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Improvement of physical and optical properties of chitosan-rice starch films pre-treated with ultrasound

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Transparent films of chitosan, rice starch and a blend of chitosan-rice starch were prepared using water, malic acid and glycerol as a plasticiser. Before casting, the film solutions were treated with ultrasound with a view to improve the physical, optical and surface properties of the films. The results showed that an ultrasonic treatment improved elasticity, moisture resistance and transparency of the films. For all ultrasound-treated films, elongation at break and tensile strength increased, especially for the blend films. Moreover, the moisture content decreased proportionally to the increase in thickness with decreasing film solubility for all treated samples. The surface of the untreated blend film was more uneven compared to chitosan and rice starch films, which improved after the treatment. The preparation of film solutions using ultrasound is an improved procedure to increase many properties of biodegradable films.

Keywords: ultrasonic treatment; biodegradable polymers; blend films; material testing.

INTRODUCTION

Packaging is a part of the goods, which causes a big environmental impact after its use. Producers of bio-based materials are keen on replacing oil-based packaging materials with green, sustainable materials which also have improved mechanical, antimicrobial and barrier properties [1, 2]. Therefore, every year, new biodegradable materials are produced. Some of the most nontoxic and widely used polymers are polysaccharides, chitosan being one of them. It is a natural polysaccharide derived from the deacetylation of chitin [3]. Chitosan has also attracted interest in packaging, especially in food packaging area as edible films and coatings [4]. From the research it is known that chitosan films have good mechanical properties, e.g., they are flexible, long lasting, of good strength and increase the storage life of fresh food [5]. They also have good barrier properties against grease due to the positive charge on the amino group under acidic conditions, where chitosan binds negatively charged molecules. Moreover, chitosan films exhibit excellent oxygen-barrier properties, due to their high crystallinity and hydrogen bonds between the molecular chains [6]. Some of the most important properties as regards food packaging are the moisture properties. Chitosan exhibits good moisture properties, however, not sufficient for food applications, as its hydrophilic nature attracts moisture [7]. In order to improve the moisture properties and functional properties of chitosan films, blending with other biopolymers and hydrophobic substances has been proposed [8, 9]. In previous research, chitosan films and chitosan blends with other natural polymers have been made [9–11]. Due to the high amount of amylase, rice starch is attractive for food packaging as a film barrier [12]. It has also been used to replace plastic film barriers as it has good mechanical properties [12–14]. Rice is the most widely used basic food in the world. Due to different climates, soil characteristics and cultures, more than 240 000 registered varieties of rice and consequently, as many different types of rice starch exist in the world [6]. The ultrasonic technology is an environmentally friendly technology which is nowadays used in food, pharmaceutical, chemical, etc., industries. With this technology, improvements in materials can be achieved. Previous research has shown a positive effect of ultrasonic treatment on the gelatinisation of starch dispersions [15]. It is known that the application of ultrasonic treatment to starch films improved the moisture properties of the treated starch and provided stronger structures [16]. Bourtoom & Chinnan studied the effect of rice starch incorporated into a chitosan film. The composite film showed an increase in tensile strength, moisture, water vapor permeability, but a decrease in elongation at break [10].

This research describes the preparation, characterisation and ultrasonic treatment of the chitosan-rice starch blend films. The aim of the research was to improve the mechanical, moisture and optical properties of chitosan, rice starch and composite chitosan-rice starch film using ultrasonic treatment. Previously, no research has been

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conducted on rice starch-chitosan blend films, and the improvement of their properties with ultrasound. Our research was focused on the effect of ultrasonic treatment on the solutions for the preparation of the mentioned films. Using ultrasound is an environmentally friendly process and it can be used for all solutions in order to improve biodegradable films. Such a treatment and materials could be used as a substitute for packaging films that are currently on the market.

MATERIALS AND METHODS

Matherials

Rice starch was obtained from Farmalabor Srl (Italy), with 14% moisture content, 1% proteins and 0.6% ashes. Chitosan, with molecular weight 20kDa and deacetylation degree higher than 85%, was purchased from Sigma Aldrich (Austria). Chitosan solutions were prepared by dissolving 2 g of chitosan in 100 ml of malic acid. Malic acid (98%) was purchased from Sigma Aldrich (Austria). Glycerol (Sigma Aldrich, Austria), was used as a plasticiser.

Preparation of film-forming dispersions

Preparation of a dispersion for rice starch film

The rice starch dispersion was prepared by dissolving 2 g of rice starch in 100 ml of distilled water and glycerol (40% w/w) was added as a plasticiser. The solution was mixed until it gelatinised (85 °C for 20 min) and then cooled to room temperature.

Preparation of solution for chitosan film

The chitosan solution was prepared by dissolving 2 g of chitosan in 100 ml (2% w/w) malic acid and glycerol (40% w/w) was added as a plasticiser. The solution was stirred at 90 °C for 5 min until chitosan was dispersed. Then the solution was cooled to room temperature. Before cooling down, the film solution was filtered through a polyester screen (mesh no. 140 with mesh opening 160 µm) with aspiration to remove small lumps from the solution.

Preparation of a solution for a chitosan-rice starch blend film

The rice starch-chitosan film was prepared by mixing 100 ml of 2% rice starch solution with 100 ml of 2% chitosan solution. After that, 40% of glycerol (w/w of total solid weight in solution) was added as a plasticiser to the solution. The total solution for the blend film was stirred at 800 rpm for 5 min at room temperature and filtered through a polyester screen with the same mesh opening as for the chitosan solution. Aspiration was performed in order to remove small lumps from the solution.

Ultrasonic treatment of solutions

After the aspiration, the solutions (for chitosan film, rice starch film and blend film) were put into an ultrasonic bath (Asonic, Ultrasonic bath), using constant 35 kHz frequency for 15 min [16].

Preparation of casting films

After the aspiration and the treatment, the mixtures (untreated and treated) were cast onto petri dishes (50 ml), spread thinly, uniformly and dried at 55 °C for 10 h. After the films were peeled off from the dishes, they were cooled at room temperature (23 °C; 55% RH). The films were stored in desiccators at 60% RH for further investigations.

Characterisation of the films

Film thickness

The thickness of the films was measured with a precision digital micrometre Mitutoyo Corporation, Japan, to the nearest 0.0001 µm at 5 random locations on each film.

Moisture content

Moisture content was determined by measuring the weight loss upon drying in a laboratory oven at 105 ± 1 °C until constant weight. Five samples per each film were tested and the results were expressed in percentage.

Water vapor permeability (WVP)

To determine the WVP of films, the ASTM E96 standard desiccant method was used [19]. The test cups were filled with silica gel (RH = 16% in the cup), where a sample was placed between the cup and the ring cover [20]. There was an air gap of 11 mm between the silica gel and the underside of the placed film. To ensure the best results of WVP, a silicone sealant was applied around the cup edge. The films with an exposed area of 50 cm^2 were tested at 90 ± 2% RH and 38 ± 2 °C for 24 h. Three replicates per each film were tested.

Film solubility (FS)

Water solubility of each film was determined as well. The samples (four samples per each film type) were dried at 105 °C for 24 h to determine the weight of the dry matter. Additional four samples of the same film type were placed in a 50 mL beaker containing 30 mL of distilled water. The beakers were covered with parafilm and stored in an environmental chamber for 1 h, where the climate conditions were 25 °C and 55% RH [21]. After that, the beakers were removed from the chamber, the films were peeled off from the beakers and gently rinsed with distilled water. All samples were then dried in an oven at 105 °C for 24 h. Three replicates per each film were tested. The total soluble matter-film solubility (FS) was calculated using the following equation [21]:

$$FS\,(\%) = \frac{(mass\ of\ the\ film\ before\ test - mass\ of\ the\ film\ after\ test)}{mass\ of\ the\ film\ before\ test} \cdot 100$$

Mechanical properties

Tensile strength (TS) and elongation at break (E) of the films were determined on a tensile testing machine Instron 6022. The samples were analysed in standard atmosphere (temperature 23°C ± 1°C and relative humidity 55% ± 2%). The cross speed head was 0.15 mm/s. Films of 6 cm in length and 0.7 cm in width were used, and a minimum of five probes for each sample was tested. During sample stretching, several load and elongation data per second were recorded until a break of the sample occurred.

Colour

The film colour was determined using the CIE colorimeter X-rite. The CIE Lab scale was used to determine L*, a* and b* colour values. A standard plate was used as the standard (L* = 92.82, a* = –1.24, b* = 0.5). Six measurements for each specimen at different locations on the samples were made. Before the colour measurements, the samples were conditioned at 55% RH and 25 ± 2 °C for 72 h.

Total colour differences (ΔE), chroma (C) and hue angle (H) were calculated with the following equations [10, 21]:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

$$\Delta L^* = L^* - L_0^*$$

$$\Delta a^* = a^* - a_0^*$$

$$\Delta b^* = b^* - b_0^*$$

$$C = (a^*)^2 + (b^*)^2$$

$$H = tan^{-1}\left(\frac{b^*}{a^*}\right) \qquad when\ a^* > 0\ and\ b^* > 0$$

$$H = 180^{\circ} + tan^{-1}\left(\frac{b^*}{a^*}\right) \qquad when\ a^* < 0$$

$$H = 360^{\circ} + tan^{-1}\left(\frac{b^*}{a^*}\right) \quad when\ a^* > 0\ and\ b^* < 0$$

where: L^*, a^*, b^* are the standard and L_0^*, a_0^*, b_0^* the sample colour parameters.

Fourier transform infrared spectroscopy (FTIR)

The FTIR spectra of the studied sample films were obtained on a Perkin Elmer spectrophotometer equipped with an attenuated total reflection (ATR) cell. The spectra were recorded over the range of 4000–800 cm^{-1}, with a resolution of 4 cm^{-1}. For each spectrum, 146 consecutive scans were averaged.

Surface properties – Scanning electron microscope (SEM)

The SEM micrographs of the film surfaces were taken with a scanning electron microscope (JSM - 6060 LV). The instrument was operated at 10 kV, at a magnification of 400×.

Statistical analysis

The results for tensile properties, thickness, moisture, WVP and FS, given in the article, represent mean values ± standard deviation. The analysis of variance-ANOVA was performed on the obtained results to establish significant differences.

RESULTS AND DISCUSSION

One of the major issues in using ultrasound in polymer processing is the controlled modification of the interaction between polymers without chemical modification. The results of previous research have shown that an ultrasonic treatment of the starch dispersion increased its solubility and clarity, but decreased viscosity [6, 15]. In this study, an ultrasonic treatment of the film solution was used in order to increase the solubility of composition components, which influences many film properties (strength, elongation, moisture and colour). The results showed that the ultrasonic treatment increased the moisture content and at the same time improved tensile properties. Generally, the film structure became stronger, more flexible and more even.

Thickness, moisture content, WVP and film solubility

The water vapour permeability (WVP) of films for food packaging should be as low as possible, because high WVP determines poor barrier properties. The thickness of films influences water vapour properties [17, 18]. The nature of films from biopolymers is mostly hydrophilic; therefore, the thickness influences the water barrier and the mechanical properties. In our research, the thickness (mean values) of films was used in the calculations for water vapour properties (TS). Table 1 shows a comparison of untreated and treated films and it can be seen that the chitosan-rice starch blend film treated with ultrasound exhibits better WVP than the untreated ones. From the literature it is known that glycerol is hydrophilic and improves moisture/barrier properties [20]. In our research, glycerol was added as a plasticiser, whereas the ultrasonic treatment had the biggest impact on WVP [20, 22]. From the obtained results it follows that the best water vapour properties are manifested by the chitosan-rice starch film treated with ultrasound (3.37 ± 0.29 g mm/m^2/day kPa, i.e. by two times lower than the untreated sample). The same trend was detected for the chitosan and rice-starch film. The WVP of untreated chitosan film decreased with the treatment from 9.11 to 8.47 g mm/m^2/day kPa. Previous research has explained that chitosan films have high oxygen but poor water vapour barrier due to their hydrophilic character, which was confirmed in our research [20–23].

As expected, the values of the moisture content of the untreated films were higher than those of the treated ones. The highest moisture content was displayed by the untreated chitosan film (11.03%) and the lowest – by the treated blend film (9.0%). The ultrasonic treatment affected all films regarding moisture absorption, with a decrease between 0.5 and 1%. The decrease was not major, yet an impact on the solution and afterwards on other film properties was detected. The acoustic activation in a ultrasonic bath caused differences in the tested films. In the case of addition of glycerol, for all tested films the observed behaviour can be a result of an increase in free volume, and a consequent decrease in WVP and moisture content. The reason is the high content of glycerol, which was present at all samples. Water solubility is important for the films used in food packaging. Stuchell & Krochta explained in their research that blend films used for packaging maintained their integrity after 24 h of incubation, which indicates that rice starch and chitosan intra- and intermolecular network remained the same, and that only monomers and non-protein material were soluble in water [24]. The obtained results showed that the solubility of the films decreased with the ultrasonic treatment. As expected, the untreated rice starch film had the highest solubility (56%), which decreased with the ultrasonic treatment (49%), but the values still remained the highest among all tested samples. From Table 1 it follows that chitosan interacted with rice starch in the blend film; therefore, the solubility was lower for treated (30%) and untreated (35%) samples than for pure rice starch film. Both, the untreated (22%) and treated (18%) chitosan films had the lowest water solubility compared to the other film samples. The ultrasonic treatment decreased water solubility and moisture content of all treated films.

The equilibrium thickness of all samples as a function of moisture content and film solubility for chitosan and blend films is shown in Fig. 1. The results show that the ultrasonic treatment reduced the ability of the chitosan film to absorb water from 11.3% to 10.8% when thickness decreased. The film solubility was lower for both treated samples. The results suggest that the interaction of chitosan with rice starch, when a film is formed, limits film solubility, which, on its turn, reduces its moisture content. Chitosan strengthened the film structure of the blend mixture and solubility in water decreased when the thickness increased.

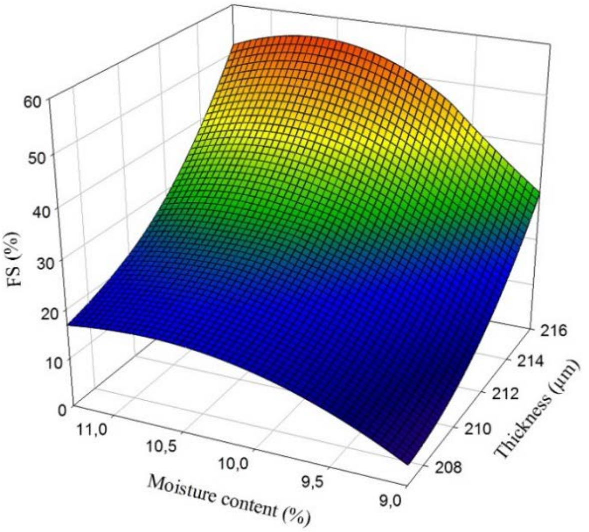

Fig. 1. Percentage of moisture content of chitosan and blend films (treated and untreated) as a function of thickness and film solubility.

Moisture content of rice starch films treated with ultrasound decreased as a function of thickness and water solubility (Fig. 2). In general, the treated films (rice starch and blend mixtures) showed decreased water solubility with respect to the percentage of moisture content and thickness. The studies of glycerol as a plasticiser have shown an increase in moisture content due to its hydrophilicity [20–23]. The presence of rice starch in the blend films can form highly cross-linked systems, preventing water molecules from penetrating into the composite films [23]. Such behaviour was confirmed in our

Table 1. Thickness, moisture content, water vapour properties (WVP) and film solubility (FS) of sample films.

	Sample	Thickness (µm)	Moisture content (%)	WVP (g mm/m^2/day kPa)	FS (%)
Untreated	Chitosan film	210 ± 2.5a	11.3 ± 0.55	9.11 ± 0.36b	22 ± 2.5
	Rice starch film	205 ± 5.0a	10.8 ± 0.69	6.45 ± 0.75b	56 ± 1.7
	Blend film	215 ± 3.3a	9.5 ± 0.23	7.92 ± 0.17b	35 ± 1.9
Ultrasound treated	Chitosan film	207 ± 6.7a	10.8 ± 0.47	8.47 ± 0.24b	18 ± 3.4
	Rice starch film	203 ± 4.2a	9.6 ± 0.18	5.45 ± 0.36b	49 ± 4.6
	Blend film	216 ± 1.2a	9.0 ± 0.78	3.37 ± 0.29b	30 ± 2.7

^{a} Mean of five replicates ± standard deviation; ^{b} Mean of three replicates ± standard deviation.

researchdue to the inclusion of glycerol and rice starch as well, since they interfere with cross-links, resulting in decreased water solubility.

Mechanical properties

Good mechanical properties such as tensile strength are very important for packaging films, due to the handling and shipping of packaged products. Elongation at break – flexibility is also very important. For such products, high tensile strength is required, but deformation and elongation should be adjusted according to the characteristics required for certain film applications. The mechanical properties of untreated films presented in the literature for chitosan and rice starch films were comparable to our results [10, 20]. The films with different components and treatment were flexible and with appropriate manageability. The results of the study of tensile strength and elongation at break of untreated and ultrasound treated films are presented in Fig. 3.

The results demonstrated that tensile strength increased with the ultrasonic treatment for all treated films. Better results of TS were obtained for treated samples and the maximum occurred for the blend of chitosan-rice starch film. The values for untreated films are slightly higher, but still comparable to those reported in the literature [17].

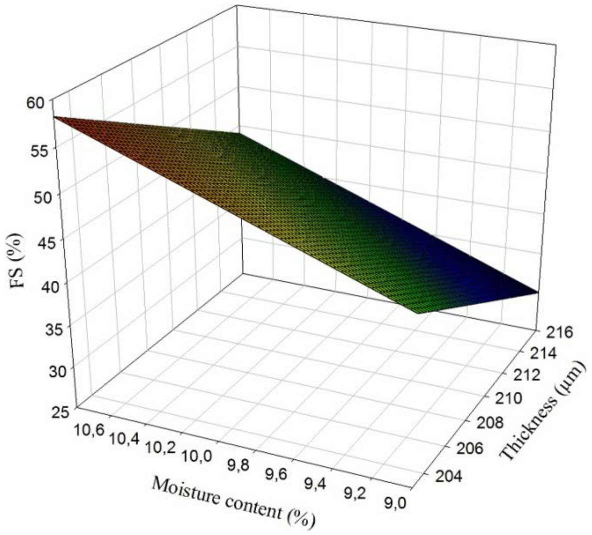

Fig. 2. Percentage of moisture content of rice starch and blend films (treated and untreated) as a function of thickness and film solubility.

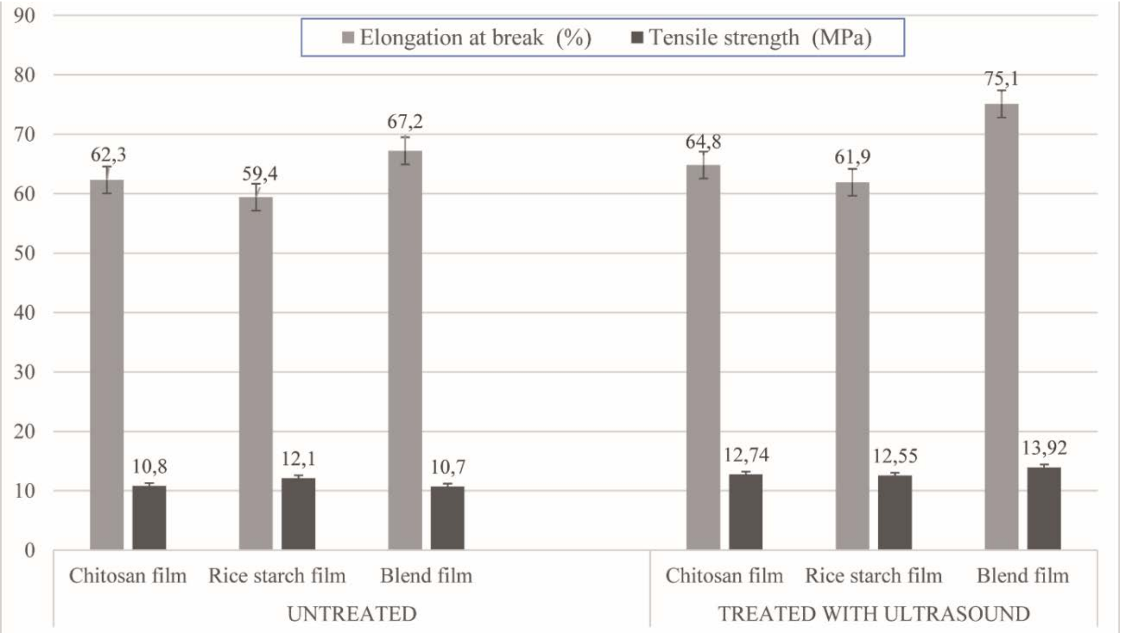

Fig. 3. Results of the study of tensile strength (TS) and elongation at break (E) of untreated and ultrasound treated films.

Table 2. Colour values (L*a*b*), colour differences (ΔE), chroma (C) and hue angle (H) of untreated and ultrasound treated films.

	Sample	L*	a*	b*	ΔE	C	H
Untreated	Chitosan film	84.06	–3.19	10.36	3.56	10.84	178.75
	Rice starch film	86.65	–4.07	9.88	6.28	10.67	178.89
	Blend film	88.92	–3.00	11.35	5.92	11.73	178.75
Ultrasound treated	Chitosan film	85.78	–2.05	9.22	2.36	9.45	178.68
	Rice starch film	91.66	–4.89	7.30	5.69	8.79	179.21
	Blend film	90.45	–2.78	9.07	5.50	9.49	178.75

The highest increase was detected for the blend of chitosan-rice starch film (30%), and for the chitosan film (18%). The treated rice starch film displayed a lower increase (4%). Elongation at break (E) is an indicator of film extensibility and is determined as the point when a film breaks at tensile testing. The values of the elongation at break were affected by the ultrasonic treatment. The highest elongation at break was obtained for blend films, which increased by 8% on ultrasonic treatment. For both rice starch and chitosan films elongation increased by 2.5%. The elongation values were higher for all samples due to the added plasticiser glycerol. Nevertheless, the elongation at break was better for all treated samples because of the increase in solubility and homogeneity of the film solutions, due to the acoustic activation in the ultrasonic bath.

Optical properties

The colour of films can be a factor in terms of consumer demands and it does not affect other analysed properties. The results are shown in Table 2. Generally, colour is an important factor of the appearance of packaging materials [25]. The total colour difference, chroma and hue angle were calculated from the colour values. The untreated chitosan films were more coloured than rice starch and blend films. It is known that chitosan has more yellowness compared to other tested samples in the research. From the L* values which indicate lightness it can be seen that the treated samples are less coloured, lighter, especially the rice starch film. The a* and b* values vary significantly between the untreated and treated samples. All films include a plasticiser which also affected the colour [10]. The hue angle was not significantly different among all sample films. The results of calculated chroma showed that the untreated samples have more yellowness than the treated ones.

FTIR analysis of films

Characteristic peaks were determined and compared with data from previously published research papers [4, 26, 27].

The spectra of untreated and treated chitosan and rice starch films are presented in Fig. 4. The spectra of the untreated films are similar to those published before [28]. In the FTIR spectrum of untreated chitosan films, peaks between 3000–3600 cm^{-1} are typical for OH stretching. The peak at 3269 cm^{-1} is an O-H stretch, at 2930 cm^{-1} it represents a CH_2 group and at 2880 cm^{-1} - CH_3, the aliphatic group of chitosan. The smaller, hardly noticeable peak at 1635 cm^{-1} is a consequence of the C=0 stretch of amide I, and the peaks at 1563 and 1565 cm^{-1} are N-H bending vibrations (amide II). An intensive peak at 1410 cm^{-1} suggests deformation vibrations of OH and CH groups, the peak at 1099 cm^{-1} is for glycosidic bonds and at 1016 cm^{-1} - for an ether group in the chitosan film. For the treated chitosan film, an increase in the peak intensity of the ether group at 1016 cm^{-1} is detected. The same higher intensity of peaks is detected for the peaks at 1096 cm^{-1}, 2932 cm^{-1} and 2881 cm^{-1}. In the FTIR spectrum of untreated rice starch film, a peak at 3230 cm^{-1} is detected, which presents the O-H stretch. The peak at 2900 cm^{-1} corresponds to the C-H stretch.

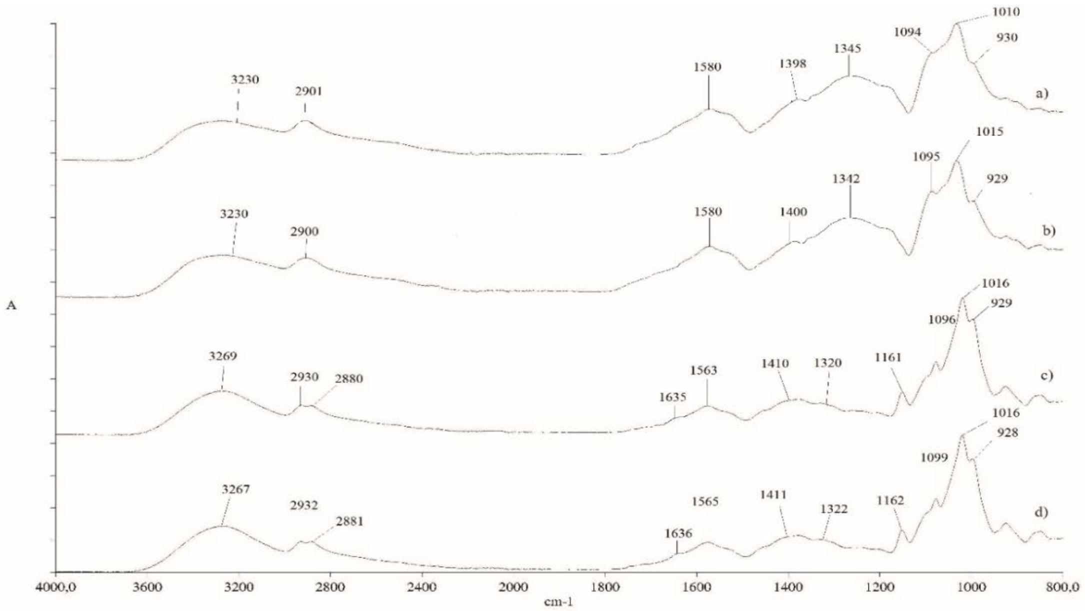

Fig. 4. FTIR spectra of untreated and ultrasound treated films: (a) untreated rice starch film, b) treated rice starch film, c) untreated chitosan film, d) treated chitosan film.

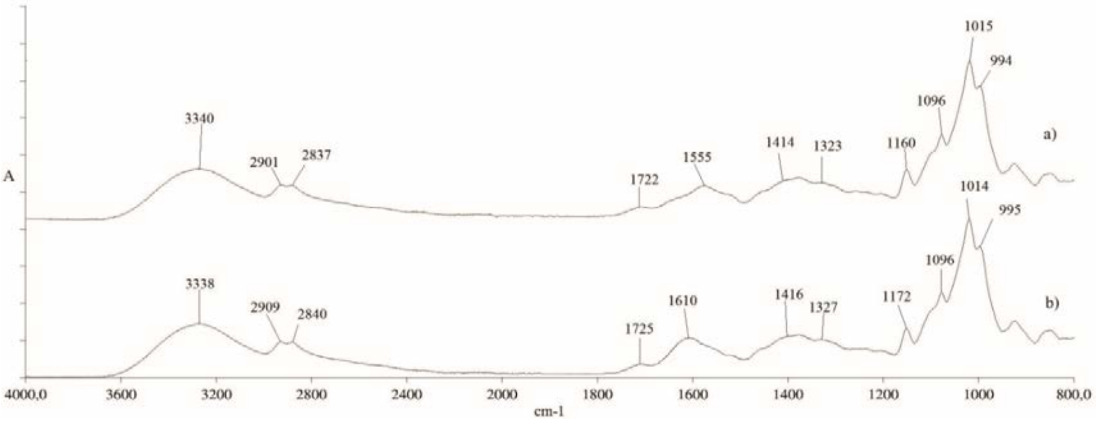

Fig. 5. FTIR spectra of (a) untreated and (b) ultrasound treated blend chitosan-rice starch films.

The peak at 1345 cm^{-1} presents the O-H of water, whereas the 1400 cm^{-1} and 1398 cm^{-1} peaks result from the deformation vibrations of OH and CH groups. For the treated rice starch films, the effect of ultrasound on the film was the same as on chitosan. The intensity of peaks slightly increased, especially for the peaks between 1600 and 1000 cm^{-1}.

In the blend of rice starch-chitosan films, physical blends *versus* chemical interactions are affected by the changes in characteristic peaks [5]. From the spectra of untreated blend films presented in Fig. 5, a decrease in the amine peak intensity at 1555 cm^{-1} and 1416 cm^{-1} can be seen. The reason for the decrease is the smaller amount of chitosan in the blend film, compared to pure chitosan film. The region between 1600 cm^{-1} and 900 cm^{-1} shows some shifts of absorption bands, which indicate interactions between the macro chains of chitosan and rice starch. The peak at 1555 cm^{-1} shifts to 1610 cm^{-1}, which suggests interactions between the hydroxyl group of rice starch and the amino group of chitosan [29]. The spectra of ultrasound treated blend film show small, yet noticeable changes in the intensities of peaks compared to the untreated blend film. The changes in the absorption bands of all ultrasound treated films were connected to the increase in the number of free mobile macromolecules rather than a breakage of starch molecules [30]. As predicted, the ultrasonic treatment improved the blend solution which became more homogeneous. It provided a dispersion capacity and as a result, more chain to chain interactions between polysaccharides were involved.

Surface characterisation

The effect of ultrasonic treatment on the surface of films was determined using a scanning electron microscope (SEM). SEM micrographs of untreated and treated films are presented in Fig. 6 (a–f). All figures show the surface of the films at 400× magnification and voltage 10 kV. The 10kV voltage was used since at higher voltage, film samples would get damaged very quickly and the determination of the surface would not be correct. 400× magnification was used, as higher magnifications degrade the surface of the analysed films. The surface micrographs revealed a smooth, even surface for all treated films. As seen in Figure 6a, the untreated chitosan film is less smooth and not as even as the film treated with ultrasound (Fig. 6b). The same trend is seen in Figs. 6c and 6d, where the SEM micrographs of rice starch are shown. From Fig. 6c it can be seen that the untreated rice starch film has a more irregular surface than the chitosan film.

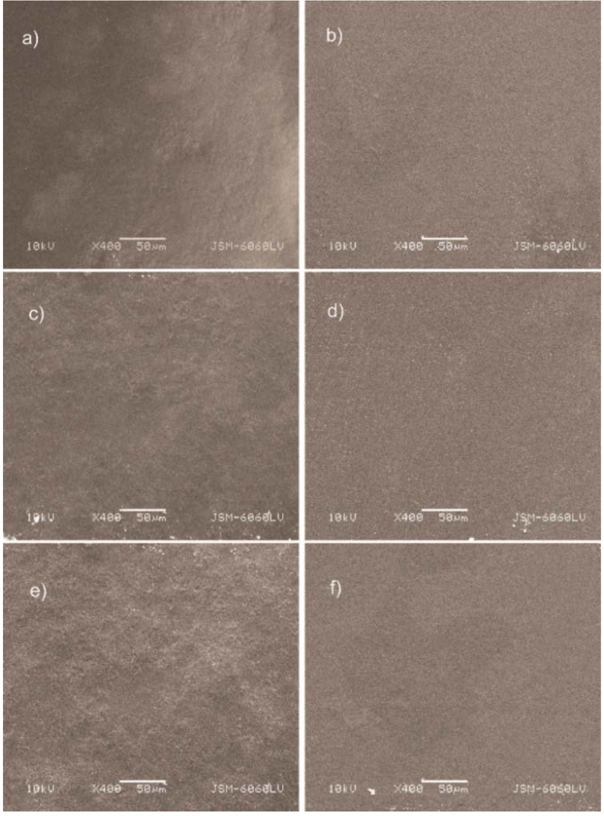

Fig. 6. SEM micrographs of untreated and ultrasound treated films: a) untreated chitosan film, b) treated chitosan film, (c) untreated rice starch film, d) treated rice starch film, e) untreated chitosan-rice starch blend film, f) treated chitosan-rice starch blend film.

The untreated chitosan rice starch blend film had a less uniform, smooth and dense structure (Figs. 6e and 6f). The ultrasonic treatment improved the homogeneity of the surface, which is a good indicator of the better structural and mechanical properties, compared to the untreated films. In general, the ultrasonic treatment helps to obtain a smooth and homogeneous surface.

CONCLUSIONS

Chitosan, rice starch and chitosan-rice starch blend films were successfully prepared, and the solutions of films were successfully treated with ultrasound. The results showed that the ultrasonic treatment had a good impact on the preparation and properties of films. The surface of films improved for all treated films. The mechanical resistance of treated films was improved, especially for the blend film. By mixing these two polymers, the characteristics of the film improved and with an ultrasonic treatment, the properties got even better. The reaction between the two polymers in the blend film was confirmed by FTIR analysis. In addition, in blend films, a decrease in water vapour permeability was detected and this could be explained with the higher glycerol content of the chitosan-rice starch blend films. There has been a lot of research performed on chitosan and rice starch films, but less on improving blend films. New studies are necessary to find the best ultrasonic procedures (regarding treatment times and frequency) to prepare the films. One of the issues to be taken into account in further research on enhancing water barriers and tensile properties of blend chitosan-rice starch films treated with ultrasound is to prepare a bi-layer or laminated films in order to ensure more effective barriers against water transfer and better mechanical properties than blend films.

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ПОДОБРЯВАНЕ НА ФИЗИЧНИТЕ И ОПТИЧНИТЕ СВОЙСТВА НА ФИЛМИТЕ ОТ ХИТОЗАН-ОРИЗОВО НИШЕСТЕ, ПРЕДВАРИТЕЛНО ТРЕТИРАНИ С УЛТРАЗВУК

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(Резюме)

Прозрачни филми от хитозан, оризово нишесте и смес от хитозан-оризово нишесте се приготвят като се използва вода, ябълчена киселина и глицерол като пластификатор. Преди отливане, филмните разтвори са третирани с ултразвук. Целта на изследването е да се постигнат подобрени физически, оптични и повърхностни свойства на филмите. Резултатите показват, че ултразвуковото лъчение подобрява еластичността, устойчивостта на влага и прозрачността на филмите. При всички ултразвуково обработени филми нараства удължаването при скъсване и якостта на опън, особено при смесени филми. Освен това, съдържанието на влага показва намаление, пропорционално на увеличаването на дебелината при намаляваща разтворимост на филма при всички третирани проби. Повърхността на необработения смесен филм е по-неравномерна в сравнение с филмите на хитозана и оризовото нишесте, които се подобряват след облъчването. Приготвянето на филмови разтвори с ултразвук е подобрена процедура за увеличаване на много свойства на биоразградими филми.