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Water vapor barrier and mechanical properties of konjac glucomannan–chitosan–soy protein isolate edible films

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ABSTRACT

The effects of polymer composition, glycerol concentration and pH of film-forming solution on water vapor permeability (WVP), tensile strength (TS) and percentage elongation at break (%*E*) of composite edible film based on konjac glucomannan (KGM), chitosan and soy protein isolate (SPI) were investigated. Of the plasticizers tested, glycerol was found to be a suitable plasticizer regarding mechanical properties and WVP. The WVPs of the films were determined to be (3.29–9.63) $\times 10^{-11}$ g m^{-1} s^{-1} Pa^{-1}, TS between 16.77 and 51.07 MPa, and %*E* between 1.29% and 10.73%, depending on film composition. Incorporation of SPI to the polymer matrix decreased both WVP and mechanical properties. Increase in both glycerol concentration and the pH of film-forming solution decreased WVP and TS but increased %*E*. The results suggest that film composition and the pH of film-forming solution are the major factors influencing the film properties.

Keywords: Konjac glucomannan; Chitosan; Soy protein isolate; Water vapor permeability; Tensile strength; Elongation at break

1. Introduction

Plastic packaging material is widely applied in food industry because of its low price, light weight, easily molding, excellent barrier and mechanical properties. However, as one kind of synthetic packaging materials, it may have potential risks to human's health possibly resulting from the migration of toxic monomer or additives to the food under special conditions. Moreover, it easily brings about "white pollution" to the environment resulting from its difficult biodegradation. Therefore, its application in food has been challenged from both food safety and environment protection. Nowadays, increasing research interest is focused on edible films made from natural biopolymers because they are of high safety and environmentally friendly.

Konjac glucomannan (KGM), chitosan and soy protein isolate (SPI) are the main renewable products which are economical, readily available, biodegradable and highly safe. They possess special nutritional and/or health-protective functions as well as good film-forming properties. For instance, KGM is found to have functions such as losing body fat, reducing the levels of blood lipids and blood glucose (Chen et al., 2006; Zhang et al., 2005). Chitosan shows good antimicrobial activity and excellent biocompatibility (Shahidi et al., 1999). In addition to being as one excellent source of complete protein for the human body, SPI can lower blood cholesterol level and demonstrates anticancer activity (Hakkak et al., 2001; Aoyama et al., 2000). For these reasons, they are widely used to prepare unitary or binary edible films (Yan et al., 2004; Brandenburg et al., 1993; Cheng et al., 2002; Sun et al., 2002; Chin et al., 1999; Tang et al., 2001, 2003; Xiao et al., 2000). However, films made from only one kind of natural film-forming polymer displays good properties in some aspects but poor in other aspects. For example, protein films exhibit better oxygen barrier and mechanical properties than polysaccharide films, while polysaccharide films generally possess poor water vapor barrier property. Thereby, two or more film-forming polymers of different categories are commonly used to prepare composite edible films by blending method, which is one of the effective methods to improve the properties of composite edible films. But recent studies on blend composite films are mainly centered on binary ones. Information on ternary composite film is poorly available to date (Wang et al., 2007; Wang and He, 2002; Sian and Ishak, 1990).

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Table 1 – Effect of film composition on the properties of films[a]

KGM	Chitosan	SPI	WVP ($\times 10^{-11}$ g m^{-1} s^{-1} Pa^{-1})	TS (MPa)	E (%)
0.375	0.375	0.00	6.29 ± 0.43	51.07 ± 4.82	10.73 ± 4.81
0.30	0.30	0.15	4.34 ± 0.21	43.32 ± 3.71	7.24 ± 1.13
0.25	0.25	0.25	4.04 ± 0.22	39.93 ± 2.82	4.55 ± 0.54
0.1875	0.1875	0.375	4.22 ± 0.31	31.56 ± 2.61	2.24 ± 0.22
0.15	0.15	0.45	5.55 ± 0.43	16.77 ± 1.63	1.29 ± 0.16
0.45	0.05	0.25	3.29 ± 0.23	50.43 ± 5.07	3.92 ± 0.43
0.35	0.15	0.25	3.95 ± 0.34	45.05 ± 4.18	4.52 ± 0.84
0.15	0.35	0.25	6.50 ± 0.52	39.80 ± 3.54	6.53 ± 0.96
0.05	0.45	0.25	9.63 ± 0.75	27.59 ± 2.61	6.83 ± 1.08

[a] The contents of KGM, chitosan and SPI were represented in g/100 mL. Glycerol content was 0.03 g/100 mL, and the pH value of all film-forming solutions was 3.

The major objectives of the present study were to prepare a new blend composite edible film with KGM, chitosan and SPI and to investigate the effects of film composition, plasticizer type and concentration and the pH of film-forming solution on its mechanical and water vapor barrier properties.

2. Experimental

2.1. Materials

SPI containing 90% (w/w) protein was purchased from Heilongjiang Sanjiang Food Company (Heilongjiang, China). Chitosan with a degree of deacetylation of 85% was obtained from Qingdao Haihui Bioengineering Company (Shandong, China). Refined konjac powder was provided by Chengdu Xieli Food Company (Sichuan, China). They all were of food grade. All other chemicals were analytically pure.

2.2. Film preparation

KGM, SPI and chitosan were correctly weighed, respectively, according to Table 1. Then, KGM and chitosan were dissolved in a given volume of distilled water and 1% (v/v) acetic acid solution, respectively, under stirring and stood at 45 °C for 2 h. SPI aqueous solution was kept first at 85 °C for 30 min and then in a water bath at 45 °C for 2 h. After filtration, the three solutions were completely mixed followed by addition of a plasticizer. The final volume of the resulting mixture was adjusted to 100 mL with distilled water. After the mixture was cooled to room temperature, 1.0 M HCl or 1.5 M NaOH solution was dropwise added to it for adjusting its pH value. It was then deaerated at 0.09 MPa for 45 min. Aliquot of the deaerated solution was poured onto a leveled circular glass plate (125 mm × 125 mm). The plate was placed in an oven at 50 °C for about 20 h. The finished intact film was peeled from the plate. All film samples were kept in a desiccator at 23 ± 2 °C and 60% RH for 3 days prior to testing.

2.3. Thickness measurement

The thickness of films was measured with a digital micrometer (Mitutoyo Manufacture Co. Ltd., Japan, sensitivity 0.001 mm) at five random positions on the film, following water vapor permeability (WVP) and preceding tensile tests. WVP and mechanical properties were calculated based on average thickness.

2.4. Determination of water vapor permeability

The WVP of films was determined gravimetrically at 25 ± 1 °C according to China National Standard GB1037-88 (1998). A small cup with a lid and containing anhydrous calcium chloride (0% RH) was prepared. The test film was placed on the cup mouth and the lid was covered followed by sealing with melt paraffin. After the paraffin solidified, the cup lid and the paraffin beside and on the bottom of the cup were taken off, the cup assembly was weighed. It was then placed in a chamber containing saturated potassium chloride solution (83 ± 2% RH) at 25 ± 1 °C for 12 h and weighed. The assembly was put in the chamber again and weighed at a given interval of time. This step was repeated until a stable permeation (the weight gain difference between two successive weighing was less than 5%). After that, the cup was continuously weighed three times and the result was averaged. WVP was calculated according to the following equation:

$$\mathrm{WVP} = \frac{\Delta m d}{A t \Delta P}$$

where WVP is in g m^{-1} s^{-1} Pa^{-1}; Δm (g) is the amount of water vapor movement across the film (weight gain); d (mm) is the film thickness; A (mm^2) is the area of the exposed film (cup mouth area); ΔP (Pa) is the actual difference in partial water vapor pressure between the two sides of the film specimen; t (s) is the time during which a stable weight gain occurred. At least three replicates of each film type were tested for WVP.

2.5. Mechanical property tests

Testing film specimens were rectangular strips (38 mm × 5.80 mm). All film strips were equilibrated at room temperature (25 ± 1 °C) for 1 week to 52 ± 2% RH in a cabinet using saturated magnesium nitrate solution. An Instron Universal Testing Instrument (Model 1011) was used to determine tensile strength (TS) and percentage elongation at break (%E) of films according to ASTM standard method D882-91 (1991). The initial grip separation and crosshead speed were set to 50 and 300 mm/min, respectively. A microcomputer was applied to record the stress–strain curves. At least five replicates of each film were tested. TS was calculated by dividing the maximum load (F, N) on the film before failure by the initial cross-sectional area (S, m^2), that is, $\mathrm{TS} = F/S$. The percentage elongation at break was obtained directly from the recorder.