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Efficacy of cellulose-based coating on enhancing the shelf life of fresh eggs

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ABSTRACT

Methylcellulose (2.00% w/v) and hydroxypropyl methylcellulose (1.00% w/v) -based coating was formulated to study the effects of polyethylene glycol-400 (PEG-400) and a stearic and palmitic acid blend (SPB) on water vapour permeability (WVP) and tensile properties. The efficacy of cellulose-based coating on fresh egg quality during 28-day storage at ambient temperature was investigated in terms of weight loss, pH, and albumen quality. The selected formulation obtained by a response surface analysis was 1.00% w/v PEG-400 and 4.00% w/v SPB. An edible cellulose-based solution was prepared for eggshell coating. A batch of fresh, grade AA 1-day eggs was coated with cellulose-based coating solution. The other batch consisted of uncoated eggs, which served as the control. Lower weight loss (4.28%) was observed in the cellulose-based coated eggs, compared to 8.83% for the uncoated eggs. The pH in albumen of coated and uncoated eggs increased from 8.71 and 8.72 to 9.44 and 9.76, respectively, after 4 weeks of storage. For albumen quality, Haugh units indicated that after 7 days, cellulose-based coated eggs changed from grade AA to grade A, and remained in grade A throughout the storage period; whereas after 5 days, uncoated eggs started to change from grade AA to grade A, and continually degraded to grade B during the 4 weeks of storage. This study highlights the promising use of cellulose-based coating to enhance the shelf life of fresh eggs.

1. Introduction

Over the last three decades, extensive research has been undertaken on the use of edible films and coatings. They have been used as moisture, gas or solute barriers in food packaging to prolong shelf life and improve overall food quality. Edible films and coatings from biopolymers have received increasing attention. Potential sources and applications of edible films and coatings have been reviewed by Guilbert et al. (1996), Debeaufort et al. (1998), and Morillon et al. (2002).

Cellulose is the most abundant organic renewable resource in the plant kingdom. Cellulose is a polysaccharide composed of linear chains of (1–4)-β-D-glucopyranosyl units. Cellulose derivatives (e.g. methylcellulose, hydroxypropyl cellulose, hydroxypropyl methylcellulose, carboxymethyl cellulose, microcrystalline cellulose) have unique physical, chemical and colloidal properties, and an ability to form films. They have been used as edible films and coatings since the 1980s (Kester and Fennema, 1986). Cellulose-based materials are very efficient oxygen and hydrocarbon barriers, and their water vapour barrier properties can be enhanced by the addition of a lipid (Rico-Peña and Torres, 1990; García et al., 2000; Yang and Paulson, 2000). Previous studies of hydroxypropyl methylcellulose films containing surfactant mixtures with different hydrophilic-lipophilic balances (HLB) showed that they have low water vapour permeability, depending on the surfactant/polymer ratio and the HLB of the surfactant mixtures (Villalobos et al., 2006). Plasticizers (e.g. glycerol, polyethylene glycol) are required for polysaccharide and protein-based edible films, in order to increase film flexibility and processability by increasing the free volume or molecular mobility of polymers. This reduces the internal hydrogen bonding between polymer chains while increasing intermolecular spacing. Plasticizers affect the ability of the system to attract water, and also generally increase film permeability to oxygen (McHugh and Krochta, 1994a,b; Sothornvit and Krochta, 2000).

Fresh eggs are an excellent protein source. Nevertheless, several problems – such as weight loss and interior quality deterioration encountered during egg storage – have caused major economic losses to the poultry industry (No et al., 2005). During storage of eggs, quality deterioration is directly associated with changes in egg white (albumen), yolk, weight, and pH. Meyer and Spencer (1973) reported the effects of various coatings, including polyvinyl alcohol, acrylic resin and zein, on shell strength and egg quality. Herald et al. (1995) studied the quality of eggs coated with wheat gluten solution. In the study by Bhale et al. (2003), the efficacy of chitosan coating on improving the shelf life of eggs was reported. In addition, Xie et al. (2002) stated that eggshells coated with soy protein isolate (SPI), whey protein isolate (WPI), carboxymethyl cellulose (CMC), or wheat gluten (WG) show greater

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puncture strength that those of non-coated eggshells. This indicated that edible coatings enhance eggshell breakage minimization. In terms of the bacterial barrier property, it was found that all treatments with these four different coatings significantly reduced post-wash dye penetration into eggs, compared to the control treatments (water, NaOCl, or Na_2CO_3 washed only).

The present study was aimed at investigating the effect of plasticizer and lipid concentrations on water vapour permeability and tensile properties of cellulose-based coatings, at optimizing the formulation of cellulose-based coatings for application on fresh eggs, using response surface methodology and at investigating the effects of optimized cellulose-based coating formula on egg quality (weight loss, pH, and albumen quality) during 28-day storage at ambient conditions.

2. Materials and methods

2.1. Materials

Food grade methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC) (Methocel® Premium EP, Dow Chemical Co., USA) were used as the carbohydrate biopolymers for coating formulations. Polyethylene glycol-400 (Carbowax, Union Carbide Corporation, USA) was added as a plasticizer. A stearic and palmitic acid blend (Sigma–Aldrich, USA) was used as a lipid source when emulsion films were prepared. Ethanol (Sigma–Aldrich, USA) and distilled water were used as a solvent. Unwashed, feces-free, fresh 1-day eggs (grade AA, 60–65 g each) were chosen for this study, and were supplied by Kasetsart University poultry farm, Department of Animal Husbandry, Faculty of Agriculture, Kasetsart University.

2.2. Coating and film formulations

Coating and film formulations were studied in two steps. A response surface analysis was first run in order to decide the final amounts of PEG-400 and the fatty acid blend (SPB) to incorporate into the formulations (Table 1). Moisture barrier and tensile properties were used as response variables. Validation of the selected formulation was investigated in a second step. Statistical design is explained in another section.

Table 1
Central composite experimental design used for investigating the effect of PEG-400 and SPB incorporated into cellulose-based coatings, and responses.

Run	Coded variables		Uncoded variables[a]		Responses[b]		
	X_1	X_2	PEG-400	SPB	WVP	TS	E
1	−1	−1	0.67	2.00	1.6683	6.69	12.55
2	−1	1	0.67	4.00	1.1772	5.83	10.32
3	1	−1	2.00	2.00	1.6848	4.11	12.96
4	1	1	2.00	4.00	1.2024	4.18	6.54
5	0	0	1.33	3.00	1.3765	5.06	7.84
6	0	0	1.33	3.00	1.3615	5.23	8.16
7	0	0	1.33	3.00	1.3697	5.28	8.32
8	0	0	1.33	3.00	1.3740	5.18	8.00
9	0	0	1.33	3.00	1.3632	5.08	7.36
10	1.414	0	2.28	3.00	1.3877	3.87	8.95
11	−1.414	0	0.39	3.00	1.3568	6.77	12.29
12	0	1.414	1.33	4.41	1.1709	4.28	7.26
13	0	−1.414	1.33	1.59	1.8645	5.04	14.64

[a] Uncoded variables: concentrations of plasticizer and moisture barrier enhancer in % w/v.

[b] WVP = water vapour permeability ($\times 10^{-6}$ g day^{-1} m^{-1} Pa^{-1}); TS = tensile strength (MPa); E = elongation (%).

2.3. Preparation of cellulose-based films

Cellulose-based coating solutions were prepared by dissolving methylcellulose (2.00% w/v) and hydroxypropyl methylcellulose (1.00% w/v) powders in a mixed solvent of ethanol and distilled water (2:1) (Kester and Fennema, 1989). Plasticizer was added to prevent brittleness; then the solution was heated on a hot plate and stirred until reaching 65 °C. Next, the fatty acid blend (SPB) was added to the solution while stirring to become homogeneous. The coating solutions were degassed in an ultrasonic water bath (Model 275D, Crest Ultrasonics Corporation, Trenton, NJ, USA) for 10 min. Cellulose-based films were cast by pouring the film-forming solutions into flat 20 × 20 cm glass plates wrapped with a linear low-density polyethylene film. The plates were dried at 60 °C in a ventilated oven for 3 h.

2.4. Water vapour permeability of cellulose-based films

Water vapour permeability (WVP) of films was determined gravimetrically at 25 ± 1 °C using a modified ASTM E96-03 method (ASTM, 2003). A container with silica gel was closed with a sample of edible film firmly fixed on top. Then the container was placed in a desiccator over a saturated salt solution of potassium iodide (KI) having a known relative humidity of 65 ± 2% RH. The films were weighed daily for 5 days on an analytical balance. Water vapour transmission rate (WVTR) was calculated according to Eq. (1):

$$\mathrm{WVTR} = x/[t \times A], \tag{1}$$

where WVTR is in g day^{-1} m^{-2}. The term x/t was calculated by linear regression from the points of weight gain and time, over a constant rate period. A is the area of the exposed film. Tests were carried out in triplicate. Water vapour permeability was calculated using Eq. (2):

$$\mathrm{WVP} = [\mathrm{WVTR} \times l]/\Delta P, \tag{2}$$

where WVP is in g day^{-1} m^{-1} Pa^{-1}, l is the film thickness and ΔP is the water vapour pressure differential across the film. A hand-held digital micrometer (Mitutoyo, Tokyo, Japan) was used for measuring film thickness. Five readings were taken for each sample: one at the sample center, and four around the perimeter.

2.5. Tensile properties of cellulose-based films

Cellulose-based film specimens (25 × 150 mm) were conditioned at 30 ± 1 °C and 50 ± 2% RH. Tensile properties were determined according to the standard method ASTM D 882-06 (ASTM, 2006) using a Testometric Micro 350 (Rochdale, England). Five samples of each film were tested. The initial grip separation and crosshead speed were set to 100 mm and 20 mm min^{-1}, respectively. The parameters determined were: tensile strength, TS (MPa); and elongation, E (%).

2.6. Preparation of cellulose-based coating solution and egg coating

Selected formula from the result of response surface methodology was used to prepare a coating solution. Selected cellulose-based coating solution was prepared in accordance with Section 2.3. A batch of fresh, grade AA 1-day eggs was immersed in a cellulose-based coating solution for approximately 15 s, conditioned at 55 °C in a water bath, by using a wire dipping loop. Eggs were then lifted from the solution and allowed to drain for approximately 5 s. The coated eggs were dried with an air dryer for 5 min before being placed on a molded-pulp container, and stored at ambient conditions (26 ± 3 °C, 65 ± 2% RH) for 4 weeks. Uncoated eggs were also stored in the same conditions. Twenty samples of coated and uncoated eggs were drawn peri-