipping (CA), citric acid + cassava starch coating (CS), citric acid + cassava starch coating with glycerol (CSG), citric acid + alginate coating (SA) and citric acid + alginate coating with glycerol (SAG). Error bar shows standard deviation.

respiration rates, indicating that there was lower oxygen available to metabolic activities of mango slices, resulting in maintenance of mechanical properties of fruits.

González-Aguilar et al. (2009) also observed firmness loss on fresh-cut papaya coated with chitosan. However, Ribeiro et al. (2007) reported no significant differences between strawberries uncoated or coated with corn starch (2% w/v) on firmness at the end of shelf life. Furthermore, Maftoonazad et al. (2008) also verified a significant beneficial effect of methyl cellulose and sodium alginate coatings on firmness retention of peaches. However, the authors observed that methyl cellulose coating was more efficient to preserve the mechanical properties of fruits than sodium alginate coating, behaviour also noticed in the present work between cassava starch and sodium alginate coatings. Qi et al. (2010) verified that chitosan coating and $CaCl_2$ treatment effectively retarded the tissue softening in apple slices.

Fontes et al. (2008) working with minimally processed apples coated with sodium alginate or cassava starch, observed tissue hardening, but the authors attributed this fact to the calcium salt addition in the coating formulation because calcium ions form complexes with cell wall pectin, improving structural integrity and promoting greater tissue firmness.

3.5. Colour parameters

Table 2 presents lightness, chroma and hue of fresh and treated samples along the storage time. The lightness L^* decreased significantly ($p \leq 0.05$) for all treatments during storage (Table 2). Control samples presented the lowest L^* values at the end of storage. Despite the citric acid dipping, SA and SAG samples showed lower lightness values from the 6th to 15th day amongst the coating treatments, while mango slices with CA, CS and CSG treatments showed better preservation of lightness until the end of storage.

Polysaccharide coatings are good gas barriers, decreasing the respiration rate and, consequently, the metabolic activities, delaying browning in fresh-cut products. According to Lee, Park, Lee, and Choi (2003), the use of polysaccharide edible coatings and antioxidants retarded browning and colour changes in fresh-cut apples. Fontes et al. (2008) verified that cassava starch coating was efficient to preserve the colour of fresh-cut apples, maintaining the L^* values throughout the storage. The authors also observed that alginate coating provided apple slices with lower lightness values than reached control samples values from day 9 on. Therefore, the colour of alginate solution, which is amber, could have contributed to the lower L^* values obtained. But, according to Olivas, Mattinson, and Barbosa-Cánovas (2007), alginate coatings delayed browning in fresh-cut apples, due to calcium chloride addition that promoted an efficient barrier to oxygen, working as an anti-browning agent and inhibiting polyphenol oxidase by its interaction with copper at the polyphenol oxidase active site. Rojas-Graü et al. (2008) and Oms-Oliu et al. (2008b) reported that alginate coating containing N-acetylcysteine and calcium chloride maintained apples and pears wedges free from browning during storage of 23 and 14 days, respectively. Qi et al. (2010) observed that chitosan coating maintained L^* of apple slices during 8 days and the use of ascorbic acid and citric acid enhanced the inhibitory browning effect of the coating.

Regarding chroma C^* values, the use of cassava starch and alginate coatings did not affect the mangoes colour intensity and the storage time had significant effect ($p \leq 0.05$) for all treatments, showing a reduction on C^* along the storage (Table 2). The C^* values of SA and SAG samples decreased significantly from the 6th day on. Reduction of C^* values, associated to the lower L^* values, resulted in darker slices. The colour of alginate solutions probably influenced on C^* parameter, resulting in lower values for samples coated with this polysaccharide. At the end of storage, all other treatments did not differ significantly ($p \leq 0.05$) with respect to chroma C^*.

CA samples showed higher H^* parameter ($p \leq 0.05$) in comparison to the other treated mango slices at the beginning of storage (Table 2). As C^* parameter, the hue also decreased throughout storage. However, the H^* decrease was lower on CA, CS and CSG treatments. Significant differences were observed at the end of storage and the treatments CA and CSG showed higher H^* values ($p \leq 0.05$), implying in better maintenance of these colour parameter. Oms-Oliu et al. (2008b) also verified that fresh-cut 'Flor de Invierno' pears treated with antioxidants (N-acetylcysteine and glutathione) and edible coatings (gellan, pectin and alginate) presented higher H^* values than the uncoated samples at the end of storage.

In a general way, CA, CS and CSG treatments provided a better maintenance of colour characteristics, due to the combined effect of citric acid dipping and cassava starch coating. Citric acid delayed browning along the storage and the edible coatings acted as a gas barrier, decreasing the respiration rate of mango pieces (Table 1), which resulted in mango slices with lower respiration rates and higher L^*, C^* and H^* values when compared to control, SA and SAG samples.

4. Conclusions

Cassava starch coatings (CS and CSG) reduced weight loss and maintained the mechanical properties and colour parameters, while fresh-cut mangoes coated with sodium alginate coatings (SA and SAG) presented lower stress at failure and browning along the storage time. However, all coated samples presented lower respiration rate than the control sample. Citric acid dipping (CA) was efficient in preserving colour parameters and also reduced the respiration rate, but showed negative effect on weight loss and mechanical properties

Table 2
Lightness L* (a), chroma C* (b) and Hue angle H* (c) of fresh-cut mangoes subjected to different treatments during storage at 5 °C.

Colour parameter	Time [days]	Control	CA	CS	CSG	AS	SAG
L*	1	70.70 ± 1.08^{aA}	71.14 ± 0.35^{aA}	69.77 ± 0.21^{aA}	69.44 ± 1.16^{aA}	70.62 ± 0.89^{aA}	71.43 ± 0.82^{aA}
	6	67.70 ± 0.62^{aB}	71.00 ± 0.41^{bA}	67.37 ± 0.32^{aB}	69.98 ± 1.19^{bA}	62.79 ± 0.74^{cB}	65.64 ± 0.67^{dB}
	9	61.94 ± 1.05^{aC}	65.56 ± 1.09^{bB}	65.05 ± 0.96^{bC}	67.70 ± 0.89^{bB}	61.93 ± 0.88^{aB}	63.41 ± 0.64^{cC}
	15	55.53 ± 0.83^{aD}	61.98 ± 1.00^{bC}	63.63 ± 0.24^{cC}	62.59 ± 0.97^{bcC}	56.66 ± 0.89^{aC}	59.52 ± 0.89^{bD}
C*	1	77.39 ± 0.82^{aA}	77.08 ± 0.45^{aA}	77.80 ± 1.11^{aA}	77.22 ± 0.93^{aA}	77.61 ± 0.95^{aA}	79.47 ± 0.95^{bA}
	6	64.30 ± 0.83^{aB}	66.60 ± 0.63^{bB}	70.92 ± 0.83^{cB}	68.40 ± 0.99^{cB}	73.52 ± 1.05^{dB}	72.38 ± 0.78^{cdB}
	9	63.02 ± 0.83^{aBC}	65.87 ± 1.06^{abB}	66.78 ± 0.78^{bC}	67.51 ± 0.50^{bB}	65.86 ± 0.91^{abC}	65.78 ± 0.60^{abC}
	15	62.30 ± 0.50^{aC}	64.58 ± 0.58^{bB}	64.90 ± 1.08^{bC}	65.88 ± 0.62^{bC}	62.40 ± 0.98^{aD}	62.74 ± 1.01^{aD}
H*	1	77.39 ± 0.46^{aA}	79.49 ± 1.02^{bA}	77.50 ± 0.47^{aA}	78.18 ± 0.54^{aA}	77.78 ± 0.94^{aA}	77.6 ± 0.98^{aA}
	6	75.83 ± 0.72^{aB}	78.46 ± 0.47^{bA}	76.25 ± 0.50^{aB}	77.89 ± 0.23^{bA}	75.78 ± 0.46^{aB}	77.35 ± 0.23^{bA}
	9	75.24 ± 0.84^{aB}	77.58 ± 1.02^{bAB}	76.17 ± 0.80^{aB}	77.76 ± 0.11^{bA}	75.43 ± 0.98^{aB}	75.27 ± 0.95^{aB}
	15	73.79 ± 0.30^{aC}	77.35 ± 0.50^{bB}	75.47 ± 0.89^{cB}	77.35 ± 0.22^{bA}	74.72 ± 1.07^{aB}	74.97 ± 1.05^{aB}

Control = fresh-cut mangoes untreated; CA = only citric acid dipping; CS = citric acid + cassava starch coating; CSG = citric + cassava starch coating with glycerol; SA = citric acid + alginate coating; SAG = citric + alginate coating with glycerol.
Different letters (small: amongst different treatments for the same time; capital: amongst different times for the same treatment) indicate statistically significant differences ($p \leq 0.05$).

of uncoated samples. Samples recovered with coatings containing glycerol did not show statistical differences from coated samples without plasticiser with respect to weight loss, mechanical properties and colour parameters throughout storage. In a general way, the association of citric acid and cassava starch coatings (CS and CSG) was efficient to reduce the respiration rate and maintain mechanical properties and colour characteristics of mango slices during 15 days of storage.

Acknowledgements

The authors are grateful to FAPESP (process numbers: 06/03263-9, 08/55343-1 and 09/51420-4), Capes and CNPq for their financial support.

References

Agriculture and Agri-Food Canada (2010). Packaged Foods in the United States – Market Indicator Report [www page]. URL. http://www.flowerscanadagrowers.com/upload/Market%20Indicator%20Report.pdf.
Andrés, C. S., Giannuzzi, L., & Zaritzky, N. E. (2002). Quality parameters of packaged refrigerated apple cubes in orange juice. *LWT Food Science and Technology*, *35*, 670−679.
Beaulieu, J. C., & Lea, J. M. (2003). Volatile and quality changes in fresh-cut mangoes prepared from firm-ripe and soft-ripe fruit, stored in clamshell containers and passive MAP. *Postharvest Biology and Technology*, *30*, 15−28.
Bico, S. L. S., Raposo, M. F. J., Morais, R. M. S. C., & Morais, A. M. M. B. (2009). Combined effects of chemical dip and/or carrageenan coating and/or controlled atmosphere on quality of fresh-cut banana. *Food Control*, *20*, 508−514.
Bierhals, V. S., Chiumarelli, M., & Hubinger, M. D. (2011). Effect of cassava starch coating on quality and shelf life of fresh-cut pineapple (*Ananas Comosus* L. Merril cv "Pérola"). *Journal of Food Science*, *76*, E62−E72.
Brennan, M., Le Port, G., & GormLey, R. (2000). Postharvest treatment with citric acid or hydrogen peroxide to extend the shelf life of fresh sliced mushrooms. *LWT Food Science and Technology*, *33*, 285−289.
CEAGESP (2004). Programa Brasileiro para Modernização da Horticultura, São Paulo, Brazil [www page]. URL. http://www.ceagesp.gov.br/produtor/tecnicas/classific/fc_manga.
Chien, P. J., Sheu, F., & Yang, F. -H. (2007). Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *Journal of Food Engineering*, *78*, 225−229.
Chiumarelli, M., Pereira, L. M., Ferrari, C. C., Sarantópoulos, C. I. G. L., & Hubinger, M. D. (2010). Cassava starch coating and citric acid to preserve quality parameters of fresh-cut "Tommy Atkins" mango. *Journal of Food Science*, *75*, E297−E304.
Colla, E., Sobral, P. J. A., & Menegalli, F. C. (2006). *Amaranthus cruentus* flour edible films: influence of stearic acid addition, plasticizer concentration, and emulsion stirring speed on water vapor permeability and mechanical properties. *Journal of Agricultural and Food Chemistry*, *54*, 6645−6653.
Cunha, G. A. P. C., Sampaio, J. M. M., Nascimento, A. S., Santos Filho, H. P., & Medina, V. M. (1994). *Manga para exportação: aspectos técnicos da produção*. Brasília: EMBRAPA – SPI.
FAO. Food and Agriculture Organization of the United Nations (2010). Prodution and Trade [www page]. URL. http://faostat.fao.org/site/291/default.aspx.
Ferrari, C. C., Carmello-Guerreiro, S. M., Bolini, H. M. A., & Hubinger, M. D. (2010). Structural changes, mechanical properties and sensory preference of osmodehydrated melon pieces with sucrose and calcium lactate solutions. *International Journal of Food Properties*, *13*, 112−130.
Ferrari, C. C., & Hubinger, M. D. (2008). Evaluation of the mechanical properties and diffusion coefficients of osmodehydrated melon cubes. *International Journal of Food Science & Technology*, *43*, 2065−2074.
Fontes, L. C. B., Sarmento, S. B. S., Spoto, M. H. F., & Dias, C. T. S. (2008). Preservation of minimally processed apple using edible coatings. *Ciência e Tecnologia de Alimentos*, *28*, 872−880.
Garcia, E., & Barrett, D. M. (2002). Preservative treatments for fresh-cut fruits and vegetables. In O. Lamikanra (Ed.), *Fresh-cut fruits and vegetables: science, technology and market* (pp. 267−304). Boca Raton: CRC Press.
Garcia, L. C., Pereira, L. M., Sarantópoulos, C. I. G. L., & Hubinger, M. D. (2010). Selection of an edible starch coating for minimally processed strawberry. *Food and Bioprocess Technology*, *3*, 834−842.
González-Aguilar, G. A., Celis, J., Sotelo-Mundo, R. R., De La Rosa, L. A., Rodrigo-Garcia, J., & Alvarez-Parrilla, E. (2008). Physiological and biochemical changes of different fresh-cut mango cultivars stored at 5 °C. *International Journal of Food Science & Technology*, *43*, 91−101.
González-Aguilar, G. A., Valenzuela-Soto, E., Lizardi-Mendoza, J., Goycoolea, F., Martínez- Téllez, M. A., Villegas-Ochoa, M. A., et al. (2009). Effect of chitosan coating in preventing deterioration and preserving the quality of fresh-cut papaya 'Maradol'. *Journal of the Science of Food and Agriculture*, *89*, 15−23.
Ito, A. P., Tonon, R. V., Park, K. J., & Hubinger, M. D. (2007). Influence of process conditions on the mass transfer kinetics of pulsed vacuum osmotically dehydrated mango slices. *Drying Technology*, *25*, 1769−1777.
Krochta, J. M. (2002). Proteins as raw materials for films and coatings: definitions, current status, and opportunities. In A. Gennadios (Ed.), *Protein-based Films and Coatings* (pp. 1−41). Florida: CRC Press.
Lee, J. Y., Park, H. J., Lee, C. Y., & Choi, W. Y. (2003). Extending shelf-life of minimally processed apples with edible coatings and antibrowning agents. *LWT Food Science and Technology*, *36*, 323−329.
Maftoonazad, N., Ramaswamy, H. S., & Marcotte, M. (2008). Shelf-life extension of peaches through sodium alginate and methyl cellulose edible coatings. *International Journal of Food Science & Technology*, *43*, 951−957.
Mancini, F., & McHugh, T. H. (2000). Fruit-alginate interactions in novel restructured products. *Nahrung/Food*, *44*, 152−157.
Moda, E. M., Spoto, M. H. F., Horii, J., & Zocchi, S. S. (2005). Use of hydrogen peroxide and citric acid for conservation of fresh *Pleurotus sajor-caju* mushrooms. *Ciência e Tecnologia de Alimentos*, *25*, 291−296.
Olivas, G. I., Mattinson, D. S., & Barbosa-Cánovas, G. V. (2007). Alginate coatings for preservation of minimally processed 'Gala' apples. *Postharvest Biology and Technology*, *45*, 89−96.
Oms-Oliu, G., Soliva-Fortuny, R., & Martin-Belloso, O. (2008a). Using polysaccharide-based edible coatings to enhance quality and antioxidant properties of fresh-cut melon. *LWT Food Science and Technology*, *41*, 1862−1870.
Oms-Oliu, G., Soliva-Fortuny, R., & Martin-Belloso, O. (2008b). Edible coatings with antibrowning agents to maintain sensory quality and antioxidant properties of fresh-cut pears. *Postharvest Biology and Technology*, *50*, 87−94.
Pareta, R., & Edirisinghe, M. J. (2006). A novel method for the preparation of starch films and coatings. *Carbohydrate Polymer*, *63*, 425−431.
Pereira, L. M., Rodrigues, A. C. C., Sarantópoulos, C. I. G. L., Junqueira, V. C. A., Cunha, R. L., & Hubinger, M. D. (2004). Influence of modified atmosphere packaging and osmotic dehydration on the quality maintenance of minimally processed guavas. *Journal of Food Science*, *69*, 172−177.
Qi, H., Hu, W., Jiang, A., & Tian, M. (2010). Extending shelf-life of fresh-cut 'Fuji' apples with chitosan-coatings. *Innovative Food Science & Emerging Technologies*, doi:10.1016/j.ifset.2010.11.001.
Raybaudi-Massilia, R. M., Rojas-Graü, M. A., Mosqueda-Melgar, J., & Martin-Belloso, O. (2008). Comparative study on essential oils incorporated into an alginate-based edible coating to assure the safety and quality of fresh-cut Fuji apples. *Journal of Food Protection*, *71*, 1150−1161.
Ribeiro, C., Vicente, A. A., Teixeira, J. A., & Miranda, C. (2007). Optimization of edible coating composition to retard strawberry fruit senescence. *Postharvest Biology and Technology*, *44*, 63−70.
Rocculi, P., Galino, F. G., Mendonza, F., Wadsö, L., Romani, S., Dalla-Rosa, M., et al. (2007). Effects of the application of anti-browning substances on the metabolic

activity and sugar composition of fresh-cut potatoes. *Postharvest Biology and Technology*, *43*, 151—157.

Rodrigues, L. K., Pereira, L. M., Ferrari, C. C., Sarantópoulos, C. I. G. L., & Hubinger, M. D. (2008). Shelf life of mango slices stored under passive modified atmosphere packaging. *Ciência e Tecnologia de Alimentos*, *28*, 271—278.

Rojas-Graü, M. A., Tapia, M. S., & Martin-Belloso, O. (2008). Using polysaccharide-based edible coatings to maintain quality of fresh-cut Fuji apples. *LWT Food Science and Technology*, *41*, 139—147.

Rojas-Graü, M. A., Tapia, M. S., Rodríguez, F. J., Carmona, A. J., & Martin-Belloso, O. (2007). Alginate and gellan-based edible coatings as carriers of antibrowning agents applied on fresh-cut Fuji apples. *Food Hydrocolloids*, *21*, 118—127.

Soliva-Fortuny, R. C., & Martín-Belloso, O. (2003). New advances in extending the shelf life of fresh-cut fruits: a review. *Trends in Food Science and Technology*, *14*, 341—353.

Sothornvit, R., & Rodsamran, P. (2010). Mango film coated for fresh-cut mango in modified atmosphere packaging. *International Journal of Food Science & Technology*, *45*, 1689—1695.

Tapia, M. S., Rojas-Graü, M. A., Carmona, A., Rodríguez, F. J., Soliva-Fortuny, R., & Martin-Belloso, O. (2008). Use of alginate- and gellan-based coatings for improving barrier, texture and nutritional properties of fresh-cut papaya. *Food Hydrocolloids*, *22*, 1493—1503.

Toivonen, P. M. A., & Brummell, D. A. (2008). Biochemical bases of appearance and texture changes in fresh-cut fruit and vegetables. *Postharvest Biology and Technology*, *48*, 1—14.

Varanyanond, W., Naohara, J., Wongkrajang, K., & Manabe, M. (1999). Changes in pectin content and average molecular weight of pectin during maturation of the mango 'Kaew'. *Food Science and Technology Research*, *5*, 362—364.

Vieira, A.P., Vieites, R.L. & Evangelista, R.M. (2000). Cassava starch coating in minimally processed pineapple. In SBCTA (Ed.), *Proceedings of the 17th CBCTA*. 8–10 August 2000, Fortaleza, Brazil. [CD-ROM].