



Modelling the effect of guar gum on physical, optical, barrier and mechanical properties of potato starch based composite film



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ABSTRACT

The composition of potato starch (PS) and guar gum (GG) based biodegradable composite film was optimised based on physical, optical, mechanical and barrier properties. The rotatable central composite design applying desirability function was used to assess the effect of PS (2.5–4.5%), GG (0.2–0.8%) and glycerol (15–35%). The optimisation was performed considering minimization of film solubility, opacity, yellowness index and water vapour permeability; and maximization tensile strength and percentage elongation at break. Viscosity of film forming solution; thickness, moisture content and whiteness index of the films were also evaluated. The optimum value of PS, GG and glycerol was 3.7%, 0.4% and 15% (of total solids), respectively. All the independent variables depicted significant effect on the responses ($p < 0.05$) except starch which did not exhibit any statistically significant effect on WVP. The structural characterisation of the optimised film was also analysed by FESEM and XRD which point to the semi-crystalline nature of the developed film.

1. Introduction

Pollution caused by synthetic plastics is a serious concern in modern civilization. Synthetic plastics derived from petroleum sources are resistant to microbial degradation. Therefore, continuous use of these plastics generate enormous solid waste, which are harmful to wild life as well as marine ecosystem. However, synthetic plastics are preferred for food packaging application due to high strength, stretch-ability, good water vapour and gas barrier properties, transparency and low cost (Bae et al., 2008). Moreover, recycling of these food-contaminated packaging materials are often costly (Siracusa et al., 2008). In view of aforementioned drawbacks, the use of eco-friendly biodegradable polymer as a substitute of synthetic plastics has attracted the attention of the research workers over the years.

The different polysaccharides, such as starch, cellulose derivatives, chitosan, pectin and others have been extensively studied for bio-degradable film preparation (Rhim & Ng, 2007). Among these, starch is widely studied because of its abundance in nature and thermoplastic behaviour. Moreover, the cost of starch obtained from plant sources is comparable with respect to other synthetic polymers, such as low density polyethylene (LDPE), polystyrene (PS) and Polyethylene terephthalate (PET) (Krochta & De Mulder-Johnston, 1997).

Starch is a polymer of D-glucose units linked by α -D-glycosidic bonds, which consists of amylose and amylopectin molecules.

Depending on the sources, the amylose and amylopectin content of the starch varies and therefore, starch based films exhibit different properties. High amylose starch shows high tensile strength and high young modulus, but low strain at break (Rindlav-Westling et al., 1998) and better stability on aging (Hu et al., 2009). Therefore, potato starch with high amylose content can be used for developing biodegradable film. However, potato starch cannot produce efficient polymer film owing to high water affinity and poor mechanical properties compared to synthetic plastics (Wu et al., 2009). It was observed that physicochemical characteristics of starch-based films depend on crystallinity of the polymer matrix. In this context, researchers have noticed that incorporation of other carbohydrates having similar structural compatibility, into starch matrix can modify the physicochemical properties of the films (Jiménez, Fabra, Talens, & Chiralt, 2012). Therefore, incorporation of guar gum, a polysaccharide, into potato starch in optimum proportion can introduce a potential film to the realm of biodegradable polymer.

Guar gum is a galacto-mannan having a mannose to galactose ratio of 1:6 obtained from the Indian cluster bean (*Cyamopsis tetragonoloba*) (Dea & Morrison, 1975). The backbone of guar gum is a linear chain of β -(1–4)-mannopyranose units with α -(1–6) - galactopyranose units as a side chain of every second mannose (Fernandes et al., 1993). In the food and non-food industries, such as pharmaceutical, biomedical and cosmetic industries, guar gum is used as a stiffener. The synergistic

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effect of guar gum with other hydrocolloids (xanthan gum, agar, carrageenan and starch) has been reviewed (Cui et al., 2006). However, there are a few reports on development of guar gum based biodegradable film. Saberi et al. (2016) optimised the guar gum and pea starch based film using physical and optical properties. In another study, the incorporation of guar gum and xanthan gum into mango kernel starch showed improved mechanical properties and a homogenous film matrix (Nawab et al., 2017). However, current literature reveals that no work has been conducted on potato starch-guar gum based composite film. The present work was, therefore, taken up for optimisation of potato starch (PS) and guar gum (GG) based on physical, optical, mechanical and barrier properties of the composite film.

2. Materials and methods

2.1. Materials

Potato starch was purchased from Sigma Aldrich (India). Guar gum was procured from Danisco India. Glycerol (Anhydrous) was supplied by Merck Life Science Pvt. Ltd., India.

2.2. Film preparation procedure

Film was prepared by casting method according to Saberi et al. (2016) with some modification. Initially, potato starch and guar gum at a particular proportion based on experimental design were dissolved in warm distilled water (40 °C) by continuous gentle stirring (100 rpm) for 10 min, and then glycerol was added. The solution was therefore, heated up to 90 °C for 20 min along with continuous stirring (700 rpm) for complete gelatinization of starch followed by cooling at room temperature (25 °C). The degassing process was then, carried out in vacuum dryer to remove entrapped gases from the film forming solution. The casting of the solution was accomplished by spreader on teflon sheet, and dried at 37 °C for 24 h. The casted films were then, conditioned for 72 h at 75% RH and 25 °C.

2.3. Viscosity of film forming solution

Viscosity of the film forming solution was measured using spindle (no. 3) at 100 rpm by Brookfield Viscometer (DV-I).

2.4. Thickness

A strip of 40 × 15 mm was cut and thickness was measured randomly at 10 different places using digital thickness gauge (Mitutoyo ID-F125, Japan) with instrument accuracy of 0.001 mm and average value was taken for thickness measurement.

2.5. Moisture content

For moisture content measurement, a dimension of 40 × 15 mm strips were snipped from the prepared film sheet. The strips were dried in hot air oven at 90 °C for 24 h to avoid any loss of plasticizer (Saberi et al., 2016). Initial and final weight of the strips were measured to calculate moisture content of the film according to Eq. (1). The measurement was done in triplicate.

$$\text{Moisture Content in wet basis (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \quad (1)$$

2.6. Solubility in water

Solubility of the film in water is defined as the percentage soluble matter present in the film and measured according to Farahnaky, Saberi, and Majzoobi (2013). A specimen of the film (40 × 15 mm) was

trimmed and immersed into 50 ml of distilled water, which was placed into a water bath at 25 °C and kept for 24 h. Water was, then, discarded and sample was dried at 90 °C for 24 h in hot air oven and weighed. The percentage solubility of the film (SOL) in water was measured according to Eq. (2):

$$\text{SOL (\%)} = \frac{M_w(1-MC) - M_d}{M_w(1-MC)} \times 100 \quad (2)$$

Where, MC = moisture content in fraction, M_w = Initial weight (g), M_d = Final dry weight (g)

2.7. Opacity

Opacity (OP) of the films was determined according to the modified British Standard Institution (BSI) standard (Mali et al., 2004) using spectrophotometer. The films were cut in a rectangular shape of 3 cm long and 1 cm wide and placed into a cuvette. The absorbance spectrum was measured between 400–800 nm in spectrophotometer (EPOCH 2, BioTek). The opacity was measured by calculating area under curve and the unit was in absorbance unit × nm (AU.nm).

2.8. Colour parameters

The colour of PS-GG films were measured using a portable colorimeter (Konica Minolta Sensing, Inc., Osaka, Japan) in the L^* (lightness), a^* (red-green) and b^* (yellow-blue) colour spaces at constant lighting conditions. To determine total colour difference of different samples L^* , a^* , and b^* value were measured with respect to the standard white plate ($L_0^* = 97.67$, $a_0^* = 0.22$, $b_0^* = 0.95$) as a reference. The following Eqs. (3), (4) and (5) were used to determine total colour difference (ΔE), yellowness index (YI) and whiteness index (WI), respectively.

$$\Delta E = \sqrt{(L_1^* - L_0^*)^2 + (a_1^* - a_0^*)^2 + (b_1^* - b_0^*)^2} \quad (3)$$

$$\text{YI} = \frac{142.86b^*}{L^*} \quad (4)$$

$$\text{WI} = \sqrt{100 - (100 - L^*)^2 + (a^*)^2 + (b^*)^2} \quad (5)$$

Each observation was taken in triplicate and average value was worked out.

2.9. Mechanical properties

Tensile strength (TS) and percentage elongation at break (%EAB) of the film were measured using Universal Testing Machine (INSTRON 5965 U 2597) equipped with 5 KN load cell according to Fernández, De Apodaca, Cebrián, Villarán, & Maté, (2007). A strip of the film (100 × 15 mm) was cut and held between the grips maintaining distance of 40 mm. The measurement was taken at a crosshead speed of 10 mm/min. All samples were used in triplicates for evaluating the mechanical properties of the films.

2.10. Water vapour permeability

Water vapour permeability (WVP) was determined by gravimetric method using perspex cup according to Fernández et al. (2007) with a few modifications. An eight mm diameter disk of sample from the developed film was cut and placed on the leak proof perspex cup. Dried silica was kept inside the cup with overhead clearance of 1 cm to maintain relative humidity 7% and saturated potassium nitrate solution was kept in the desiccator to obtain 93% RH at 25 °C. The test cup with sample was kept inside a desiccator at 25 °C for 24 h. Water vapour transmission rate (WVTR) was calculated from the weight gain by the silica (g/s) divided by the permeation cell area (m²). The following equations were used for WVP (g. mm/ Pa. m. Sec) measurement:

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