Carbohydrate Polymers 104 (2014) 50–58

Contents lists available at ScienceDirect

Carbohydrate Polymers

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

Characterization of a new biodegradable edible film made from salep glucomannan

Abdullah Kurt[a,c], Talip Kahyaoglu[a,b,*]

[a] Department of Food Engineering, Engineering Faculty, Ondokuz Mayıs University, 55139, Samsun, Turkey
[b] Department of Food Engineering, Chemistry-Metallurgical Faculty, Yıldız Technical University, 34210 Istanbul, Turkey
[c] Department of Food Engineering, Engineering and Architecture Faculty, Bitlis Eren University, 13000 Bitlis, Turkey

ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form
16 December 2013
Accepted 2 January 2014
Available online 9 January 2014

Keywords:
Edible films
Salep
Glucomannan
Galactomannan
Film properties
Rheology

ABSTRACT

The aims of this study were to report the film-forming properties of salep glucomannan (SG) and characterize its physical, barrier, mechanical, sorption and thermal properties for the first time. Galactomannan films (LBG, locust bean gum; GG, guar gum) were also prepared to compare with SG films. The steady and oscillatory rheological behaviors of the film solution were evaluated. The viscosity of the SG was less dependent than that of LBG and GG on temperature. The physical properties of SG films showed good potential for food applications. The oxygen and water vapor barrier properties of SG were better than LBG and GG films. SG film was less mechanically resistant than LBG but more flexible than galactomannan films. The highest transition temperature (T_g) was determined to be $-11.46 \pm 0.65\,^{\circ}\mathrm{C}$ for SG film. The results showed that SG has good potential for use in producing an edible film for various food applications.

1. Introduction

Mannans are one of the most abundant hemicelluloses present as supporting and storage polysaccharides in the cell wall, legume seeds, and plant tubers (Mikkonen, 2009; Rowell, Pettersen, Han, Rowell, & Tshabalala, 2005). The gums from leguminous seeds (locust bean gum, LBG; guar gum, GG) and plant tubers (konjac glucomannan, KGM, from *Amorphophallus konjac*; salep glucomannan, SG, from the *Orchidaceae* family) are classified as mannans. Glucomannan is a chain consisting of glucose and mannose connected by β-(1→4) glycosidic bonds. Galactomannan is linked by β-(1→4) glycosidic bonds, with a galactose substitution at the C-6 position. These high molecular weight polymers are known as hydrocolloids and interact strongly with water. Hydrocolloids are used in the food industry for their thickening, gelling, stabilizing, texture-modification and film-forming properties. Salep has also received considerable attention for the same purposes (Farhoosh & Riazi, 2007; Pourjavadi, Fakoorpoor, & Hosseine, 2013).

Salep is the roots or tubers of *Orchidaceae* species. It is largely collected in Eastern Mediterranean countries and produced on an average 20 tons in Turkey every year (Hossain, 2011). The tubers of naturally grown orchids are dried and then ground to produce salep powder. Glucomannan is the most important polysaccharide constituent in salep. Salep is commonly used as a traditional beverage and a stabilizer for hard serve ice cream. As a hydrocolloid, the rheological behavior of salep in different food systems has been extensively reported in the literature (Ayar, Sert, & Akbulut, 2009; Karaman, Yilmaz, & Kayacier, 2013; Razavi & Karazhiyan, 2009; Tekinşen & Güner, 2010; Yasar, Kahyaoglu, & Sahan, 2009; Yilmaz, Karaman, & Kayacier, 2013). Hydrocolloids are also the main sources of edible films. In contrast, there is no report on the film-forming properties of salep glucomannan.

Edible films are defined as a thin layer placed on or between food components. Polysaccharides and proteins are used with plasticizers to form the film. Edible and biodegradable films can be used to reduce the migration of moisture, oxygen, and carbon dioxide, which improves the shelf-life and appearance of food products. The barrier, mechanical and thermal properties are the significant characteristics that are evaluated for the application of films. The utilization of renewable sources, such as hydrocolloids, for edible films is of primary interest for researchers due to its economic and environmental impact of them (Cerqueira et al., 2011).

Glucomannan and galactomannan has attracted considerable attention because of abundance, film forming capacity and biodegradability of them (Mikkonen and Tenkanen, 2012; Tester and Al-Ghazzewi, 2013). Among the glucomannan, the KGM edible

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[*] Corresponding author at: Food Engineering Department, Chemistry & Metallurgical Faculty, Yildiz Technical University, Davutpasa Campus 34210, Istanbul, Turkey. Tel.: +90 212 383 4577; fax: +90 212 383 4571.
E-mail address: talipk@yildiz.edu.tr (T. Kahyaoglu).

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http://dx.doi.org/10.1016/j.carbpol.2014.01.003

film has been widely studied (Mikkonen, 2009). However, SG has not been investigated from a film-forming perspective. Nieto (2009) reported that linear, high molecular weight, non-ionic polysaccharide gums form strong films. Pourjavadi et al. (2013) reported similar properties for salep glucomannan. Therefore, SG could be an alternative biodegradable film and an enhancer of film properties as KGM, which was used to obtain a highly functional blend film by mixing with different polymers, such as starch and gelatin (Chambi & Grosso, 2011; Chen, Liu, Chen, Chen, & Chang, 2008; Nair, Jyothi, Sajeev, & Misra, 2011).

There is no published information about the film-forming properties of salep glucomannan. Therefore the main objectives of this study were (i) to evaluate the edible film-forming properties of salep glucomannan (as a new source) for the first time; (ii) to compare its physical, mechanical, barrier, and thermal properties with locust bean and guar gum films.

2. Materials and methods

2.1. Materials

Dried and finely ground salep roots were purchased from a supplier in Kastamonu, Turkey. Guar gum and locust bean gum were kindly donated by Incom (Mersin, Turkey). The plasticizer glycerol (99% purity) was from Sigma Chemical Co. (St. Louis, MO, USA).

2.2. Film preparation

The plasticized glycerol films in this study were prepared by means of the casting and solvent evaporation method. In each solution, the weight of dry matter was 1.5 g per 100 mL water. Glycerol was added at 10% (w/w with respect to the amount of gum) in solution. Film-forming solutions were obtained by the solubilization of SG, GG, and LBG in 50 mL water by continual mixing in a water bath at 95 °C for 30 min. The film-forming solutions were centrifuged at 1500 g for 5 min to remove air bubbles and insoluble solids that could damage the film's appearance. The solutions (40 mL) were then cast in Teflon plates (13 cm diameter) and dried at 40 °C for 15 h to obtain dry films. Before the characterization of the physical, barrier, and mechanical properties, the films were kept in a conditioning desiccators at 43% (K_2CO_3 saturated solution) relative humidity (RH) for more than one week at room temperature to ensure the equilibrium of the water in the films. To determine the thermal sorption properties and FT-IR spectra, peeled films were conditioned under 0% RH (silica gels) at room temperature for a week before testing.

2.3. Rheological analysis of the film-forming solutions

The rheological measurements of the film-forming solutions were made with a rheometer (HAAKE Mars III; Thermo Scientific, Germany) with a cone and plate system (diameter: 3.5 mm, cone angle: 2°, gap between cone and plate: 0.105 mm). The samples were allowed to equilibrate for 5 min at the desired temperature (30, 60, 90 °C), and the measurements were then conducted at these temperatures. The shear rate increased linearly from 0 to 100 s^{-1} over 5 min. The flow behavior index (n) and consistency index (K) values were computed by fitting the power law model, Eq. (1).

$$\tau = K \times \gamma^n \quad (0 < n < 1) \tag{1}$$

where τ is the shear stress (Pa), γ is the shear rate (s^{-1}), K is the consistency index (Pa s^n), and n is the flow behavior index (dimensionless).

The consistency index, which is an indication of the viscous nature of the samples, was used to describe the variation in viscosity with temperature by fitting to the Arrhenius model, Eq. (2) (Farhoosh & Riazi, 2007).

$$\ln k = \ln A + \frac{E_A}{RT} \tag{2}$$

where A is the frequency factor (Pa s^n), E_A is the activation energy (kJ/mol), R is the universal gas constant (kJ/mol K), and T is the absolute temperature (K).

Oscillatory (dynamic) tests were conducted for all samples at 30, 60, 90 °C from 0.1 to 10 Hz at 1 Pa (in the linear viscoelastic range assessed by the stress sweep test). The samples were allowed to rest for 5 min after loading (gap between cone and plate: 0.7 mm). In these tests, the storage (G'), loss (G'') modulus (Pa), and tan δ (G''/G') were computed from raw data.

2.4. Physical properties of edible film

2.4.1. Moisture content

The moisture content of the films is stated as the percentage of water removed from the initial mass sample. It was analyzed gravimetrically by drying the samples at 105 °C for 24 h (AOAC, 2005). The experiments were performed on samples in triplicate.

2.4.2. Film thickness and density measurements

The thickness of the films was determined using a digital micrometer (Mitutoyo, Manufacturing Co. Ltd., Japan, 0.001 mm accuracy). Ten measurements were made at random positions on the film samples, and the mean values were calculated. The film density was determined from the ratio between the weight and volume (thickness × area). The density experiments were conducted in triplicate, and are reported as mean values.

2.4.3. Total soluble matter

The total soluble matter (TSM) of the films was calculated by employing the method described by Pelissari, Andrade-Mahecha, Sobral, and Menegalli (2013). The initial dry matter of the preconditioned film pieces (20 mm × 20 mm) was determined by drying in an air-circulating oven at 100 °C for 24 h (W_i). These film pieces were immersed in 50 mL distilled water containing sodium azide (0.002% w/v) to prevent microbial growth and stored at room temperature for 24 h under periodic agitation. The insoluble matter was separated carefully and dried at 105 °C for 24 h for determination of the final dry weight (W_f). All tests were carried out in triplicate, and the total soluble matter (%) in the film was calculated according to Eq. (3).

$$TSM = \frac{W_i - W_f}{W_i} \times 100 \tag{3}$$

where W_i is the initial dry matter of the sample (g) and W_f is the final dry matter of the sample (g).

2.5. Color and film transparency

The L (lightness), a (greenness and redness) and b (blueness and yellowness) values of the films were determined by a Minolta Chromameter (CR-400, Minolta Camera Co., Osaka, Japan). These values were determined by taking five readings at different positions on each film.

The film transparency was calculated according to the method of Park, Je, and Kim (2004) by measuring the film absorbance at 600 nm using a UV spectrophotometer (Helios Gama, England). The samples were cut into rectangular pieces based on the lateral area of the spectrophotometer test cell and placed in the test cell. The