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Physical Properties of Extruded Products as Affected by Cheese Whey

ABSTRACT

Corn, rice and potato flour were extruded with sweet whey solids (SWS) or whey protein concentrate (WPC) using low and high shear extrusion processing conditions. WPC added at product content of 25% had minimal effect on the texture of extruded products. Expansion and breaking strength were improved in some processes through changes in extrusion shear and moisture. Whey product incorporation resulted in reduced specific mechanical energy input to the process. Increasing whey product concentration beyond 25% reduced expansion and water absorption indices significantly, affecting textural hardness. Product quality characteristics were directly related to the whey product content.

Key Words: corn, breaking strength, extrusion, whey proteins, water absorption

INTRODUCTION

MANY SNACK FOODS HAVE LOW NUTRIENT densities and are often fortified with proteins (Singh et al., 1991). Cheese whey products are abundant sources of high quality proteins; their incorporation would provide a balanced protein profile, and thus, value enhancement to extruded foods. Utilization of whey products in foods is still below 50% of total production (Anon. 1994).

Variations in feed composition such as moisture, type of carbohydrate, and protein content directly influence qualities of finished products (Phillips et al., 1984). Addition of small amounts of proteins (< 5%) enhances textural properties of extruded products (Singh et al., 1991). Extrusion cooking of cereals is widely practiced (Della Valle et al., 1995; Barres et al., 1990; Grenus et al., 1993). Fortification with whey proteins to enhance nutritional quality however has been limited due to reported adverse effects when protein supplementation is in significant amounts (> 10%). Inclusion of whey proteins in such quantities tends to reduce expansion, an important textural parameter (Onwulata and Heymann, 1994; Kim and Maga, 1987; Martinez-Serna and Villota, 1992).

Twin-screw extrusion provides the versatility for increasing the production of whey protein fortified products. Textural characteristics of such products and co-products can be improved by low moisture extrusion (Miller, 1985), by changing screw configuration or by adding reverse screw elements (Gogoi et al., 1996). Twin-screw extrusion can enhance mechanical energy transfer, which may help reduce the reported negative textural effects of whey protein substitution in single-screw extrusion (Edemir et al., 1992; Barres et al., 1990). Therefore, our objectives were to investigate the effects of incorporating whey products at high concentrations on physical properties of extruded snacks made with corn meal, potato or rice flour, and to identify processing conditions that could result in improved quality.

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MATERIALS & METHODS

CORN MEAL, POTATO FLOUR, RICE FLOUR, whey protein concentrate (WPC), and sweet whey solids (SWS) were purchased from a commercial supplier (J. M. Swank Co. North Liberty, IA) and proximate compositions were recorded (Table 1), based on manufacturers' specifications.

A ZSK-30 twin-screw extruder (Werner Pfleiderer Co., Ramsey, NJ) with a smooth barrel was used. The extruder had 9 zones, and the last 3 barrel temperatures were set at 100, 110 and 125°C, respectively. Melt temperature was monitored behind the die. The die plate was fitted with two circular inserts of 3.18 mm diameter each. The screw elements (Fig. 1) were selected to provide low shear at 300 rpm, and then, by adding kneading blocks to the configuration, create high shear at 300 rpm. Feed was conveyed into the extruder with a series 6300 digital feeder, type T-35 twin screw volumetric feeder (K-tron Corp., Pitman, NJ). The feed screw speed was set at 600 rpm, corresponding to rates of 5.42, 6.54 and 3.45 kg/h, for corn meal, potato flour, and rice flour, respectively. Water was added at 1.02 L/h with an electromagnetic dosing pump (Milton Roy, Acton, MA). Samples were collected after 25 min processing, dried in a laboratory oven at

Table 1 — Proximate analysis of products (%)[a]

	Corn	Potato	Rice	SWS	WPC
Carbohydrate	76.1	80.5	78.3	75.0	60.0
Protein	9.0	10.0	8.5	12.1	34.0
Fat	2.3	0.5	1.2	1.5	3.0
Moisture	12.6	9.0	12.0	5.0	3.0

[a]Approximate percent composition from manufacturers Specifications. SWS=Sweet Whey Solids; WPC=Whey Protein Concentrate.

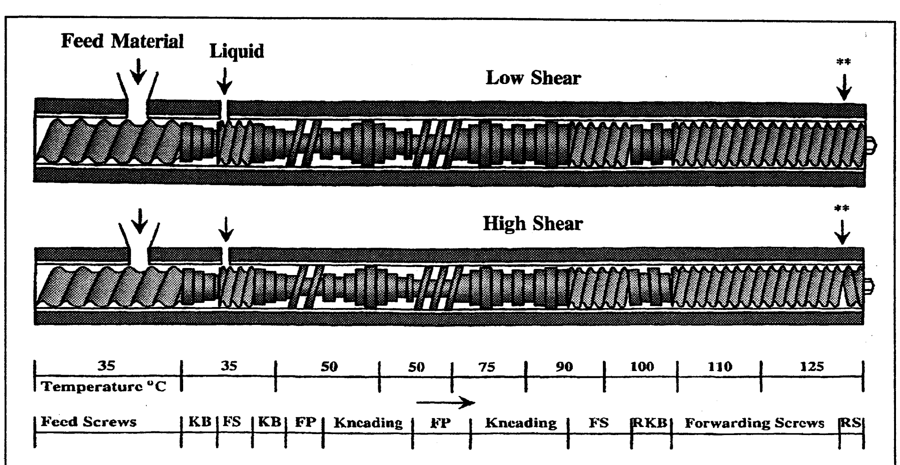

Fig. 1 — Screw configuration profile for low shear and high shear extrusion processing. KB = kneading blocks; FS = forwarding screws; FP=forwarding paddle; ** = site for thermocouple to measure product temperature; RS = reverse screws; RKB = reverse kneading blocks.

120°C, for 5 min, and stored at 4.4°C until analyzed.

A full factorial design for 3 types of flour and two proteins (3 × 2), was replicated. Analysis of variance was used to identify differences in physical properties at various processing conditions. Duncan's multiple range test was used for mean separation; correlation coefficients were calculated. Due to expected experimental variations (typical of extrusion processing), we did not pool control samples. Trends were compared within each experiment. The Statistical Analysis System (SAS) package was used (SAS Institute Inc, Cary, NC) in all cases. Significance of differences was defined at $p \leq 0.05$.

A Gardener (Model TCM) infrared spectrophotometer (BYK-Gardener, Inc., Silver Spring, MD), equipped with illuminant A, was used to measure the color of extruded products. Products were scanned through a small angle port (2°). Hunter L, a, b values were used to calculate total color difference (ΔE), defined as the square root of ($L^2 + a^2 + b^2$). Standard reference tile values were (L=98.34; a = -0.21; b = 0.19). Color determinations were made immediately after extrusion, and after overnight vacuum drying at 90°C. Four readings were taken for each sample.

Radial expansion (mm) was determined with a digital Vernier caliper (Monostat Corp. Switzerland), by measuring the diameter of each of 10 samples for every replication within a treatment. The expansion index (EI) was derived by dividing radial expansion by die orifice diameter (3.18 mm).

Puffed products (10g) were used for solid substance density determination. The samples were ground in a laboratory blender. Solid substance density of the extruded products was determined with an air pycnometer (Horiba Instruments Inc, Model VM 100, Irvine, CA). The extruded products (2 g) were dried in a vacuum oven to constant weight at 100°C, and moisture was reported as loss in weight (AOAC, 1997).

The Texture Analyzer TA-XT2 (Stable Micro Systems, Surrey, England), with a Warner-Bratzler shear cell (1 mm thick blade) and a 500N load cell, cross-head speed 0.2 mm/sec, was used. Breaking strength (kg) was determined by measuring the maximum force required to break the extruded samples (~50 mm) in the shear cell. Data reported are averages of 10 samples.

Water absorption (WAI) and water solubility (WSI) indices were determined by modifying the methods reported by Jin et al. (1995). Samples were ground and sifted through a 210 micron sieve and 1.0g (±0.005g) was placed in a centrifuge tube and 10 ml distilled water added. After standing 15 min (shaking every 5 min), the samples were centrifuged for 15 min at 1000 × *g* (Econospin Model, Sorvall Instruments, Wilmington, DE). The supernatant was decanted, and the weight gain in the gel was noted.

Table 2—Properties of extrudates based on composition of corn meal product[a]

		Whey protein concentrate		Sweet whey solids	
	0	25%	50%	25%	50%
Feed moisture	13.6	14.4	17.4	13.7	14.3
Low shear moisture	11.5	13.1	11.0	10.3	9.4
Color (ΔE)	57.7	63.6	53.1	58.4	53.3
WAI	4.8	4.3	4.2	3.4	3.0
WSI	8.0	14.0	21.0	9.0	20.0
High shear moisture	11.3	10.0	6.0	9.2	8.7
Color (ΔE)	54.4	55.0	68.3	54.4	60.3
WAI	4.83	4.58	3.92	4.15	2.76
WSI	7.0	6.0	11.0	7.8	8.9

[a]Particle density (g/cm³): 1.5±0.2 Pooled Standard Deviations: Moisture ± 0.94: Color (ΔE): total color difference ($\sqrt{(L^2+a^2+b^2)}$ ± 1.6: WAI (water absorption index) ± 0.41: WSI (water solubility index) ± 0.4.

WAI was calculated as the weight gain of the gel dry weight. The supernatant was decanted into a tared aluminum pan. The pan and supernatant were dried overnight under vacuum at 90°C. Water solubility index was determined as weight of dried supernatant/weight of dry sample × 100.

Specific mechanical energy (SME) was derived from the ratio of net energy input to the extruder (power and mechanical shear) to the feed flow rate through the extruder (Kirby et al., 1989).

RESULTS

Corn products

The results of incorporating whey products at 25% or 50% in corn meal at high and low shear extrusion conditions were compared (Table 2). The moisture contents of the extruded products varied ($p<0.05$) with type of shear except for rice at low shear condition. Higher shear resulted in higher moisture loss, and increase in melt temperature from 120 to 128°C. Sweet whey solids (SWS) reduced post extrusion product moisture content.

Substitution of whey products changed the colors of extruded products. Under low shear, the color darkened slightly with addition of 25% SWS, whereas at higher concentrations of both whey products the total color was considerably lighter. When high shear conditions were used, color darkened at 50%. Color differences were related to whey product concentration and degree of shear.

Water absorption indices for corn meal showed declines ($p<0.05$) with the addition of whey products, especially at 50% substitution. Type of whey or degree of shear produced differences ($p<0.05$) in water absorption. Solubility indices increased with the addition of whey products. The degree of cook, determined by shear and temperature history, influenced the WSI (Kirby et al., 1989). Distinct decreases in WAI were observed at 50% whey product substitution, low shear. Whey product substitution made the products more soluble, but resulting extruded products lost water absorption capacity. Reduction in torque was noted during the processing of cheese whey substituted products (data not shown) and SME values were consequently reduced.

Expansion and breaking strength of corn meal extruded with both whey products were compared for low shear (Fig. 2) and for high shear (Fig. 3). Product expansion decreased ($p<0.05$) with the addition of both whey products. Increases in breaking strength correlated with reduced expansion at 50% whey product substitution.

Potato products

Data for whey products substitution in potato flour were also compared (Table 3). Type of whey and degree of shear produced

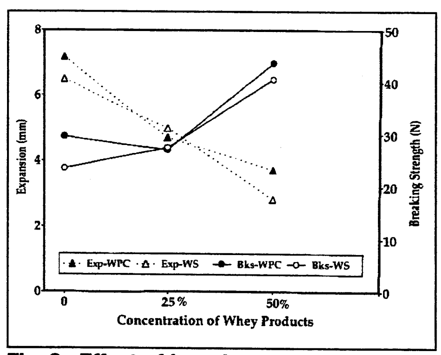

Fig. 2—Effect of low shear extrusion on the expansion and breaking strength of corn meal product.

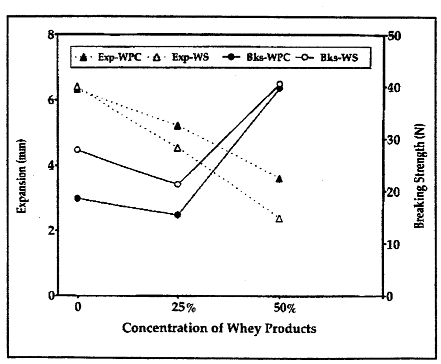

Fig. 3—Effect of high shear extrusion on the expansion and breaking strength of corn meal product.

Table 4—Properties of extrudates based on composition of rice product[a]

	0	Whey protein concentrate 25%	Whey protein concentrate 50%	Sweet whey solids 25%	Sweet whey solids 50%
Feed moisture	21.7	19.3	25.1	8.5%	12.0
Low shear moisture	14.9	16.9	16.3	16.9	16.8
Color (ΔE)	53.5	53.6	49.9	58.9	56.4
WAI	4.1	3.83	3.91	3.54	3.77
WSI	4.5	14.0	12.5	6.0	18.0
High shear moisture	15.4	19.3	24.3	10.8	8.8
Color (ΔE)	50.7	61.3	66.1	58.9	59.1
WAI	4.26	2.75	3.96	3.11	2.95
WSI	3.70	4.70	16.0	8.2	11.80

[a]Particle density (g/cm^3): 1.5 ± 0.2 Pooled Standard Deviations: Moisture ± 0.62: Color (ΔE): total color difference ($\sqrt{(L^2+a^2+b^2)}$ ± 1.72: WAI (water absorption index) ± 0.51: WSI (water solubility index) ± 0.33.

cell walls and were harder (Mercier, 1979; Kitabatake et al., 1985). Water-holding capacity and expansion of extruded products is affected by moisture (Bhattacharya and Hanna, 1987). It is necessary to adjust the water content carefully to result in expansion with whey incorporated products. Increased structural binding of water may have reduced moisture available for flash-off and consequently reduced expansion.

Water absorption and solubility

Water absorption and solubility of extrudates followed a predictable pattern. The shear history, temperature and moisture affected water solubility and absorption, which are indicators of degree of gelatinization (Kirby et al., 1989). Moisture content of the extruded products correlated highly with both absorption and solubility indices (R^2=0.98) for high shear processes, but inversely with the lower shear process. High shear tended to reduce solubility and increase water absorption, depending on type of flour and protein concentration. The main effect of incorporating whey products was to reduce absorption indices and increase solubility of extrudates (except for potato and sweet whey solids). One reason for the anomaly may be the differences in protein content. With the addition of cheese whey solids, the extrudate became a high protein product. Within products the response to increased protein content was nonlinear and did not follow a defined trend. Therefore, the need for further study for optimization is indicated. Similar effects have been reported for whey incorporation (Kim and Maga, 1987) and for increased shear processes (Jin et al., 1995). Though Kim and Maga (1987) reported no differences as a result of increasing screw speed, Kirby et al. (1989) reported that changing screw configuration changed absorption and solubility indices which we confirmed.

Color

Product color is a strong indicator of thermal history within the extruder. Differences in color of extrudate are to be expected among carbohydrate types and notable differences were observed with shear. Along with product and shear type, the concentration of whey product affected total color difference. Adding whey products at 25% tended to increase total color difference; substituting 50% whey products lightened the color. The difference in lactose content is a factor in increased browning. Moisture content correlated with color, confirming the reported protective effects of moisture on color (Berset, 1989). The appeal of an expanded product is to a great extent affected by its physical characteristics. Thermal history is dependent on mechanical energy dissipation (SME), barrel energy input, and cooling from added water (Berset, 1989; Mulvaney et al., 1992). Heating generally had the greatest effects on the color of the high shear products.

Expansion and breaking strength

The largest influence on expansion is exerted by moisture content and temperature history (Phillips et al., 1984). Expansion and breaking force are inversely correlated (Martinez-Serna and Villota, 1992). The addition of whey proteins reduces expansion and consequently increases breaking strength (Martinez-Serna and Villota, 1992; Peri and Casiraghi, 1983). This has been ascribed to protein-protein interactions at higher levels of protein concentration. The protein fractions reinforce the product cell wall and increase breaking strength (Singh et al., 1991). This may be the cause of our anomalous results observed after inclusion of whey products. Shear history may have shifted glass transition, increasing breaking strength. Though the products were expanded, they remained in a glassy state. There is considerable interaction of process conditions, shear rate, moisture and melt temperatures and product type, on the expansion of extruded products (Kirby et al., 1989; Owusu-Ansah et al., 1984; Alverez-Martinez et al., 1988).

Whey substitution

The addition of whey proteins to extruded products has resulted in notable reduction in radial expansion (Kim and Maga, 1987). Martinez-Serna and Villota, (1992), also reported a 30% decrease in expansion ratio due to modification of viscoelastic characteristics during extrusion with the addition of 20% whey protein isolate. The interaction of starches and protein-protein interactions, are considerable when adding whey proteins in large quantities. As starches and proteins form complexes, physical modifications such as extrusion processing lead to changes in solubility, water absorption and paste viscosity (Davidson et al., 1984; Colonna et al., 1989; Launay and Lisch, 1983). Brittleness, breaking strength and expansion are affected (Gomez et al., 1988). In our results, the effect of whey substitution in various products may have been due to case-hardening, which would limit expansion and increase water holding capacity. Off-line state change prior to extrusion cooking may alleviate observed instances of case-hardening.

CONCLUSIONS

THE PROTEIN CONTENT OF EXTRUDED SNACKS CAN BE IMPROVED through the inclusion of whey products and, by process modification, maintain product properties. Whey products will require considerable modification to produce an expanded crunchy product. Adding milk proteins such as casein, SWS or WPC improves the nutritional quality profile. Evaporation of water is a main cause of product expansion, but other variables (shear, type of protein, carbohydrate) increase the complexity and the difficulty in extruding expanded products. Adequate control of moisture and standardization of product will improve extrusion processing of cheese whey products. The incorporation of considerable (>10%) amounts of whey products would reduce expansion and increase water holding capacity. Product expansion increased directly with decreased moisture at high shear; for whey substituted products, however, breaking strength did not decrease.

Table 3—Properties of extrudates based on composition of potato product[a]

		Whey protein concentrate		Sweet whey solids	
	0	25%	50%	25%	50%
Feed moisture	14.9	14.7	18.7	14.5	18.9
Low shear moisture	14.7	14.2	14.8	10.3	9.4
Color (ΔE)	54.3	50.2	54.3	58.4	53.3
WAI	2.9	2.5	2.5	3.4	3.0
WSI	9.4	13.0	15.0	9.0	20.0
High shear moisture	13.1	14.2	17.8	9.2	8.7
Color (ΔE)	55.4	57.1	57.1	54.4	60.3
WAI	2.80	2.70	3.92	4.15	2.76
WSI	8.8	19.0	11.0	7.8	8.9

[a]Particle density (g/cm^3): 1.5 ± 0.2. Pooled Standard Deviations: Moisture ± 0.74: Color (ΔE): total color difference ($\surd(L^2+a^2+b^2)$ ± 1.5: WAI (water absorption index) ± 0.31: WSI (water solubility index) ± 0.34.

different ($p<0.01$) products. The product containing SWS and WPC at 50% bound considerably more water at higher shear. The color of expanded potato products was affected by the degree of shear, by concentration and type of whey product. Increasing SWS concentration at high shear increased color difference from the control at 25% substitution but decreased it at 50% substitution. Water absorption decreased with the addition of whey products under low and high shear, except for SWS, which showed increased absorption at 50% substitution only. Water absorption was not affected by degree of shear. Solubility increased ($p<0.05$) with the substitution of whey products, except for SWS under high shear.

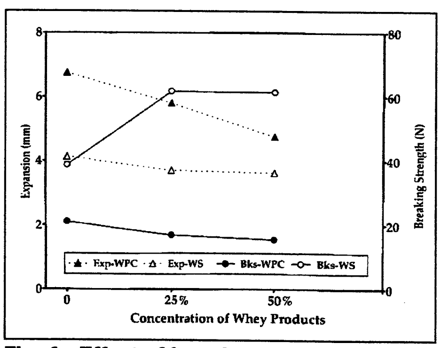

Fig. 4—Effect of low shear extrusion on the expansion and breaking strength of potato product.

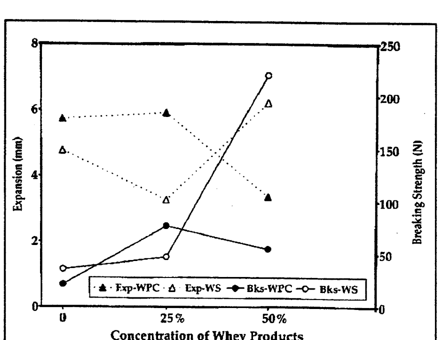

Fig. 5—Effect of high shear extrusion on the expansion and breaking strength of potato product.

Expansion and breaking strength of products for both low shear (Fig. 4) and high shear (Fig. 5) were compared. Expansion decreased with addition of WPC. Potato flour extruded with WPC expanded more than that extruded with SWS and the products had higher breaking strength. The degree of shear made a difference in breaking strength. There were differences ($p<0.05$) in expansion due to the amount of shear. The type of whey added affected final product characteristics depending on shear, moisture and temperature history.

Rice products

The results of extruding rice flour with whey products were compared (Table 4). Substituting whey products increased water retention in extruded rice products, except with SWS under high shear. Color differences were observed at high shear ($p<0.05$) due to the inclusion of whey products. Water absorption decreased, with the inclusion of whey products. Increasing the degree of shear resulted in further decreases in absorption index. Solubility indices increased with addition of whey products, but the degree of shear was not as important as the concentration of protein. At higher concentrations (50%), solubility increased ($p<0.01$). The type and concentration of whey product affected both expansion and breaking strength. Breaking strength increased as expansion decreased (Fig. 6) with WPC at low shear. Higher shear (Fig. 7) had a more marked effect on the product. Expansion increased with the addition of SWS at 25%, but decreased sharply at 50% substitution. Breaking strength was very responsive to expansion with SWS. However, for the rice and WPC product, breaking strength increased with expansion.

DISCUSSION

Moisture

Moisture has the greatest influence on quality of finished products. It is especially critical in the expansion of puffed products (Miller, 1985). Degree of shear produces changes, but changing the screw configuration to increase shear cannot be done online as readily as changing moisture content. Therefore, off-line modification of either protein or carbohydrate source was necessary. In our study, extruded product moisture varied mainly with changes in shear, and with type of flour ($p<0.01$). The type of flour accounted for variations in the initial moisture content (Table 1). Inclusion of whey products increased moisture retention by binding water, and thus such extrudates would require more drying. This could be modified by high shear extrusion, which changes the thermodynamics, and increases temperature and flash off at the die (Miller, 1985). Product quality attributes such as expansion and degree of cook as inferred from absorption and solubility indices are directly correlated with moisture (Kirby et al., 1989). Moisture, solubility indices and breaking strength were significantly correlated ($R^2=0.92$) for 100% corn; but not with either substituted whey product.

Moisture within the extruder acted as a heat sink thereby reducing the melt temperature. As the melt temperature decreased, the product became less viscous, and pressure was increased. Increasing shear rate by changing to high shear extrusion reduced the effects of moisture, but led to considerable instability. Similarly puffed products with high moisture content tended to have thicker

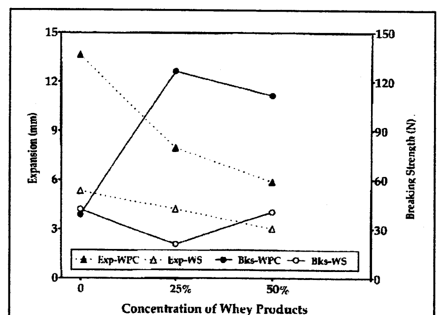

Fig. 6—Effect of low shear extrusion on the expansion and breaking strength of rice product.

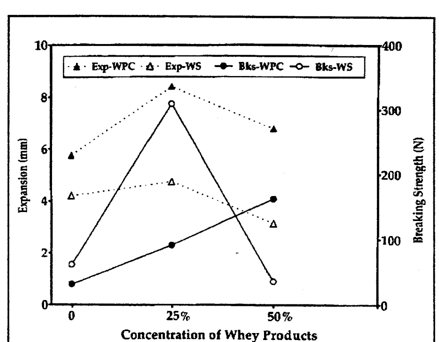

Fig. 7—Effect of high shear extrusion on the expansion and breaking strength of rice product.