High-Temperature, Short-Time Extrusion of Wheat Gluten and a Bran-Like Fraction[1]

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ABSTRACT

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This study investigated the changes that occur in physical properties of extruded wheat gluten, peelings mixture due to variation of process temperature, and the ratio of two added ingredients. Physical properties examined were bulk density, percent rehydration, and integrity of the extrudate. Process temperature over a range of 130–190° C was shown to be significant for the three physical properties measured. An increase in process temperature appeared to enhance extrudate expansion. Bulk density decreased as process temperature increased and as percent moisture decreased. Increasing moisture between 20 and 29% appeared to reduce expansion at a given temperature. Percent rehydration was negatively correlated with bulk density, increased with process temperature, and decreased with higher moisture.

Cereals have been processed by extrusion for over 30 years. Extrusion processing of vegetable protein for texturization is a more recent development, with industrial research in the area beginning in the early 1960s (Harper 1982). Despite a great deal of commercial interest in product and process development, published data on extrusion is limited. Defatted soy flour is the protein source most commonly used in extrusion texturization. Published research on extrusion of other vegetable proteins, including wheat gluten, is extremely limited. That which is available is primarily in the patent literature (Atkinson 1970, Baker et al 1975, Hayes and Tewey 1975, Feldbrugge et al 1975).

The objective of this study was to test products from a proposed commercial wheat gluten and wheat starch separation system as ingredients in the production of a texturized protein product. We investigated the effects of varying ingredient moisture, process temperature, and ratio of a by-product fraction to gluten.

MATERIALS AND METHODS

Description and Preparation of Raw Material

Vital wheat gluten was donated by Midwest Solvents Co., Inc., Atchison, Kansas. "Peelings" was the producer's name for screenings obtained during the wet milling of whole wheat in a proposed commercial separation system (Table I). Because of the limited availability of actual peelings from that system, a simulated peelings fraction was prepared from a mixture of bran, shorts, and germ collected from the Kansas State University pilot flour mill. Each of these three components was finely ground through an Alpine pin mill (model 160z; Augsburg, F.R.G.) before blending. The simulated peelings were a mixture of 87% bran, 8% shorts, and 5% germ. The average particle size of the mixture was 300 μm with an SgW (geometric log normal standard deviation) of 1.65.

Each sample was a mixture of gluten and varying amounts of simulated peelings (0–15%) to which water was added in a Hobart mixer using a McDuffey bowl and fork. The mixing bowl was fitted with a stainless steel cover to prevent excessive sample loss during mixing. Distilled water necessary to bring 1,500 g of sample to the desired moisture level, between 20 and 29%, was added while the mixer was running. This time varied depending on the amount of water added. Mixing was continued for 5 min after all water was added. The sample was extruded immediately after mixing.

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Extruder Description and Operation

All extrusion trials were carried out with a Brabender single screw extruder (model 2403; South Hackensack, NJ). The extruder barrel was 47.65 cm in length and 1.905 cm in diameter. The extruder had three temperature control zones and a 4:1 compression ratio stainless steel screw fitted with a torpedo point to fill the void volume at the end of the extruder. Extrusion was through a carbon steel, side-discharge die. The discharge opening of the die was 3.81 cm from the extruder barrel and was a square 0.635 cm on a side. Processing temperatures were fixed in zones 1 (25° C) and 2 (100° C). The temperature of zone 3 was varied between 130 and 190° C. Screw speed was maintained at 150 rpm. The extruder was conditioned by running 25% moisture ground corn until uniform flow was achieved. Then sample material was extruded for 2 min before collection began.

After extrusion, samples were air-dried overnight at room temperature, then ground through a laboratory Ross roller mill (22.9 × 15.2 cm), and sized on a Gyro-Lab sifter. Material retained for testing passed through wire mesh screen no. 3 1/2 (5.66-mm opening) but remained on a no. 8 screen (2.38-mm opening).

Measurement of the Extrudate's Physical Properties

The bulk density of samples was determined by weighing the quantity required to fill a known volume.

A 10-min rehydration was evaluated by allowing 5 g of sample to soak in 50 ml of water (25° C) for 10 min. After rehydration, excess water was removed through a Buchner funnel lined with Whatman No. 4 filter paper. Rehydration was calculated as the percent weight increase, based on "as is" weight of the original sample. A 12-hr rehydration was performed in the same manner, except that the sample was allowed to rehydrate in a sealed container.

Rate of rehydration was evaluated by selecting three samples covering the range of available bulk densities. Eight subsamples (5 g each) were taken from each bulk density sample and rehydrated in 150 ml of water (25° C). The subsamples were rehydrated for times of 5–360 min.

The integrity test was performed by placing a 25-g sample in a glass container with 150 ml of distilled water. The sample was heated in a sealed vessel until 1.68 atm of steam pressure was obtained. Temperature and pressure were maintained for 15 min, then the sample was cooled and decanted. The solid fraction was transferred to a 1,000-ml boiling flask and stirred at 500 rpm for 10 min. The sample was spread evenly over a no. 6 Tyler screen. Five aliquots of water (500 ml each) were poured over the sample. Material retained on the screen was dried at 130° C for 15 hr. Dry matter loss was calculated as percent weight decrease, based on the original dry weight of the sample. The mean standard deviation for duplicated runs was 0.33%.

For scanning electron microscopic examination, short pieces of extrudate samples were cut to expose a cross section of the extrudate. The samples were mounted on aluminum studs and vacuum coated with gold palladium. They were examined with an

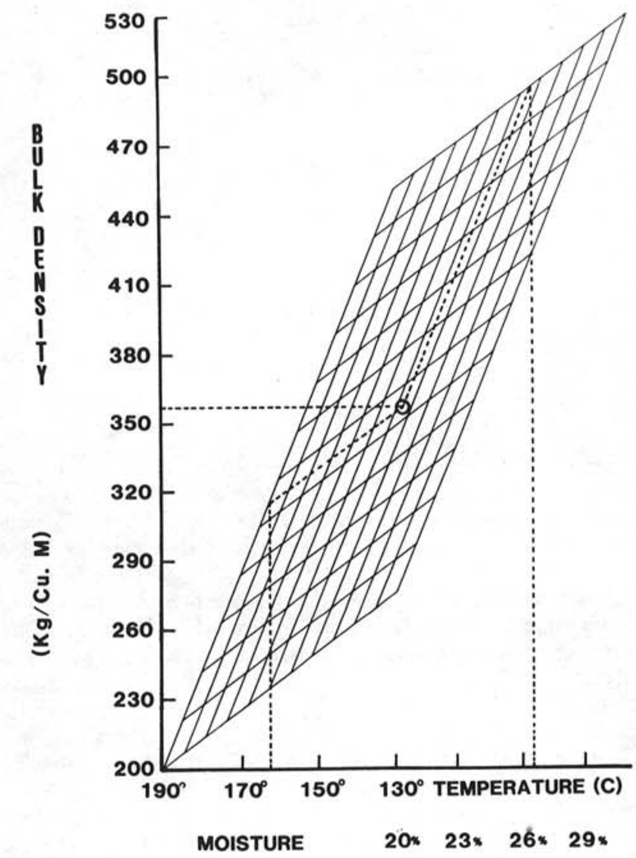

Fig. 1. Bulk density of extrudates.

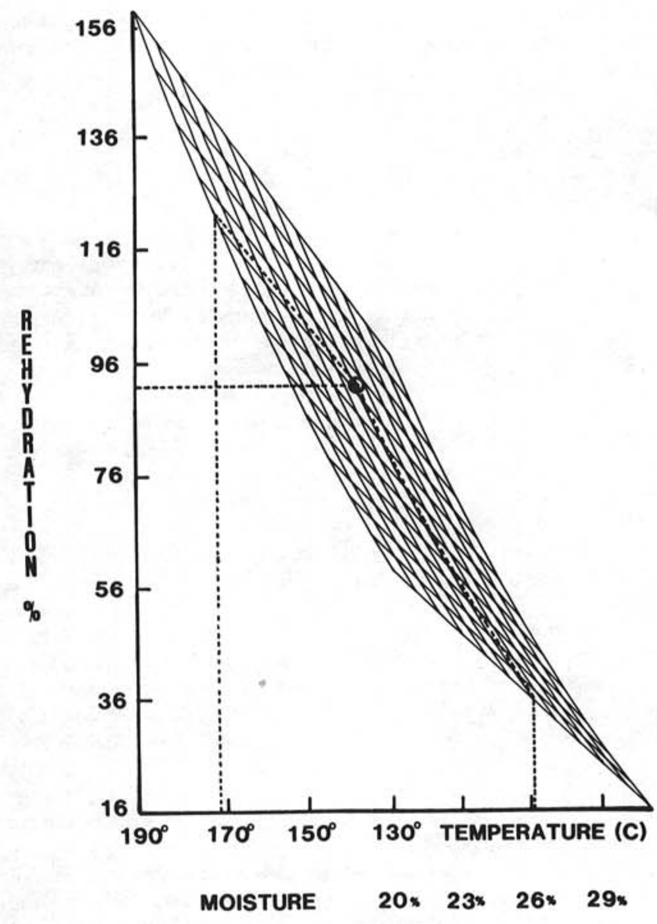

Fig. 2. Ten-minute rehydration of extrudates.

ETEC U-1 Auto Scan electron microscope (Perkin Elmer Electron Beam Technology, Hayward, CA).

Experimental Design

Five treatment levels each of temperature, moisture, and peelings were selected. Fifteen of the possible 125 combinations were tested

TABLE I
Proximate Analysis[a] of Wheat Gluten, Peelings, and Simulated Peelings

Component	Wheat Gluten	Peelings	Simulated Peelings
% Nitrogen	13.2	2.9	3.1
Crude protein (N × 5.7)	75.5	16.7	17.9
Ash	0.9	6.1	6.7
Ether extract	1.1	3.1	3.4
Crude fiber	0.3	11.2	9.8
Nitrogen-free extract	22.3	62.9	62.2

[a] All values on a dry matter basis.

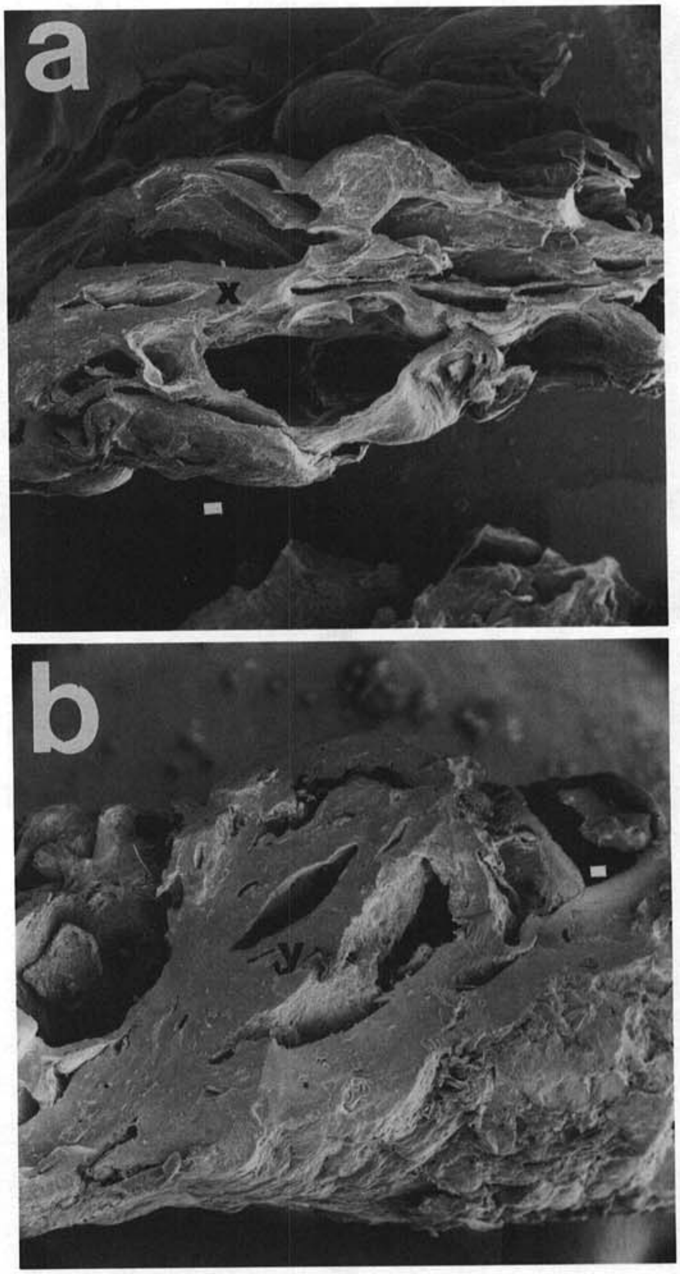

Fig. 3. Scanning electron micrograph of extrudates. **a,** Cross section of highly expanded extrudates; X is cell wall (bar = 100 μm). **b,** Cross section of less expanded extrudates; Y is cell wall (bar = 100 μm).

according to a central composite rotational design (Cochran and Cox 1957). Product data were analyzed by the regression analysis portion of the SAS program (SAS Institute, Inc.: Raleigh, NC; 1982 release). The regression equations were plotted with option G3D of the SAS/Graph program.

RESULTS AND DISCUSSION

Bulk Density

The effect on bulk density of process temperature in zone 3 and percent moisture of feedstock is shown in Figure 1. The bulk density of the extrudate varied directly with moisture and inversely with temperature. A similar relationship has been found with soybean meal (Cumming et al 1972) and with cottonseed meal (Taranto et al 1975). Peelings quantity did not have a significant ($P < 0.05$) effect. The influence of process temperature on the extrudate is thought to be a function of cooking. As temperature increases, the material is more fully cooked and acquires more plasticity. As stated by Taranto et al (1975), the more fully cooked material allows for more expansion and reduced density.

Bulk density varied directly with moisture content of the feedstock. The elastic nature of gluten, and the fact that high-moisture samples extruded at low temperatures were observed to be wet after extrusion, may provide an explanation for the increase in bulk density. When material exits the die, flash evaporation takes place, drying the extrudates. Lower moisture samples appear to flash off sufficient water to set the gluten in the expanded state. Samples of higher moisture appeared to expand initially to the same degree as lower moisture samples, but it is likely that a smaller percentage of water was driven off, resulting in the observed wet extrudate. This might allow the gluten to contract, producing a denser extrudate.

Rehydration

Figure 2 shows the effect of process temperature and percent moisture of the feedstock on the rehydration of the extrudate.

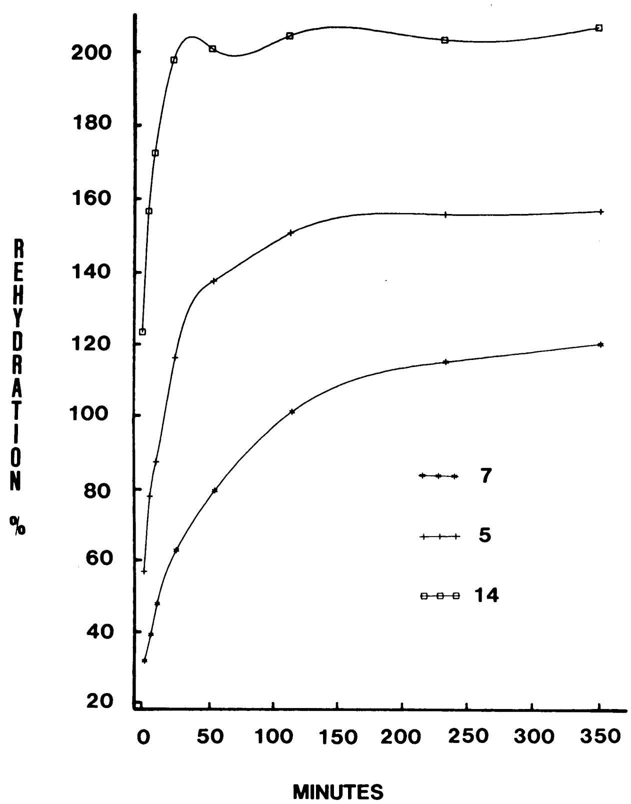

Fig. 4. Rate of absorption of three extrudates covering the observed range of bulk density: **7** = most dense extrudate; **5** = intermediate density extrudate; **14** = least dense extrudate.

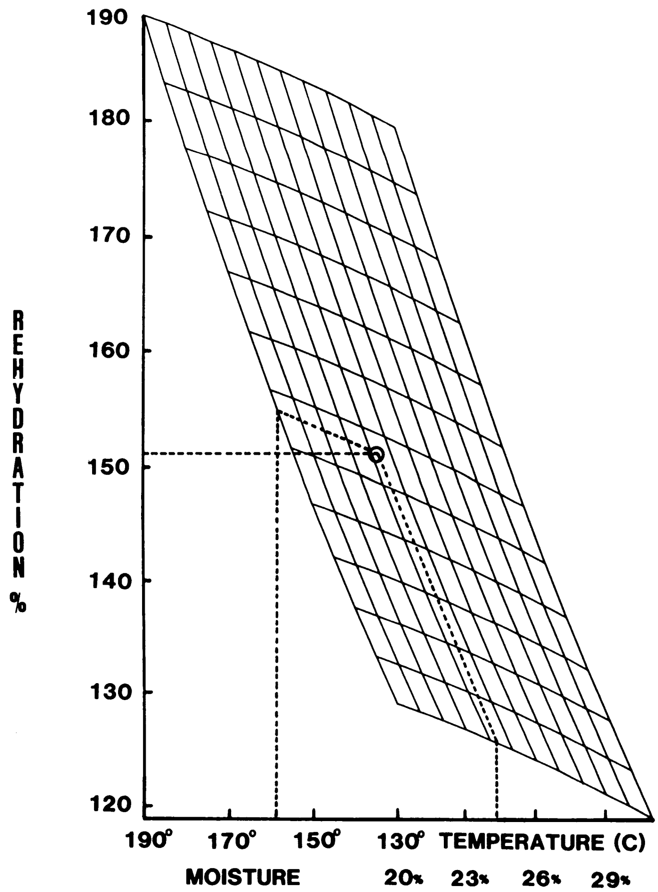

Fig. 5. Twelve-hour rehydration of extrudates.

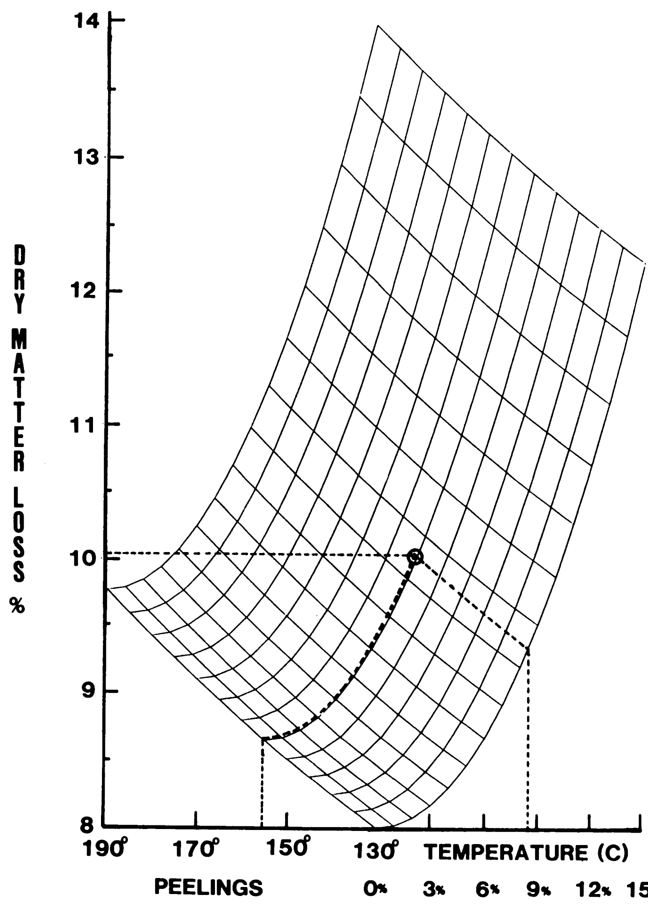

Fig. 6. Dry matter loss of extrudates measured after the integrity test.

Percent peelings was not significant ($P<0.05$). Percent rehydration varied directly with process temperature and inversely with percent moisture. Bulk density was inversely correlated with rehydration. This was to be expected because expansion is the controlling factor for both of these properties. Lower bulk density extrudates had large cells with thin cell walls. Lower bulk density extrudates also appeared to have more cells per unit weight, giving the extrudate a more spongelike structure (Fig. 3). Cumming et al (1972) found similar results for defatted soybean meal using a boiling water rehydration. They concluded that the more spongelike the structure, the more water imbibed by the product.

Because of the short time involved in rehydration (10 min), we thought that the rate of absorption might have an effect on the percent rehydration measured. Figure 4 depicts the rate of absorption of three extrudates covering the observed range of bulk densities. Clearly, the highly expanded (least dense) extrudate does absorb water faster. In Figure 5, where rehydration time was 12 hr, the extrudates were fully rehydrated, and the rate of rehydration was not a factor. The relationship between percent rehydration, process temperature, and percent moisture was the same as for the 10-min rehydration of those samples. Thus, while the rate of absorption varies between extrudates, it is closely related to total absorptive capacity.

Physical Integrity of Extrudates

The dry matter loss of the extrudate determined by the integrity test (Fig. 6) varied directly with both percent peelings and process temperature. Percent moisture did not have a significant ($P<0.05$) effect on extrudate integrity.

Peelings did not lose their structural integrity (Fig. 7) and remained as individual particles throughout the extrusion process. Individual peelings particles enhanced the dry matter loss by being

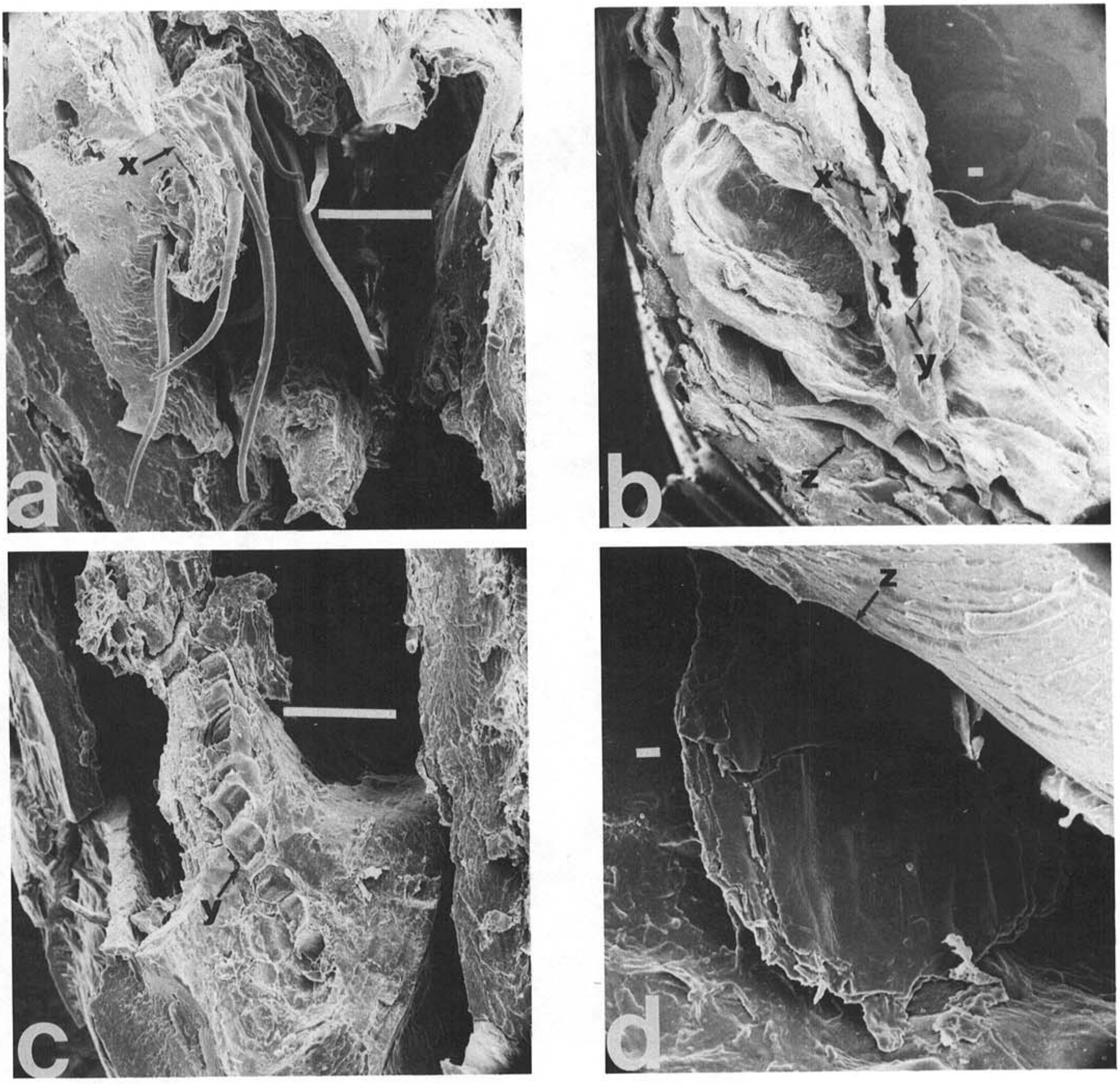

Fig. 7. Scanning electron micrographs of extrudates. **a,** Embedded bran particle **(X)** (bar = 100 μm). **b,** Cross section showing embedded bran particles X, Y, and Z, which correspond to X, Y, and Z in enlarged views **a, c,** and **d** (bar = 100 μm). **c,** Embedded aleurone structure **(Y)** (bar = 100 μm). **d,** Embedded bran particle **(Z)** (bar = 10 μm).

embedded in the extrudate. Kinsella (1978) stated that protein molecules unfold, become aligned in the direction of flow, and form fibrous sheaths. The extrudate mass was forced to align around the intact peelings particles, leaving them embedded in the extrudate matrix. These peelings in the extrudate matrix possibly weaken the extrudate by destroying the continuity of the aligned mass.

Increasing process temperature increased dry matter loss. Increased starch solubilization at higher temperatures is a likely explanation for this. Higher process temperature also produced a more expanded product with thinner cell walls, which also could weaken the extrudate.

CONCLUSION

Process temperature, percent moisture, and percent peelings were significantly related to one or more of the measured physical properties of the extrudate. Process temperature appeared to have the greatest effect, since it was significant for all three extrudate properties examined. Moisture content of the feedstock is inversely related to process temperature in its effect on expansion. High-moisture samples expand less, possibly because the gluten has time to contract before it sets. Increased expansion affects rehydration two ways. It gives the extrudate a more spongelike structure, which allows for an increased absorption, and a greater surface area, which also affects the rate of absorption. Rehydration is inversely correlated with bulk density. This is logical, since expansion is a controlling factor for both properties. Expansion may also be responsible for magnifying the amount of dry matter loss of the extrudate. Expansion produces thin cell walls, which may break up during the integrity test. The extrudate from thin cell walls could also let more soluble material diffuse out during the cooking part of the integrity test, resulting in increased dry matter loss.

Peelings were significant to dry matter loss, possibly by disrupting the continuity of the extrudate mass. This was the only extrudate property significantly affected by peelings.

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