Research Article

Application of chitosan emulsion as a coating on Kraft paper

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Abstract

Kraft paper was coated with chitosan emulsion film. The novelty of this paper is the formation of a packaging bilayer system in only one drying step, which combines a biodegradable polymer emulsion (chitosan and palmitic acid) with Kraft paper. This system is described in detail and characterized for barrier properties (water vapor permeability rate (WVPR), air permeability and water absorption capacity (Cobb test)), mechanical properties (tensile properties, Taber stiffness and tear strength) and structural properties. The application of chitosan coating (3.5 g m^{-2}, wet basis) on Kraft paper sheets provides a significantly lower WVPR (by *ca* 43%) and water absorption capacity (by *ca* 35%) as compared to uncoated Kraft paper. The incorporation of palmitic acid into the chitosan film solutions at 1.8 g m^{-2} improves the properties of Kraft paper even more by further reducing the WVPR and water absorption capacity by 51 and 41%, respectively. The air resistance of the coated Kraft systems is lower by 8- and 11-fold compared to uncoated Kraft paper, which could be associated with the chitosan film acting as a gas barrier and as a coating agent that fills the pores between cellulose fibers.
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Keywords: chitosan emulsion; Kraft paper; coating; mechanical properties; moisture barrier

INTRODUCTION

The packaging sector contributes significantly to the world economy and is growing rapidly in some European countries, such as France and Italy, with sales of about €20 billion.[1] There will always be specialized and unavoidable needs, but it should be routine for designers and marketers to consider packaging at an early stage to minimize costs and environmental impacts.[2] Packaging industries related to this field are always seeking new materials to improve the efficiency and functionality of packaging systems. Chitosan is an abundant, natural polysaccharide obtained from fishing industry waste. It comprises a linear sequence of monomeric sugars β-(1–4)-2-acetamido-2-deoxy-D-glucose (*N*-acetylglucosamine) and glucosamine derived from chitin deacetylation. Chitosan is a good alternative for the partial replacement of synthetic polymers due to it being a renewable resource and its biodegradability and capacity to form resistant, elastic and flexible films.[3] Chitosan films also provide efficient oxygen barriers; however, they are poor water vapor barriers, which can be improved by incorporation of a hydrophobic compound (i.e. lipid), forming an emulsified film. The lipids stearic, oleic, linoleic and palmitic acids in chitosan films reduce the affinity of the matrix for water molecules.[4–9]

Paper is a biodegradable material widely applied in the packaging sector.[10] It is essentially comprised of spontaneous crosslinks between cellulose fibers via hydrogen bonding. The formation of hydrogen bonds in cellulose and cellulose derivatives is considered to be one of the most important factors influencing their physical and chemical properties.[11] Paper is manufactured from a slurry generally composed of 99 wt% water and 1 wt% pulp fiber;[12] the pulp fiber is produced from wood chips by acid or alkaline hydrolysis, in which lignin in wood pulp is dissolved

and removed by washing to leave only cellulose fibers.[13] Cellulose is an organic material that can be re-grown quickly and has outstanding properties and useful applications.[14] Cellulose fibers for papermaking are microporous with a pore size ranging from 0.1 to 3 Å. The structure of the fibers and the morphology of the fibrous matrix are generally modified during the paper manufacturing process, i.e. the porosity of the cellulose matrix is changed.[15] Kraft paper is widely used in packaging applications but its porous structure makes it highly permeable to gases.[16] It is formed of a structural matrix that connects cellulose and non-cellulose chains (hemicellulose and lignin) by hydrogen bonding. Its low cost favors its application in the packaging sector (electronics, food, pharmaceuticals, etc.). It is still necessary to search for solutions to improve the mechanical properties, moisture and gas barrier properties and water absorption capacity. These properties directly influence the integrity and quality of packed products. Water vapor barrier and water resistance properties may be

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improved by changing the wettability of a paper surface with sizing agents or through coating with hydrophobic materials such as paraffin wax, polyethylene, poly(ethylene terephthalate) and poly(butylene terephthalate).[17,18] Films based on proteins (whey protein, calcium caseinate, wheat gluten) and polysaccharides (cassava starch, corn starch, chitosan) can potentially act as alternatives, to reduce the need for synthetic polymers, for coating cellulose-based packaging, providing an environmentally friendly package system.[10,18–21]

The application of chitosan as a coating on Kraft paper sheets could be an alternative to commercial bilayer systems that often use synthetic polymers as coatings. The advantages of chitosan are its biodegradability and recyclability, which could reduce the amount of waste,[4–7] and its ready compatibility with paper matrices. The combination of chitosan with paper is not new. It has been used as an additive in papermaking and for surface treatments to improve the properties of paper. Chitosan coating (0–30 g m^{-2}) adheres well to Kraft paper (342 g m^{-2}) and reduces the oxygen permeability.[18] Incorporation of chitosan in the stock solution of the papermaking process results in a better paper consistency and provides good mechanical and gas barrier properties.[22] Generally, biobased coatings containing natural polymers are typically hydrophilic and have limited liquid water and water vapor barrier properties.[23] This can be improved incorporating hydrophobic substances such as natural waxes, fatty acids, surfactants and resins. Impermeability has been improved in this way in various composite films made from proteins or polysaccharides: for example, in whey protein films by incorporating acetylated monoglyceride,[8] palmitic acid and stearic acid,[24] and in chitosan films by incorporating lauric acid, palmitic acid, octanoic acid, butyric acid, methyl laurate, acetylated monoglycerides and propylene glycol monoesters.[26] A report has not been found in the literature that combines an emulsified chitosan coating with Kraft paper.

The aim of the work reported here was to develop a biodegradable packaging material combining emulsified chitosan film and Kraft paper applying one drying step and to analyze the effects of chitosan and lipid concentration on the bilayer packaging properties (coating homogeneity, mechanical properties, moisture barrier properties and water absorption capacity).

MATERIALS AND METHODS

Materials
Chitosan (Primex, ChitoClear®, lot TM 2227, degree of deacetylation = 82%, (weight-average molecular weight) M_w = 1.71 × 10^5 g mol^{-1}, Iceland), acetic acid (Synth, Brazil), stearic acid (Synth, Brazil), palmitic acid (Synth, Brazil) and Kraft paper sheet (200 g m^{-2}, Klabin, Brazil) were used.

Chitosan solubilization
Chitosan filmogenic suspensions were prepared by dispersing 3.0 and 4.0 wt% of chitosan in aqueous acetic acid under continuous agitation. The stoichiometric amount of acetic acid was calculated from the weight of the sample, taking account of the degree of acetylation (18%) and the weight of chitosan to achieve protonation of all the NH$_2$ sites. The dispersions were stirred until the chitosan was fully dissolved.

Chitosan emulsion
Emulsified filmogenic suspensions of 4 wt% chitosan were obtained by adding palmitic acid (PA) at various concentrations

(0.25, 1.00 and 2.00 wt%) under continuous agitation. The lipid was liquefied by heating to temperatures above the melting point (temperature of solution was 90 °C). The suspension was emulsified using a power stirrer (Fisaton model 713D, São Paulo, Brazil) at 5000 rpm for 10 min.[7] The same procedure was adopted for the addition of stearic acid (SA) at 2.0 wt% concentration.

Kraft paper–film packaging systems
Sheets of Kraft paper (0.045 m^2) were coated with filmogenic suspensions of chitosan equivalent to 2.6 or 3.5 g m^{-2} (each coated sheet) using a 40 μm wire bar coater (TKB Erichsen, Brazil). The coated paper sheets were dried at 200 °C for 1 min.

Scanning electron microscopy
Kraft paper sheets, both uncoated and coated with 2.6 and 3.5 g m^{-2} of chitosan, were cut and the microstructure was analyzed using SEM with LEO equipment (model LEO 440i) under the following conditions: accelerating voltage = 15 kV, distance = 25 mm, current = 200 pA, vacuum = 10^{-5} torr (1.3 × 10^{-3} Pa).

Coating evaluation: colored solution penetration
Uncoated and coated Kraft paper sheets were cut into 10 × 10 cm^2 samples. A solution of 0.5 wt% of rhodamine in isopropanol was applied to the whole coated paper sheet, using a cotton swab held by metallic tweezers. The sample was maintained in a vertical position and dried in an oven at 50 °C overnight. The uniformity of the coating was evaluated by the presence of reddish spots on the opposite surface, indicating a leak or capillary penetration of the solution.

Preconditioning
Uncoated and coated Kraft paper sheets were preconditioned at 23 ± 1 °C and 50 ± 2% relative humidity before analysis, in accordance with the ASTM D685-93 standard method.[26]

Water vapor permeability rate (WVPR)
WVPR was determined based on a standard gravimetric method (ASTM E96-05).[26] The coated paper sheets were fixed on the top of an aluminium capsule containing a hygroscopic salt (calcium carbonate). The capsule was weighed and placed in a chamber at 23 °C and 75% relative humidity. The effective permeation area was 50 cm^2. The test was performed by periodical weighing. The results are expressed in g H$_2$O m^{-2} day^{-1}. There were at least five replicates per experiment and one control.

Water absorption capacity: Cobb test
Water absorption capacity was determined in accordance with standard T441om-90.[27] The weight gain was measured using Mettler AE 163 analytical scales. The results are expressed in g m^{-2}. There were at least 10 replicates per experiment.

Paper moisture content
The moisture content of the uncoated and coated Kraft paper sheets was determined using the ASTM D644-94 standard method.[26] A test specimen of approximately 2 g was previously weighed and placed in an oven at 105 ± 2 °C until constant weight was attained. The sample dry weight was determined and the moisture content was expressed as percentage of water loss in relation to the initial sample weight. Analyses were performed in triplicate. Results are expressed in g H$_2$O (100 g paper)$^{-1}$.

Air resistance: Gurley method

Air resistance was determined based on the ASTM D726-94 standard method.[26] A sample was cut, fixed in the porosimeter and submitted to air pressure. The time required for the passage of 100 mL of air through the paper surface was measured using a Gurley-type apparatus (model PGH-T, Regmed, Brazil). The results are expressed in s $(100 \text{ mL})^{-1}$. There were at least 10 replicates per experiment.

Tensile properties

Tensile properties were determined as specified in ASTM D823-93.[26] Uncoated and coated Kraft paper sheets were cut into samples with a width of 15.0 ± 0.1 mm and a length of 180.0 ± 0.1 mm, machine direction (MD) and cross direction (CD), using a guillotine (Regmed, Brazil). Tensile properties were measured using a dynamometer (model D-21, Regmed, Brazil) with a 500 N load cell and a speed of 20 mm min^{-1}. Tensile initial grip separation was set at 180 mm. The tensile strength is expressed in kgf $(15 \text{ mm})^{-1}$ and elongation was calculated from the difference in distance between grips holding the samples before and after break. There were at least 10 replicates per experiment.

Taber stiffness

Taber stiffness was determined using standard method T489om-92.[27] Uncoated and coated Kraft paper sheets were cut into samples of 38×70 mm^2 in the MD and CD using a guillotine (Regmed, Brazil). Taber stiffness was measured at an angle of $15°$ using Taber stiffness equipment (model RI 5000, Regmed, Brazil). Results are expressed in mN. There were at least 10 replicates per experiment.

Tear strength: Elmendorf method

The tear strength was determined in accordance with standard T414om-88.[27] Test specimens were cut to a size of 50.0×76.0 mm^2 in the MD and CD using a duly calibrated mold. Tear strength was evaluated using an Elmendorf device (model Ed 1600, Regmed, Brazil). There were at least 10 replicates per experiment. The results are expressed in mN.

Statistical analyses

Statistical analyses were carried out with the Statistic version 5.0 program (Statisc Inc., USA). Differences between the means were detected using a multiple comparison Tukey test.

Table 1. Concentrations of film–Kraft paper systems

Original formulation (by weight)	Solids concentration on paper surface (g m^{-2})		Sample designation
	Chitosan	Lipid	
Uncoated Kraft	–	–	Kraft CF
3% chitosan	2.6	–	Kraft C3
4% chitosan	3.5	–	Kraft C4
4% chitosan + 0.2 SA	3.5	0.2 SA	Kraft C4+SA 0.2
4% chitosan + 0.2 PA	3.5	0.2 PA	Kraft C4+PA 0.2
4% chitosan + 0.9 PA	3.5	0.9 PA	Kraft C4+PA 0.9
4% chitosan + 1.8 PA	3.5	1.8 PA	Kraft C4+PA 1.8

RESULTS AND DISCUSSION

Commercial Kraft paper sheets (200 g m^{-2}) were used to prepare chitosan film–Kraft paper bilayer packaging systems. The surfaces of the paper sheets were coated with chitosan films that were found to be continuous, homogeneous and of low thickness. The formulation variables studied were concentration of chitosan (3.0 and 4.0 wt%) and concentration and type of lipid (palmitic acid and stearic acid; 0.25, 1.00 and 2.00 wt%) in the original coating suspension. Table 1 gives the formulations used to coat the Kraft paper sheets.

Microstructure

SEM image analysis was initially employed to observe the surface of uncoated and coated Kraft paper sheets. The effect of chitosan coating on Kraft paper is clearly observed through SEM image analysis (Fig. 1). Chitosan was deposited on the heterogeneous surface of the original Kraft CF, characterized by a cellulose fiber interlacement. Chitosan chains are able to modify the surface of uncoated Kraft paper, filling the interfibrillary cellulose spaces and forming smooth surfaces. Increasing the chitosan concentration from 3 to 4 wt% means more total solids are deposited on the paper surface (from 2.6 to 3.5 g m^{-2} (wet basis) for Kraft C3 and Kraft C4, respectively). The paper coated with 3.5 g m^{-2} shows a more uniform and homogeneous surface (Fig. 1(c)). By applying another biopolymer, Rhim *et al.*[17] observed a smoother and more homogeneous surface on poly(lactic acid) (PLA)-coated paperboard, which is also associated with the covered and filled pores of the fibrous structure of the paperboard. Han and Krochta[21]
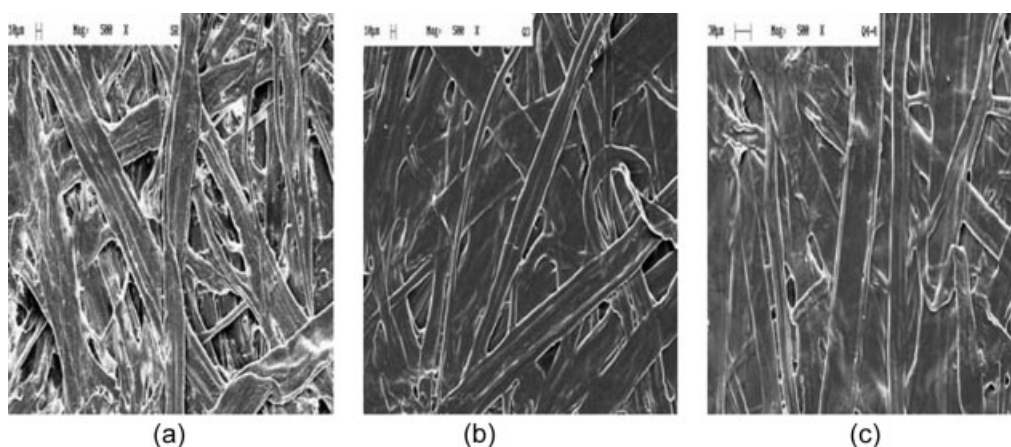

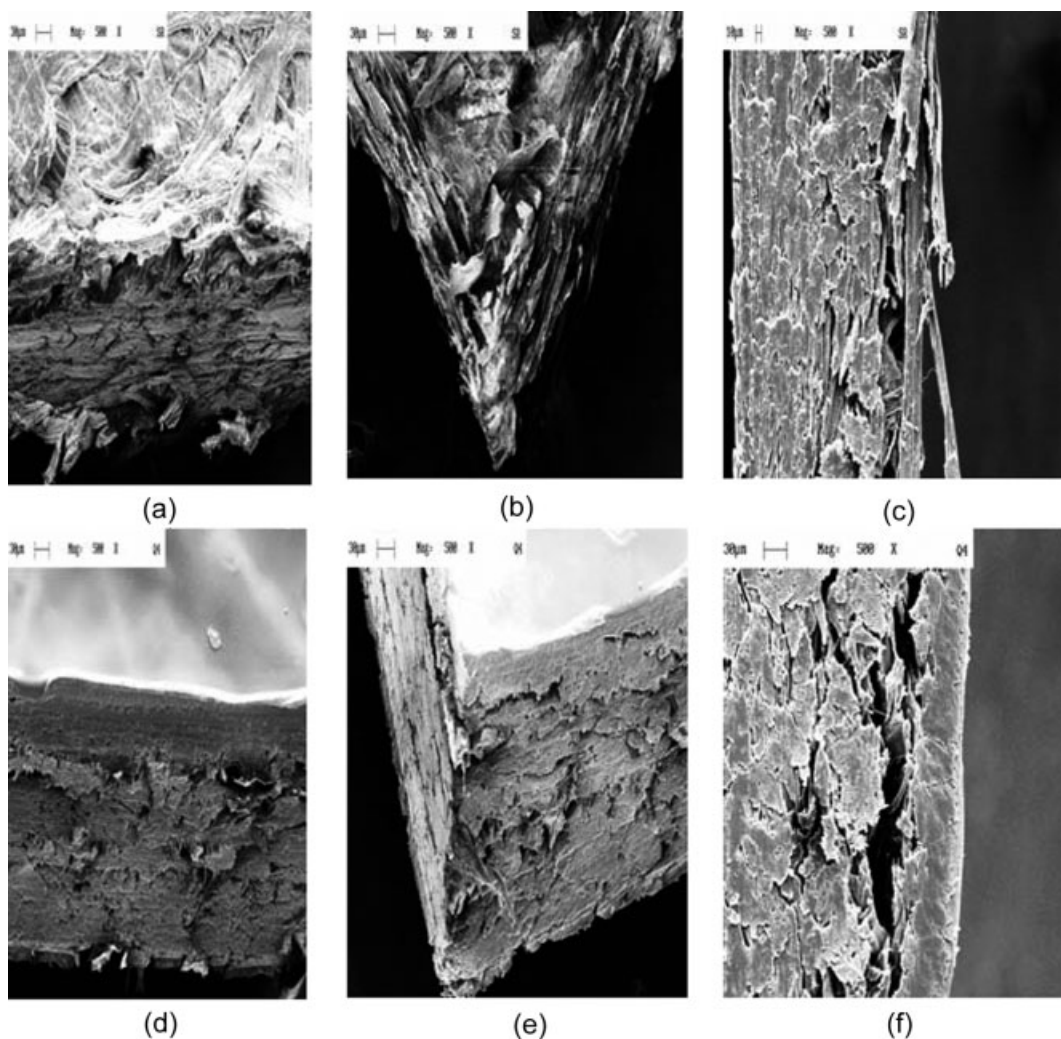**Figure 1.** SEM images of Kraft paper surface: (a) Kraft CF; (b) Kraft C3; (c) Kraft C4.

Figure 2. SEM images of Kraft paper packaging systems: (a–c) uncoated paper; (d–f) Kraft C4.

also demonstrated using SEM images that whey protein isolate coating produces a more homogeneous and smooth coating surface than uncoated paper and the smoothness of paper increases as higher coating weight is applied.

Figure 2 shows different views (surface, horizontal fracture and vertical fracture) of coated and uncoated Kraft paper. The cross-sectional view of Kraft paper indicates that chitosan impregnates the cellulose fibers on Kraft C4. Besides forming a continuous film on the paper surface, the coating agent also fills the internal porous space of the Kraft paper. It was not possible to measure the thickness of the chitosan coating due to low chitosan weight and the high penetration into the cellulose matrix. Bordenave *et al.*[28] previously observed using infrared spectroscopy and SEM that, on applying chitosan at 1.6 g m^{-2} on a paper surface, the polymer deeply penetrated into the paper, embedding the cellulose fibers instead of forming a layer. Gastaldi *et al.*[19] studied the coating of paper with wheat gluten, calcium caseinate and corn starch, showing that impregnation of paper fibers varied from 4.8 to 63.3 wt% depending on the polymer coating. Fernandes *et al.*[29] observed that chitosan penetration into paper sheets occurred progressively showing a saturation after three layers of coating with polymer suspension.

Coating evaluation

The homogeneity and uniformity of the chitosan coating on the Kraft paper surface were investigated by evaluating the permeation of a colored solution of rhodamine B. Amongst the desired properties of paper, one of the most important is the controlled capacity for penetration of aqueous solutions. A larger number of colored spots were observed on the back surface of Kraft C3 than on the back surface of Kraft C4 (Fig. 3), since Kraft C4 contains a higher load of chitosan than Kraft C3. A higher total solids content of the chitosan coating could fill more pores of the fibrous structure of the Kraft paper, and also forming a film barrier. Chitosan films applied on Kraft papers improved paper surface properties.[30]

Water vapor permeability rate

A chitosan coating is able to reduce the WVPR of Kraft paper from 1073 g H$_2$O m^{-2} day^{-1} for Kraft CF to 710 g H$_2$O m^{-2} day^{-1} for Kraft C3 and 606 g H$_2$O m^{-2} day^{-1} for Kraft C4, representing a 34 and 44% reduction, respectively (Table 2). This effect can be explained in terms of the microstructure of the coated papers and the pores being filled with chitosan which reduces the permeation of water vapor molecules through the void spaces between cellulose fibers. The total solids per unit of area influences
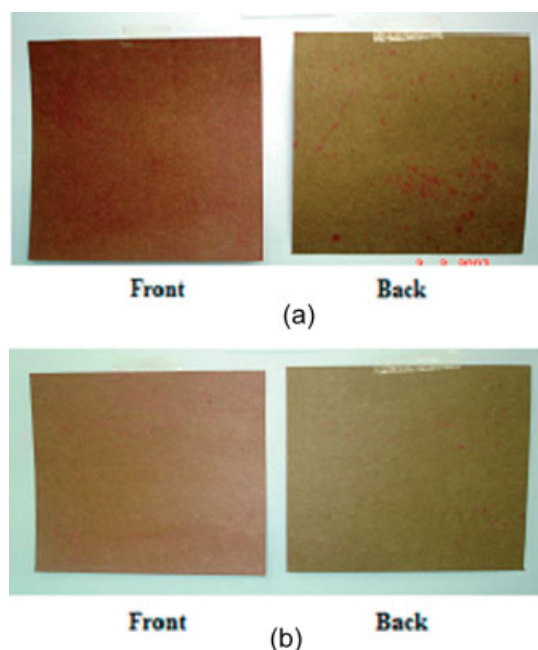
Figure 3. Kraft paper sheets coated with chitosan: (a) Kraft C3; (b) Kraft C4.

Table 2. WVPR and water absorption of coated and uncoated Kraft paper packaging systems

Sample	WVPR ($g\,H_2O\,m^{-2}\,day^{-1}$)	Water absorption ($g\,m^{-2}$)
Kraft CF	1074.3 ± 51.1^a	39.0 ± 4.1^a
Kraft C3	710.1 ± 70.1^b	24.7 ± 3.4^b
Kraft C4	606.0 ± 31.8^c	30.1 ± 5.1^c
Kraft C4+SA 0.2	658.9 ± 31.8^{bc}	27.1 ± 2.0^c
Kraft C4+PA 0.2	527.4 ± 31.2^c	26.2 ± 3.5^c
Kraft C4+PA 0.9	627.6 ± 32.1^{bc}	25.6 ± 1.3^c
Kraft C4+PA 1.8	553.2 ± 32.2^c	23.0 ± 1.6^d

Means in the same column with different superscripts differ significantly ($p \leq 0.05$) according to Tukey's test.

the WVPR of chitosan films.[7] Similar results were obtained by Vartiainen et al.[23] in that applying $1.5\,g\,m^{-2}$ of chitosan suspension on $80\,g\,m^{-2}$ copy paper, the WVTR was $681\,g\,H_2O\,m^{-2}\,day^{-1}$ determined under typical storage conditions for apples and kiwi fruit ($3.5\,^{\circ}C$ and 95% relative humidity). Fernandes et al.[31] obtained a WVPR reduction of approximately 42% as compared to uncoated paper applying five layers of chitosan suspension (2.0% w/v) on *Eucalyptus globulus*-based paper sheets. In this work, for each coating layer application, the chitosan was deposited on paper surface and then it was dried for 120 s at $100\,^{\circ}C$. For PLA-coated paperboard, similar results were found, in which WVPR values were two orders of magnitude lower than those for uncoated paperboard.[17]

The lowest WVPR was found for Kraft C4, which was the formulation chosen for subsequent experiments including those with fatty acids. Initially the lowest concentration ($0.2\,g\,m^{-2}$) of SA and PA was incorporated into the chitosan filmogenic suspension in order to compare the fatty acids. WVPR values were measured indicating a reduction of 51 and 39% for Kraft C4+PA 0.2 and Kraft C4+SA 0.2 (Table 2). Increasing the PA concentration from 0.9 to
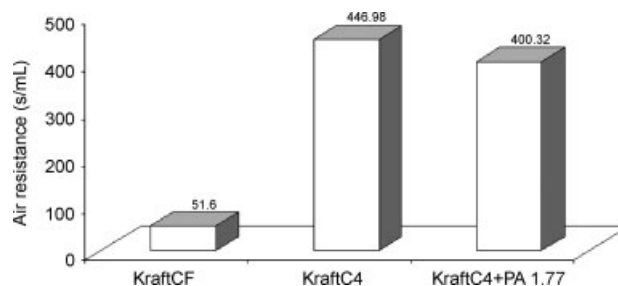

Figure 4. Air resistance of uncoated and coated Kraft paper.

$1.8\,g\,m^{-2}$ does not significantly further improve the WVPR values (627.57 ± 32.10 and $553.18\pm32.15\,g\,H_2O\,m^{-2}\,day^{-1}$, respectively). Coating paper sheets ($80\,g\,m^{-2}$) using hydrophobic substances (beeswax or SA) incorporated in hydropropylmethylcellulose matrix reduced significantly the WVPR as compared to uncoated paper.[22] The same results were found applying sodium caseinate and carnauba wax on paper sheets.[32] It is very important to improve the WVPR of cellulose-based packaging that is to be used as corrugated boxes to transport fresh produce being exposed to high-moisture conditions.[17] Despond et al.[16] applied a three-layer material, carnauba wax–chitosan–paper, characterized by $7\,g\,m^{-2}$ of chitosan and $2\,g\,m^{-2}$ of carnauba wax, observing that the WVPR values were lower than for chitosan–paper system. In this system, the carnauba wax solution was deposited on the dried chitosan layer followed by drying at $110\,^{\circ}C$.

Water absorption: Cobb method and moisture content

In cellulosic materials, water absorption depends on the type of cellulose and the coating material. Water absorption indicates the resistance to water of coated paper when it is directly in contact with water. Cobb tests were performed on the seven samples listed in Table 2. Chitosan coating ($2.6\,g\,m^{-2}$) is able to reduce the water absorption by up to 35%. These results are threefold higher than the water absorption reduction obtained for PLA-coated paper,[17] which could be associated with the hydrophilicity characteristic of chitosan molecules.

Good results were obtained by Matsui et al.[20] who impregnated recycled Kraft paper with starch acetate, reporting a fourfold improvement in the water absorption rate. In the present work, the incorporation of both lipids, SA and PA, into the chitosan film formulation does not statistically reduce water absorption values.

The moisture content is lower for samples of coated than for uncoated Kraft paper. However, there is no statistical difference between the moisture content values for Kraft C4 and Kraft C4+PA 1.8.

Air resistance: Gurley method

The resistance to air flow of paper is proportional to the thickness and weight per unit area, and it is also related to the porosity of the paper. It usually refers to the relation between the area formed by the material pores and the total superficial area. Air resistance is measured as the time required for a fixed volume of air to pass through a test specimen. Resistance to air flow is determined to verify the coating and to predict the absorption rate of paints and adhesives. Analyses of Kraft CF, Kraft C4 and Kraft C4+PA 1.8 were performed. The results are shown in Fig. 4.

Chitosan and emulsified chitosan coatings increase the air resistance of the Kraft paper. These results are a good indication

Table 3. Moisture content, maximum force, elongation at break, stiffness and tear strength of uncoated and coated Kraft paper sheets in the MD and CD of paper manufacturing

Property		Sample		
		Kraft CF	Kraft C4	Kraft C4+PA 1.8
Moisture content (g H$_2$O (100 g)$^{-1}$)		7.4 ± 0.0[a]	6.9 ± 0.0[b]	6.9 ± 0.1[b]
Force (kgf (15 mm)$^{-1}$)	MD	27.0 ± 1.0[ab]	28.0 ± 1.3[a]	26.8 ± 1.6[b]
	CD	11.2 ± 0.5[ab]	11.6 ± 0.6[a]	10.7 ± 0.7[b]
Elongation (mm)	MD	4.7 ± 0.2[a]	5.0 ± 0.7[a]	4.7 ± 0.4[a]
	CD	7.0 ± 0.6[a]	7.0 ± 1.1[a]	6.0 ± 0.8[b]
Stiffness (mN)	MD	122.1 ± 14.2[a]	150.1 ± 13.6[b]	141.6 ± 30.2[ab]
	CD	109.8 ± 12.4[a]	73.4 ± 5.6[b]	84.3 ± 14.4[b]
Tear strength (gf)	MD	28 ± 2.5[a]	26 ± 2.8[a]	28 ± 2.2[a]
	CD	43 ± 3.0[a]	37 ± 1.7[b]	39 ± 3.7

Means in the same row with different superscripts differ significantly ($p \leq 0.05$) according to Tukey's test.

that chitosan molecules really fill the pores of the cellulose fiber network as well as the coating forming a continuous thin film over the surface. Also, this might be associated with the property of chitosan films to provide efficient barriers against gases.[8,33] Fernandes *et al.*[31] obtained similar results for chitosan coating on non-commercial Kraft paper, with the air permeability decreasing as the amount of chitosan coating increased.

Mechanical properties

The mechanical properties of the bilayer Kraft paper were analyzed in terms of elongation and maximum force at break, stiffness and tear strength. The tensile tests were performed on Kraft CF, Kraft C4 and Kraft C4+PA 1.8 samples. The results are summarized in Table 3.

Tensile strength is an important property of packaging materials that measures the ability of cellulose-based packaging to resist before breaking under tension. Statistically significant differences in tensile strength were not obtained in either the MD or CD and for elongation in the MD. However, in the CD the elongation is 13.3% lower for Kraft C4+PA 1.8 than Kraft CF. This reduction could be associated with the lower strength of fiber–fiber interactions in the paper matrix, which may be partially due to the coated material impregnated into the cellulose structure. The mechanical properties of chitosan–Kraft paper systems are still controlled by the cellulose fiber matrix which is dependent on the strength of fibers, their surface area and length and the bonding strength between them.[17]

Similar results were obtained by Bordenave *et al.*[28] and Kjellgren *et al.*,[34] who found that the mechanical properties of chitosan-coated paper remained almost unchanged with a slightly reduced Young's modulus. Matsui *et al.*[20] did not observe significant differences in the mechanical properties of uncoated Kraft paper and that coated with starch acetate.

Stiffness

In the MD, the stiffness of Kraft C4 and Kraft C4+PA 1.8 is not statistically different, and, moreover, both have a lower stiffness

than uncoated Kraft paper. In the CD, the coatings provide a higher stiffness than Kraft CF. Chitosan could act as a plasticizer in the coated paper system due to the introduction of a positive charge with the predominant negative charge of cellulose fibers, perturbing their interactions and cohesion.[28] According to the literature, values in the MD are always higher those in the CD due to fiber alignment.[35]

Tear strength

Tear strength is the force required to tear a test specimen after a cut has already been started.[35] In the MD, the tear strength of Kraft CF, Kraft C4 and Kraft C4+PA 1.8 is not statistically different (Table 3). In the CD, Kraft C4 and Kraft C4+PA 1.8 have a lower tear strength, with a reduction by a similar amount (12%) compared to Kraft CF. Gällstedt *et al.*[22] observed that on increasing the chitosan coating weight (0 to 30 g m^{-2}) on Kraft paper (342 g m^{-2}), higher fracture stress, fracture strain and tear resistance were achieved.

CONCLUSIONS

A chitosan emulsion film–Kraft paper bilayer packaging system was described in detail. This system can be considered as an interesting ecofriendly alternative to Kraft paper coated with synthetic polymers (such as polyethylene). The application of chitosan coating (3.5 g m^{-2}, wet basis) on Kraft paper sheets provided a significantly lower WVPR (by *ca* 43%) and water absorption capacity (by *ca* 35%) as compared to uncoated Kraft paper. The chitosan emulsion coating on Kraft paper improved the water barrier properties as compared to uncoated Kraft paper. The incorporation of 1.8 g m^{-2} of PA into the chitosan coating suspension improved the properties of Kraft paper, reducing the WVPR and water absorption capacity by 51 and 41%, respectively, as compared to uncoated Kraft paper. The air resistances of Kraft C4 and Kraft C4+PA 1.8 were lower by 8- and 11-fold, respectively, compared to Kraft CF. The coating did not significantly change the elongation and tensile strength of Kraft paper sheets. Based on these characteristics, it should be possible to apply emulsified chitosan–Kraft paper for packaging of products that require selective gas and moisture barriers (e.g. fresh foods such as vegetables and fruits).

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