Influence of Type and Concentration of Plasticizers on the Properties of Edible Film From Mung Bean Proteins

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ABSTRACT

Edible film from mung bean proteins (*Vigna radiate (L.) Wilczek*) were developed based on formulation conditions explored in the previous study. The aim of this study was to investigate the influence of type and concentration of plasticizer on the properties of edible films obtained from mung bean protein. Type and concentration of plasticizer significantly ($p<0.05$) affected the mechanical and barrier properties of the films. As plasticizer concentration increased, tensile strength decreased concomitant with increase in elongation at break and water vapor permeability. The similar trend behavior was observed for the film solubility and protein solubility, which increased with increasing plasticizer concentration. Sorbitol plasticized films provided the most brittle and tensile strength was the highest (2.40 - 7.23 MPa); however, its effect on water vapor permeability was low (44.38 - 64.48 g.mm/m^2.d.kPa). In contrast, polyethylene glycol and glycerol plasticized films exhibited flexible structure, even though, the tensile strength was low (2.39-5.07 and 2.28 - 3.75 MPa, respectively), resulting in increased water vapor permeability (78.38 - 204.19 and 125.16 - 238.20 g.mm/m^2.d.kPa). Sorbitol plasticized films, showed higher both film solubility and protein solubility compared to polyethylene glycol and glycerol plasticized films. Mung bean protein films plasticized with sorbitol were yellowish color as indicated by higher b* compared to polyethylene glycol and glycerol plasticized films. It was observed that the films plasticized with sorbitol and polyethylene glycol had lower moisture content than those with glycerol.

Keywords: edible films, mung bean proteins, plasticizer, mechanical properties, barrier properties

1. INTRODUCTION

The advantages of edible films over other traditional synthetics are that as they can be consumed with the packaged products. Constant progress in the technology of synthetic film preparation has expanded and supported their utilization in the food industry. However, most synthetic films are petrochemical-based and non-biodegradable; it takes a several hundred years to degrade petroleum-based synthetic plastics, which have caused serious solid waste contamination in the world [1]. In contrast, edible films use renewable resources as raw materials and are biodegradable, making them more compatible with the environment. Additionally, other adjuncts such as antimicrobials, antioxidants, nutrients, colorants, etc. are easier to add to edible films, thus further enhancing their protective functions. Edible films can be produced from protein, polysaccharide and lipid materials [2]. Among them, proteins-based edible films are the most attractive. These films have impressive gas barrier properties compared with those prepared from lipids and polysaccharides. When they are not moist, the O_2 permeability of soy protein-based film was 500, 260, 540 and 670 times lower than that of low-density polyethylene, methylcellulose, starch and pectin respectively [3]. The mechanical properties of protein-based edible films are also better than that of polysaccharide and fat-based films because proteins have a unique structure (based on 20 different monomers) which confers a wider range of functional properties, especially a high intermolecular binding potential [4]. Protein-based edible films can form bonds at different positions and offer high potential for forming numerous linkages [5]. The interest in the study of plant protein films has increased during the past decade, and research on the properties of such films has been outlined in recent literature including soy proteins [6-10], corn zein [11], [12], wheat proteins [6], [13-15], cotton seed proteins [16], pea proteins [17], peanut protein [18], and sunflower proteins [19].

Mung bean is the primary crop produced in the Thailand. In industrial mung bean starch-noodle manufacturing process, mung bean starch is washed with alkaline solution to remove proteins to produce a colorless and characteristic of noodle. As results of washing, approximately 20-30% of proteins are loss in the process. Using mung bean protein cannot only reduce the negative environment impact and costs of waste disposal, but may generate potential profits

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especially in the form of edible films from mung bean proteins. In order to overcome its shortcoming, Bourtoom [20] had been studied and reported that, an edible films from mung bean protein had mechanical properties better than those other protein sources. In addition, it's showed lower both tensile strength and elongation at break than high density polyethylene, polyvinyl chloride, cellulose acetate and polyester. However, edible films from mung bean had higher tensile strength than low density polyethylene film. A major component of edible films is the plasticizer, as well as the film-forming polymer. The addition of a plasticizer agent to edible film is required to overcome film brittleness, caused by high intermolecular forces. Plasticizers are generally small molecules such as polyols like sorbitol, glycerol and polyethylene glycol (PEG) that intersperse and intercalate among and between polymer chains, disrupting hydrogen bonding and spreading the chains apart, which not only increases flexibility, but also water vapor and gas permeabilities [14], [21], [22]. In previous work by the author [20], edible films from mung bean protein was determined. However, when no plasticizer was introduced in the film solution, the edible films were relatively brittle. The brittleness of the films was most determined by the strength of polymer-polymer interaction, which was controlled by the polymer chemistry and addition of plasticizer. Information on the effects of sorbitol, glycerol and polyethylene glycol (PEG) on edible films from mung bean protein is poorly available at present. The aim of this investigation was to make a comparative study of different types of plasticizers and their concentrations incorporated into edible films from mung bean protein.

2. METERIAL AND METHODS

Preparation of Mung Bean Protein

Mung bean (Uthong-1 S.) proteins were prepared by using the classical method of alkaline extraction and acid precipitation from mung bean flour. Mung bean flour was mixed with distilled water in the ratio of 1:10, stirring and adjusting the final pH to the 9.0 using 1 M NaOH. The suspension was extracted for 1 h using magnetic stirrer and centrifuged for 30 min at 4 °C, 8000 rpm (Model J2-21M, Beckman Instruments Inc., Palo Alto, USA). The pH of the supernatant was adjusted to 4.5 by 1 M of HCl to allow precipitation and then centrifuge for 30 min at 4 °C, 8000 rpm. The isoelectric form of wet protein concentrate was then freeze-dried for 24 h (Dura - Top/Dura - Dry MP, Model TD97A001, FTS Systems, Inc.), ground and placed in plastic box and stored at -20 °C until used.

Preparation of Mung Bean Proteins Films

Freeze-dried mung bean and/or red bean proteins (93.52% and 90.26%, respectively) were dissolved in distilled water (3 g/100 ml) to prepare film-solutions. The pH of films solution was adjusted to 9.5 prior to adding plasticizer (sorbitol, glycerol and polyethylene glycol-400) at various amounts (30, 40, 50 and 60% of protein). All components were homogenized (10000 rpm for 2 min) and heated at 75 °C for 30 min [20]. The film-solution was cooled to room temperature, followed by vacuum application to remove any dissolved air before pouring onto leveled non-stick trays to set. Once set, the trays were held overnight at 55 °C undisturbed, and then cooled to ambient temperature before peeling the films off the plates. Film samples were stored in plastic bags and held in desiccators at 55+5 % RH for further testing.

Films Testing and Conditioning

Conditioning: All films were conditioning prior to permeability and mechanical tests according to Standard method, D618-61 [23]. Films used for testing water vapor permeability (WVP), tensile strength (TS) and elongation (E) were conditioned at 60% RH and 25+2 °C by placing them in a desiccator over a saturated solution of Mg $(NO_3)_2$ $.6H_2O$ for 48 h or more. For other tests, films were transferred to plastic bags after peeling and placed in desiccator.

Films thickness: Thickness of the films was measured with a micrometer (Gotech Testing Machine, Model GT-313-A, Japan) to the nearest 0.01 mm at five random locations around the films. Precision of the thickness measurements was +5%. Mean thickness for each sample was calculated and used in water vapor permeability (WVP) and tensile strength TS) calculation.

Films Solubility: Method modified from Stuchell and Krochta [24] was used to measure films solubility. Film pieces 20 mm x 20 mm were dried at 70 °C in a vacuum oven (3.4 kPa) for 24 h, and then weighted to the nearest 0.0001 g for the initial dry weight. Films were immersed into 20 ml of distilled water in 50 ml screw centrifuge tube containing 0.01 % potassium sorbate. The tubes were capped and placed in shaking water bath for 24 h at 25 + 2 °C. The solution was removed and set aside for later testing of protein solubility as described later. The remaining solution and film pieces were pour onto (Whatman #1) qualitative filter paper, rinsed with 10 ml distilled water, and dried at 70 °C in a vacuum oven for 24 h and dried weight of films were determined. Triple measurements were done for each treatment triplicate. Total soluble matter was calculated from the initial gross weight and final dry weight using the following equation:

$$Sf = \left(w_{fbt} - w_{fat}\right) \times 100 \,/\, w_{fbt} \tag{1}$$

where

$Sf =$ film solubility (%)
$w_{fbt} =$ film weight before test
$w_{fat} =$ film weight after test

Protein Solubility: Solution set aside from films solubility was analyzed for protein content by the Lowry method [25]. A 0.5 ml of test solution was placed in a test tube. A 2.5 ml of the mixture of 0.2-M sodium hydroxide and 4% sodium carbonate was pipetted into each sample and vortexed to mix thoroughly and stand for 10 min. Then 0.25 ml Folin ciocalture & phenol reagent was added into each sample and vortexted to mix thoroughly and stand for 30 min at room temperature. Absorbance at 750 nm was determined by diode array spectrophotometer (Hewlett Packard Model 6541A, Avondale, PA). A standard curve was developed using bovine serum albumin. The protein solubility (% *Sp*) was calculated as followed:

$$Sp = \left(w_{ps} \mp 100\right) / \left(w_{i} \times p_{f} \times f_{m}\right) \qquad (2)$$

Where

$Sp =$ Protein solubility (%)
$w_{ps} =$ weight of protein in 20 ml solution
$w_{i} =$ initial weight of film
$p_{f} =$ protein in film (%)
$f_{m} =$ dry matter of film (%)

Film Color: A Hunter Lab (Hunter Associates Laboratory, Inc., Reston, Verginia) was used to determined film L, a and b color value (L = 0 (black) to 100 (white); a = -60 (green) to +60 (red); and b = -60 (blue) to +60 (yellow). Color (means of five measurements at different locations on each specimen) was measured on 10 cm x 10 cm. Prior to color measurement, film specimens were conditioned at 50% RH and 23+2 ºC for 3 days.

Water Vapor Permeability: The gravimetric Modified Cup Method based on ASTM E96-92 [26] was used to determine the water vapor permeability of films. The test cups were filled with 20 g of silica gel (desiccant) to produce a 0% RH below the films. A sample of mung bean protein films was placed in between the cup and the ring cover of each cup coated with silicone sealant (LITHELEN, Leybold System Gmbh, Germany) and held with four screws around the cup's circumference. The air gap was at approximately 1.0 cm between the film surface and desiccant. The water vapor transmission rates of each film were measured at 55 + 5 % RH and 25 + 2 ºC. After taking initial weight of the test cup, it was placed into an environmental chamber with an air velocity rate of 350 ft/min (Incubator, Model KBF 115). Weight gain measurements were taken by weighing the test cup to the nearest 0.0001 g with an electronic scale (Sartorious Corp.) every 3 h for 18 h. A plot of weight gained versus time was used to determine the water vapor transmission rates. The slope of the linear portion of this plot represented the steady state amount of water vapor diffusing through the film per unit time (g/h). Water vapor transmission rates were expressed in gram units, per square meter, per day. Steady state over time (slope) yielded a regression coefficient of 0.99 or greater. Nine samples per treatment were tested. The water vapor permeability of film was calculated by multiplying the steady water vapor transmission rates by the film thickness and dividing that by the water vapor pressure difference across the films.

Tensile Strength and Elongation at Break: Tensile strength was performed with an Instron universal testing instrument (LLOYD Instrument, Model LR30K, Hants, England) as per ASTM D882-91 Standard Method [27]. Fifteen samples, 2.54 cm x 10 cm, were cut from each film. Initial grip separation and cross head speed were set at 50 mm and 50 mm/min, respectively. Tensile strength was calculated by dividing the maximum force at break by initial specimen cross-sectional area, and percent elongation at break was calculated as follows;

$$E = 100 \times \left(d_{after} - d_{before}\right) / d_{before} \qquad (3)$$

Where *d* was the distance between grips holding the specimen before or after the break of the specimen.

Moisture sorption studies: Water sorption isotherms were determined by placing mung bean proteins films into a controlled humidity environment at a constant temperature until equilibrium. After drying at 75 ºC and < 1 mmHg pressure for 24 h, EYELATM, Model VOS-300VD, Japan), the films were placed into environments of various relative humidities above salt solutions in desiccators. The relative humidities were 11% RH (lithium chloride), 23% RH (potassium acetate), 33% RH (magnesium nitrate), 43% RH (potassium carbonate), 52% RH (magnesium nitrate), 59% RH (sodium bromide), 75% RH (sodium chloride), 85% RH (potassium chloride), and 95% RH (disodium hydrogen phosphate). The sorption experiments were carried out by keeping approximately 1,000 mg of blend films (2 cm x 2 cm) in desiccators, removing at frequent intervals and weighing until they reach constant weight (within +5%). All chemicals were of analytical grade (AR).

Statistical Analysis

A completely randomized experimental design was used to characterize the composite films. Analysis of variance (ANOVA) was used to compare mean differences of the samples. If the differences in mean existed, multiple comparisons were performed using Duncan's Multiple Range Test (DMRT).

3. RESULTS AND DISCUSSION

Tensile Strength and Elongation at Break

Edible films may be subjected to various types of stress during use; the determination of the mechanical properties involves not only scientific but also technological and practical aspects [28]. Tensile strength is the maximum tensile stress sustained by the sample during the tension test. If maximum tensile stress occurs at either the yield point or the breaking point, it is designated tensile strength at yield or at break respectively [29]. Elongation at break is an indication of a film's flexibility and stretch ability (extensibility). Preliminary work demonstrated that edible films from mung bean protein formed without plasticizer as relatively brittle and broke easily when peeled off. Hence desirable mechanical properties of edible films were improved by using three types of plasticizer (sorbitol, glycerol and polyethylene glycol) at different concentrations (30, 40, 50 and 60%). The mechanical properties of films plasticized by sorbitol, glycerol, polyethylene glycol, at different concentration were assessed by measuring their tensile strength and elongation at break. The results are depicted in Figure 1A - 1B. It was observed that an increase in the content of these plasticizers resulted in decrease in mechanical resistance (decrease in tensile strength) and trend to increase in extensibility (increase in elongation at break). Tensile strength decreased from 7.23 to 2.40, 3.75 to 1.25 and 5.07 to 2.39 MPa when the sorbitol, glycerol and polyethylene glycol content increased from 30 to 60 % w/w., while, elongation at break increased from 6.73 to 27.66, 15.59 to 21.25 and 9.16 to 24.81%. Sorbitol, glycerol and polyethylene glycol are low molecular weight hydrophilic molecules that could easily fit into protein chains and establish hydrogen bonding with reactive groups of proteins. Bringing together plasticizers and proteins induced formation protein-plasticizer interactions to the detriment of protein-protein interactions. As a consequence, the density of intermolecular interaction in material decreased and the free volume between polymer chains increased [30]. The changes in mechanical properties as affected by hydrophilic plasticizers were observed for various hydrocolloid-based films [31], [32]. The mechanical properties of sorbitol, glycerol and polyethylene glycol plasticized films at an equal concentration were compared (1A-1B). The sorbitol plasticized films had significantly ($p < 0.05$) higher tensile strength and lower elongation at break than polyethylene glycol and glycerol and plasticized films at all concentrations. This could be attributed to the ring molecular conformation of sorbitol molecules, which may sterically hinder insertion between the protein chains resulted in less effective in disrupting the protein-protein interruptions. McHugh and Krochta [33] studied whey protein isolated/sorbitol (1:1) and whey protein isolated/glycerol (2:3) films and presented similar tensile strength values. They concluded that a higher amount of sorbitol than glycerol was needed to obtain similar tensile strength properties. The glycerol and polyethylene glycol plasticized films were more stretchable than the sorbitol plasticized films (Figure 1B), suggesting that glycerol and polyethylene glycol could be a more effective plasticizer in edible films than sorbitol. The effectiveness of glycerol and polyethylene glycol in the edible films from mung bean protein are most likely due to its small size and configuration which allows it to be more readily inserted between the polymer chains, and consequently exert more influence on the mechanical properties than the larger molecule. Donhowe and Fennema [34] found that plasticizer with low molecular weights such as glycerol was more effective than those with high molecular weights in methylcellulose-based films. Similarly, McHugh and Krochta [33] suggested that smaller size plasticizer was more effective than larger size plasticizer in whey protein films. In addition, at an equal percentage concentration, the total number of glycerol molecules in the film-solution was greater than that of the higher molecular weight polyethylene glycol, therefore glycerol had more functional groups (-OH) than polyethylene glycol, which should promote the plasticizer-polymers interactions in the films [33]; [34]. Gennadios et al. [13] reported that, the polar group (-OH) along plasticizer chains are believed to developed polymer-plasticizer hydrogen bonds replacing the polymer-polymer interaction in the biopolymer films. Molecular size, configuration and total number of functional hydroxide groups of the plasticizer as well as its compatibility with the polymer could affect the interactions between the plasticizer and the polymer [35].

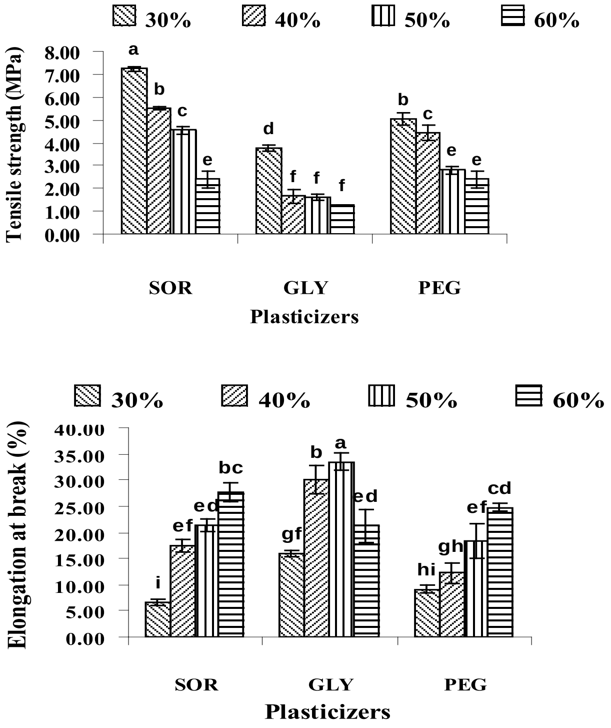

Figure 1A, B Effect of plasticizer type and concentration on the tensile strength and elongation at break of edible films from mung bean proteins. Standard error bars are shown. a-i; means with different letters represent significantly different value at $p < 0.05$ using Duncan's Multiple Range Test, where, SOR = sorbitol, GLY = glycerol and PEG = poly ethylene glycol-400.

Water Vapor Permeability

As a food packaging, film is often required to avoid or at least to decrease moisture transfer between the food and the surrounding atmosphere, and water vapor permeability should be as low as possible [36]. Water vapor permeability is a proportional constant assumed to be independent of the water vapor pressure gradient applied across the films. However, hydrophilic materials, such as protein films, deviate from this ideal behavior due to the interactions of permeating water molecules with polar groups in the film's structure [37]. Deviation from the ideal behavior can also be induced by the effects of structure on materials [38]. Water vapor permeability of edible films from mung bean proteins with different type and concentration of plasticizer were examined (Figure 2). The water vapor permeability increased with increasing of plasticizer concentration. The water vapor permeability increased from 44.38 to 68.48, 125.16 to 238.20 and 78.38-204.18 g.mm/m2.d.kPa respectively, when the concentration of sorbitol, glycerol and polyethylene glycol increased from 30 to 60 % w/w (Figure 2). This tendency could be explained by structural modifications of the protein network. The incorporation of plasticizers modified the molecular organization of the protein network, with an increase in free volume. The network becomes less dense and as a consequence more permeable [39]. Permeability increased with plasticizer content could be related to hydrophillicity of plasticizer molecules. Introducing hydrophillic plasticizers, favorable to adsorption and desorption of water molecules, was reported to enhance the water vapor permeability of hydrocolloid-based films [32]; [40]. Comparing of the successive values of the water vapor permeability for each plasticized films was shown in Figure 2.

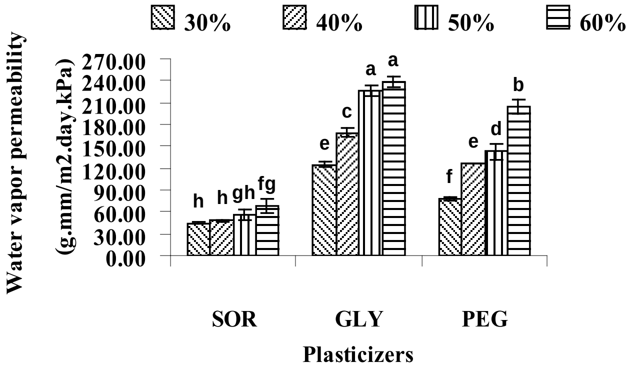

Figure 2 Effect of plasticizer type and concentration on the water vapor permeability of edible films from mung bean proteins. Standard error bars are shown. a-h; means with different letters represent significantly different value at $p < 0.05$ using Duncan' Multiple Range Test, where, SOR = sorbitol, GLY = glycerol and PEG = poly ethylene glycol.

Films plasticized with sorbitol had lower water vapor permeability than those with polyethylene glycol and glycerol at each plasticizer concentration, respectively due to the fact that sorbitol had ability to bind less water than polyethylene glycol and glycerol and, thereby, provided a lower water vapor permeability [40]. Chick and Ustanol [41] reported that casein-based films plasticized with glycerol had higher water vapor permeability values than films plasticized with sorbitol when the same amounts of plasticizers were used. The high hydrophillicity of glycerol and polyethylene glycol molecules, which is favorable to the adsorption of water molecules, could also be contribute to the increase in the films water vapor permeability [13]. The increase in water vapor permeability with increasing hydrophillicity plasticizer concentration was also common in edible films [30]; [40]. Sorbal et al. [21] reported that hydrophilicity of the plasticizers will increase the water content of the films, consequently increasing the mobility of the molecules. In addition, increasing water content could also affect permeate solubility in the films.

Film and Protein Solubility

From visual observations and irrespective of plasticizer type and content, the edible films from mung bean proteins clearly did not lose integrity after a 24 h immersion in water. Irrespective of the type, an increase in plasticizer content leads to an increase in films and proteins solubility (Figure 3A-3B). It could be hastily concluded that hydrophilic plasticizers enhanced films solubility in water. Low molecular weight protein chains (i.e. monomers and small peptides) formed during storage of film solutions and entrapped in the network [4] could then constitute the protein-based materials that solubilize in water. The dry matter solubilized in water was likely to be composed mainly of the plasticizer. The protein network was then not likely to solubilize or disperse in water. High interaction density and more certainly, the presence of intermolecular covalent bonds or "physical knots" (i.e. chain entailments) are responsible for partial insolubility of these films. This water solubility behavior could not be generalized, and understanding the films solubility remains a complex subject. Plasticizer solubilization in water was already observed for films based on wheat gluten or treated soy proteins or transglutaminase catalytic cross-linking whey protein [8], [14]. Stuchell and Krochta [8] pointed out that increase in the content of protein solubilized in water was obtained when the hydrophilic content of treated whey protein-and soy protein-based films increased. A decrease in the polymer network interaction density due to the presence of plasticizer was thus associated with this increase in solubility property. The lowest films and proteins solubility of edible films from mung bean proteins plasticized by 30% w/w of these plasticizers were noticed, while increasing the amount of plasticizer content showed higher films solubility and proteins solubility (Figure 3). It could be explained that, at higher content of plasticizer, more molecules of plasticizer were untrapped in the protein cross linked network and able to escape into solution, while, lower content of plasticizer gave lowered plasticizer molecules untrapped in the crosslinked network and less ability to escape into solution. The films and protein solubilities were higher for the sorbitol followed by polyethylene glycol plasticized films comparing with those plasticized with glycerol. The sorbitol and polyethylene glycol had a ring and height molecular weight, which may sterically hinder insertion between the protein chains [35] thus, facilitated its escape into solution, while glycerol have a small molecules, which promote the insertion between protein-protein chains.

Films Color and transparency

The results of the measurements performed on the films color were expressed in accordance with the CIELAB system, and the rectangular coordinates (L*, a* and b*) were defined. The color of films was more affected by the nature of the plasticizer rather than by concentration. L* and a* values of edible film mung bean proteins plasticized by sorbitol, glycerol and polyethylene glycol seemed not significantly different ($p > 0.05$) (Fig. 4). In contrast, increased yellowness (b*) occurred when higher plasticizer concentration involving with glycerol and sorbitol were used (Figure 4). This was somewhat expected since color change mainly depend on the type of plasticizer.

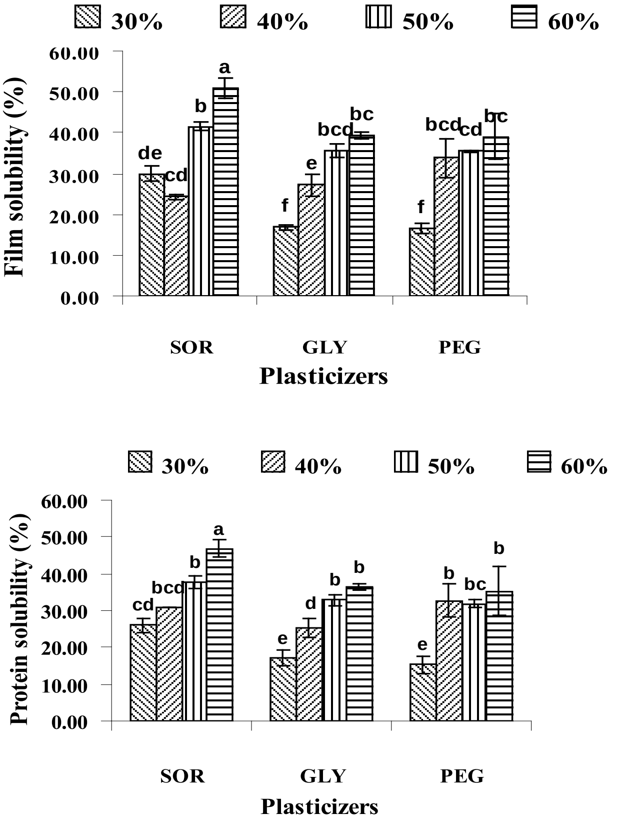

Figure 3A, B Effect of plasticizer type and concentration on the film and protein solubility of edible films from mung bean proteins. Standard error bars are shown. a-f; means with different letters represent significantly different value at $p < 0.05$ using Duncan's Multiple Range Test, where, SOR = sorbitol, GLY = glycerol and PEG = poly ethylene glycol.

Moisture sorption properties

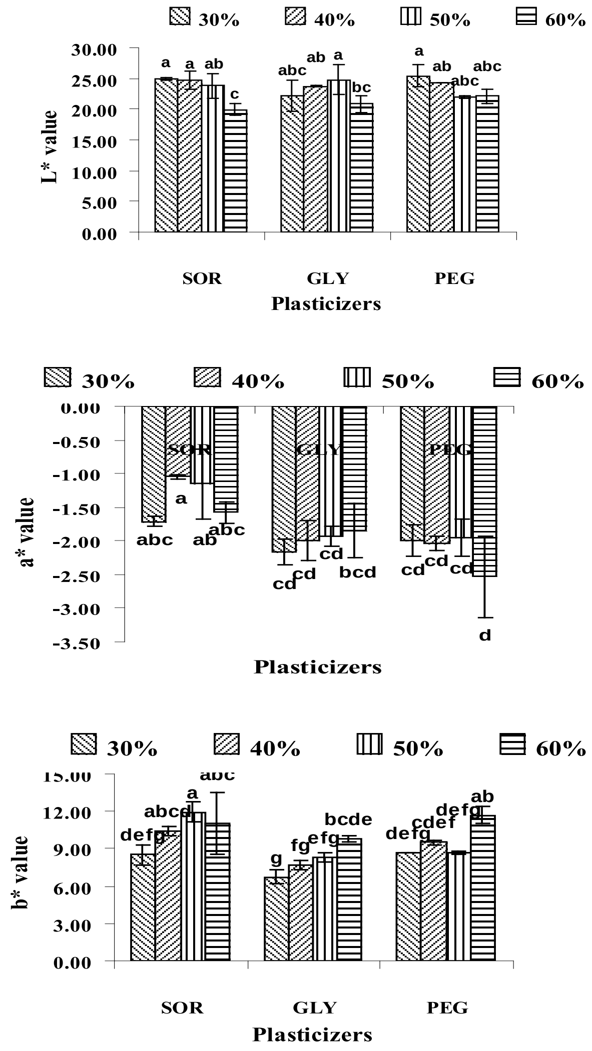

Figure 4A, B, C Effect of plasticizer type and concentration on the L*, a* and b* of edible films from mung bean proteins. Standard error bars are shown. a-g; means with different letters represent significantly different value at $p < 0.05$ using Duncan's Multiple Range Test, where, SOR = sorbitol, GLY = glycerol and PEG = poly ethylene glycol.

The relationship between aw and moisture content (at constant temperature) is described by moisture isotherm. Moisture content of the films increases at elevated water activity (aw). The time to reach equilibrium moisture content (EMC) was about 20 - 24 days at lower humidity and 13-16 days at higher humidities. The sorption isotherm curves for EMC (db) obtained from different type of plasticizer of mung bean protein films are shown in Figure 5. At lower aw the slope of the curve was less; with increase in aw the slope increased rapidly. Experimental data for moisture adsorption at 27+2 °C revealed sigmoid shape curves for all. The EMC of glycerol and sorbitol plasticized mung bean protein films showed logarithmic increase at above 0.59 aw and reached to highest moisture content of 52.21% and 47.64% at 0.95 aw, whereas PEG plasticized mung bean protein films had lowest moisture content of 45.32%. The films plasticized with sorbitol and polyethylene glycol had lower moisture than those with glycerol could be due to the fact that sorbitol and polyethylene glycol had ability to bind less water than glycerol thereby, provided lower moisture content. Addition, Gennadios et al. [13] reported that the rich of hydrophillicity of glycerol molecules, which is favorable to the adsorption of water molecules, could also be contribute to the increase in moisture in the films. This results show similar study of Chick and Ustanol [41] who reported that casein-based films plasticized with glycerol had higher water vapor permeability and moisture content than films plasticized with sorbitol when the same amounts of plasticizers were used.

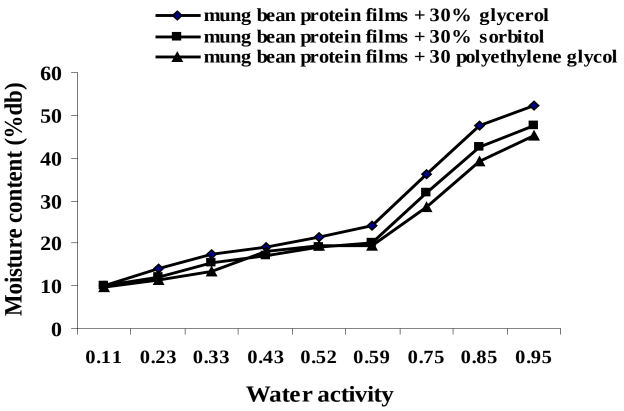

Figure 5 Effect of plasticizer type and concentration on sorption isotherm of mung bean protein films.

4. CONCLUSION

The results of this study pointed out that as plasticizer concentration increased, tensile strength decreased concomitant with increase in elongation at break and water vapor permeability of the films. Sorbitol plasticized films provided the films with highest mechanical resistance, but the poorest film flexibility. In contrast, glycerol and polyethylene glycol plasticized films exhibited flexible structure; however, the mechanical resistance was low, while inversely affecting the water vapor permeability. Increasing the plasticizer concentration resulted in higher solubility. Sorbitol plasticized films, showed higher both film solubility and protein solubility compared to polyethylene glycol and glycerol plasticized films. The color of mung bean protein films were more affected by the concentration of the plasticizer used than by its type. Addition it was found that the films plasticized with sorbitol and polyethylene glycol had lower moisture content than those with glycerol.

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