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Characterization of new biodegradable edible film made from basil seed (*Ocimum basilicum* L.) gum

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ABSTRACT

It is well known that the market for edible films is experiencing remarkable growth and expected to continue. This study investigated the using of basil seed gum (BSG) as a new film-forming material under the influence of addition of glycerol (GLY) as plasticizer. Edible films based on BSG and three different concentrations of GLY (25%, 35%, and 50% w/w BSG) were developed, and their water vapor permeability (WVP), as well as physical, thermal and mechanical properties were measured. The addition of glycerol significantly increased water vapor permeability and solubility of the film ($p < 0.05$). As expected, the increase in GLY concentration from 25% to 50% (w/w) increased the extensibility, but decreased tensile strength. This suggests weaker mechanical strength and higher mobility of polymer chains by plasticizing effect of GLY. The color measurement values showed that increasing the glycerol concentration in polymer matrix caused the b and L values increased while ΔE value decreased. The electron scanning micrograph showed plasticized films as smooth, and uniform which lacked pores or cracks compared with those were not plasticized. This study revealed that the BSG had a good potential to be used in producing edible films for various food applications.

1. Introduction

Nowadays, millions of tons of plastic are produced annually all over the world, and the production and consumption continue both to increase; this increase has created serious environmental problems due to the materials' inability to biodegrade (Debeaufort, Quezada-Gallo, & Voilley, 1998). In order to solve the problems generated by plastic waste, much research effort has been done to obtain an environmentally friendly material. Recently, natural polymers have received much attention due to the environmental concerns, as well as strong requirements for economic independence of fossil resources (Janjarasskul & Krochta, 2010). Biodegradable edible films can prevent quality deterioration and increase the shelf life of food products by acting as barriers to control the transfer of moisture, oxygen, lipids, and flavors (Gontard, Duchez, Cuq, & Guilbert, 1994).

Materials available for forming films and coating generally fall into the categories of polysaccharides, proteins and lipids. Various polysaccharides have been used to prepare edible films, including starch (Osés, Niza, Ziani, & Maté, 2009), cress seed gum (Jouki, Khazaei, Ghasemlou, & HadiNezhad, 2013), quince seed mucilage (Jouki, Mortazavi, Yazdi, & Koocheki, 2013), psyllium seed gum (Ahmadi, Kalbasi-Ashtari, Oromiehie, Yarmand, & Jahandideh, 2012), tapioca (Vásconez, Flores, Campos, Alvarado, & Gerschenson, 2009), corn starch (Psomiadou, Arvanitoyannis, & Yamamoto, 1996), cellulose and cellulose derivatives such as HPMC (hydroxypropyl-methylcellulose), CMC (carboxymethyl cellulose), and MC (methylcellulose) (Pérez, Flores, Marangoni, Gerschenson, & Rojas, 2009; Sánchez-González, Vargas, González-Martínez, Chiralt, & Cháfer, 2009). However, through recent years, there is major emphasis on investigating different renewable resources for the production of edible and biodegradable films.

Basil (*Ocimum basilicum* L.) is a member of genus *Ocimum*. The genus *Ocimum* comprises between 50 and 150 species of herbs and shrubs (Hiltunen & Holm, 1999; Simon, Morales, Phippen, Vieira, & Hao, 1999). It is a popular, aromatic white-purple flowering herb grown in India and Iran (Fekri, Khayami, Heidari, & Jamee, 2008; Yousif, Scaman, Durance, & Girard, 1999). Basil seed locally called "Reyhan" in Iran, is one of the endemic plants used as a pharmaceutical plant. It has been used in traditional medicine for a long time to treat colic ulcer, dyspepsia, diarrhea and inflammations, among others ailments. The basil seed gum (BSG) extract

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has been reported to be comprised of two major fractions of glucomannan (43%), with the ratio of glucose to mannose 10:2, and (1→4)-linked xylan (24.29%) and a minor fraction of glucan (2.31%) (Razavi et al., 2009; Tharanathan and Anjaneyalu, 1975). Azoma and Sakamoto (2003) also reported the presence of highly branched arabinogalactan in addition to glucomannan and (1→4)-linked xylan. Non-starch polysaccharides including galactomannans (*e.g.* guar, fenugreek and locust bean) and glucomannans (*e.g.* konjac) are one of the important categories of plant-based polysaccharides (Li, Xie, & Kennedy, 2006; Cui, Ikeda, & Eskin, 2007). Glucomannans containing carboxylic groups (—COOH) have a pK_a value of 3.0 (Du, Dai, Liu, & Dankovich, 2006). Above this pK_a value, the polysaccharide is negatively charged due to the ionization of the carboxylic group. BSG has a great potential to be utilized as a thickening and stabilizing ingredient in food systems (Rafe, Razavi, & Khan, 2012). Recently, Razavi, Bostan, and Rezaie (2010) studied physico-mechanical properties of basil seeds. They also reported optimal extraction conditions of gum from basil seeds, in terms of pH, temperature and water/seed ratio (Razavi et al., 2009). Investigation into rheological properties showed that BSG demonstrate a non-Newtonian pseudoplastic behavior. It also exhibit a very high zero shear viscosity and a yield stress (Hosseini-Parvar, Matia-Merino, Goh, Razavi, & Mortazavi, 2010). This seed has shown to have reasonable amounts of gum with good functional properties which is comparable with other commercial food hydrocolloids (Mirhosseini & Amid, 2012). Preliminary studies in our lab showed that BSG can produce films with good appearance and satisfactory mechanical properties (data not shown). In addition, when compared with other polysaccharides, BSG has several important advantages, such as low production cost, hydrophilic, biocompatible and biodegradable characteristics as well as good rheological properties, which are factors that enable it to have excellent potential as a film-forming agent. However, no previous work is found in the literature on the production of edible biodegradable films based on BSG. On the other hand, in order to increase the workability and flexibility of edible films, various plasticizers, usually polyols, have been widely used. Glycerol (GLY) is one of the most preferred and widely studied plasticizers. GLY is a hydrophilic plasticizer, which when added at the correct level with respect to the biopolymer content, can reduce intermolecular forces and increase the mobility of polymer chains, a process generally used to improve the mechanical properties of edible films (Ghasemlou, Khodaiyan, & Oromiehie, 2011).

Thus, the aim of this study was to develop a new edible film based on BSG and to examine the physical, mechanical, barrier, and microstructural properties of the resulting films as a function of varying concentrations of GLY as plasticizer.

2. Material and methods

2.1. Materials

The basil seeds were obtained from the local medical market in Tehran, Iran. The seeds were cleaned up and stored at 4 °C in sealed containers until they were tested. Ethanol 96% was purchased from Razi Corporation (Tehran, Iran). Magnesium nitrate and sodium chloride (used to equilibrate films at 53% RH and 75% RH, respectively) and calcium chloride together with GLY were purchased from Sigma Chemical Co. (St. Louis, MO). All other reagents used were of analytical grade.

2.2. Extraction of BSG

The following procedure was developed to extract BSG from basil seeds. About 10 g basil seeds were first washed at least four times in an excess amount of ethanol in order to remove all foreign matter such as dust, dirt, stones, and chaff. After removing ethanol from the seeds by filtration followed by evaporation in an oven at 70 °C, they were steeped in distilled water (water to seed 10:1) at 35 °C for 8 h. Then, the swollen seeds were stirred with a rod paddle blender (Rondo-2500, KA702, France) at 1500 rpm for 10 min to scrape the gum layer off the seed surface. Separation of the gum from the swollen seeds was achieved by filtration with cheese cloth and the insoluble residue if any was filtered out, leaving a concentration of 14% (w/w). Mathews, Singhal, and Kulkarni (1993) found the purified (alcoholic precipitation) extracted basil seed gum (BSG) contain a small fraction of residual protein (~1.5%), ~9.7% fat, ~3.3% ash and ~80% carbohydrate contents. Fig. 1 shows these seeds before and after swelling in water.

2.3. Preparation of BSG films

To prepare film-forming solution, the solution (14% (w/w)) was then mixed with GLY as a plasticizer in 25%, 35%, and 50% (w/w) based on BSG weight. Following the addition of GLY, stirring was continued for a further 15 min at 55 °C. The film-forming solutions were degassed under vacuum for 5 min to remove bubbles that could become pinholes after drying up. BSG films were cast by pouring the mixture onto a Teflon plate placed on a leveled granite surface for approximately 18 h at room temperature and room relative humidity. Dried films were peeled off the casting surface and stored inside desiccators at 25 ± 1 °C until the evaluation phase. Films were conditioned at room temperature (25 °C) and 53% RH in chambers containing saturated solutions of $Mg(NO_3)_2$ prior to all analyzes.

2.4. Determination of physical properties of films

2.4.1. Film thickness and density measurements

The film thickness was measured using manual digital micrometer (Mitutoyo No. 293-766, Tokyo, Japan) to the nearest 0.001 mm. Measurements were made in at least, ten random locations for each film, and an average value was calculated. The average value was used in calculations for tensile properties and WVP tests. Film density was calculated by dividing the film weight by the film volume, where the film volume was calculated by multiplying the film area by the thickness (Larotonda, Matsui, Sobral, & Laurindo, 2005).

2.4.2. Moisture content

Prior to determining film properties, samples were conditioned at 25 °C and 53% relative humidity (RH) for 48 h. Film moisture content was determined through the weight loss through which the film went after a 24 h oven drying at 90 °C. Preliminary experiments showed us that 24 h was enough to dry up samples. The temperature was chosen to avoid loss of plasticizer.

2.4.3. Film solubility in water

Solubility of BSG films in water was measured following the method of Jouki, Yazdi, Mortazavi, and Koocheki (2013). Film samples were dried at 95 °C for 24 h in a laboratory oven and then weighed to determine initial solid content. Pre-weighed film samples (1 cm × 3 cm) were immersed under constant agitation in 50 ml of distilled water for 6 h at 25 °C. After that period, the remaining pieces of films were filtered and dried at 110 °C to constant weight (final dry weight). The solubility was reported as the difference between the initial and final dry matter with respect to the initial dry matter.

2.4.4. Contact angle measurements

The contact angle is defined as the angle between the baseline of the drop and the tangent line at the point of contact of the water

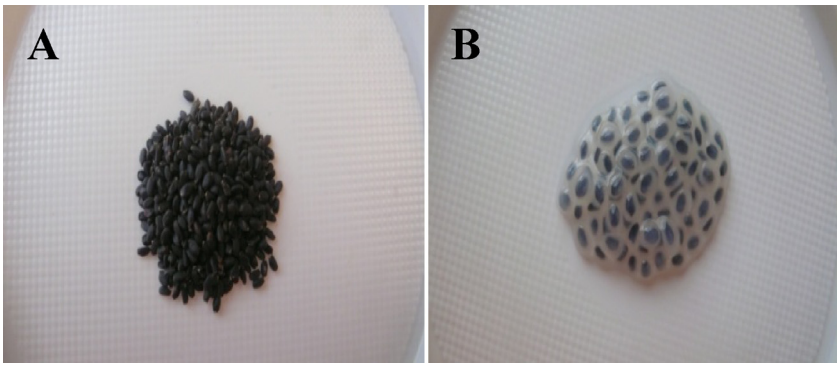

Fig. 1. Basil seeds before (A) and after (B) swelling in water.

droplet with the surface (Ojagh, Rezaei, Razavi, & Hosseini, 2010). Contact angles were measured with the sessile drop technique, by depositing a drop of a liquid onto the film surface. The instrument used was a goniometer (Krüss G10, Germany) with a 5 μL drop of distilled water. The contact angle measurements were carried out in open air at a relative humidity of 30% RH and at a room temperature of 25 °C. The angle of the tangent to the basis of the droplet (contact angle) was measured and expressed in degrees. To obtain a reliable contact angle for each film sample, this test was repeated at least six times and the mean values were calculated.

2.5. Water vapor permeability

The water vapor transmission of the films was determined gravimetrically according to ASTM E96 method (ASTM, 1995) with a 75% RH gradient at 25 °C. Permeation cells containing anhydrous calcium chloride (0% RH) were sealed by the test film (0.00263 m^2 film area) using melted paraffin (leaving an air gap of 1 cm between the film and the desiccant). To maintain a 75% RH gradient across the film, a sodium-chloride-saturated solution (75% RH) (Merck, Darmstadt, Germany) was used in the desiccators. The RH inside the cell was always lower than outside, and water-vapor transport was determined using the weight gain of the cell at a steady state of transfer. Changes in the weight of the cell were recorded to the nearest 0.0001 g and plotted as a function of time. The slope of each line was calculated by linear regression ($r^2 > 0.99$), and the water-vapor transmission rate was calculated through the slope of the straight line (g/s) divided by the test area (m^2). All values for water-vapor transmission rate (WVTR) were corrected for air-gap distance between the calcium chloride and the film surface according to the equations of Gennadios et al. (1994).

$$\mathrm{WVTR} = \frac{\text{slope}}{\text{film area}} = \frac{\Delta m}{\Delta t \times A} \quad (1)$$

After the permeation tests, the film thickness was measured and water-vapor permeability (WVP) (g Pa^{-1} s^{-1} m^{-1}) was calculated as:

$$\mathrm{WVP} = \frac{\Delta m}{A\,\Delta t}\frac{X}{\Delta p} \quad (2)$$

where $\Delta m/\Delta t$ is the weight of moisture gain per unit of time (g/s), X is the average film thickness (mm), A is the area of the exposed film surface (m^2), and Δp is the water vapor pressure difference between the two sides of the film (Pa). WVP was measured for three replicated samples for each type of film.

2.6. Color measurement

The color of the films was determined using a colorimeter (Minolta CR300 Series, Minolta Camera Co. Ltd., Osaka, Japan). Film specimens were placed on a white standard plate ($L^* = 93.49$, $a^* = 0.25$, $b^* = 0.09$) and the lightness (L) and chromaticity parameters a (red-green) and b (yellow-blue) were measured. Three readings on different sites of each film were recorded. Eqs. (3) and (4) were used to calculate the total color difference (ΔE) and whiteness (WI) indexes of samples, respectively (Bolin & Huxsoll, 1991).

$$\Delta E = \sqrt{(L^* - L)^2 + (a^* - a)^2 + (b^* - b)^2} \quad (3)$$

$$\mathrm{WI} = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \quad (4)$$

where L^*, a^*, and b^* are the standard color parameter values and L, a, and b are the color parameter values of the sample.

2.7. Mechanical properties

The film's mechanical properties were determined through tension tests, using a Testometric Machine M350-10CT (Testometric Co. Ltd., Rochdale, Lancashire, England) in accordance with the ASTM D882 standard (ASTM, 2001). Prior to the test, the films were cut in rectangular strips of 15.4 mm by 100 mm and preconditioned for 48 h at 25 °C and 53% RH inside desiccators containing saturated solutions of magnesium nitrate. The BSG films were clamped between grips and force and deformation were recorded during extension at 50 mm/min, with an initial distance of 50 mm between the grips. Elongation at break (deformation divided by initial grip separation and multiplied by 100) and maximum force were obtained from force *versus* deformation curves. Tensile strength was calculated by dividing maximum force by film cross section (thickness × width). At least 4 replications of each test sample were run to achieve dependable data.

2.8. Thermal analysis

Thermal properties of the films were determined by differential scanning calorimetry (DSC) (Model F3 200 DSC Netzsch, Germany). Samples were scanned at a heating rate of 10 °C/min between temperature ranges of (−100)–(+200) °C. Glass transition temperature (Tg) was identified as the midpoint temperature of the shift in the baseline due to the change in the heat capacity upon glass transition. Also the melting point (Tm) of the films was determined.

2.9. Film microstructure

The surface and internal structure of the films were evaluated using a scanning electron microscopy (EM-3200, KYKY, China). The BSG films containing 35% glycerol were fractured in liquid nitrogen, mounted on specimen holder using an aluminum tape, and sputtered with a thin layer of gold using a BAL-TEC SCD 005 sputter

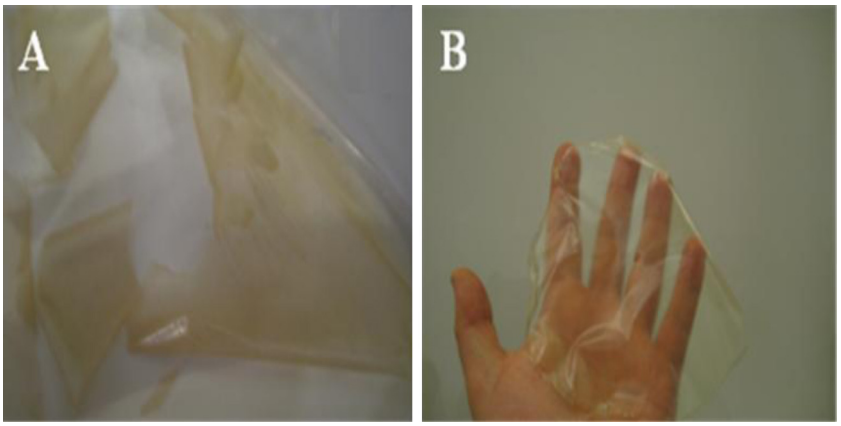

Fig. 2. Two pattern formations of basil seed gum (BSG) films: without plasticizer (A) and with plasticizer (B).

coater (BALTEC AG, Balzers, Liechtenstein). All samples were examined under high vacuum condition and at an accelerating voltage of 25.0 kV. Samples were photographed at tilt angles of 60–90° to the electron beam to obtain cross section views.

2.10. Statistical analysis

Statistics on a completely randomized design were performed with the analysis of variance (ANOVA) procedure using SAS software (Version 9.1; Statistical Analysis System Institute Inc., Cary, NC, USA). Duncan's multiple range tests were used to compare the difference among mean values of films' properties at the significance level of 0.05.

3. Results and discussion

3.1. Physical properties of films

Preliminary studies were carried out to determine the plasticizer content range for film formulation. Unplasticized BSG films were brittle and required care in peeling from the casting surface (Fig. 2A). The incorporation of GLY increased flexibility of BSG films and made them easier to handle (Fig. 2B).

However, the addition of GLY more than 50% (w/w) (film dry weight basis) resulted in sticky and wet films. Stickiness of GLY plasticized films may have resulted from phase separation and diffusion of GLY to the surface of the film (Ghasemlou, Khodaiyan, Oromiehie, & Yarmand, 2011). The lowest effective GLY concentration was 25% (w/w) (film dry weight basis); below this concentration, the films showed similar behavior to that of films prepared without GLY.

Table 1 shows the impact of incorporating GLY on the physical properties of BSG films. There was not much variation in the thickness of GLY incorporated films, ranging between 0.058 and 0.074 mm. The film density decreased upon GLY addition but showed very small variations. Moreover the GLY-containing films had higher moisture-content values than those of the control films; this difference was significant ($p < 0.05$). In addition increasing the level of GLY led to increases in the films' moisture content. It is often reported in the literature that the moisture content of hydrocolloid films increases with an increase in plasticizer concentration (Kristo & Biliaderis, 2006; Zhang & Han, 2006). These results were similar to those achieved by Ghasemlou, Khodaiyan, Oromiehie, and Yarmand (2011), whose kefiran films tended to become more hydrophilic with an increase in plasticizer content. They explained this behavior by the fact that GLY acts as a water-holding agent, with the higher number of water molecules in GLY-plasticized films increasing plasticizing activity.

The film solubility is an important property of edible films because potential food applications may require good water insolubility to enhance product integrity and water resistance (Stuchell & Krochta, 1994). The solubility of the films ($p < 0.05$) increased significantly with an increase in the concentration of GLY in the formulation. Although the water solubility of the unplasticized BSG film (47.34%) were lower than those of cress seed gum (48.3%) (Jouki, Khazaei, et al., 2013), this difference was not significant ($p > 0.05$). In GLY plasticized BSG films, GLY can reduce interactions between biopolymer molecules and increase solubility due to its hydrophilic nature giving the polymer molecules higher affinity to bind to water (Lourdin, Coignard, Bizot, & Colonna, 1997). Solubility was the highest with the use of the highest concentration of GLY at 50% (w/w).

3.2. Water contact angle

Surface-tension characterization through contact angle measurements can be a good way to determine how hydrophilic a film is (Pearoval, Debeaufort, Desprea, & Voille, 2002). Table 1 shows the water contact angle measurements for the samples. There was significant difference among contact angles for films with different GLY content ($p < 0.05$). An increase in the amount of GLY as a plasticizer led to a gradually decreasing contact angle value of BSG films due to hydrophilicity of GLY. It is accepted that water contact angle will increase with an increase in surface hydrophobicity. The results in this study showed that the addition of plasticizers diminished the films' water contact angle. Plasticization, therefore, resulted in decreasing hydrophobicity of the films. The higher hydrophilicity of the samples is attributable to the hygroscopicity (water-binding capacity) of the plasticizer (Carneiro-da-Cunha et al., 2009). These results revealed that water contact angles of BSG films were between 30° and 90°. Therefore, these films were less readily wetted and had similar behavior to that of most of the polysaccharide-based edible films.

3.3. Color measurement

Film color can be a factor in terms of consumer acceptance. Table 2 shows the *L*, *a*, and *b* CIE Lab color values, total color difference (ΔE), and whiteness index (WI) of films.

BSG films had a slightly yellow appearance, as indicated by a significant ($p < 0.05$) increase in the *L* and *b* values. However, no significant ($p > 0.05$) difference in values for *a* were detected.

Table 1
Physical properties of basil seed gum (BSG) films incorporated with various glycerol concentrations as plasticizer[a,b].

Glycerol conc. (%, w/w) (based on BSG content)	Moisture content (%)	Density (g/cm^3)	Thickness (mm)	Solubility in water (%)	Water contact angle (°)
0	16.23 ± 0.16d	1.31 ± 0.01a	0.058 ± 0.002c	47.34 ± 0.68d	83.42 ± 3.26a
25	17.43 ± 0.16c	1.27 ± 0.02b	0.064 ± 0.003b	49.65 ± 1.01c	75.92 ± 3.11b
35	17.92 ± 0.25b	1.27 ± 0.02c	0.067 ± 0.003b	51.93 ± 0.87b	66.40 ± 1.95c
50	18.54 ± 0.23a	1.23 ± 0.01d	0.074 ± 0.003a	53.78 ± 0.94a	39.17 ± 2.37d

All measurements were performed at 25 °C and 53% RH.
[a] Means within each column with same letters are not significantly different ($p < 0.05$).
[b] Data are means ± SD.

These results agreed with visual observations. Color changes due to incorporation of plasticizer can be more fully described using other color functions (Ghanbarzadeh, Almasi, & Entezami, 2010), such as ΔE, which indicates the degree of total color difference from the standard color plate, and WI, which indicates degree of whiteness. ΔE values were significantly ($p < 0.05$) lower than those that of unplasticized ones (increased clearness). In contrast, WI increased with an increase in GLY content. Similar effects on the color parameters for the glycerol addition to the film matrix have been previously reported for cress seed gum (Jouki, Khazaei, et al., 2013).

3.4. Water vapor permeability (WVP)

Table 3 shows the water vapor permeability (WVP) values of BSG films with different GLY concentrations.

There was a significant difference between the WVTR and WVP values of films made with different GLY concentrations ($p < 0.05$). The WVP was 1.69 g s^{-1} m^{-1} Pa^{-1} × 10^{-10} for the control sample (without plasticizer). WVP increased significantly with an increase in GLY content. An increase in plasticizer concentration normally causes a rise in the WVP of hygroscopic or hydrophilic films due to a reorganization of the polysaccharide network and a consequent increase of the free volume and segmental motions (Sothornvit & Krochta, 2001), allowing water molecules to diffuse more easily and giving a higher WVP. Additionally, at higher GLY concentrations, GLY could cluster with itself to open the polymer structure, enhancing the permeability of the film to moisture. It was observed that at equal concentration of BSG, the films with a GLY concentration of 50% were more permeable to water vapor than those of 25% and were less efficient against water vapor transfer. WVP of films is dependent on both solubility coefficient and diffusion rate of water in film which, in turn, is dependent on partial pressure of water vapor (Pearoval et al., 2002). Thus, lower WVP of plasticized films, compared to those films without plasticizer could result from coincidental effect of both solubility coefficient and diffusion rate. The same set of behaviors is shown in the work of Ahmadi et al. (2012), who found that an increase in the GLY concentration increased the WVP of psyllium seed gum films. The BSG film with 35% glycerol had higher WVP (2.02×10^{-10} g s^{-1} m^{-1} Pa s^{-1}) than similar data for psyllium seed gum films (1.88×10^{-10} g s^{-1} m^{-1} Pa s^{-1}) (Ahmadi et al., 2012) and quince seed mucilage (7.62×10^{-11} g s^{-1} m^{-1} Pa s^{-1}) (Jouki, Mortazavi, et al., 2013) at the same plasticizer level (35%). The moisture barrier properties of the BSG films were better than those of corn starch (2.62×10^{-7} g Pa^{-1} h^{-1} m^{-1}) (Ghanbarzadeh, Almasi, & Entezami, 2011), and cress seed gum (2.27×10^{-10} g Pa^{-1} h^{-1} m^{-1}) (Jouki, Khazaei, et al., 2013), respectively. These differences are probably due to the difference in the source of polysaccharide of prepared films and the differences in the thickness of BSG films (0.067 mm) in comparison with psyllium seed gum films (0.072 mm), corn starch films (0.080 mm) and cress seed gum films (0.073 mm). Since one of the major functions of films is to prevent water migration in foods, the low WVP would suite the use of these films in foods with low or intermediate moisture, such as nuts.

3.5. Mechanical properties

Mechanical properties reflect the durability of films and their ability to enhance the mechanical integrity of foods. The effect of incorporating GLY on mechanical properties of BSG films is presented in Table 3. The presence of GLY in films caused significant differences in tensile strength (TS) and elongation at break (EB). In fact, films without GLY presented greater TS and lower EB. In addition, a tendency to a higher EB was observed as the concentration of GLY increased ($p < 0.05$) (Table 3). Incorporation of GLY molecules into BSG films probably established GLY-BSG hydrogen bonds replacing some of the BSG–BSG hydrogen bonds. As a result, direct interactions between the molecular chains were reduced, and the chain segmental mobility was increased, causing the mechanical strength of the films to decrease and their extensibility to enhance. This effect of incremental increases in plasticizer concentration on mechanical properties has been broadly discussed in the literature (Cuq, Gontard, Aymard, & Guilbert, 1997; McHugh & Krochta, 1994). The TS of BSG films was almost two times higher than that reported for psyllium seed gum with GLY as plasticizer (Ahmadi et al., 2012), whereas EB of BSG films was almost equal to the EB of psyllium seed gum based films.

3.6. Thermal properties

The results of DSC measurements indicated only one glass transition temperature (Tg) for the BSG films (Table 4). The decrease in the melting point may be caused by a decrease in the number of hydroxyl groups in the BSG molecules which can form strong hydrogen bonds among polymer chains. Additionally, the increase in plasticizer content probably made the BSG molecules

Table 2
Color values including, *L*, *a*, and *b*, total color difference (ΔE) and whiteness index (WI) of basil seed gum (BSG) films as a function of glycerol concentration[a,b].

Glycerol conc. (%, w/w) (based on BSG content)	*L*	*a*	*b*	ΔE	WI
0	64.34 ± 0.60d	−0.57 ± 0.02a	3.07 ± 0.19d	29.89 ± 0.42a	63.39 ± 0.74d
25	69.89 ± 0.42c	−0.57 ± 0.04a	3.39 ± 0.16c	24.49 ± 0.30b	69.72 ± 0.87c
35	76.57 ± 0.54b	−0.58 ± 0.02a	3.77 ± 0.15b	18.01 ± 0.48c	74.39 ± 1.10b
50	79.44 ± 0.39a	−0.56 ± 0.03a	4.16 ± 0.21a	15.78 ± 0.55d	79.82 ± 1.27a

All measurements were performed at 25 °C and 53% RH.
[a] Means within each column with same letters are not significantly different ($p < 0.05$).
[b] Data are means ± SD.

Table 3
Water vapor transmission rate, water vapor permeability and mechanical properties for basil seed gum (BSG) films incorporated with various glycerol concentrations as plasticizer[a,b].

Glycerol conc. (%, w/w) (based on BSG content)	Water vapor transmission rate (WVTR) ($\times 10^{-3}$ g H_2O s^{-1} m^{-2})	Water vapor permeability (WVP) ($\times 10^{-10}$ g H_2O m^{-2} s^{-1} MPa^{-1})	Tensile strength (MPa)	Elongation at break (%)
0	4.72 ± 0.06d	1.69 ± 0.06d	31.69 ± 0.43a	18.55 ± 2.44d
25	4.87 ± 0.06c	1.83 ± 0.05c	29.58 ± 0.49b	26.89 ± 2.30c
35	5.09 ± 0.09b	2.02 ± 0.03b	25.22 ± 0.32c	32.50 ± 2.58b
50	5.26 ± 0.08a	2.24 ± 0.03a	18.14 ± 0.28d	39.37 ± 2.79a

[a] Means within each column with same letters are not significantly different ($p < 0.05$).
[b] Data are means ± SD.

Table 4
Thermal properties of basil seed gum (BSG) films as a function of glycerol concentration.

Glycerol conc. (%, w/w) (based on BSG content)	Tg (°C)	Tm (°C)
0	29.9	165.3
25	−31.1	164.8
35	−41.1	164.6
50	−51.3	164.3

All measurements were performed at 25 °C and 53% RH.

more mobile. Below Tg, films are rigid and brittle, whereas above it films become flexible and pliable (Mali, Sakanaka, Yamashita, & Grossmann, 2005). Another major consequence of a glass transition in film structures is an increase in the molecular mobility which may lead to changes in the film barrier properties (Jasse, Seuver, & Mathlouthi, 1994). The decrease in Tg and melting temperature (Tm) accompanied by increased plasticizer content was expected, and had been observed in other studies too (Ghanbarzadeh & Oromiehi, 2009; Ghasemlou, Khodaiyan, Oromiehie, & Yarmand, 2011; Gontard, Guilbert, & Cuq, 1993). Similar results were obtained by Arvanitoyannis, Psomiadou, Nakayama, Aiba, and Yamamoto (1997) with films of gelatin/starch blends plasticized with glycerol or sorbitol.

3.7. Film microstructure

Scanning electron microscopy (SEM) can provide a better understanding of the relationships of water vapor transmission, mechanical, and optical properties with the films' structural characteristics (Jouki, Khazaei, et al., 2013). Fig. 3 shows the SEM micrographs of the outer surface (left) and cross section (right) for both the control and glycerol-containing films.

SEM micrograph of plasticized films showed smooth and uniform surface morphology without pores or cracks compared with those films without glycerol. SEM observations of BSG films with different glycerol concentrations did not present any notable differences in structure. These results were similar to those achieved by Jouki, Khazaei et al. (2013), whose CSG films tended to become more smooth and uniform surface with an increase in plasticizer content.

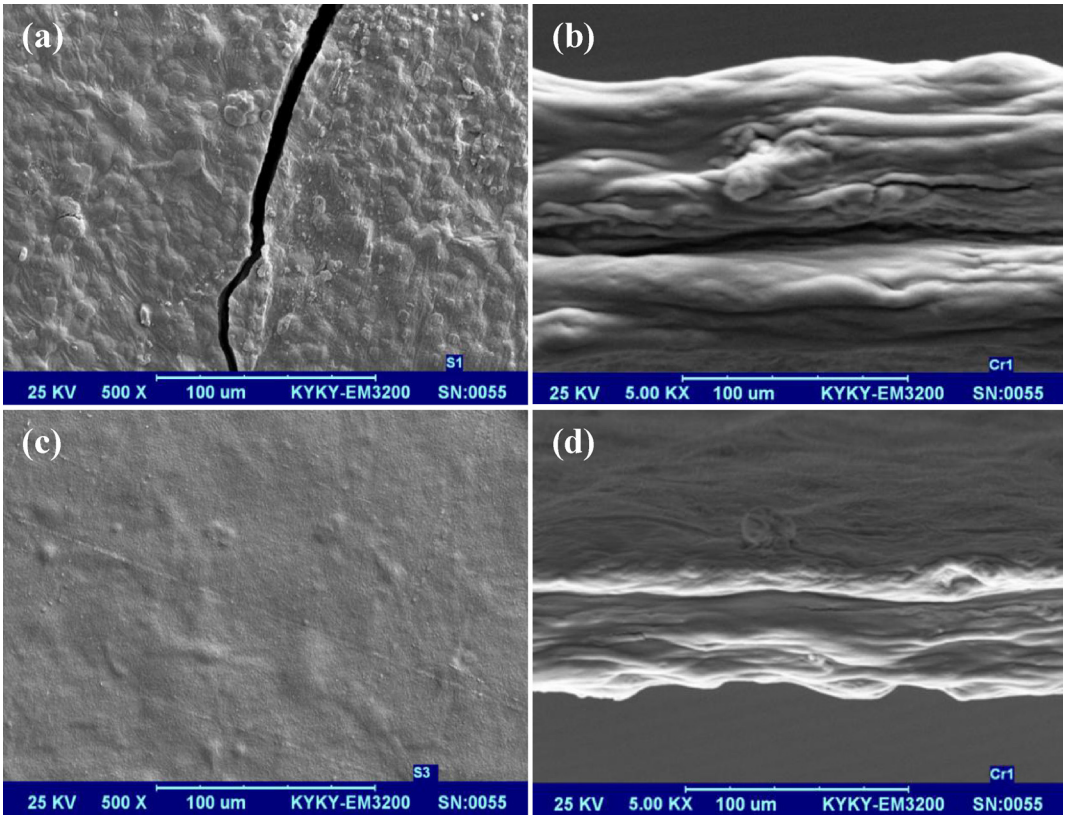

Fig. 3. Scanning electron microscopic images of BSG-based films: (a and b) unplasticized and (c and d) plasticized with 35% (w/w) glycerol (GLY); surfaces (left) viewed at a magnification of 2500× and cross-section (right) viewed at a magnification of 5000×, respectively.

4. Conclusion

This is the first report that demonstrates the ability to form films of polysaccharide extracted from basil seed. BSG appears to be a very interesting raw material for the preparation of edible films and coatings. The process developed here produced transparent films with good mechanical properties and excellent barrier properties. GLY had an essential role in making homogenous flexible films and also affected physical and mechanical properties of BSG films. Overall, the best properties of BSG based films were observed in GLY-plasticized films. Generally, the TS of the films decreased and EB increased with increasing concentrations of GLY. Such films can be used to extend the shelf-life of foods. At the level of 25% (w/w) of glycerol, BSG films had the lowest WVP values (1.83×10^{-10} g $H_2O\ m^{-2}\ s^{-1}\ MPa^{-1}$), *E*% (26.89%) and water solubility (49.65%) and the highest values for TS (29.58 MPa), water contact angle (75.92°) and Tg (−31.1 °C). Based on DSC results, the glass transition temperature (Tg) of the films decreased with the glycerol content. Due to lower WVP value of films produced in this study (in comparison with other polysaccharide based films), BSG films could be a potential alternative for synthetic packaging, mainly for the purpose of storing foods with low or intermediate moisture such as nuts. Further investigations are needed to test the effectiveness of these films on selected food systems.

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