Original Research Article

Effect of Heat Curing of Film-Forming Solution on the Properties of Soy Protein Films

Abstract

This study aimed to investigate the impact of heat treatment on the properties of soy protein isolate film-forming solutions. The solutions, consisting of soy protein isolate, glycerol, and phosphate buffer, were subjected to heat treatment at 65, 75, and 85°C for 2, 4, or 6 h. The resulting films were then analyzed for tensile strength, elongation at break, film solubility, color parameters, and transparency. The results indicated that increasing the heat-curing temperature led to an increase in tensile strength, film transparency, and a yellowish color (positive b*) in the films, as well as a decrease in water solubility and elongation at break. Notably, the film cured at 85°C for 2 h exhibited the highest tensile strength, film solubility, and elongation at break, compared to both the control and other heat-cured films. However, the film heated at 75°C showed a better elongation at break. Overall, the findings suggest that heat curing of film-forming solutions at temperatures between 75 and 85°C has the potential to improve the properties of soy protein isolate films.

Keywords: Biodegradable film, Film-forming solution, Heat Curing, Soy protein film, Tensile strength.

Introduction

Research towards developing environmentally safe and biodegradable materials based on natural biopolymers is growing in an effort to replace petroleum-based plastics and films. Polysaccharides, proteins, lipids, and/or a combination of these substances are all included in these biopolymers (Swain et al., 2004). Until now, a lot of studies have been conducted on proteins used in films and coatings, such as whey protein (Diaz et al., 2016), soy proteins (Shakil and Thanachan 2022), sesame protein (Fathi et al.,2018), peanut proteins (Liu et al., 2004), gelatin (Cao et al., 2006), wheat gluten (Micard et al., 2000), corn zein and egg albumin (Rhim et al., 1999).

Soy protein has received the most attention among them due to its exceptional film-forming capabilities. Nevertheless, for practical applications, especially in high humidity circumstances, soy protein film has inferior mechanical strength and moisture barrier

properties (Ou, and Kwok, 2004). Several studies have focused on enhancing the mechanical and barrier qualities of soy protein films via physical, chemical, or enzymatic treatment. These studies included UV irradiation (Shakil 2022b), Phenolic Acid Addition (Insaward et al., 2015), heat curing (Gennadios et al.,1996), and enzymatic cross-linking (Stuchell and Krochta 1994). Heat curing, one of these modification techniques for soy protein film, has been promoted as an effective way to enhance protein film characteristics (Insaward et al., 2014; Gennadios et al.,1996; Kim et al., 2002). Proteins unfold during heat curing to reveal their hydrophobic interior, particularly the sulfhydryl group. The formation of inter- and intra-molecular disulfide connections is caused by the further induction of the thiol-disulfide exchange reaction by heating (Chiralt et al., 2018). Most of the previous studies applied heat curing on cast (preformed film) soy protein films. From the literature search, few studies found the application of heat curing on the film-forming solution of soy protein isolate films.

Therefore, the purpose of this study was to evaluate the impact of different heat curing temperatures and times on the properties of soy protein isolate films, including their tensile strength, elongation at break, water solubility, color, and surface hydrophobicity.

Materials and Method

Materials

Soy protein isolate (90% protein, wet basis) and glycerol, Sodium Phosphate Dibasic Heptahydrate, and Sodium Phosphate Monobasic Monohydrate were purchased from a scientific chemical store in Dhaka, Bangladesh.

Film formation procedure

With some adjustments, the technique reported by Shakil and Mahawanich, 2022 was used to produce soy protein isolate (SPI) films. The control film (without heat curing) was obtained by dissolving 5 g of soy protein isolate and 2.75 g of glycerol in 92.25 g of phosphate buffer (pH 7.4) and homogenizing the mixture at 22,000 rpm for 2 min. The solution was heated at 70°C for 30 min for partial denaturation of protein and again homogenized at the same conditions. The air bubble from the solution was removed using cheesecloth and cast on level Teflon®- coated glass plates. The film-forming solution was at 40°C for 24 h and the film sample was stored at 50% RH for 48 h before analyses.

Heat curing of SPI film

Film-forming solution of SPI was subjected to heat curing at 65, 75, and 85 °C for 2, 4, or 6 h. After that, the solution was cooled and homogenized at 22,000 rpm for 2 min. Other film preparation steps were the same as the control film.

Thickness of film

A hand-held micrometer (B.C. Ames Co., Waltham, MA, USA) was used to measure the film thickness to the closest 0.15-0.17 mm. To determine the film's tensile strength, five thickness measurements were taken along the length of each specimen, and the average value was utilized in the calculation.

Tensile strength and elongation at break

Tensile strength (TS) and elongation at break (EAB) were measured using an Instron Universal Testing Machine (Model 5566, Instron Corp., Canton, MA, USA) in accordance with ASTM Standard Method D 882-91. (ASTM, 1995b). The initial gap separation and cross-head speed were both set to 50 mm and 1 mm/s. The peak load (N) was divided by the initial cross-sectional area (m^2) of the specimen to calculate TS in MPa. EAB was measured as a percentage by dividing the end length of the point of sample rupture by the initial length of the specimen (50 mm). The TS and EAB tests were repeated three times for each type of film.

Color

To determine the color values of films, a portable colorimeter (CR-300 Minolta Chroma Meter; Minolta Camera Co., Osaka, Japan) was used. The Hunter Lab color scale was employed to measure color in the CIELAB system with a 10° observer and D65 illuminant. The film specimens were positioned on a white plate for measurement. Color measurements were taken at five randomly selected positions on each film sample and then averaged to obtain the color values for each replicate.

Transparency

The transparency of a film sample was evaluated by determining its % transmittance based on the ASTM D1746 method (ASTM, 2015). To do this, a film sample was cut to precise dimensions (10 mm × 40 mm) and fixed to the interior of a glass cuvette. A visible spectrophotometer (model GENESYS20, Thermo Scientific, Waltham, MA, USA) was used to measure %transmittance at 500 nm

Fim solubility

The method outlined by Insaward et al. (2015) was employed to determine the water solubility of the film samples. The total soluble matter was calculated using the equation:

% Total soluble matter = (initial dry weight - final dry weight)/initial dry weight × 100.

Statistical Analysis

The experiments were carried out in three replicates, utilizing a completely randomized design. The data were analyzed using Analysis of Variance, and to determine the difference between sample means at p=0.05, Duncan's new multiple range tests were employed. These tests were conducted using SPSS Statistics 27.0 (IBM, Armonk, NY, USA).

Result and Discussion

Mechanical properties

The tensile strength (TS) of Unheated (control) SPI films was 2.10 ± 0.15 MPa. Heat curing temperature significantly affected the TS of SPI film as shown in Figure 1. TS increased with increasing heating curing temperature. TS of films heated at 65°C and 75°C showed an increasing trend with increasing heat curing time, whereas film heated at 85°C exhibited a decreasing trend. The decrease of TS with increasing heat curing time of film-forming solution may be due to more denaturation of protein. Across all heating time intervals, films subjected to heat treatment at 85°C exhibited higher TS compared to those treated at 65°C and 75°C. The films treated at 85°C for 2 h demonstrated a significantly greater tensile strength as compared to the other treated and untreated control ($p \leq 0.05$). A similar effect of heat curing on the film-forming solution has also been reported by Tanjina et al., 2023.

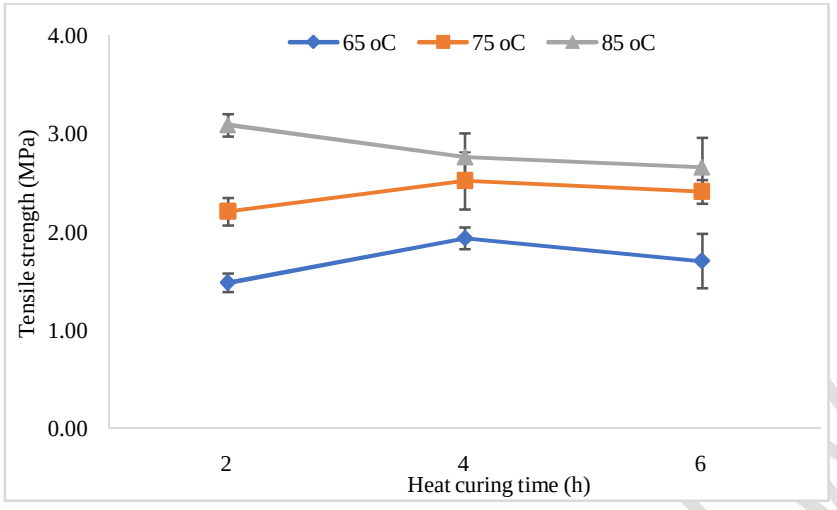

Figure 1: Tensile strength of SPI film heated at 65, 75 and 85 °C for 2, 4 and 6 h.

The elongation at break (EB) is also significantly affected by heat curing temperature and time as depicted in Figure 2. The EB values fluctuated within the heat curing time with a decreasing trend corresponding with the heat curing time. Heating the film-forming solution at 85°C significantly reduced the %EB of the film with increasing heat curing time. The highest %EB was obtained from the film-forming solution heated at 75°C for 4 h. The current finding is consistent with the study conducted by Weng et al. in 2007, which examined the impact of heat curing on Surimi Film, an edible film-forming solution. It is believed that exposing the film-forming solution to high temperatures for extended periods can lead to protein denaturation, thereby affecting the physical properties, protein-protein interaction, and polymer morphology of the protein film.

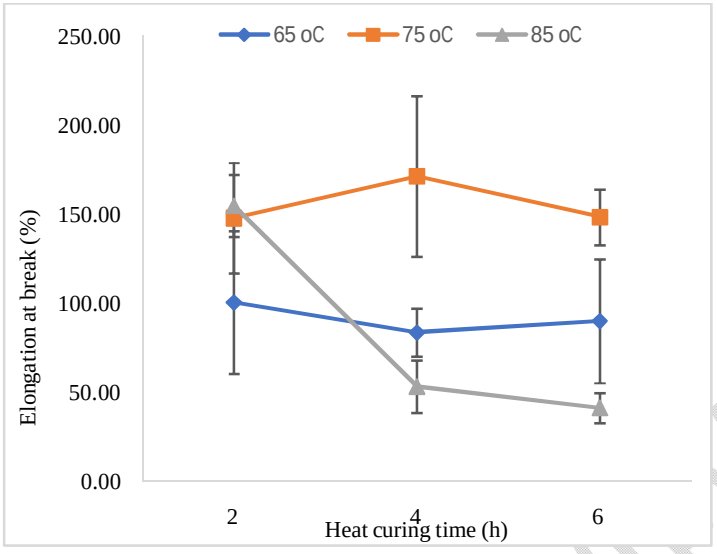

Figure 2: Elongation at break (%) of SPI film heated at 65, 75 and 85 °C for 2, 4 and 6 h.

Transparency and color value

The transparency and color value (+b) of the films are summarized in Table-1. Heating temperature and time significantly affected the transparency of SPI film. All heat-treated films were more transparent compared to the control (43%) except the film heated at 65°C for 2 h. Transparency of all heat-treated films increased with increasing heating curing temperature and time except for the film heated at 75°C for 4 h. The highest (71.14%) and lowest (38.67%) transparency was demonstrated by the films heated at 85°C for 6 h and 65°C for 2 h. The increase of transparency upon increasing the heat-curing temperature of the film-forming solution may be due to the formation of a more transparent film-forming dispersion.

The color value +b* indicates the yellowness of the film as presented in Table 1. Heat curing of the film-forming solution at 65 and 75°C did not show any effect on the +b* value of the film. However, the film-forming solution heated at 85°C significantly affected the +b* value with increasing heat curing time which means produces a more yellowish film. Heat curing at 85°C for 6 h demonstrated more yellowish color of the film. According to the findings, it appears that subjecting the solution to heat treatment may promote the development of a yellow pigment, particularly through the Maillard reaction. Manzocco et al. (2000) observed that any alterations in color resulting from the Maillard reaction are invariably linked to heat-induced processes.

Table 1: Transparency and color values (+b) of heat-cured SPI film.

	Temperature (°C)	Heat curing time (h)			
		0	2	4	6
Transparency	65	43.00±1.75 ^{f}	38.67±0.59 ^{h}	56.67±1.32 ^{d}	53.08±0.75 ^{e}
	75	43.00±1.75 ^{f}	57.90±0.29 ^{cd}	52.07±0.98 ^{e}	59.40±0.65 ^{c}
	85	43.00±1.75 ^{f}	66.64±0.37 ^{b}	56.43±2.96 ^{cd}	71.14±0.18 ^{a}
+b* value (yellowness)	65	8.34±1.63 ^{c}	9.22±0.95 ^{bc}	9.49±2.05 ^{bc}	10.35±2.05 ^{bc}
	75	8.34±1.63 ^{c}	8.31±1.58 ^{c}	8.92±2.15 ^{c}	8.83±2.90 ^{c}
	85	8.34±1.63 ^{c}	10.95±2.71 ^{b}	15.19±2.85 ^{ab}	19.80±2.99 ^{a}

Film Solubility

The solubility of a film can serve as an indicator of the film's integrity and resistance to water. The solubility of heat-treated soy protein film is presented in Table 2. The solubility of the films was affected by changes in heat curing time and temperature. The solubility of the control sample was 49.42%. Heat curing of film-forming solution at 75 and 85°C showed a lower water solubility of film compared to the control. The lowest solubility (29.69%) was found for the film heated at 85°C for 6 h. The higher water solubility of the film indicates a weaker structure. Similar decreasing trend of solubility at 75°C with increasing heat curing time has also been reported for edible surimi film (Weng et al. in 2007).

Table 2: film solubility of heat-treated SPI film.

	Temperature (°C)	Heat curing time (h)			
		0	2	4	6
Film solubility (%)	65	49.42±3.70 ^{b}	58.54±2.30 ^{a}	48.65±2.17 ^{b}	52.66±2.85 ^{b}
	75	49.42±3.70 ^{b}	43.75±2.34 ^{c}	40.14±2.29 ^{cd}	37.81±2.27 ^{d}
	85	49.42±3.70 ^{b}	34.04±1.25 ^{de}	32.78±2.09 ^{e}	29.69±2.28 ^{e}

Conclusion

This study examined the impact of heat treatment on the properties of soy protein isolate film, with film-forming solutions being heated at 65, 75, and 85°C for 2, 4, or 6 hours. Results showed that increasing the heat-curing temperature led to higher tensile strength, film transparency, and yellowish color (positive b*) of the films, but lower water solubility and elongation at break. Among the tested conditions, the film cured at 85°C for 2 hours demonstrated the highest tensile strength, film solubility, and elongation at break, surpassing both the control and other heat-cured films. Based on these findings, heat curing of film-forming solutions within the range of 75-85°C has the potential to enhance the properties of soy protein isolate films.

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