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Effect of xanthan gum on the physical and mechanical properties of gelatin-carboxymethyl cellulose film blends

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ABSTRACT

The aim of this study is to develop composite edible films from three different polymers to induce cross-link reactions that improved the quality of films made from two polymer types. Gelatin-carboxymethyl cellulose (CMC)-xanthan gum films were prepared by casting to study effects from the addition of different concentrations (0, 5, 10, 15, 20 and 25%, w/w solid) of xanthan gum to gelatin-CMC film. Physical and mechanical properties of the respective films were evaluated. The addition of xanthan gum increased the thickness, moisture content and water vapour permeability of gelatin-CMC film ($p < 0.05$). Furthermore, Ultraviolet (UV) light shielding increased along with reduced visible light transparency ($p < 0.05$) and increased thermal stability (T_g) ($p < 0.05$). No new functional groups formed although slight shifts in intensity values by Fourier Transform Infrared (FTIR) spectroscopy were observed. X-ray diffraction (XRD) analysis showed a diminished crystalline peak. The resulted films also demonstrated lower tensile strength with diminished elongation at the break point, as well as higher puncture force and lower puncture deformation, indicating higher puncture resistance than comparable gelatin-CMC film. Overall, gelatin-CMC film with xanthan gum (5%, w/w solid) demonstrated improved physical and mechanical properties more than films prepared from comparable formulations.

1. Introduction

Food packaging is a crucial step in food manufacturing. Packaging contains and protects foods from physical damage and also from biological and chemical deterioration while providing multiple conveniences for consumers, including brand identity and contents. (Kim, Min, & Kim, 2014).

Presently, packaging films are used for perishable produce, meat and fish. Plastic films made from synthetic polymers have been increasingly used for food packaging due to their low price, easy moulding and superior mechanical and barrier properties (Jia, Fang, & Yao, 2009). However, they are non-degradable and non-renewable and cause serious environmental waste and pollution (Mu, Guo, Li, Lin, & Li, 2012). Consequently, biodegradable edible films have been developed as alternative packaging materials and are of great interest for many researchers. Edible films are made from polysaccharides such as cellulose derivatives, chitosan, starch and various vegetable and microbial gums; proteins such as gelatin, corn zein, wheat gluten and soy protein; and lipids such as waxes, fatty acids and resins (Bourtoom, 2008).

Protein derivatives are the most attractive biopolymers for edible film formulations because they provide high nutritional value, superior mechanical properties and exhibit the most impressive O_2 gas barrier (Ou, Kwok, & Kang, 2004). Gelatin, obtained by the controlled hydrolysis of insoluble fibrous collagen components of skin, bones and connective tissues generated as waste during animal slaughtering and processing (Guo, Ge, Li, Mu, & Li, 2014), is presently the most preferable protein derivative as the base material for formulating edible films. This is due to its natural abundance, biodegradability, low cost and excellent functional and filmogenic properties (Arvanitoyannis, 2002). Gelatin-based films are also thin, flexible and useful for several food packaging applications, including drug delivery (Boanini, Rubini, Panzavolta, & Bigi, 2010). However, gelatin-based films alone present several problems that limit food packaging applications because they are brittle, have poor water vapour resistance, poor thermal stability and absorb moisture (Bigi, Cojazzi, Panzavolta, Roveri, & Rubini, 2002). The addition of plasticizers such as glycerol and sorbitol has been shown to reduce brittleness but at the same time, increase water permeability (Sobral, Menegalli, Hubinger, & Roques, 2001).

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Crosslinking techniques introduced in the preparation of films forms intermolecular bonds between polymer chains (Hager, Vallons, & Arendt, 2012) which enhances water resistance, cohesion, rigidity and mechanical strength (Tropini, Lens, Mulder, & Silvestre, 2004). The blending of one or more polymer types can enhance crosslinking. Studies have shown improved gelatin film properties by blending with carboxymethyl cellulose (CMC) (Wiwatwongwana & Pattana, 2010) or xanthan gum (Guo et al., 2014).

CMC is a water soluble cellulose derivative with anionic linear β-(1→4)-linked glycopyranose residue (Su, Huang, Yuan, Wang, & Li, 2010) produced by the partial substitution of 2, 3, and 6 cellulose hydroxyl groups by carboxymethyl groups (Tong, Xiao, & Lim, 2008). Researchers are highly motivated to produce edible films from CMC due to their ability to form a continuous matrix (Ghanbarzadeh & Almasi, 2011). In contrast to gelatin films, CMC-based films are also easily water soluble as it contains a hydrophobic polysaccharide backbone and many hydrophilic carboxyl groups (Su et al., 2010). CMC also improves protein film mechanical properties by increasing thermal stability and the elasticity modulus (Wiwatwongwana & Pattana, 2010) as shown by the blending of soy protein isolate films with CMC (Su et al., 2010).

Xanthan gum is a pentasaccharide. It is a heteropolysaccharide which consists of D-glucose, D-mannose and D-glucuronic acid units that is derived from bacteria and fungi (Sworn, 2000). It is produced by submerged aerobic fermentation of a pure *Xanthomonas campestris* culture after undergoing submerged aerobic fermentation (Guo et al., 2014). Xanthan gum's film forming properties comprise pseudo-plastic rheological behaviour in an aqueous environment that is amenable to film fabrication because it is readily dispersed in cold or hot water with very little effect on its viscosity from either temperature or pH (Baldwin, Hagenmaier, & Bai, 2012). Gelatin films blended with xanthan gum produce a very transparent film with excellent ultraviolet light resistance, low total soluble matter and moisture content, low water vapour permeability, improved mechanical properties and thermal stability (Guo et al., 2014).

Gelatin based film generally has good functional properties, however it has several problems that limit application as packaging materials as reported in several studies. It is brittle, has poor water vapour barrier, thermal stability and can absorb high moisture (Bigi et al., 2002). Besides, its mechanical strength is also lower than that of synthetic polymers film (Bourtoom, 2008). Addition of plasticizers like glycerol and sorbitol reduced the brittleness of films but they increased water permeability of the film (Sobral et al., 2001). In addition, crosslinking method that has been introduced to improve the functional properties of edible films still has some limitations was reported by several researchers where; physical crosslinking is difficult to obtain the desired amount of crosslinking (Yao, Liu, Chang, Hsu, & Chen, 2004), chemical crosslinking can lead to toxicity problem that make the film produced is no longer edible (Cao, Fu, & He, 2007) and enzymatic crosslinking has limited availability and high production cost (Galietta, di Gioia, Guilbert, & Cuq, 1998). Therefore, other types of natural and biodegradable cross-linkers that are free from the problems mentioned above have to be used as the alternative. Xanthan gum was reported to be compatible cross-linker to be blended with various materials; it may dissolves directly in many highly acidic, alkaline, alcoholic systems containing different components. It is also compatible with commercially available thickeners such as sodium alginate, carboxymethyl cellulose (CMC) and starch (Sharma, Naresh, Dhuldhoya, Merchant, & Merchant, 2006). Hence, the present work used xanthan gum as a crosslinking agent to form a potentially new natural and biodegradable composite film as an alternative material for food packaging industry. Therefore, the objectives of this study were to formulate gelatin-CMC-xanthan gum blended films and determine the physical and mechanical properties at different concentrations of xanthan gum added.

2. Material and methods

2.1. Materials

Bovine skin gelatin (Type B, ~225 Bloom), carboxymethyl cellulose (CMC), xanthan gum and glycerol (plasticizer) were purchased from Sigma Aldrich (St. Louis, MO, USA).

2.2. Methods

2.2.1. Film preparation

The film forming solutions were prepared according to the method described by Jahit et al. (2016), with some modification. The gelatin solution was prepared by dissolving gelatin powder (80%, w/w solid) in distilled water at room temperature for 30 min followed by heating at 50 °C for 20 min under continuous stirring. The CMC solution was prepared by dissolving CMC powder (20%, w/w solid) in distilled water while stirring at 50 °C for 30 min. The xanthan gum solution was prepared by dissolving xanthan gum powder (5, 10, 15, 20 and 25%, w/w solid) in distilled water while stirring for 30 min at room temperature (Arismendi et al., 2013). The prepared three separate solutions were mixed and blended together with glycerol (30%, w/w solid). The blending mechanism was demonstrated in Table 1. The mixture was constantly stirred at 50 °C for 20 min for gelatinization. Approximately 25 ml of each film forming solution was cast on a Petri dish and oven dried at 45 °C for 48 h.

Table 1
Formulation of film forming solution of gelatin based film blended with CMC and xanthan gum (gelatin/CMC/xanthan gum).

Film formulations	Composition of film forming solution				
	Gelatin (g)	CMC (g)	Xanthan gum (g)	Glycerol (g)	Water (ml)
Ctrl-control (80/20/0)	3.2	0.8	–	1.2	100
A Xanthan gum 5% (80/20/5)	3.2	0.8	0.2	1.2	100
B Xanthan gum 10% (80/20/10)	3.2	0.8	0.4	1.2	100
C Xanthan gum 15% (80/20/15)	3.2	0.8	0.6	1.2	100
D Xanthan gum 20% (80/20/20)	3.2	0.8	0.8	1.2	100
E Xanthan gum 25% (80/20/25)	3.2	0.8	1.0	1.2	100