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Soy protein-fortified expanded extrudates: Baseline study using normal corn starch

Normell Jhoe E. de Mesa [a,*], Sajid Alavi [a], Narpinder Singh [b], Yong-Cheng Shi [a], Hulya Dogan [a], Yijun Sang [a]

[a] Department of Grain Science and Industry, Kansas State University, 201 Shellenberger Hall, Manhattan, Kansas 66506, United States
[b] Department of Food Science and Technology, Guru Nanak Dev University, Amritsar-143 005, India

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ABSTRACT

Soy protein supplementation increases the nutritional value of starch-based expanded snacks. A systematic study was conducted to serve as baseline for optimizing the addition of soy protein concentrate (SPC). Physical and microstructural properties of native corn starch–soy protein concentrate (CS–SPC) extrudates were investigated in relation to the macromolecular changes in starch during extrusion. The effects of extruder screw speed (230 and 330 rpm) and SPC concentration (0%, 5%, 10%, 15%, 20%) on the abovementioned parameters were determined. Increasing screw speed resulted in higher specific mechanical energy (SME) and expansion, and lower mechanical strength. On the other hand, addition of 5–20% SPC led to lower SME and expansion, and higher mechanical strength. X-ray micrographs showed smaller yet more cells, and cell wall thickening with SPC addition. Water absorption index increased and water solubility index decreased with increase in screw speed and SPC level. Increasing screw speed resulted in a slight shift towards smaller molecular weight fractions of starch, as determined by gel permeation chromatography.

1. Introduction

Soy protein is widely used in food applications due to its functionality and health benefits (Liu, 1997; Riaz, 2006). Effective October 1999, the US Food and Drug Administration has approved the use of soy protein health claims on food labels based on human intervention studies and clinical trials that show a high association between consumption of soy protein and the reduced risk of coronary heart disease (e-CFR 101.82, 1999). In addition to the cholesterol lowering effect of soy protein, it has anticarcinogenic effects, and it deters obesity, diabetes, digestive tract irritation, and bone and kidney diseases (Friedman and Brandon, 2001; Messina and Barnes, 1991).

While starch is the primary ingredient in expanded breakfast cereals and snacks, soy protein can enhance the nutritional value of these products. Incorporation of soy protein can significantly impact the mechanical, physico-chemical and microstructural properties of foods. Several studies have investigated the addition of soy protein to extruded starch products with conflicting results (Chang et al., 2001; Faubion and Hosney, 1982; Ghorpade et al., 1997; Li et al., 2007; Zasypkin and Lee, 1998). Chang et al. (2001) found that radial expansion increased on addition of up to 25% SPC to a cassava starch-based matrix. Further addition of SPC decreased the radial expansion. Additionally, with increasing soy protein concentrate, hardness decreased, water absorption index (WAI) increased, and water solubility index (WSI) decreased. Faubion and Hosney (1982) reported that the expansion of wheat starch with 1–8% soy protein isolate was higher than that of pure starch. However, at 10% soy protein isolate, expansion decreased. Ghorpade et al. (1997), on the other hand, showed that increasing the percentage of soy protein isolate from 10% to 30% in corn starch extrudates did not significantly affect bulk density and the percentage of open pores. Zasypkin and Lee (1998) showed that increasing the proportion of soybean flour to 10% in a wheat flour-soybean flour blend resulted in a decrease in expansion ratio (ER) at 16% in-barrel moisture content (MC), and an increase in ER at 17–18% MC. Further addition of soy flour up to 40% led to continuous decrease in expansion ratio. Beyond 40%, the trends for ER were again dependent on MC and also a possible phase inversion occurring beyond that level of soy flour. Li et al. (2005) reported that the addition of soybean flour to corn meal in the range of 0 to 40% increased ER. They also found significant interactions between MC and soy flour levels.

In addition to ingredient composition, processing parameters, such as MC and screw speed, also affect extrudate properties. Effect of MC has already been discussed above. By modeling the behavior of ER as a function of screw speed, soybean flour concentration and MC, Li et al. (2005) showed that the highest ER can be achieved at 200 rpm, and that increasing screw speed to 275 and 350 rpm resulted in a drop in expansion. These results are in contrast to those of Seker (2005) who reported enhanced expansion with increasing screw speed.

* Corresponding author. Tel.: +17855324073; fax: +17855324017.
E-mail address: jhoe@ksu.edu (N.J.E. de Mesa).

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From the preceding discussion, it is clear that while studies have been done on the effect of formulation and process variables on expanded extrudates based on starch and soy protein, results have been conflicting and the underlying mechanism impacting the physico-chemical properties of these extrudates is unclear. Molecular level changes in starch and soy protein, and their interaction during extrusion are also not well understood. Hence, a systematic investigation on the interactions between starch and soy protein is needed to serve as a baseline. This would assist in maximizing soy protein levels in extrusion-puffed foods, either through starch modification or process improvement. The specific objective of this study was to evaluate the physical and microstructural characteristics of expanded extrudates based on native corn starch–soy protein concentrate blends, and relate these to the macromolecular changes in starch during extrusion. The latter was achieved using gel permeation chromatography (GPC) and standard measurements of water absorption and solubility indices. GPC helped in assessing the changes in starch molecular weight distribution brought about by extrusion.

2. Materials and methods

2.1. Materials

Unmodified corn starch (CS) had ~25% amylose and 75% amylopectin (Cargill Gel 03457, Cargill, Inc., Minneapolis, MN) and soy protein concentrate (SPC) had 71% protein, db (Procon™ 2000, The Solae Company, St. Louis, MO). CS–SPC blends were prepared using a batch ribbon blender (Wenger Manufacturing, Sabetha, KS), in the following ratios – 100:0, 95:5, 90:10, 85:15 and 80:20.

2.2. Extrusion system

A Wenger TX-52 twin-screw extruder (Wenger Manufacturing, Sabetha, KS), with screw diameter of 52 mm, L/D ratio of 16:1, and a circular die with an opening of 4.75 mm was used to process all the blends. The extruder barrel had six heads, with the first five measuring 156 mm each in length and the last measuring 78 mm. The barrel temperatures and screw profile are shown in Fig. 1. The CS–SPC blends were extruded at two screw speeds, 230 and 330 rpm. The dry raw material feed rate was 75 kg/h. Water flow into the preconditioner and extruder were 5.0 kg/h and 4.7 kg/h, respectively, to achieve an in-barrel moisture of 22% (wb). Extruder conditions were allowed to stabilize for approximately 10 min before samples were collected. Ribbons of samples were collected from the extruder, dried at 55 °C for 3 h in a Thelco Laboratory Oven (Model 160 DM, Precision Scientific, Chicago, IL), and cut into 2.0 cm lengths.

2.3. Specific mechanical energy (SME)

The mechanical energy input per unit mass of extrudate was calculated as follows

$$\mathrm{SME} = \frac{\frac{(\tau-\tau_0)}{100} \times P_{\mathrm{rated}} \times \frac{N}{N_{\mathrm{rated}}}}{\dot{m}} \quad (1)$$

where τ is the measured torque, τ_0 is the no-load torque (assumed to be 0%), P_{rated} is the rated power for the extruder (22.37 kJ/s), N is the measured extruder screw speed in rpm, N_{rated} is the rated extruder screw speed (336 rpm), and $\dot{m}$ is the mass flow rate (75 kg/h).

2.4. Measures of expansion

Bulk density (BD) was obtained by taking the weight of the 2 cm samples (w_{sample}) that filled a specified volume ($V_{\mathrm{container}}$ = 1 L). The average of three measurements was taken and BD was computed as in Eq. (2).

$$\mathrm{BD} = \frac{w_{\mathrm{sample}}}{V_{\mathrm{container}}}. \quad (2)$$

Piece densities (ρ) were obtained by dividing the mass of the sample (w_{piece}) by its volume (V_{piece}). The latter was computed based on piece dimensions (diameter, d and length, l) measured using digital calipers (Digimatic Solar, Mitutoyo, Japan). Ten 2 cm long pieces were measured, and for each piece, the average of two diameter measurements was recorded. Eq. (3) shows the formula used.

$$\rho = \frac{w_{\mathrm{piece}}}{V_{\mathrm{piece}}} = \frac{4w_{\mathrm{piece}}}{\pi d^2 l} \quad (3)$$

Sectional expansion ratio (ER) was computed using Eq. (4).

$$\mathrm{ER} = \frac{d^2}{d_{\mathrm{die}}^2} \quad (4)$$

where d_{die} is the die diameter and d is the extrudate diameter.

2.5. Image acquisition and void fraction

Representative samples from each treatment were selected for image analysis. A desktop X-ray microtomography (XMT) imaging system (Model 1072, SkyScan, Aartselaar, Belgium) was used to scan the samples. The XMT was set at 20 kV/100 μA to obtain optimum contrast between solid and gaseous phases. For each sample, a set of three two-dimensional virtual "slices" were obtained after reconstruction. Calculations of cellular parameters were made using an image analysis software (Sigma Scan Pro, Systat, San Jose, CA). The total void area (A_{void}) and cell wall area ($A_{\mathrm{cell\ wall}}$) were processed by the software, and the data were used to calculate void fraction (VF), as shown in Eq. (5). Details of XMT scanning, image reconstruction, thresholding, and microstructural parameters have been described previously (Trater et al. 2005).

$$\%\mathrm{VF} = \frac{A_{\mathrm{void}}}{A_{\mathrm{void}} + A_{\mathrm{cell\ wall}}} \times 100 \quad (5)$$

2.6. Mechanical properties

Force-deformation data for each extrudate were obtained using a Texture Analyzer (Model TA-XT2*i*, Stable Micro Systems, Surrey, United Kingdom) fitted with a 25 kg load cell and a 38 mm diameter test probe. Using the compression mode, samples were compressed to 70% of their original height (20 mm) at a test speed of 10 mm/s. Thirty measurements were taken for each treatment. A force-deformation curve was obtained, and the number of peaks, n, integral of the curve, S (or area below the curve from 0% to 70% strain) and distance of compression, x, were computed. Using n, S and x values, average crushing force (F_{cr}) and crispness work (W_{c}) were calculated (Bouvier et al. 1997).

$$F_{\mathrm{cr}} = \frac{S}{x}(\mathrm{N}) \quad (6)$$

$$W_c = \frac{S}{n}(\mathrm{N\ mm}) \quad (7)$$

2.7. Water absorption and solubility indices

The procedure used by Gujral and Singh (2002) was used to determine the water absorption (WAI) and water solubility (WSI) indices. The extrudates were ground and sifted using a 250 μm sieve. Ground samples ($w_{\mathrm{dry\,solid}}$, 2.5 g) were dispersed in 25 mL