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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

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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.

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 1000,000 t 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 and Li, 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

* Corresponding author at: Department of Textiles, Merchandising & Fashion Design, University of Nebraska-Lincoln, Lincoln, NE 68583-0802, USA.
E-mail address: yyang2@unl.edu (Y. Yang).

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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 1000,000 t 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 t 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, 2011), 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. (2006) and Cuq et al. (1997) reported that sugars, such as glucose, galactose and fructose could plasticize zein films . 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 et al., 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.

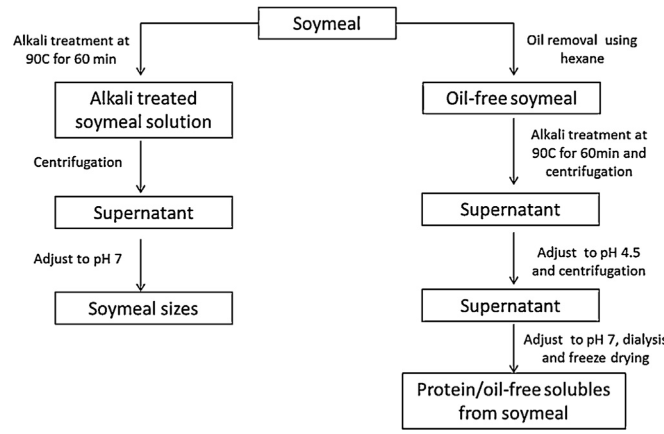

Fig. 1. Preparation of soymeal sizes and protein/oil-free solubles from soymeal.

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.

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 h (Kumar et al., 2002). Then, the meal was air-dried in a fume hood for 12 h 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 h. Finally, the protein/oil-free solubles were collected by freeze drying.