Alkali
extraction

↑ film elongation
↑ adhesion of
protein sizes

Amphiphilicity:
good adhesion to
hydrophobic and
hydrophilic
fibers

↑ elongation of soy
protein films

Good sizes properties

- High film flexibility
 - High adhesion
 - High Abrasion resistance
- Good biodegradability

Functions of soymeal compositions in textile sizing

Yi Zhao^a, Helan Xu^a, Bingnan Mu^a, Lan Xu^b, Robina Hogan^c, Yiqi Yang^{*a,d,e}

^a Department of Textiles, Merchandising & Fashion Design, University of

Nebraska-Lincoln, Lincoln, NE, 68583-0802, USA

^b Department of Agronomy and Horticulture, 279 Plant Science Hall, University of

Nebraska-Lincoln, Lincoln, NE 68583-0915, USA

^c Omni Tech Intl/Hogan Consulting, 2415 Tattersail Dr, Charlotte, NC 28210, USA

^d Department of Biological Systems Engineering, University of Nebraska-Lincoln,

Lincoln, NE, 68583-0802, USA

^e Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln,

Lincoln, NE, 68583-0802, USA

* Corresponding author: Yiqi Yang

Phone: 402-472-5197; Fax: 402-472-0640; Email: yyang2@unl.edu

ABSTRACT

Soymeal, which contains natural plasticizer and tackifier, has been used to fabricate biodegradable and low-cost warp sizes, with potential for replacing non-biodegradable polyvinyl alcohol (PVA) sizes for large-quantity industrial applications. Warp sizes from soyprotein isolates (SPI) have been reported as a potential substitute for PVA sizes, which contribute to high chemical oxygen demand in textile effluents and cause serious water pollution. However, sizes from SPI are high in cost and need additional plasticizers to overcome brittleness of films. In this research, the developed low-cost soymeal sizes contain soyprotein as majority and saccharides/saponified-oil from soymeal as minorities. Comparing to films from triethanolamine-plasticized SPI sizes, the soymeal size had about 30.1%, 25.2% and 8.3% higher film flexibility, adhesion to yarns and abrasion resistance, respectively. Saccharides in soymeal and saponified oil formed during size extraction functioned as plant-based additives with capability of improving adhesion of protein sizing pastes to cotton and/or polyester yarns and increasing elongation of protein-based size films. Successful utilization of soymeal in textile sizing will lead to its large-quantity application, resulting in high value addition to agricultural byproducts and profound impact on soybean industry and textile industry.

Keywords:

Soymeal; Biodegradable warp sizes; Polyvinyl alcohol; Saccharides; Saponified oil

1. Introduction

Developing warp sizes with low cost, good biodegradability and good size performances is important for sustainable textile industry. Warp sizing, an indispensable process during textile fabrication, directly influences production efficiency and quality of woven fabrics. PVA sizes are widely used for weaving of high-count cotton, polyester yarns and polyester blends. Currently, PVA shares about 20%-25% of the global market of about 1,000,000 metric tons of textile sizes annually (Lacasse and Werner 2004; Reddy et al., 2013). However, PVA sizes are no longer the best warp sizing due to its poor biodegradability and increasingly strict emission standard of industrial effluents. Nowadays, PVA has been banned for use during warp sizing in some European countries (Zhang et al., 2003). Non-biodegradable PVA desized from fabrics contributed about 40% of textile chemical oxygen demand (COD) during textile processing and caused serious water pollution (Shaw et al., 2002; Zhao et al., 2015a).

Currently, protein isolates based sizes, with similar weaving efficiency but much higher biodegradability compared to PVA sizes, have been developed in our previous studies. Physical modifications, such as adding hydramine, endowed soyprotein with sizing performances similar to PVA sizes (Zhao et al., 2015b). However, using soyprotein isolates (SPI) as raw materials for textile sizes is hard to be carried out in real industry due to their high cost. Low-cost agricultural byproducts and wastes, such as distillers grains and chicken feathers, have potential of being converted into protein-based sizes (Reddy et al., 2013; Reddy et al., 2014). However, corn distillers

grains have low protein yield (25% - 30%) (Reddy et al, 2011; Xu et al., 2015); while keratin in chicken feather has high degree of crosslink and poor film formability via low-cost alkali treatment (Rouse et al., 2010; Xu et al., 2014), and thus has poor capability of protecting warp yarns during high-speed weaving. Therefore, developing a biodegradable sizing agent with cost lower than and size properties similar to or higher than SPI based sizes is crucial to sustainable textile industry.

Soymeal with much lower price and potentially better sizing performances could be an alternative for SPI to produce industrial-quantity sizes. Soymeal is readily available in large quantities with annual production of around 172 million metric tons, low cost (\$0.18-0.25 per lb) and good biodegradability as a co-product from edible oil and bio-diesel production (Xu and Hanna 2009; Robert et al., 2014). Soymeal has been used as fillers or extenders of plastics (Wang et al., 1996), plywood bonding agent (Kumar et al., 2002), additives or coating of paper (Selling et al., 2013; Arboleda et al., 2014; Salam et al., 2015) and protein-based composites (Matthews et al., 2011; Khansari et al., 2013; Rahman et al., 2014) or scaffolds for tissue engineering (Huang et al., 2012; Zhao et al., 2014). However, consumption of soymeal in the above application areas could be low. On the other hand, textile sizes have a global consumption of about 1,000,000 metric tons every year (Lacasse and Werner, 2004). If soymeal is successfully made into warp sizes and substitute 20% of the current global textile size usage, more than 200,000 metric tons of soymeal will be consumed annually. Therefore, utilization of soymeal in textile sizing will lead to large-quantity application of soymeal, resulting in high value addition of agricultural

byproducts and profound impact on soybean industry and textile industry.

Soymeal contains high amount of protein, saccharides and a little soy oil (Sun, 2005), most of which are useful in warp sizing. Soyprotein has been reported with good film formability (Zhu et al., 2013). However, films from 100% SPI are too brittle to be used for the protection of warp yarns during high-speed weaving (Zhao et al, 2015b). Thus, additives, such as glycerol, triethanolamine (TEA), polyols and hydramine were added to overcome brittleness of soyprotein films (Sanchez et al., 1998; Sessa et al., 2006; Tian et al., 2009). For the sizes directly developed from soymeal, proteins serve as majority, while saccharides and lipids are as minorities. The saccharides and lipids in soymeal could function as natural lubricants to increase film flexibility, and keep biodegradability of soyprotein-based sizes at the same time. Ghanbarzadeh et al. and Cuq et al. reported that sugars, such as glucose, galactose and fructose could plasticize zein films (Cuq et al., 1997; Ghanbarzadeh et al., 2006). Vieira and Cao studied plastic effect of emulsive soybean oil on mechanical properties of poly(3-hydroxybutyrate-co-3-hydroxyvaltrate) films and gelatin films (Cao, 2009; Vieira et al., 2011). However, using saccharides and lipids in soymeal to improve properties of protein sizes has never been reported.

In this research, biodegradable sizes from low-cost soymeal were developed. Functions of saccharides and oil in soymeal on tensile properties of soymeal films and adhesion of soymeal sizes to cotton, poly-cotton and polyester yarns have been studied. Comparisons of soymeal sizes with commercial PVA sizes as well as with reported plasticized SPI sizes (SPI-TEA), in terms of tensile properties of films,

stability of viscosity, adhesion to yarns, abrasion resistance of sized yarns, desizing efficiency and biodegradability, demonstrated that biodegradable and cost-effective soymeal sizes had higher size performance than the plasticized SPI sizes and could potentially replace PVA sizes for warp sizing.

2. Materials and methods

2.1 Materials

Soymeal (062459) and SPI (PRO-FAM 646) were provided by ADM International, Decatur, IL. Soymeal contains around 50% protein, 30% saccharides, fibers, and small amount of oil and ash etc. Protein content of SPI is higher than 90%, while moisture percent is around 6%. The 100% polyester fabrics, polyester/cotton (50/50) fabrics and 100% cotton fabrics used in the study were supplied by Glorious Textile Factory (Zhejiang, China), and have warp/weft density of 60/48, 70/52 and 90/72 per inch, respectively. The polyester/cotton (50/50) yarns (45s) and cotton yarns (30s) were purchased from Shuford Yarns LLC (Hickory, NC, USA). The 100% polyester yarns (45s) were supplied by Nantong Textile Co., Ltd. (Jiangsu, China). PVA (Elvanol T25) with a hydrolysis degree of 86–89% was purchased from a commercial sizing agent supplier in USA. Other chemicals used in this study were purchased from VWR International.

2.2 Preparation of sizes from soymeal, SPI and PVA

Soymeal sizes were fabricated directly from soymeal via alkaline treatment, as shown in Fig. 1. Soymeal was treated in alkaline solutions (1 wt.% of NaOH based on the weight of soymeal) at 90 °C for 60 min with liquor to meal ratio of 7.5:1. The

dispersion was centrifuged at 9000 rcf for 15 min. The supernatant was adjusted to pH 7 using dilute HCl. The solid content of the solution was around 5.8%.

SPI sizes and PVA sizes were used for comparison. Sizes from SPI were prepared by heating 6 wt.% soyprotein solutions, which contained 20 wt.% triethanolamine (TEA) (base on weight of soyprotein), at pH 10 and 90 °C for 30 min. pH was adjusted by 10 wt.% sodium hydroxide. After heating, the pH of the solution was adjusted to 7 using diluted HCl. PVA sizes with 6% concentration were prepared by dispersed in water and heated at 90 °C for 30 min.

Fig. 1

2.3 Preparation of protein/oil-free solubles from soymeal sizes

To study effect of compositions of soymeal sizes on tensile properties of size films, one of major compositions in soymeal sizes, protein/oil-free solubles, was extracted from soymeal sizes and was added into commercial SPI by different concentrations to form films. Detailed steps are shown in Fig. 1. Firstly, oil was removed from soymeal by soxhlet extraction with a 1:10 meal to hexane weight ratio at 70 °C for 24 hr (Kumar et al., 2002). Then, the meal was air-dried in a fume hood for 12 hr to obtain the oil-free soymeal. The oil-free soymeal were treated in 1% sodium hydroxide (NaOH) solution with a liquor to soymeal ratio of 7.5:1 at 90 °C for 60 min. The dispersion was centrifuged at 9000 rcf for 15 min. The supernatant was collected as oil-free soymeal sizes. Protein/oil-free solubles were collected by removing protein from oil-free soymeal sizes through acid precipitation at isoelectric point of soyprotein (pH 4.5) (Brandenburg et al., 1993) and centrifugation at 9000 rcf.

The supernatant was adjusted to pH 7 using diluted sodium hydroxide. Sodium salt was removed from the supernatant by dialysis for 24 hr. Finally, the protein/oil-free solubles were collected by freeze drying.

2.4 Preparation of saponified soy oil

To study effect of compositions of soymeal sizes on tensile properties of sizes films, another composition in soymeal sizes, saponified soy oil, was prepared. Sodium hydroxide solution (25 wt.% concentration) was slowly added into the soy oil. Ratio of alkaline solution to soy oil is 1:2. The mixture was heated at 100 °C for 3 hr with stir to obtain saponified oil (Haas, 2005).

2.5 Effect of saponified oil and protein/oil-free solubles from soymeal on tensile properties of soyprotein films.

Saponified soy oil (1 wt.%, 3 wt.%, 5 wt.%, and 10 wt.%, based on weight of SPI) was added into the soyprotein solution with stir at 700 rpm for 30 min under room temperature. Here, the soyprotein solutions were prepared by heating 6 wt.% SPI solutions with 1 wt.% NaOH (based on weight of soyprotein) at 90 °C for 30 min. Finally, pH of the mixed solution was adjusted to 7.

Similarly, different amounts of the protein/oil-free solubles from soymeal sizes (5 wt.%, 10 wt.%, 20 wt.% and 30 wt.%, based on the weight of SPI) were added into the soyprotein solution with stir at 700 rpm for 30 min under room temperature. Finally, pH of the mixed soyprotein solution was adjusted to 7.

2.6 Film casting and tensile properties

The solutions, including soymeal sizes, SPI sizes, PVA sizes, SPI + saponified oil

solution and SPI solution with protein/oil-free soymeal solubles, were cast onto Teflon coated glass plates and air-dried in a fume hood at room temperature for 12 hr. Then the films were conditioned at 20 °C and 65% relative humidity for about 34 hr before tensile testing. Thickness of the films was 0.19 ± 0.01 mm. Films were tested on a MTS tensile tester QTest 10 (MTS systems corporation, USA) for tensile properties according to ASTM Standard 822e.

2.7 Combustion nitrogen of soymeal extractant

Content of combustion nitrogen (AOAC, 2000) was analyzed using a Leco FP-528 Nitrogen Combustion Analyzer (Leco, St. Joseph, MI). The powder of soymeal extractant was recovered by filter paper and introduced into the analyzer for determination of crude protein.

2.8 Fourier Transform Infrared Spectrometry (FTIR) of soymeal sizes

FTIR was used to verify the chemical structures of soymeal sizes. The soyprotein powder and the dried soymeal sizes were prepared. Measurements were taken on a Nicolet NEXUS 670 (Thermo-Nicolet, Waltham, MA) spectrophotometer through the diffuse reflectance technique from 400 to 4000 cm^{-1} with a resolution of 4 cm^{-1} , and 64 scans. The FTIR spectra obtained were analyzed using OMNIC software (Thermo Electron Corp., USA).

2.9 High Performance Liquid Chromatograms (HPLC)

The freeze-dried protein/oil-free solubles were dissolved in a 0.005 mol/l sulfuric acid at 65 °C for 5 min. The liquor to solubles ratio was 8:1. After centrifugation at 13000 rcf (centrifuge 5424, Eppendorf, USA), supernatant was collected. HPLC

analysis of the supernatant was performed on an Ultimate 3000 liquid chromatograph equipped with an Aminex HPX-87H column (300 mm x 7.8 mm, Bio-Rad, Hercules, USA) and RI-101 detector (Shodex, New York, USA). A 0.005 mol/l sulfuric acid was used as the mobile phase. The sample (15 µl) was injected and eluted at a flow rate of 0.6 mL/min at 65 °C. The standard saccharides and chemical reagent grade glycerol were used as standards.

2.10 Apparent viscosity of sizing solution

Viscosity of the sizing solutions was tested in a R/S plus rheometer (Brookfield, mA, USA) using a CC-25 spindle and cup in a water bath of 90 °C. Solid content of the sizing solutions was around 5.5-6 wt.%. Size solutions were first preheated in 90 °C oven for 10 min to arrive 90 °C. Then, the size solutions were heated in 90 °C oven from 0 to 4.5 hr. Viscosity of the sizing agents were tested every 30 min. Since a tank of sizes is usually used up for around 2 hr in industry, we measured the viscosity of soymeal sizes, SPI sizes and PVA sizes, which heated in 90 °C oven from 0 hr to 4.5 hr.

2.11 Adhesion properties

Adhesion is an important property of textile sizes (Jin et al., 2011). Adhesion of sizes to cotton, polyester and polyester/cotton were evaluated by testing peel force between two fabrics, which were glued by sizes. Peel force of fabrics was measured according to the method ASTM D1876 – 08. To obtain different add-on on every two pieces of fabrics, two pieces of same fabrics were dipped in the sizes with different concentration and went through 1 lb roller together. The sized samples were

conditioned at 20 °C and 65% humidity for 34 hr. Peel tests were carried out on a MTS tensile tester QTest 10 (MTS systems corporation, USA). On each peel force-strain curve, 20 highest values were collected to calculate average peel force.

2.12 Abrasion resistance

Cotton, polyester, and polyester/cotton yarns were winded on plastic frames respectively and dipped in the size solutions with different concentrations, and finally went through 1 lb roller. The sized samples were conditioned at 20 °C and 65% relative humidity for 34 hr. Abrasion resistance of sized yarns was tested on Y731D cohesion tester (Changzhou Huafang Textile Instrument Co., Ltd, China). Sized yarns with known add-on were fasten and rubbed until broken. Abrasion cycles were recorded automatically. Reciprocating stroke is 90 mm and abrasion speed is 80 cycles/min.

2.13 Desizing

The woven fabrics with a known amount of percent add-ons were desized to determine the efficiency of removal of the sizes from the fabrics. Desizing usually includes wash and rinse with liquor-to-fabric ratio of about 30:1, 20:1, 10:1 or 5:1 each cycle (Samaha et al., 2005; Chen et al., 2013). To evaluate the desizability of sizes in hot water and room temperature water, 90 and 20 °C are usually used (Du et al., 2007; Peng et al., 2009; Chen et al., 2013). Since the soymeal sizes could almost be completely removed from polyester, polyester/cotton and cotton fabrics after 1 cycle of wash and 1 cycle of rinse, desizing was done by treating the sized fabrics in water with 1 cycles of wash and 1 cycle of rinse under 90 °C and 20 °C for 5 min,

respectively. Wash ratio and rinse ratio were 10:1 and 5:1, respectively. The solvent used for removing sizes was distilled water. After desizing, the fabrics were dried in an oven and weighed. The fabrics were weighed before and after desizing, and the loss in weight was calculated. At the same time, unsized fabrics were treated under the same wash and rinse conditions. After drying, the unsized fabrics were weighed before and after wash-rinse treatment to calculate hairiness loss in weight. Finally, weight of hairiness loss was subtracted from the weight loss of the fabrics before and after desizing to determine desizing efficiency.

2.14 Biodegradation

To determine the biodegradation of the sizing solutions, waste water sludge from sewage treatment plant (Lincoln, NE, USA) were collected. The concentration of sizes in the textile mill is 300 mg/L (Ghaly et al., 2014). COD in sizes solution was measured according to U.S. Environmental Protection Agency method 800 using digital reactor block DRB 200 (HACH, DE). Five-day biochemical oxygen demand (BOD₅) was determined according to American Public Health Association guidelines in the standard methods for the examination of wastewater using optical dissolved oxygen meter HQ440d (HACH, DE). Total nitrogen of the soyprotein sizes in the sludge was measured by UV/vis spectrophotometer DU 720 (Beckman Coulter, USA) and calculated based on the alkaline persulfate oxidation digestion method. Ammonia nitrogen was measured by the above spectrophotometer and calculated using salicylate and hypochlorite in an alkaline phosphate buffer (Reddy et al., 2013).

2.15 Statistical Analysis

All the experiments were repeated for at least three times to report average and standard errors. Data generated was analyzed using Tukey's multiple-pair wise comparison using SAS program (SAS Institute, Raleigh, NC). Within the level of $\alpha=0.05$, significant difference could be told between two data points.

3. Results and discussion

3.1 Analysis of compositions in soymeal sizes

Table 1

As shown in Table 1, protein/oil-free solubles and soyprotein were the major compositions in soymeal sizes while peptides and saponified oil were the minorities. There was about 52 wt.% of soyprotein, 41 wt.% of protein/oil-free solubles and about 0.02 wt.% of soy oil in soymeal sizes, although soy oil shared about 2.3 wt.% of solid soymeal. Protein/oil-free solubles are probably composed of saccharides and soluble fiber, etc. Further analysis will be carried out later via FTIR and HPLC. Soy oil mainly contains triglycerides and fatty acid, including linoleic, oleic, stearic acids and etc. (Kim and Sharma 2012; Yao and Tang 2013). During alkali extraction, oil in soymeal was highly probably reacted with sodium hydroxide via saponification, leading to production of anionic surfactants and glycerol. The saponification was shown in the following reaction.

Reaction 1. Saponification of triglycerides

As shown in Fig. 2, soymeal sizes probably contain saccharides. The FTIR spectra of soymeal sizes and SPI show almost the same peaks after 1046 cm^{-1} , including O-H stretching at 3300 cm^{-1} , C-H stretching of amine at 2930 cm^{-1} , C=O stretching of amide group at 1650 cm^{-1} , N-H bending of amine at 1541 cm^{-1} , and O-H bending of carboxyl group at 1400 cm^{-1} ; Peaks at 1246 cm^{-1} represent amide III and peaks at 1046 cm^{-1} represent C-N stretch vibration of amine (Ma et al., 2013). Compared to SPI, the spectrum of soymeal sizes showed different peaks at wavenumber of 925 cm^{-1} and 995 cm^{-1} representing C-O stretch vibration of sucrose (Ibrahim et al., 2006), indicating the potential existence of saccharides in soymeal sizes.

Fig. 2

HPLC results could further identify the compositions of saccharides and saponified oils in soymeal sizes after analysis of protein-free solubles from soymeal sizes. As shown in Fig. 3, the protein-free solubles from soymeal sizes eluted out at 8.84 min and 13.44 min, respectively. The standard glucose, sucrose and glycerol had retention times of 8.83 min, 8.73 min and 13.43 min, respectively. Therefore, the protein-free solubles from soymeal sizes highly probably contained sucrose or glucose. The results are in accordance with the previous FTIR results. In addition, existence of glycerol in the solubles proved occurrence of saponification between oil in soymeal and sodium hydroxide, as there was no glycerol in raw soymeal.

Fig. 3

3.2 Effect of protein-free components in soymeal sizes on tensile properties of protein

films

Fig. 4a shows the effect of protein/oil-free water solubles from soymeal sizes on mechanical properties of SPI films. Increasing concentration of the water solubles from 5% to 30% (base on the weight of soyprotein) increased strain of SPI films by 287.1%, while decreased tensile strength by 19.6%. The water solubles consist of peptides and saccharides. Peptides have capability of plasticizing protein films (Tuck et al., 2014), leading to increased flexibility and decreased tensile strength of SPI films. In addition, saccharides in soymeal such as sucrose could plasticize protein films, leading to increased elongation but decreased tensile strength of the films (Cao et al., 2009).

Fig. 4

With no oil or only untreated soy oil, SPI films were too brittle to be tested. Ductility of soyprotein films was remarkably enhanced after adding saponified oil. As shown in Fig. 4b, increasing concentration of saponified soy oil from 3 wt.% to 10 wt.% led to 469.1% increase in elongation but 25.4% decrease in tensile strength of soyprotein films. Soy oil was treated with a strong base, which accelerated cleavage of the ester bond and generates glycerol and anionic surfactant. Glycerol could break hydrogen bonding between protein molecules and thus increase intermolecular slippage, leading to increased flexibility and decrease tensile strength of SPI films. Anionic surfactant from saponified oil could unfold soyprotein and increase slippage space between molecules, leading to increased elongation of the protein films. However, with an excess of saponified oil, the amount of soyprotein in the films

decrease further, leading to decreased tensile properties of films.

In general, saccharides/peptides in soymeal and saponified soy oil formed during preparation of soymeal sizes could substantially improve flexibility but slightly decrease tensile strength of SPI films.

In industry, sized yarns go through three temperature utilities at range of 140-150 °C to be dried before weaving. In this study, morphology of size films, which were dried at actual sizing drying temperature, were observed. Casting films were firstly heated in 80 °C for 2 hr and then were completely dried at 140 °C for 15 min. Fig. 5 showed images of films from SPI control, SPI + protein-free-solubles, SPI + saponified oil, and soymeal sizes after 140 °C drying. Without adding additives, such as saponified oil or protein-free-solubles from soymeal, control SPI films were broken due to shrinkage and brittleness. That was because without plasticizers or surfactants, soyprotein molecules folded and entangled during the film formation. Crystallinity of SPI films with 0% 10% and 20% glycerol was also measured to prove the disentanglement and decrystallization of soyprotein molecules after adding plasticizers. Increasing the amount of plasticizers from 0% to 20% decreased protein crystallinity substantially, from 27% to 8%. Therefore, plasticizers or surfactants could decrease brittleness of SPI films. Similarly, films from SPI + protein-free-solubles, SPI + saponified oil, and soymeal sizes contain natural plasticizers or surfactants, and thus had good flexibility and film formability.

Fig. 5

3.3 Comparisons of tensile properties of size films

Table 2

Tensile properties of films from soymeal, SPI and PVA were shown in Table 2. Since adding 10% saponified oil increased tensile properties of soyprotein films at most, 10% saponified oil was chosen to add into soymeal sizes to make modified soymeal films. Compared to soymeal sizes, films from soymeal sizes + 10% saponified oil showed higher elongation but lower tensile strength. Glycerol produced from oil saponification could plasticize protein in soymeal sizes, while anionic surfactants produced from oil saponification are capable of unfolding protein molecules. Plasticization increased flexibility but decreased tensile strength of the soymeal films. Besides, protein in soymeal sizes unfolded by anionic surfactants had larger slippage space, leading to improved film elongation.

Compared to TEA, saponified oil provided soymeal films with higher strength, elongation and work of rupture. It was probably because TEA can more easily break H-bonds between or within protein compared to saponified oil. High amount of H-bonds breakage resulted in decreased tensile strength of films from soymeal sizes. In addition, anionic surfactants from saponified oil have higher capability in unfolding protein in soymeal sizes due to their strong electrostatic repulsion after attaching to protein. Unfolded molecules have more slippage space, leading to higher elongation of films. Compared to films from SPI + 20% TEA, films from soymeal sizes + 5% TEA contained less TEA as plasticizer, less protein content, and more salts, and thus had lower tensile strength and elongation.

In general, films from soymeal sizes + saponified oil had higher tensile

elongation but lower strength and work of rupture compared to SPI (soyprotein + 20% TEA) or PVA films, still demonstrating potential of using soymeal for warp sizing.

3.4 Viscosity of sizing solutions

Soymeal sizing solution had good viscosity stability. As shown in Fig. 6, viscosity of soymeal sizes had no significant decrease until 2.5 hr. After that, viscosity of soymeal sizes decreased gradually and finally arrived 88% of the original viscosity. Similarly, soyprotein isolate sizes and PVA sizes showed 12% and 13.6% decrease in viscosity after heating for 4.5 hr. PVA sizes probably contain additives, such as lubricants, softeners, emulsifiers and finishing and wetting agents (Chen et al., 2013), which might be degraded during 90 °C treatment. In addition, the PVA sizes in partially hydrolysis grades, contain residual poly(vinyl acetate), which also might be degraded during high temperature treatment. Natural macromolecules in soymeal sizes and soyprotein isolate sizes also could degrade during high temperature treatment. However, soymeal, soyprotein isolate and PVA sizes had similar decrease in apparent viscosity as cooking time increased. Therefore, viscosity stability of soymeal sizing paste was acceptable. The value at 1 hr is usually considered as apparent viscosity of sizing paste. As shown in Fig. 6, the apparent viscosities of soymeal and soyprotein isolate sizing pastes at 1 hr were slightly lower than that of PVA sizes, and were within the range reported for commonly used sizes (Cacho, 1980).

Fig. 6

3.5 Adhesion of sizes

As shown in Fig. 7, soymeal sizes had good adhesion to yarns, especially to cotton and polyester/cotton yarns. In Fig. 7a, soymeal sizes had higher adhesion to polyester yarns at low add-on than SPI sizes and PVA sizes. At high add-on, soymeal sizes had slightly lower adhesion than PVA sizes, although soymeal sizes still showed higher adhesion than SPI sizes. In Fig. 7b and 7c, soymeal sizes showed substantially higher adhesion to polyester/cotton and cotton than SPI sizes and PVA sizes. Adhesion of sizing pastes is usually influenced by their wettability, permeability and cohesion with fibers.

Contact angles of soymeal sizes, soyprotein isolate sizes and PVA sizes on cotton fibers were 96.01° , 120.82° 121.75° respectively, and 93.78° , 117.22° and 119.85° on polyester fibers respectively. Orders of contact angles of three sizes on both of cotton and polyester yarns are $\text{PVA} > \text{SPI} > \text{soymeal}$, indicating soymeal sizing paste had the highest wettability among the three sizes. Accordingly, soymeal sizes had the highest adhesion among three sizes. For soyprotein and PVA, difference between their contact angles was not obvious and thus was difficult to estimate their adhesion.

Without external squeezing, permeability of sizing paste on yarns is determined by their surface tension. In this study, yarns were dipped in sizes and squeezed by pressure roller to control the same amount of add-on. Therefore, permeability of three sizes was similar.

As shown in adhesion results, adhesion order of sizing pastes on polyester is $\text{soymeal} > \text{PVA} > \text{SPI}$, and the order of sizing pastes on cotton is $\text{soymeal} > \text{SPI} > \text{PVA}$. Thus, besides of wettability and permeability, adhesion of sizes is also

influenced by other factors, such as cohesion between sizes and fibers. Protein in soymeal sizes and soyprotein isolates sizes has both of hydrophobicity and hydrophilicity, leading to good adhesion to cotton and polyester. PVA with a complete alcoholysis has good adhesion to hydrophilic cotton fibers. However, PVA with a partial alcoholysis has better adhesion to hydrophobic polyester fibers. In this study, PVA sizes have a hydrolysis degree of 86–89%. Therefore, on cotton and polyester/cotton, soyprotein isolate sizes had adhesion higher than PVA sizes; on polyester, the PVA sizes had adhesion higher than soyprotein isolate sizes. In addition, sucrose in soymeal had potential of improving formability and tensile properties of soymeal films and improving adhesion of soymeal sizes. Therefore, soymeal sizes showed higher adhesion to three types of yarns as compared with the soyprotein isolate sizes.

Fig. 7

As shown in Fig. 8, increasing concentration of sucrose from 0% to 60% in soyprotein solution increased peel resistance of polyester, cotton and poly-cotton fabrics, indicating improved adhesion of soyprotein sizes. Sucrose could plasticize soyprotein and introduced more hydroxyl groups into soyprotein, probably leading to higher adhesion to fabrics, especially to hydrophilic cotton fabrics. High peel load between the fabrics, which sized with pure sucrose solution (40%), demonstrated its potential capability of binding polyester, cotton and poly-cotton fabrics. Cotton fabrics with 128.8% add-on of sucrose showed around 7.51 N of peel load, while polyester fabrics with 114.6% add-on and poly-cotton fabrics with 103.3% add-on of

sucrose had around 2.733 N and 5.472 N of peel load, respectively. However, increasing concentration of sucrose from 60% to 100% in soyprotein solution decreased adhesion of soyprotein sizes. It was probably because of substantially reduced soyprotein concentration in the sized fabrics.

Fig. 8

3.6 Abrasion resistance of sized yarns

As shown in Fig. 9, soymeal sized yarns had good abrasion resistance, especially for sized cotton and polyester/cotton yarns. Compared to the plasticized SPI sizes, soymeal sizes show similar or slightly higher abrasion resistance due to their higher adhesion and film elongation. Fig. 9a showed abrasion resistance of soymeal sized polyester yarns was similar to PVA. In Fig. 9b and 9c, compared to PVA sizes, soymeal had similar or higher abrasion resistance on poly-cotton and cotton yarns. It was probably because soymeal sizes had higher adhesion to cotton and to polyester/cotton and higher film flexibility than PVA. Therefore, soymeal sizes have high potential of substituting PVA sizes to protect warp yarns from abrasion during weaving.

Fig. 9

3.7 Desizing efficiency

Table 3

Good desizability is also a requirement for textile sizes. After weaving, sizes will be removed from fabrics through rinsing. Desizing efficiency mainly influenced dyeing quality and water consumption during fabric production (Chen et al., 2013).

As shown in Table 3, soymeal sizes had desizing efficiency higher than or similar to PVA sizes on polyester and poly-cotton fabrics. However, on cotton fabrics, soymeal showed lower desizing efficiency than PVA. It was mainly because soymeal sizes had higher adhesion to cotton fibers, while PVA sizes had higher adhesion to hydrophobic polyester fibers. In addition, in 90 °C or 20 °C water bath, desizing efficiency of soymeal sizes was higher than 90%, indicating their good desizability and the potential for low-temperature desizing. Therefore, if PVA sizes are successfully substituted with soymeal sizes, less energy and water will be consumed in textile desizing.

3.8 Biodegradability

COD and nitrogen content are two of major emission indexes of textile desizing effluents. As shown in Fig. 10a, soymeal sizes had lower COD than PVA and the plasticized SPI sizes during 5 days treatment. After 5 days treatment in activated sludge, COD of PVA sizes reduced to 398.3 ± 8.4 mg/L from 520.4 ± 10 mg/L, while COD of soymeal sizes decreased to 70 ± 4.5 mg/L from 402 ± 9.9 mg/L. Soymeal sizes contain protein, saccharides and saponified oil as nutrients for micro-organisms and therefore were largely degraded in the sludge. However, PVA molecules had poor biodegradability and PVA sizes still contain about 400 mg/ L COD, which was much higher than the allowable concentration (110 mg/L) when effluent was discharged. As shown in Fig. 10b, soymeal sizes and plasticized SPI sizes had substantially higher BOD₅ value than PVA sizes before sludge treatment, indicating soymeal sizes and plasticized SPI sizes had substantially higher biodegradability than PVA. After 5 days

treatment, soymeal sizes and plasticized SPI sizes showed 975.8% and 640.9% higher BOD₅ compared to PVA sizes. As compared with plasticized SPI sizes, soymeal sizes had higher biodegradability due to its comparatively lower COD and higher BOD₅ during 5 days treatment in activated sludge. Unlike the plasticized SPI sizes, all compositions in soymeal sizes are plant-based, leading to higher biodegradability of soymeal sizes.

Fig. 10c showed that the amount of total and ammonia nitrogen released from the soymeal sizes and SPI sizes during 5 days of treatment in activated sludge. There was a substantial decline in the total nitrogen after 1 day treatment in the activated sludge. A corresponding increase in ammonia nitrogen was shown until day 1 and then the ammonia nitrogen released from soymeal and SPI sizes decreased rapidly. In addition, soymeal sizes showed lower level of total and ammonia nitrogen than the SPI sizes during 5 days treatment, indicating nitrogen released from soymeal desizing effluent would be much lower than the allowance (<25 mg/L) (Yang and Reddy, 2013).

Fig. 10

4. Conclusions

In conclusion, biodegradable and low-cost soymeal sizes have high potential of replacing PVA sizes for warp sizing. Compared to the high-cost plasticized SPI sizes, which have weaving efficiency similar to or higher than PVA sizes, low-cost soymeal sizes have higher film flexibility, adhesion to yarns and abrasion resistance, indicating good properties of soymeal sizes. Saccharides in soymeal and saponified oil formed during soymeal extraction have been found as natural additives with capability of

improving adhesion of soyprotein sizes to cotton and/or polyester yarns and increasing elongation of soyprotein sizes films. The developed soymeal sizes have desizability similar to or higher than commercial PVA sizes on cotton, polyester/cotton and polyester. In addition, low-cost soymeal sizes contain lower level of total and ammonia nitrogen than the plasticized SPI sizes and have much higher biodegradability in activated sludge than the commercial PVA sizes. Therefore, the large-quantity utilization of soymeal in textile sizing will promote soybean industry and sustainable textile industry.

Acknowledgments

This research was financially supported by the United Soybean Board Domestic Programs (1440-512-5296), USDA-National Institute of Food and Agriculture (Multi-State Project S1054 (NEB 37-037) and Hatch Act), and the Agricultural Research Division at the University of Nebraska Lincoln. Yi is grateful to China Scholarship Council and John and Louise Skala Fellowship for their financial support.

References

- Arboleda, J.C., Niemi, N., Kumpunen, J., Lucia, L.A., Rojas, O.J., 2014. Soyprotein-Based Polyelectrolyte Complexes as Biobased Wood Fiber Dry Strength Agents. *ACS Sustain. Chem. Eng.* 2 (10), 2267-2274.
- Brandenburg, A.H., Weller, C.L., Testin, R.F., 1993. Edible films and coatings from soyprotein. *J. Food Sci.* 58 (5) 1086-1089.
- Cacho, J. W., 1980. CMC Warp Sizing vs. Polyvinyl Alcohol. *Text. Chem. Color.* 12(4).
- Cao, N., Yang, X.M., Fu, Y.H., 2009. Effects of various plasticizers on mechanical and water vapor barrier properties of gelatin films. *Food Hydrocolloid.* 23 (3) 729-735.
- Chen, L.H., Reddy, N., Yang, Y.Q., 2013. Remediation of environmental pollution by substituting poly (vinyl alcohol) with biodegradable warp size from wheat gluten. *Environ. Sci. Technol.* 47 (9), 4505-4511.
- Cuq, B., Gontard, N., Cuq, J.L., Guilbert, S., 1997. Selected functional properties of fish myofibrillar protein-based films as affected by hydrophilic plasticizers. *J. Agric. Food Chem.* 45 (3), 622-626.
- Du, G., Liu, L., Song, Z., Hua, Z., Zhu, Y., Chen, J., 2007. Production of polyvinyl alcohol - degrading enzyme with *Janthinobacterium* sp. and its application in cotton fabric desizing. *Biotechnol. J.* 2(6), 752-758.
- Ghanbarzadeh, B., Oromiehie, A.R., Musavi, M., D-Jomeh, Z.E., Rad, E.R., Milani, J., 2006. Effect of plasticizing sugars on rheological and thermal properties of

535 zein resins and mechanical properties of zein films. Food Res. Int. 39 (8),
 536 882-890.

537 Ghaly, A.E., Ananthashankar, R., Alhattab, M., Ramakrishnan, V.V., 2014.
 538 Production, Characterization and Treatment of Textile Effluents: A Critical
 539 Review. J Chem, Eng. Process Technol. 5, 182.

540 Haas, M.J., 2005. Improving the economics of biodiesel production through the use of
 541 low value lipids as feedstocks: vegetable oil soapstock. Fuel Process. Technol.
 542 86 (10), 1087-1096.

543 Huang C., Geng, X., Ke Q.F., Mo X.M., Salem S.A., Mohamed E., 2012. Preparation
 544 of composite tubular grafts for vascular repair via electrospinning. Prog. Nat.
 545 Sci. 22 (2), 108-114.

546 Ibrahim, M., Alaam, M., El-Haes, H., Jalbout, A.F., Leon, A.D., 2006. Analysis of the
 547 structure and vibrational spectra of glucose and fructose. Eclet. Qu. 31 (3),
 548 15-21.

549 Jin, E.Q., Zhu, Z.F., Yang, Y.Q., Miao, G.C, & Li, M.L., 2011. Blending water -
 550 soluble aliphatic–aromatic copolyester in starch for enhancing the adhesion of
 551 sizing paste to polyester fibers. Journal of the Textile Institute. 102 (8),
 552 681-688.

553 Khansari, S., Sinha-Ray, S., Alexander, L.Y., Pourdeyhim, B., 2013.
 554 Biopolymer-Based Nanofiber Mats and Their Mechanical Characterization.
 555 Ind. Eng. Chem. Res. 52 (43), 15104-15113.

556 Kim, J. R., Sharma, S., 2012. The development and comparison of bio-thermoset

557 plastics from epoxidized plant oils. *Ind. Crop. Prod.* 36(1), 485-499.

558 Kumar, R., Choudhary, V., Mishra, S., Varma, I.K., Mattiason, B., 2002. Adhesives
559 and plastics based on soyprotein products. *Ind. Crop. Prod.* 16 (3), 155-172.

560 Lacasse, K., Werner, B., 2004. *Textile Chemicals: Environmental data and facts.*
561 Springer Science & Business Media, Germany.

562 Matthews, L.B., Kunkel, M.E., Acton, J.C., Ogale, A.A., Dawson, P.L., 2011.
563 Bioavailability of Soyprotein and Corn Zein Films. *Food and Nutrition*
564 *Sciences.*

565 Ma, B.M., Li, X., Qin, A.W., He, C.J., 2013. A comparative study on the chitosan
566 membranes prepared from glycine hydrochloride and acetic acid. *Carbohydr.*
567 *Polym.* 91(2), 477-482.

568 Peng, S., Gao, Z., Sun, J., Yao, L., Qiu, Y., 2009. Influence of argon/oxygen
569 atmospheric dielectric barrier discharge treatment on desizing and scouring of
570 poly (vinyl alcohol) on cotton fabrics. *Appl. Surf. Sci.* 255(23), 9458-9462.

571 Rahman, M.M., Netravali, A.N., Tiimob, B.J., Rangari, V.K., 2014. Bioderived
572 “Green” Composite from Soyprotein and Eggshell Nanopowder. *ACS Sustain.*
573 *Chem. Eng.* 2 (10), 2329-2337.

574 Reddy, N., Hu, C.Y., Yan, K., Yang, Y.Q., 2011. Acetylation of corn distillers dried
575 grains. *Appl. Energy.* 88 (5), 1664-1670.

576 Reddy, N., Zhang, Y., Yang, Y.Q., 2013. Corn distillers dried grains as sustainable and
577 environmentally friendly warp sizes. *ACS Sustain. Chem. Eng.* 1 (12),
578 1564-1571.

579 Reddy, N., Chen, L.H., Zhang, Y., Yang, Y.Q., 2014. Reducing environmental
 580 pollution of the textile industry using keratin as alternative sizing agent to poly
 581 (vinyl alcohol). *J. Clean Prod.* 65, 561-567.

582 Robert, A.M., David B.J., Kevin, B.H., 2014. Corn ethanol-higher value coproducts
 583 and recovery of corn oil.
 584 http://bioenergy.illinois.edu/news/biorefinery/pp_moreau.pdf (accessed Oct 20,
 585 2015)

586 Rouse, J.G., Mark, E., Van, D., 2010. A review of keratin-based biomaterials for
 587 biomedical applications. *Materials* 3 (2), 999-1014.

588 Salam, A., Lucia, L.A., Jameel, H.A., 2015. New Class of Biobased Paper Dry
 589 Strength Agents: Synthesis and Characterization of Soy-Based Polymers. *ACS*
 590 *Sustain. Chem. Eng.* 3 (3), 524-532.

591 Samaha, S. H., Nasr, H. E., Hebeish, A., 2005. Synthesis and characterization of
 592 starch-poly (vinyl acetate) graft copolymers and their saponified form. *J.*
 593 *Polym. Res.* 12(5), 343-353.

594 Sanchez, A.C., Popineau, Y., Mangavel, C., Larre, C., Gueguen, J., 1998. Effect of
 595 different plasticizers on the mechanical and surface properties of wheat gliadin
 596 films. *J. Agr. Food Chem.* 46 (11), 4539-4544.

597 Selling, G.W., Hojilla-Evangelista, M.P., Evangelista, R.L., Isbell, T., Price, N., Doll,
 598 K.M., 2013. Extraction of proteins from pennycress seeds and press cake. *Ind.*
 599 *Crop. Prod.* 41, 113-119.

600 Sessa, D.J., Selling, G.W., Willett, J.L., Palmquist, D.E., 2006. Viscosity control of

601 zein processing with sodium dodecyl sulfate. *Ind. Crop. Prod.* 23(1), 15-22.
 602 Shaw, C.B., Carliell, C.M., Wheatley, A.D., 2002. Anaerobic/aerobic treatment of
 603 coloured textile effluents using sequencing batch reactors. *Water Res.* 36(8),
 604 1993-2001.
 605 Sun, X.S., 2011. Isolation and processing of plant materials. In *Bio-Based Polymers*
 606 and Composites, Wool, R., Sun, X.S. Eds, Academic Press, U.S.
 607 Tian, H.F., Liu, D.G., Zhang, L., 2009. Structure and Properties of Soyprotein Films
 608 Plasticized with Hydroxyamine. *J. Appl. Polym. Sci.* 111 (3), 1549-1556.
 609 Tuck, C. S., Latham, A., Lee, P. W., Barone, J. R. 2014. Wheat gluten plasticized with
 610 its own hydrolysate. *J. Polym. Environ.* 22(4), 430-438.
 611 Vieira, M.G.A., da Silva, M.A., dos Santos, L.O., Beppu, M.M., 2011. Natural-based
 612 plasticizers and biopolymer films: A review. *Eur. Polym. J.* 47 (3), 254-263.
 613 Wang, S., Sue, H.J., Jane, J., 1996. Effects of polyhydric alcohols on the mechanical
 614 properties of soyprotein plastics. *J. Macromol. Sci. A.* 33 (5) 557-569.
 615 Xu, Y. X., Hanna, M. A., 2009. Synthesis and characterization of hazelnut oil-based
 616 biodiesel. *Ind. Crop. Prod.* 29(2), 473-479.
 617 Xu, H., Cai, S., Xu, L. and Yang, Y., 2014. Water-stable three-dimensional ultrafine
 618 fibrous scaffolds from keratin for cartilage tissue engineering. *Langmuir*, 30
 619 (28) 8461-8470.
 620 Xu, H., Liu, P., Mi, X., Xu, L. and Yang, Y., 2015. Potent and regularizable
 621 crosslinking of ultrafine fibrous protein scaffolds for tissue engineering using
 622 a cytocompatible disaccharide derivative. *J. Mater. Chem. B*, 3 (17)

623 3609-3616.

624 Yang, Y.Q., Reddy, N., 2013. Potential of using plant proteins and chicken feathers
625 for cotton warp sizing. *Cellulose*. 20 (4), 2163-2174.

626 Yao, K.J., Tang, C.B., 2013. Controlled polymerization of next-generation renewable
627 monomers and beyond. *Macromolecules* 46 (5), 1689-1712.

628 Zhang, X., Li, W.L., 2003. Synthesis and properties of graft oxidation starch sizing
629 agent. *J. Appl. Polym. Sci.* , 88(6), 1563-1566.

630 Zhao, Y., Jiang, Q.R., Xu, H.L., Reddy, N., Xu, L., Yang, Y.Q., 2014.
631 Cytocompatible and water - stable camelina protein films for tissue
632 engineering. *J. Biomed. Mater. Res. B*. 102 (4), 729-736.

633 Zhao, Y., Zhao, Y.Z., Xu, H.L., Yang, Y.Q., 2015a. A Sustainable Slashing Industry
634 Using Biodegradable Sizes from Modified Soyprotein To Replace Petro-Based
635 Poly (Vinyl Alcohol). *Environ. Sci. Technol.* 49 (4), 2391-2397.

636 Zhao, Y.Z., Zhao, Y., Yang, Y.Q., 2015b. Modified soyprotein to substitute
637 non-degradable petrochemicals for slashing industry. *Ind. Crop. Prod.* 67
638 466-474.

639 Zhu, Y., Douglass, E., Theyson, T., Hogan, R., Kotek, R., 2013. Cellulose and
640 Soyproteins Based Membrane Networks. *Macromolecular Symposia*. 329(1),
641 70-86.

642

Figure captions

Fig. 1. Preparation of soymeal sizes and protein/oil-free solubles from soymeal.

Fig. 2. FTIR spectra of soyprotein and solubles from soymeal.

Fig. 3. HPLC chromatograms of a) protein-free solubles from soymeal sizes b) standard glucose c) standard sucrose d) standard glycerol. The sample (15 μ l) was injected and eluted at a flow rate of 0.6 mL/min at 65 °C.

Fig. 4. Effect of protein-free solubles and saponified oil in soymeal sizes on tensile properties of soyprotein isolates films. a) protein-free solubles from soymeal sizes; b) saponified soy oil. Data points with different numbers, letters, or symbols indicate statistically significant difference.

Fig. 5. Digital images of films from a) control soyprotein isolates (alkali treated SPI); b) control SPI + protein/oil-free solubles from soymeal sizes; c) control SPI + saponified soy oil; d) soymeal sizes. Films were observed after drying at 140 °C for 15 min.

Fig. 6. Change in viscosity of sizing pastes from soymeal, PVA and soyprotein isolates during 4.5 hr heating at 90 °C. Soymeal: soymeal sizes with extra 10% saponified oil; Soyprotein isolates: soyprotein isolates sizes (SPI with 20 wt.% triethanolamine).

Fig. 7. Adhesion of sizing agents to a) polyester fabrics; b) cotton fabrics; c) polyester/cotton (50/50) fabrics. Soyprotein isolates: soyprotein isolates sizes (SPI with 20 wt.% triethanolamine); soymeal: soymeal sizes with extra 10% saponified oil. Data points with same numbers, letters, or symbols indicate no statistically significant

difference.

Fig. 8. Effect of sucrose on adhesion of soyprotein sizing paste to cotton, poly-cotton and polyester. Add-on on polyester, cotton and poly-cotton (50/50) fabrics was 11.2%-15%, 12%-16% and 12%-15.7%. Data points with different numbers, letters, or symbols indicate statistically significant difference.

Fig. 9. Abrasion resistance of sized a) polyester yarns; b) cotton yarns; c) polyester/cotton (50/50) yarns. Soyprotein isolates: soyprotein isolates sizes (SPI with 20 wt.% triethanolamine); soymeal: soymeal sizes with extra 10% saponified oil . Data points with different numbers, letters, or symbols indicate statistically significant difference.

Fig. 10. Changes in a) chemical oxygen demand (COD) b) Five-day biochemical oxygen demand (BOD₅) c) Total and ammonia nitrogen of PVA, soyprotein isolates (with 20% TEA) and soymeal sizes treated in activated sludge for 5 days. Data points with different numbers, letters, or symbols indicate statistically significant difference.

681 **Table 1** Compositions of soymeal and soymeal sizes

Items	Protein content %	Protein-free Solubles %	Soy oil %	Saponified oil %
Soymeal	47.02 ± 0.22	33.99 ± 1.2	2.3 ± 0.2	0
Soymeal sizes	52.18 ± 0.45	40.68 ± 0.8	0.02±0.003	~2.2

682 *moisture percentages of soymeal and soymeal sizes particles are 10.62% ± 0.11%
683 and 4.95% ± 0.15%.

684

Table 2 Comparisons of tensile properties of soymeal films, soyprotein isolate films and PVA films.

Films	wt.% of additives	Elongation (%)	Strength (MPa)	Work of rupture (mJ)
Soymeal sizes	-	78.8±16.3 ^a	5.5±0.4 ^A	9.5±1.5 [#]
Soymeal sizes	10% saponified oil	214.7±16.2 ^c	4.7±0.2 ^B	14.0±0.5 [^]
Soymeal sizes	5% TEA	146.6±9.7 ^b	3.3±0.2 ^C	8.3±1.2 [#]
Soyprotein isolates	20% TEA	165.0±5.1 ^c	9.9±0.3 ^D	21.2±0.9 ^{&}
PVA sizes	-	150.2±4.3 ^b	24.1±0.7 ^E	50.1±1.1 ⁺

* wt.% of additives based on weight of solid soymeal sizes, soyprotein isolates of PVA. Data points with the same letter or symbol indicate no statistically significant difference.

Table 3 Comparison of the desizability (percent size removed) for soymeal and PVA treated polyester, poly-cotton and cotton fabrics at various desizing conditions.

Types of fabrics	Desizing temperature, °C	% Size removed	
		Soymeal	PVA
Polyester	90	99.93 ± 0.02	94.51 ± 2.58
	20	99.37 ± 0.58	72.88 ± 4.26
Polyester/cotton 50/50	90	98.28 ± 0.51 ^a	98.22 ± 1.61 ^a
	20	95.62 ± 0.88	88.69 ± 3.89
Cotton	90	92.06 ± 1.01	99.81 ± 0.11
	20	90.52 ± 0.94 ^b	90.33 ± 1.25 ^b

1 cycles of wash and 1 cycle of rinse for 5 min respectively. Wash ratio and rinse ratio (liquor to fabrics) were 10:1 and 5:1 respectively. Add-on of woven fabric is 9.3 wt.% to 11.6 wt.%. Soymeal: soymeal extractant with 10 wt.% saponified oil. Data points with the same letters indicate no statistically significant difference.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10