Extrusion of Soybean and Wheat Flour as Affected by Moisture Content

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ABSTRACT

The effect of moisture content (MC) on texture and properties of extrudates with varied ratios of soybean flour (SF) and wheat flour (WF) was studied. A single-screw extruder was used at screw speed 200 rpm. MCs of blends were 16, 17 or 18%, w.b. The properties of extrudates depended on flow rate of the material during extrusion. The flow rate revealed a nonlinear dependence on the blend composition and the MC at the same volume of filling of the screw feeding section. The expansion ratio of WF or SF extrudates increased with lowering of the MC. Unexpectedly, the expansion ratio decreased with lower MC for the composite extrudates. Optimal extrudate properties at 16% (w.b.) MC corresponded to 80, 90 or 100% (d.b.) WF and 20, 10% or no SF, respectively. At 17 and 18% MC, optimal properties were found for products containing 80 or 90% WF and 20 or 10% SF, respectively.

Key Words: soybean flour, wheat flour, soy/wheat blends, extrusion

INTRODUCTION

CURRENTLY, WE ARE DEVELOPING FOOD PRODUCTS BASED ON SOY and wheat for onboard food production during long-term manned space missions. It is critical for space missions and Advanced Life Support (ALS) systems to expand the number of products which can be produced from limited crops (Bourland, 1993; Fu et al., 1995). A compact single-screw extruder could be useful in developing a range of acceptable textured foods. Textured soybean proteins and puffed wheat flour are well-known products fabricated by HTST-extrusion (Faubion and Hoseney, 1982a; Harper, 1989). In addition to single component extrudates, a product based on a blend of soybean and wheat flour could be developed. Such composite extrudates comprised of complementary proteins could have increased nutritional value, and better textural or other functional properties. The concept of soybean/wheat blends has been considered for bread (Tsen and Hoover; 1973, Ranhotra and Loewe, 1974), pasta (Morad et al., 1980) and other products (Snider and Kwon, 1987). We tested this concept for application to ready-to-eat extrusion products.

With a model system of soybean protein isolate (SPI) and potato starch, Yuriev et al. (1995) showed that their blending markedly improved the texture and functional properties of the expanded extrudates. The addition of 10–40% w/w SPI to starch increased an expansion ratio of the composite extrudates, especially at higher shear rates. This effect was also found for wheat gluten/potato starch blends (Yuriev et al., 1994). Textural modifications of extrusion products through blending of the components were reported for several blends by Nyanzi and Maga (1992), Sotillo et al. (1994), and Valle et al.(1994). In many cases, the increased expansion ratio correlated with better texture of the products. Besides biopolymer composition, water content of an extruded raw material is critical for the process (Camire et al., 1991; Falcone and Phillips, 1988; Faubion and Hoseney, 1982b). However the effect of moisture content on the extrusion of blends has not been reported in detail.

The objective of our study was to investigate the effects of moisture content on the processing of soybean flour/wheat flour blends with a single-screw extruder and subsequently the development of puffed extrudates with optimum textural and other qualities.

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MATERIALS & METHODS

Blend preparation

Whole bran wheat flour (WF) (wheat-a-laxa) and defatted soybean flour (SF) were purchased from General Mills, Inc. and ADM, respectively. According to their specifications, wheat flour contains 13.8% protein, 70% carbohydrates and 2.0% fat (d.b.). The granular composition was as follows: on a US #20 sieve, there was about 11% flour; #45, 14%; #80, 20%; and #120, 18%. Thirty-seven percent of the flour passed through a US #120 sieve. The defatted soybean flour contained 55.6% protein, 36.6% carbohydrates and 1.3% fat.

WF and SF powders were mixed at various weight ratios, and the total moisture contents of the blends were adjusted to the desired values with a KitchenAid mixer (model K5SS, KitchenAid Inc., St. Joseph, MI). Weights of the components to be mixed were calculated according to the following formula:

$$c_{SF} = [r_{SF}*M*(100 - w)]/[100*(100 - w_{SF})]$$
$$c_{WF} = [r_{WF}*M*(100 - w)]/[100*(100 - w_{WF})]$$
$$w_x = M - c_{SF} - c_{WF}$$

where c_{SF} or c_{WF} was mass of SF or WF powder, respectively, r_{SF} or r_{WF} was a percentage of SF or WF in the blend, d.b. ($r_{SF} + r_{WF} = 100\%$); M was the total mass of the blend; w, the moisture of the final blend, %, w.b.; w_x was the water to be added; and w_{SF} and w_{WF} were the moisture of SF and WF, respectively.

The wet materials were stored in sealed plastic bags for 24h at 5°C prior to extrusion. The moisture content of the blends was measured by drying the samples to a constant weight in a vacuum oven at 105°C. We found that the MC of a blend fell into the range [x−0.4%, x], where x was a calculated MC. A somewhat lower MC was probably due to evaporation during mixing. The MC of a blend was measured twice and the difference was 0.1% in most cases and 0.2% for the rest. For MC, we refer to calculated values.

Extrusion

A single-screw laboratory extruder, (model 2003, L/D 20:1, C.W. Brabender Instruments, Inc., South Hackensack, NJ) was used to process the SF/WF blends. The compression ratio of the screw was 3:1. The screw had a linearly tapered rod and 20 equidistantly positioned flights. The screw speed was kept constant at 200 rpm. The selected screw speed was close to maximal (240 rpm), providing maximal output. The temperature of the feed zone was 60°C, and the temperature of the metering zone and extruder die was 160–165°C. The extruder was fed manually through a conical hopper, keeping the flights of the screw filled and avoiding accumulation of the material in the hopper. This type of feeding provided the close to maximal flow rate for the selected process parameters and for a composition of the extruded material. For a specific composition, the process was stabilized and the flow rate was constant (unless otherwise indicated) within 3 to 5 min. Measurements were taken after a 10 min run. The feeding rate in the stable process was a sole function of the material composition.

A round channel die with a separate infolding heater was used (Fig. 1). The die had a channel with a 45-degree entrance angle, a 3-mm diameter and a 90-mm length.

Measurements

The mass flow rate (Q_M) was calculated as the mass of material extruded per minute. Calculations were made from the data on the product output (Q_E) and the moisture of the product (extrudate) (w_E, % w.b.) according to the following formula:

$$Q_M = Q_E [(100 - w_E)/(100 - w).$$

Water contents of the samples and the product output, determined as mass of the final product were measured about 1h after extrusion. Water content was measured by drying the samples to a constant weight under vacuum at 105°C.

Expansion ratio of the extrudates (E) was calculated as:

$$E = D/D_o$$

where *D and* D_o were the diameters of the extrudate and the die channel, respectively.

The textural properties of the extrudates were evaluated with a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY). A three-point bend rig with a support length (bridge) of 30 mm and a rounded plate probe (15 mm × 5 mm, R=5 mm) exerting force in the middle of the bridge were used to test extrudates in the bend mode (Vickers, 1987; Vickers and Christensen, 1980). The deformation rate was 0.1 mm/s. Data were processed with an XT-RA Dimension software package (Stable Micro Systems, Haslemere, Surrey, UK). Failure force and deformation corresponding to the maximal exerted force were measured. Failure stress was calculated as a maximal force divided by a cross-section area of the samples at the point of failure. An initial slope of the stress-deformation curve was calculated. This will be referred to as an apparent elastic module of the extrudates.

Color evaluation

Extrudates were milled with a compact impact mill (model ZM1, GlenMills Inc., Maywood, NJ) equipped with a screen (0.12 mm hole size). The color space parameters L*, a* and b* of the powders were measured with a Minolta Chroma Meter using a CR-210 measuring head (Minolta Corp., Ramsey, NJ).

Calculations

Mean values are presented with a confidence interval calculated at P=0.95. Mean values were calculated from two measurements for the product output, two for the extrudate water content, nine for the expansion ratio, seven for the failure force and deformation, from three readings (one sample) for the color space parameters.

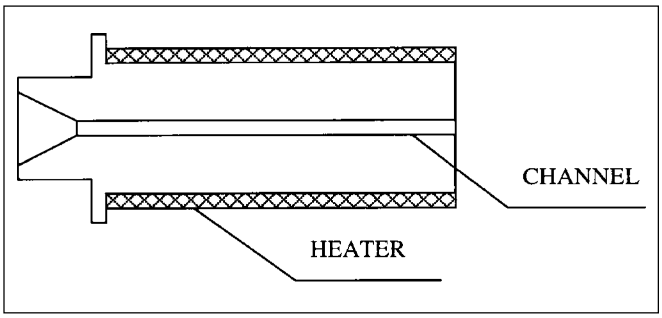

Fig. 1—A simplified diagram of the extruder die.

RESULTS & DISCUSSION

THE FLOW RATE REVEALED AN ESSENTIALLY NONLINEAR DEPENdence on blend composition at a fixed water content (Fig. 2). The dependencies were rather similar at various water contents. Maximum values of flow rate were observed for SF or WF alone while the minimum values corresponded to intermediate compositions. The flow rate was higher for WF as compared to that of SF.

A nonlinear behavior of flow and feeding rate vs blend composition is the important feature of the single-screw extruder. When the process parameters and the extruder geometry are selected, the rheological properties of material determine the feeding and flow rate in a stable extrusion process rather than the feeding rate controlling the flow rate. At a lower feed rate the extrusion process might be unstable, while overfeeding would lead to an accumulation of material in the feeder.

From the nonlinear behavior of the flow rate we concluded that rheological properties of the extruded blends did not depend linearly on the mass or the volume fractions of the components in the blends. This may indicate a multiphase character of the melt in the extruder (Yuriev et al., 1995; Zasypkin et al., 1992). The minimum flow rate at the intermediate blend compositions (50–70% WF in the blends) could be assigned to a phase inversion that is a transition from the protein-rich (soybean) continuous phase to the polysaccharide-based (wheat starch) one. As clearly demonstrated with a model system comprised of SPI and potato starch (Zasypkin et al., 1992), the transition from a continuous protein phase filled with starch particles to a continuous starch phase filled with protein particles occurred at around 60% starch. In the area of compositions corresponding to a phase inversion, the continuous phase does not exist in the entire system. This was probably why lowest flow rates (Fig. 2) were at 50–70% WF in the blends. The decreasing water content in the blends further complicated the extrusion process, and lowered the flow rate to almost zero.

The effect of blend composition on product output was followed (Table 1). The dependencies of the product output on blend composition (not shown) were similar to those of flow rate although a vapor release at the die outlet lowered the product output in comparison with the flow rate. The lower water content of the blends decreased both the flow rate and the product output for SF or WF alone as well as for most but not all blends (Fig. 2, Table 1).

The expansion ratio of extrudates vs the blend composition were

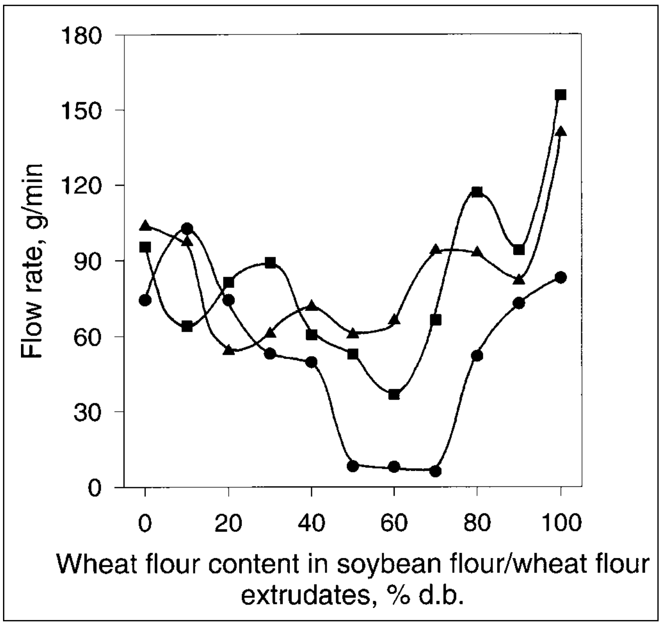

Fig. 2—Flow rate at the die exit as related to wheat flour content in extruded soybean flour/wheat flour blends. ● 16%, ■ 17%, ▲ 18% w.b. of moisture content in extruded blends.

Table 1—Product output (g/min) at different compositions and water contents of the extruded SF/WF blends

Wheat flour % d.b.	16% water, w.b.	17% water, w.b.	18% water, w.b.
0	67.9	89.0	94.8
10	92.9	59	88.1
20	66.9	75.5	49.1
30	47.7	81.5	55.1
40	45.2	55.6	65.1
50	7.5	48.4	55.3
60	7.2	33.7	60.1
70	5.5	60.7	85.1
80	47.4	106.5	83.6
90	66.2	86	74.1
100	75.6	143.7	128.6

compared (Fig. 3). The addition of 10% WF to SF promoted a decrease in expansion ratio while 10% SF markedly increased the expansion ratio, except at a 16% moisture content where WF extrudates revealed the highest expansion ratio. The supposed phase inversion lowered the expansion ratio at around 60% WF in the blends, which was more pronounced when the moisture content was decreased. The expansion ratio of the extruded SF or WF alone increased with a lowering water content while for extruded blends expansion ratio remained the same or was lower. Falcone and Phillips (1988) had reported a similar trend for blends of cowpea and sorghum flours, the result of a varied flow rate for the different blends.

The expansion ratio was partially affected by flow rate (Fig. 2 and 3). The flow rate in the range of 20–80% WF positively correlated with the expansion ratio at all levels of moisture. The moisture content of extrudates in the range of 30–80% WF in the blends was above the minimum value. There was no simple correlation between flow rate and expansion ratio for WF or SF alone or for compositions containing 10% of any component. At 17% and 18% water a sharp increase in flow rate for extrudates containing WF alone was accompanied by a drop in expansion ratio. The relatively low flow rate at 16% moisture allowed the highest expansion ratio for both WF and SF extrudates.

The textures of extrudates were evaluated at 16% moisture in the extruded blends. These extrudates had higher expansion ratios for WF and SF, the lowest moisture contents and desirable crispness. Texture

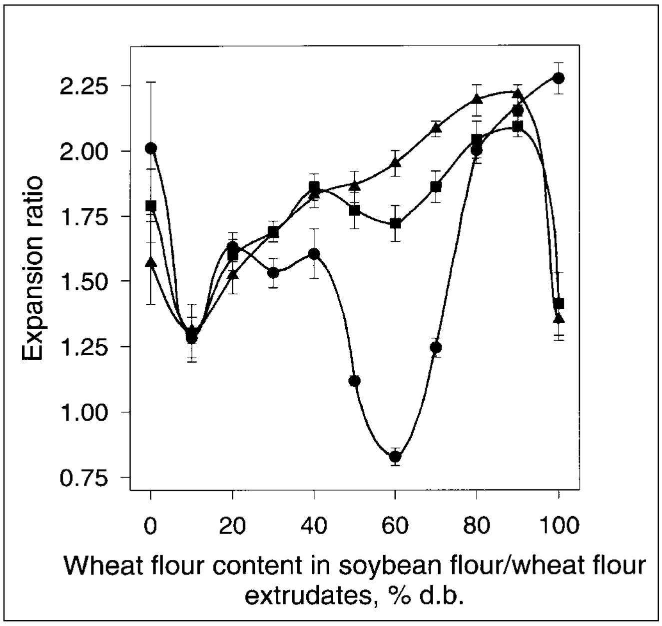

Fig. 3—Expansion ratio of extrudates as related to wheat flour content in extruded soybean flour/wheat flour blends. ● 16%, ■ 17%, ▲ 18% w.b. of moisture content in the extruded blends.

Table 2—L*, a* and b* color parameters of the soybean flour/wheat flour extrudates[a]

Wheat flour % d.b.	0	10	20	30	40	50	60	70	80	90	100
L	80.8	82.2	79.4	71.3	69.6	59.2	60.9	60.1	72.0	77.2	77.9
a	0.69	0.71	2.3	6.3	6.9	11.0	10.3	10.0	5.0	2.39	2.6
b	20.4	20.6	20.8	24.1	23.3	26.3	26.0	25.3	21.6	16.4	15.5

[a]The extruded blends contained 16% w.b. of water before extrusion.

studies revealed the composition sensitivity of failure stress and deformation of the extrudates (Fig. 4). Failure stress was minimal at 80% WF. At the same time, the failure deformation increased with increasing WF above 60%. This combination, along with the increased expansion ratio, provided a desirable crispness. A definite correlation could be found between moisture content of extrudates and apparent elasticity modulus (Fig. 4 and 5). At a lower moisture (corresponding to 10–40% WF, Fig. 5), the modulus was higher and progressively decreased (Fig. 4) with increasing water content in the extrudates at >50% WF. Thus, both structure and moisture content of extrudates affected mechanical properties and texture.

Color parameters of extrudates were compared (Table 2) as an important feature of product appearance. Color is also an indicator of residence time in the extruder and the intensity of the Maillard reaction. Extrudates based on a blend with 16% moisture content were

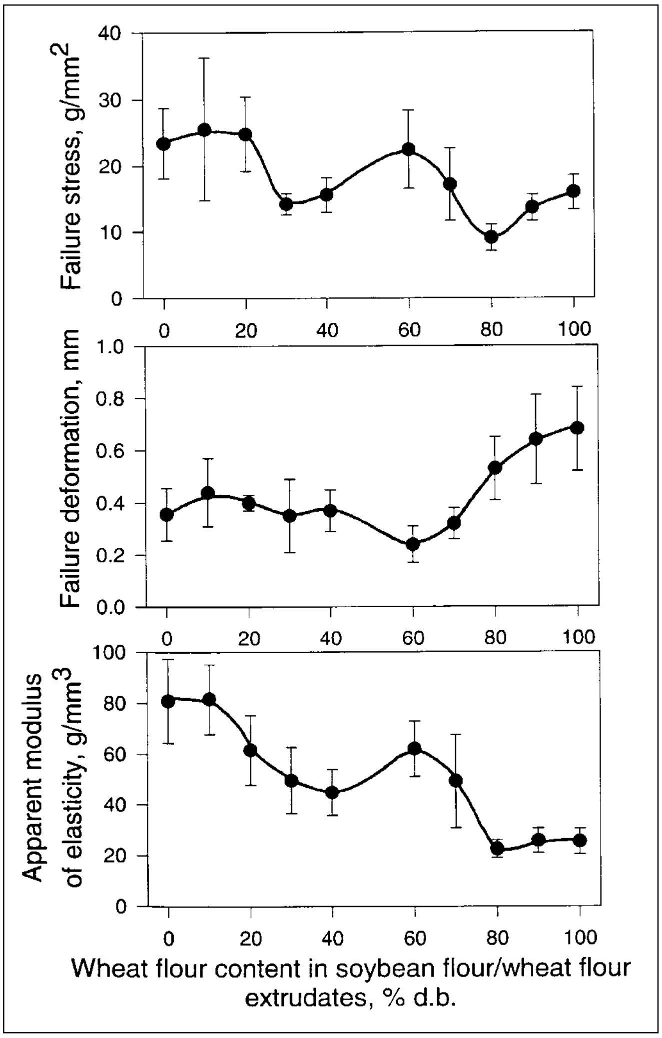

Fig. 4—Failure stress, failure deformation and apparent elasticity modulus of extrudates as related to wheat flour content in extruded soybean flour/wheat flour blends.

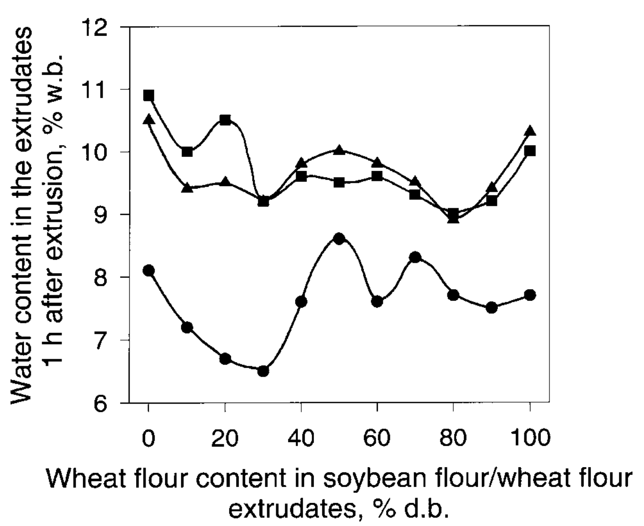

Fig. 5—Moisture content in extrudates 1h after extrusion as related to wheat flour content in extruded soybean flour/wheat flour blends. ● 16%, ■ 17%, ▲ 18% w.b. of moisture content in the extruded blends.

analyzed since they had a better texture and acceptability. The extrudates based on separate components were lighter than the mixed extrudates. The darkest extrudates had compositions in the supposed phase inversion area. These extrudates also displayed the highest levels of red and yellow color components attributed to the dark brown color of the extrudates at 50% and 60% WF. Colors of the extrudates were related to residence times of the materials and correlated with flow rates (Fig. 2). Evidently, lower flow rates promoted development of a darker color, resulting from intensive Maillard reactions. Thus, extrudates based on WF, SF and blends containing up to 20% of any component could be suitable for practical applications.

The expansion and texture formation of extrudates is complex even for products based on a single component. Viscoelastic properties of the melt, mechanism of bubble nucleation and growth, as well as plastisizing properties of water in the transition from fluid (melt) to viscoelastic and subsequently to glassy state, are all important for expansion and final texture of extrudates. Multicomponent and multiphase structure of the melt would modify each of these processes, ultimately affecting expansion and texture of the products.

From data on the extrusion of some synthetic polymers, it is known that multiphase structure promotes an increased elastic recovery when any of the polymers is added to the another (Tsebrenko et al., 1974; Tsebrenko, 1991). The phase inversion usually occurred in the vicinity of 50% of each of the polymers in the blend and markedly lowered expansion. These experiments were conducted in the absence of the product expansion caused by plastisizer release. Data on extrusion of soybean protein or wheat gluten-potato starch blends revealed that the elastic recovery contributed to the total expansion that comprised both elastic recovery and vapor release (Yuriev et al., 1994, 1995). We observed similar results when 10% or 20% SF enhanced expansion of WF and typical minimum was observed around 50% of either component in the blend, which might be due to phase inversion. However, more studies are needed to bridge the gaps in the field of texture formation in composite extrudates.

CONCLUSION

PROPERTIES OF EXTRUDED SF/WF BLENDS IN A SINGLE-SCREW extruder at close to maximal feeding rate depended on the flow rate in the extruder and flow rate depended on feed composition. The dependencies of flow rate and extrudate properties vs feed composition were essentially nonlinear and the multiphase structure and phase inversion in the range of 50–70% WF, were possible explanations of the dependencies. Extruded SF or WF alone increased in expansion ratio by increasing with lowering of moisture content. For blends, expansion ratio remained the same or was lower at lower moisture contents. Mixed extrudates comprised of 80% WF/20% SF, and 90% WF/10% SF or 100% WF had the best texture, highest expansion ratio, longest shelf-life with almost maximal extruder performance at 16% moisture in extruded blends. The higher moisture content resulted in a slight impairment of textural properties of extrudates from 80% WF/20% SF or 90% WF/10% SF blends. The blends had low sensitivity to feed moisture content, therefore process control was simpler than for SF or WF alone. Extruded blends could be the basis for ready-to-eat products and extruded SF alone or blends with up to 20% WF could be used as textured protein.

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