Biodegradable Edible Films from Renewable Sources-potential for their Application in Fried Foods

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ABSTRACT

The objective this study was to evaluate the physical, physicochemical, morphological, mechanical and barrier properties of edible films obtained from pectin, sodium alginate or methylcellulose, aiming to evaluate their performance in minimizing the incorporation of oil. The pectin film presented the lowest water vapor permeability, thickness, water solubility, tensile strength, elongation and time for the film to change its color and size after contact with oil. The alginate film presented the greatest tensile strength and elongation and the lowest oxygen permeability. The methylcellulose film showed the longest time to change its color and size. The alginate film was the most indicated as a coating, since it showed the greatest tensile strength and elongation, which guarantees that the coating covers the chips uniformly and would have the least chance of rupturing during processing and it also shows low oxygen permeability making gas exchanges and oxidation of the final product more difficult.

Key words: Edible films, low methoxyl pectin, sodium alginate, methylcellulose, fried foods

INTRODUCTION

The use of edible films and coatings for food products appears to be a recent technique, but the application of waxes has been used in China since the XII and XIII centuries, in order to retard dehydration and improve their appearance (Debeaufort et al., 1998).

With respect to the nomenclature, the majority of researchers use the terms film and coating indiscriminately. However a coating is a fine layer of material applied and formed directly on the surface of the product, whereas a film is pre-formed separately and subsequently applied to the product (Gontard and Guilbert, 1995; Krochta and DeMulder, 1997).

The function of films and coatings is to inhibit or reduce the migration of moisture, oxygen, carbon dioxide, lipids and aromas, amongst others, since they provide semi-permeable barriers. In addition they can transport food additives such as antioxidants, antimicrobial agents and flavors and/or improve the mechanical integrity and/or handling characteristics of the food (Krochta and DeMulder, 1997).

The macromolecules must be dispersed or dissolved in a solvent (water, ethanol or organic acids) in order to form an edible coating and a plastifier must be added to obtain the filmogenic solution, which can then be applied directly to the product. The process is completed by evaporation of the

solvent or drying (Gontard *et al.*, 1994; Cuq *et al.*, 1997). The macromolecules most used in the elaboration of edible films and coatings are proteins (gelatin, casein, egg albumin, wheat gluten, zein and myofibrillar proteins), polysaccharides (starch and starch derivatives, pectin, cellulose and cellulose derivatives, alginate and carrageenan) and lipids (acetylated monoglycerides, stearic acid, waxes and fatty acid esters) or a combination of these (Cuq *et al.*, 1995). Plastifiers are defined as substances with high melting points, which, when added to another material cause changes in the physical, chemical and mechanical properties of the material (McHugh and Krochta, 1994). Plastifiers result in an increase in flexibility of the polymer chains and an increase in mechanical resistance, decreasing possible discontinuities and brittle zones (Krochta *et al.*, 1994), in addition to improving the adhesiveness of the film (Lin *et al.*, 2000).

Films elaborated from polysaccharides or proteins possess excellent mechanical, optical and organoleptic properties, but are sensitive to moisture and have a high coefficient of water vapor permeability. To the contrary, coatings composed of lipids show good water vapor barrier properties, but are opaque and lack flexibility in addition to presenting an after taste, which could influence the organoleptic characteristics of the food. A combination of the biopolymers has the advantage of aggregating the positive aspects of each of the constituents (Gallo *et al.*, 2000).

Hydrocolloids, lipids or a combination of both are the coatings most used to reduce oil migration into the food during frying. Hydrocolloids are of special interest since they show good oxygen, carbon dioxide and lipid barrier properties (Williams and Mittal, 1999) and proteins, cellulose derivatives, alginates, pectins and other polysaccharides are amongst the hydrocolloids most widely used as coatings. Two criteria are of importance in the choice of a material for use as a barrier against the incorporation of oil into a product during frying: its permeability with respect to the oil and its resistance at high temperatures (Albert and Mittal, 2002).

Mallikarjunan *et al.* (1997) used 47 mm diameter spheres of macerated potato as a model to study the effect of coatings made from corn zein, methoxymethylcellulose and methylcellulose and managed to reduce the oil content by 59, 61.4 and 83.65%, respectively.

Querido (2005) studied the use of pectin (1, 2 and 3%) and sodium alginate (1 and 2%) coatings for apples as a barrier to oil incorporation. Concentrations of 2% of both coatings were found to be efficient when used as edible coatings immediately before frying, reducing oil incorporation into the final product by 60%.

The objective of the present study was to evaluate the physical, physicochemical, morphological, mechanical and barrier properties of edible, biodegradable films obtained from low methoxyl pectin, sodium alginate or methylcellulose, aiming to evaluate their performance in minimizing the incorporation of oil when applied as coatings for sweet potato chips.

MATERIALS AND METHODS

Material: The materials used to elaborate the films were: (1) low-esterified pectin (30%), amydated (18%), with the commercial name of GENU® type LM-102AS pectin, obtained from citrus fruits and provided by CPKelco Brasil S/A (Limeira, SP, Brazil); (2) sodium alginate with the commercial name of PROTANAL LF 20/40 donated by FMC Química do Brasil LTDA (Campinas, SP, Brazil); (3) methylcellulose with the commercial name of METHOCEL A 15 FG provided by Dow Brasil S.A (São Paulo, SP, Brazil); (4) glycerol (Synth, Diadema, SP, Brazil) and (5) calcium chloride (Synth, Diadema, SP, Brazil).

The study was conducted at the State University of Campinas, Department of Food Technology in the period from 01/08/2007 to 01/12/2009.

Film elaboration

Low methoxyl pectin film: The following procedure was adopted to elaborate the pectin films: (1) dissolve 1% glycerol (in relation to the macromolecule) in 2000 mL water at 60°C and stir for 5 min on a magnetic stirrer; (2) subsequently add 4% pectin, maintaining the temperature at 60°C and stir for a further 20 min on the magnetic stirrer to completely dissolve the material; (3) add 0.06% $CaCl_2$ and continue stirring at 60°C for another 5 min. Fifty-five milliliter aliquots of this solution were spread on Plexiglas® plates and maintained at 35°C in an oven with air circulation (aiming to simulate drying of the coatings on sweet potato chips) for 24 h.

Sodium alginate film: The sodium alginate films were obtained by dissolving 0.5% glycerol (in relation to the macromolecule) in 700 mL distilled water at 70°C and after stirring for 5 min on a magnetic stirrer, 2% sodium alginate was added and stirring continued for another 20 min to completely dissolve the material. Fifty-five milliliter aliquots of this solution were deposited on Plexiglas® plates and maintained at 35°C in an oven with air circulation for 24 h to dry the coating.

Methylcellulose film: In order to elaborate the methylcellulose films, 0.5% glycerol (in relation to the macromolecule) was first dissolved in 245 g of distilled water at 70°C and after stirring for 5 min on the magnetic stirrer, 2% methylcellulose and 455 g of chilled (2°C) distilled water were added and stirred for a further 15 min. The final solution was then placed in an ultrasound bath (model T1440 from Thornton) for 5 min to minimize bubble formation. Fifty-five milliliter aliquots of this solution were pipetted onto Plexiglas® plates and maintained at 35°C in an oven with air circulation for 24 h to dry the coating.

Film characterization: Before the analyses, all the dried films were placed in desiccators at 25°C and 50% RH (using a saturated magnesium nitrate solution) for 48 h.

Visual aspect: Visual and tactile analyses were carried out for each type of film produced, aiming to select those films that were homogenous (evaluation of the presence or absence of insoluble particles and uniformity of color), showing continuity (without cracks or brittle zones) and ease of handling (ease in removing the films from the support).

Thickness: Film thickness was measured using a micrometer (Model MDC-25 M from Mitutoyo, MFG, Japan). The thickness was determined as the mean of ten random measurements at different points of the film.

Water vapor permeability: The Water Vapor Permeability (WVP) of the films was determined gravimetrically according to the standard method E-96-95 of (ASTM, 1995a, b). A disk of the film was placed in a cell containing calcium chloride, which was conditioned in a desiccator with controlled temperature and relative humidity (25°C and 75% RH, using a saturated sodium chloride solution). The water vapor diffusing across the film was determined from the increase in mass of the calcium chloride, measured every 24 h for 7 days in quadruplicate.

The water vapor permeability (WVP) was calculated using the following equation:

$$WVP = \frac{Mp \times thickness}{A \times Time \times \Delta p} \qquad (1)$$

Where:

M_p = Corresponds to the rate of moisture absorption (g)

A = The area of film surface exposed (m^2)

Δp = The difference in partial pressure across the film (g mm/m^2 dKPa)

Water solubility: The water solubility of the films was determined by the method proposed by Gontard *et al.* (1994). The samples were prepared in quadruplicate, being cut into 2 cm diameter disks. The initial dry mass of the films was obtained after drying in an oven at 105°C with air circulation for 24 h (model TE 394/2 from TECNAL). After the first weighing, the samples were immersed in a beaker containing 50 mL distilled water and placed on a shaker in a thermostatically controlled water bath (model 304/D from NOVA ÉTICA) for 24 h at 25°C. The soaked samples were then removed and dried in an oven for 24 h at 105°C to obtain the final dry mass. Solubility was expressed according to the following equation:

$$\text{Solubility} = \frac{(M_i - M_f)}{M_i \times 100} \qquad (2)$$

Where:

M_i = Initial dry mass (g)

M_f = Final dry mass after soaking (g)

Mechanical properties: The tensile strength and percent elongation at rupture were determined using the TA.XT2 texturometer (Stable Micro Systems, Hasleme, UK), operated according to the ASTM standard method D 882-83 (ASTM, 1995). The measurements were made at room temperature (25°C). The initial distance between the hooks and the probe velocity were 50 mm and 1 mm sec^{-1}, respectively. The samples were cut into 100 mm long by 25 mm wide pieces and six replicates were made for each sample. The Tensile Strength (TS) and the percent elongation (ELO) were calculated from Eq. 3 and 4, respectively:

$$TS = \frac{F_m}{A} \qquad (3)$$

Where:

TS = Corresponds to the tensile strength (MPa)

F_m = The maximum force at the moment of rupture of the film (N)

A = The cross-sectional area (m^2)

$$ELO = \frac{d_r}{d_{initial} \times 100} \qquad (4)$$

Where:

ELO = Corresponds to the percent elongation (%)

d_f = The distance at the moment of rupture (cm), corresponding to the difference between the initial distance between the hooks (5 cm) and the distance at the moment of rupture

$d_{initial}$ = The initial distance between the hooks (5 cm)

Oxygen permeability: The Oxygen Transmission Rate (OTR) was determined using a modification of the ASTM standard method D 3985-81 (ASTM, 1990) using the apparatus OX-TRAN 2/20 (Mocon, Inc.) at 25°C. The oxygen permeability (PO_2) was calculated from the following equation:

$$PO_2 = \frac{OTR \times e.t}{\Delta p} \qquad (5)$$

Where:
PO_2 = The oxygen permeability (cm^3 μm m^{-2} dkPa)
OTR = The oxygen transmission rate (mL m^{-2} day)
T   = Corresponds to the thickness (cm)
Δp = The difference in partial pressure between the two sides of the film (KPa)

The difference in pressure across the film corresponds to the atmospheric pressure (101.3 KPa), the film samples being subjected to 100% oxygen gas on one side and a stripping gas containing 98% nitrogen and 2% hydrogen on the other. The analyses were carried out in duplicate with the films conditioned at a temperature of 25°C and 52±2% RH for 48 h. An aluminum mask (fixed exposed area = 5 cm^2) was used to facilitate fixing the film.

Opacity: Film opacity was determined using the Hunterlab colorimeter (Colorquest II, Fairfax, USA). The determinations were carried out in triplicate after calibration of the colorimeter with a standard white background and a standard black background. Opacity was determined from the following equation:

$$Op = \frac{Opb}{Opw} \times 100 \qquad (6)$$

Where:
Op   = The film opacity (%)
Opb = Opacity of the film superimposed on the black background
Opw = Opacity of the film superimposed on the white background

Film stability on frying in oil: Film stability when submitted to a frying process in oil was evaluated aiming to simulate what would occur when the solution was applied to a food product forming a coating, before the process of immersion frying. The film samples were prepared in a way similar to the methodology used to determine water solubility. They were cut into 2 cm diameter disks in triplicate and placed in palm olein and palm stearin at 180°C and the time taken for the film color and size to change determined.

Scanning electronic microscopy: The surface and cross-sectional micro-structures were evaluated by scanning electronic microscopy (LEO 440i, Cambridge) at 5 kV. The films were maintained in desiccators containing silica gel for seven days and were then fractured. The fractured film samples were fixed onto aluminum stubs with carbon adhesive tape. In order to

confer conductivity on the films, they were covered with a 92Å thick layer of gold at a covering rate of 0.5 Å sec^{-1} in a vacuum metallizer (Polaron SC 7620) for 180 sec at 3 mA.

Statistical analysis: Significant differences between the means were identified by Tukey's test (p<0.05) and the statistical variance analyses (ANOVA) were carried out using the SAS program.

RESULTS AND DISCUSSION
Characterization of the films
Visual aspect: The pectin, alginate and methylcellulose films were characterized with respect to their visual and tactile aspects, that is, they were checked for the presence of insoluble particles, pores, fractures/ruptures and brittleness.

With respect to the pectin films, the difficulties found were brittleness and a difficulty in removing them from the Plexiglas® plates. However, using a phase diagram with different combinations of pectin (1 to 5%) and calcium chloride (0.02 to 0.16%), as carried out by Batista (2004), it was observed that a pectin concentration of 4% with 0.06% CaCl$_2$ presented the best film aspect with respect to handling, when compared to the other treatments. In the preliminary tests carried out in the present study, it was shown that the addition of the plastifier glycerol at a rate of 1% in relation to the macromolecule, provided a less brittle film, due to the increase in flexibility of the polymer chains and in the mechanical resistance, decreasing possible discontinuities and brittle zones (Gallo *et al.*, 2000).

In the case of the sodium alginate films, the main difficulty found was the high viscosity of the solution, making it difficult to pipette the film onto the Plexiglas® plates. However, by way of preliminary tests it was possible to adequate the concentration of the solution to 2% alginate, making it possible to pipette the films.

After 20 min of moderate stirring on the magnetic stirrer, the methylcellulose film solution showed the formation of a large number of bubbles, making it difficult to spread the solution on the Plexiglas® plates. Thus the solution was placed in an ultrasound bath (model T1440 from Thornton) for 5 min to minimize the formation of bubbles.

Thickness: There was no significant difference at the 5% level of significance between the mean thicknesses of the pectin and alginate films. The means and standard deviations were 0.044±0.003 and 0.047±0.005 mm, respectively. Greater values for thickness (0.066±0.004 mm) were found in another study of pectin films (4% pectin+0.06% calcium chloride), which could be explained by the drying method used, which was at 25°C (Batista *et al.*, 2005). The thickness of type 1 sodium alginate films at a concentration of 1.5 plus 0.6% glycerol was practically twice the value found here (0.101±0.001 mm), a fact which can be explained by the composition of the raw material (Zactiti, 2004).

The methylcellulose films showed the highest mean values for thickness (0.063±0.006 mm), significantly different from the pectin and sodium alginate films at the 5% level of significance. The result obtained was greater than that found by Nelson and Fennema (1991) probably due to the methodology used to elaborate the film, the aliquot used and the size of the drying support (20×112 cm).

Uniformity of film thickness is important, since it functions as the base to calculate the various functional properties of the films (Xie *et al.*, 2002).

Table 1: Water vapor permeability and water solubility of the pectin, alginate and methylcellulose films

Films	Thickness (mm)	WVP (g.mm/m^2.d. KPa)	Water solubility (%)
Pectin	0.041±0.004[b]	5.20±0.23[c]	60.83±0.35[b]
Alginate	0.049±0.007[b]	15.57±0.10[a]	100.00±0.00[a]
Methylcellulose	0.062±0.006[a]	12.43±0.21[b]	100.00±0.00[a]

Means with the same letter(s) in the same column do not differ at the 5% level of significance

Table 2: Mechanical properties of the pectin, alginate and methylcellulose films

Films	Thickness (mm)	Tensile strength (MPa)	Elongation (%)
Pectin	0.047±0.003[b]	52.98±2.13[c]	1.34±0.11[b]
Alginate	0.045±0.003[b]	112.07±0.17[a]	9.09±0.18[a]
Methylcellulose	0.064±0.006[a]	62.59±0.12[b]	9.28±0.67[a]

Means with the same letter(s) in the same column do not differ at the 5% level of significance

Water vapor permeability and water solubility: As can be seen in Table 1, the Water Vapor Permeability (WVP) values of the pectin, alginate and methylcellulose films varied between 5.20 and 15.57 g.mm/m^2.dKPa and those of water solubility between 60.83 and 100%.

With respect to Water Vapor Permeability (WVP), all the films presented a significant difference at the 5% level of significance. The films presenting the highest and lowest WVP were, respectively, that of sodium alginate (15.57 g.mm/m^2.dKPa) and pectin (5.20 g.mm/m^2.dKPa), the latter also presenting the smallest thickness. According to Park and Chinnan (1995), the water vapor permeability can vary with film thickness due to the structural changes caused by the swelling of the matrix, which affects the structure of the films due to the structural changes caused by swelling of the matrix, affecting film structure and producing internal tension, which can influence permeation.

The WVP value found for the alginate film was similar to that presented by Zactiti (2004) for type III sodium alginate films at a concentration of 1.5 plus 0.6% glycerol and dried in an oven at 40°C 18-20 h (13.59 g.mm/m^2.dKPa).

In a study on the water vapor permeability of films containing 4% pectin and 0.06% calcium chloride, Batista *et al.* (2005) reported a value of 7.21 g.mm/m^2.dKPa, higher than the value found in the present study, probably because they presented a thickness of 62%.

The methylcellulose films presented intermediate values for WVP in relation to the other films studied (12.43 g.mm/m^2.dKPa).

The water solubility of a film indicates its integrity in highly moist or aqueous environments (Vicentini, 2003). The water solubility of the alginate and methylcellulose films was 100%, that is, the films were completely soluble in water. In some cases this complete solubility in water can be beneficial, as in the case of semi-ready-to-serve products destined for cooking. However in the case of liquid foods or those exuding an aqueous solution, highly soluble bio-films are not indicated (Fakhouri *et al.*, 2007).

The water solubility of the pectin films was 60.83±0.35%, statistically different from the other films studied (Batista *et al.*, 2005) found higher values for the water solubility of pectin films (100%), evaluating films made with 4% pectin plus 0.06% glycerol.

Mechanical properties: The means for tensile strength of the films studied varied between 52.98 and 112.07 MPa, differing statistically from each other (Table 2). With respect to percent elongation of the film, the sodium alginate and methylcellulose films did not present significant differences

Table 3: Oxygen permeability of the pectin, alginate and methylcellulose films

Films	Oxygen permeability (cm³ µm/m²dkPa)
Pectin	19.49±2.04[b]
Alginate	5.66±0.00[c]
Methylcellulose	268.43±0.00[a]

Means with the same letter(s) in the same column do not differ at the 5% level of significance

between them, but the pectin film showed less elongation and less mechanical resistance (1.34 and 52.98, respectively), as also observed in compound films made of gelatin and potato starch in the proportion of (1:0.3) (Fakhouri *et al.*, 2007).

The alginate films presented the greatest tensile strength (112.07 MPa), followed by the methylcellulose films (62.59 MPa) and finally the pectin films (52.98 MPa). The values for tensile strength were higher than those reported by Briston (1988) for high density polyethylene films (17.3-34.6 MPa) and similar to the value found by Carulo (2005) for a 1.5% sodium alginate film containing 0.6% glycerol (103.46±9.91 MPa). The values reported in the literature for 4% pectin films containing 0.06% calcium chloride were higher for both tensile strength and for elongation (91.11 MPa and 2.93%), respectively (Batista, 2004).

The methylcellulose films showed the greatest elongation (9.28%), but this was still much smaller than the value found for polypropylene films (60%) (Krochta and DeMulder,1997).

Oxygen permeability: Table 3 shows the values found for the oxygen permeability of the pectin, alginate and methylcellulose films, varying from 5.66 to 268.43 cm³ µm m⁻²dkPa, being lowest for the alginate film and highest for the methylcellulose film.

The pectin film showed an intermediate value for oxygen permeability as compared to the other films studied (19.46 cm³ µm m⁻² dkPa). Similar results were obtained for films composed of 10 g gelatin, triacetin (15% in relation to the macromolecule) and stearic acid (10%) (20.49 cm³ µm m⁻² dkPa) (Bertan, 2003).

The results encountered for the oxygen permeability of the pectin, alginate and methylcellulose films show that they were all more permeable than those made from polyvinylidene chloride (PVDC) (5.1 cm³ µm m⁻ ²dkPa), although the values were lower than those of Low Density Polyethylene Films (LDPE) (1870 cm³ µm m⁻² dkPa) (McHugh and Krochta, 1994).

Opacity: The opacity of the pectin, alginate and methylcellulose films differed significantly between them at the 5% level of significance (Fig. 1). The pectin film showed the greatest opacity (3.97) followed by the alginate film (3.21) and finally the methylcellulose film (2.52). All the films were less opaque than the polyvinyl chloride (PVC) film, which presented an opacity of about 12%, possibly due to differentiation of the raw material and the way the film was elaborated (Zactiti, 2004).

The methylcellulose films showed the greatest transparency of all the films studied.

Film stability on frying: The pectin film showed the lowest stability, with changes in color and size in both palm olein (2 s) and palm stearin (3 s), showing a black color in both cases (Fig. 2, 3).

The sodium alginate film showed an intermediate contact time in both palm olein (2.5 s) and palm stearin (3.5 s). After the contact time, the film became black in the palm olein and brownish in the palm stearin (Fig. 2, 3).
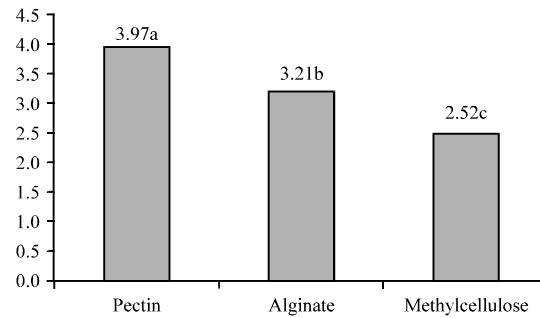
Fig. 1: Opacity of the pectin, alginate and methylcellulose films. Means with the same letter(s) did
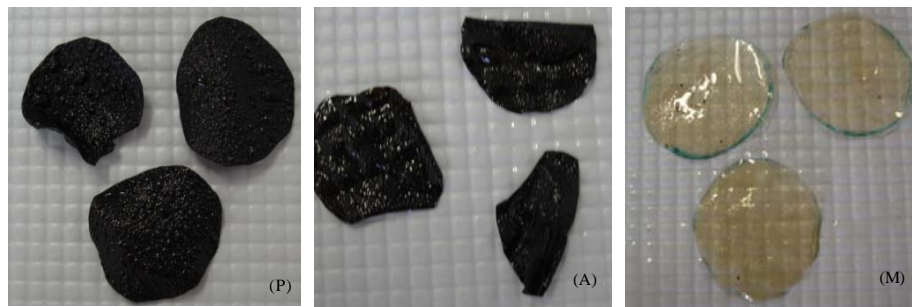not differ at the level of p ≤0.05

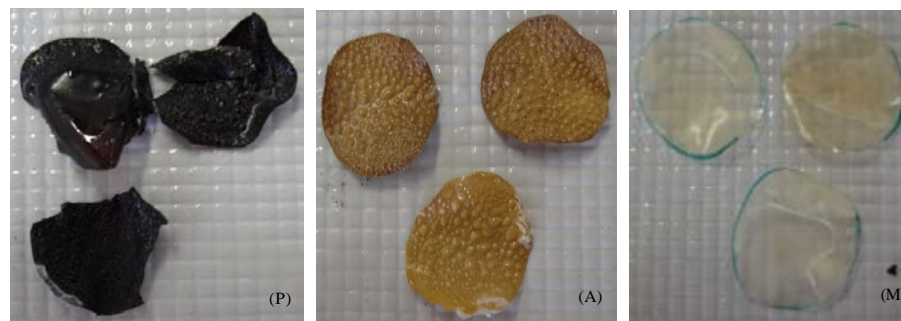Fig. 2: Pectin (P), alginate (A) and methylcellulose (M) films in contact with palm olein

Fig. 3: Pectin (P), alginate (A) and methylcellulose (M) films in contact with palm stearin

The methylcellulose film showed the longest contact time before changing its color and size in
both palm olein (3 s) and palm stearin (6 s). In both cases the color of the film did not change very
much after the contact time, presenting a yellowish final color (Fig. 2 and 3).

Comparing the two oils, the contact time for a change in color and size was always shorter in
the palm olein.

Scanning Electronic Microscopy (SEM): Figure 4-6 show the micrographs of the pectin,
alginate and methylcellulose films obtained by SEM.

The films were evaluated with respect to their surface morphology and by observing the
cross-section after frying (arrangement of the internal structure). The films were fractured using
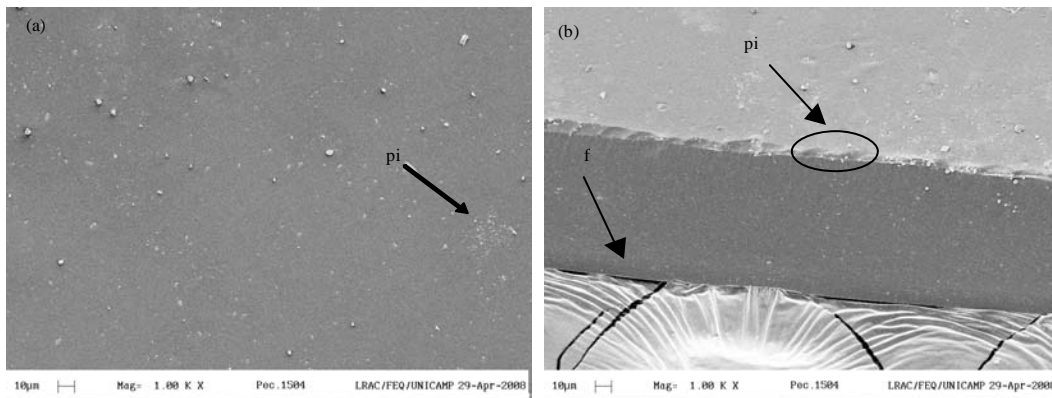
Fig. 4: Micrographs obtained by scanning electronic microscopy of the pectin films: (a) surface and (b) cross-section. pi: Insoluble particles and f: Carbon tape
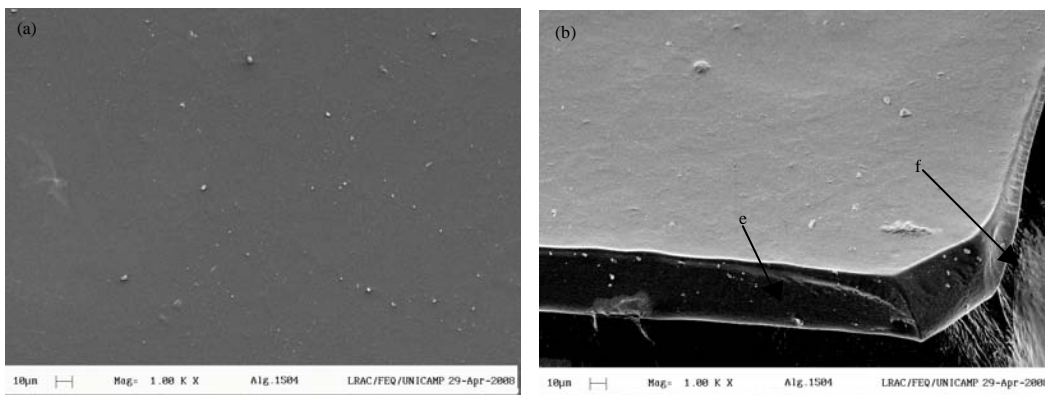

Fig. 5: Micrographs obtained by scanning electronic microscopy of the alginate films: (a) surface and (b) cross-section. e: Etripes and f: Carbon tape
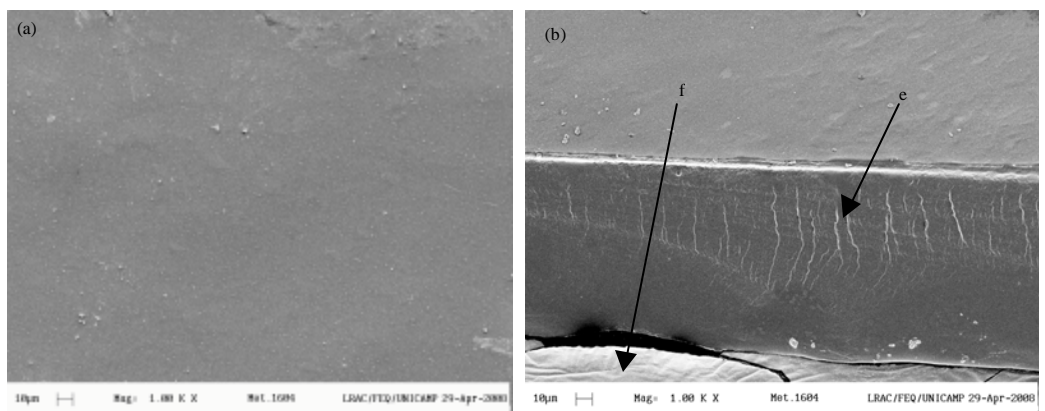

Fig. 6: Micrographs obtained by scanning electronic microscopy of the methylcellulose films: (a) surface and (b) cross-section. E: Stripes and f: Carbon tape

cutting instruments to avoid compaction of the matrix. In some of the micrographs (Fig. 4b, 5b and 6b), a small band can be seen at the bottom, corresponding to the carbon tape which provides conductivity to the film for its visualization (represented in the figures by the letter f).

In order to observe the cross-section of the film, the support holding the stubs had to be inclined. In some cases this allowed for visualization not only of the thickness of the film but also of the carbon tape to which the films were adhered for subsequent application of the gold layer and visualization in the microscope.

Figure 4a and b show the structures of the surface and cross-section, respectively, of the pectin films. The film presented a surface with a continuous smooth structure and the presence of larger particles not inserted into the film matrix, which could be due to the fracturing of the film immediately before metallizing. The presence of small agglomerates of insoluble particles (pi) was observed on the surface and in the cross-section, probably due to non-dissolved pectin. The cross-section of the pectin film was dense and compact. Studies carried out with gelatin films plastified with triacetin showed a smooth, continuous surface (Bertan, 2003).

Figure 5a and b show the structures of the surface and the cross-section, respectively, of the alginate films. This film presented a smooth surface with a homogenous structure and the presence of larger particles not inserted into the matrix of the film, which could be due to fracturing of the film prior to metallization. In their study (Lima *et al.*, 2007) also observed that 2% sodium alginate films presented a smooth surface with a homogenous structure. The cross-section of the alginate film (Fig. 5b) was dense, compact and showing small white stripes (represented by the letter e) inserted into the polymeric matrix. This behavior was also observed by Carvalho and Grosso (2004) for native gelatin films. These authors showed that the appearance of these stripes could be related to phase separation of the plastifier (glycerol) in the matrix.

Figure 6a and b show the structures of the surface and the cross-section, respectively, of the methylcellulose films. The film presented a smooth surface with a continuous structure and the presence of small white spots probably due to the non-dissolution of methylcellulose. The cross-section of the methylcellulose film (Fig. 6b) was dense, compact and showed small white stripes (represented by the letter e) inserted into the polymeric matrix, which could be related to exudation of the plastifier (glycerol) from the matrix.

CONCLUSIONS

The pectin film showed the lowest: (1) water vapor permeability, (2) thickness, (3) water solubility, (4) tensile strength and (5) elongation. On frying, it showed the shortest time to change its color and size and the final color of the film after the contact time in both palm olein and palm stearin was black.

The alginate film presented the greatest tensile strength and elongation and the smallest oxygen permeability. On frying, the contact time in the oil was intermediate, both in palm olein (2.5 s) and in palm stearin (3.5 s). After the contact time the film became black in palm olein and brownish in palm stearin.

The methylcellulose film showed the longest contact time for color and size change and in both palm olein and palm stearin, the final color was yellowish, that is, the color remained almost unaltered as compared to the film before contact.

According to the characterization of the chemical and physical properties, the alginate film would be the most indicated for use as a coating for sweet potato chips, since it presented the greatest tensile strength and elongation, guaranteeing that the coating would cover the material

uniformly, with less chance of rupturing during processing. It also showed low oxygen permeability making gaseous exchange and the oxidation of the final product more difficult. With respect to color, after frying the methylcellulose film would be more indicated, since it showed practically no change in color after the frying process.

The characterization of the pectin, alginate and methylcellulose films was carried out in order to simulate the behavior of these coatings with sweet potato chips. The selection of the coating will be done after applying them to the sweet potato chips and the one showing the lowest oil incorporation will be selected.

ACKNOWLEDGMENTS

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