Effect of Dough Properties on Extrusion-Formed and Baked Snacks[1]

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ABSTRACT

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A number of snack products are produced by extrusion forming and then baking. However, there is little information in the scientific literature on the process. We found that dough mixing time, die shape, and post-extrusion processing steps influenced the structure and the texture of the final product. The extent of product puffing during baking could be controlled by reducing dough moisture content and the introduction of a steaming step immediately after extrusion. Scanning electron microscopy analyses of the baked products showed that those produced from overmixed doughs possessed more highly aligned microstructure than did those produced from doughs mixed for short times.

Advances in extrusion technology have resulted in numerous unique products. However, information on the structural changes that take place in the raw materials as a result of the process or process variables is limited. Often, products appearing similar in structure differ in their texture. Such variations could result from differences in product microstructure, themselves the result of the large number of possible variables in the production process.

In extruded snacks, product microstructure can vary from porous and open-celled to dense and fine-celled. When high-temperature, short-time (HTST) extrusion processing is employed, moisture content, shear in the extruder, die geometry, and rate of heating are the principal factors responsible for creating porous, open-celled structures and controlling product expansion (Donovan and Pape 1977).

Similarly, snacks formed but not cooked by extrusion may subsequently be puffed by baking to produce a crisp texture. In the case of such extrusion-formed baked snacks, however, the variables important in HTST processing are not directly applicable in the control of expansion (puffing) or texture. The texture of these baked snacks depends, at least in part, upon the oven temperature and poorly understood processing conditions encountered before and during baking (Williams et al 1977a,b). Therefore, it is not clear what is responsible for changes in microstructure of these products. It is no less difficult to measure such changes quantitatively. The objectives of this study were to identify factors affecting dough and product properties of a model extrusion-formed baked snack. The product parameters investigated were changes in appearance (i.e., puffing), microstructure, and texture.

MATERIALS AND METHODS

Flours

Commercial wheat flours destined for use in baked snacks were obtained from a major snack food manufacturer. Flour proximate composition and dough physical properties are given in Table I.

Piston Extruder

The piston extruder used in this study is shown diagrammatically in Figures 1 and 2. The three parts (dough chamber, piston, and die) were manufactured by the Physics Machine Shop, Kansas State University, Manhattan, KS. Both circular (7.62 cm long, 1.27 cm diameter) and slit (1.90 × 0.32 cm slit) dies (Fig. 2) were used in these studies. The dough chamber's outer surface was grooved to hold copper heating tubing, and the slit die was water-jacketed to maintain the entire extruder and die at the desired processing temperature.

The extruder assembly was mounted on a specially designed holding platform and placed on the stage of a Carver model C laboratory press (Fred Carver, Inc., Menomonee Falls, WI), which was used to drive the extruding piston attached to the upper platform of the press.

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Baking Oven and Rack

Snack products were baked in an electrically heated reel oven (National Mfg. Co, Lincoln, NE) with the reel stopped to position two of its shelves at the same level. A 0.2 cm thick metal sheet was placed across the level shelves to form a heated "floor". Products were baked on a 20–22 gauge expanded metal sheet with 7 cm long legs that was placed on the metal sheet described above.

Dough Mixing and Extrusion

The formula used to create the control dough is given in Table II. Premix was a proprietary blend of sodium chloride, anhydrous glucose, sodium bicarbonate, sodium aluminum phosphate, sodium stearoyl lactylate, and pregelatinized corn starch obtained from M&M Mars Co. (Hackensack, NJ). Flour and the premix were preblended by hand, then placed in a 50-g farinograph bowl. Oil and water, heated to the desired temperature, were delivered directly to the flour-premix mixture. Sodium sulfite (0.006%, fwb) was added as an aqueous solution. The amount of water added as solution was subtracted from the total formula water. Mixing was for 2 min, except where noted. Dough temperature was measured immediately at the end of mixing to ensure that it had reached the desired processing temperature of 45 ± 1°C.

TABLE I
Flour Composition and Physical Properties[a]

Flour	Moisture (%)	Protein (%)	Ash (%)	Falling Number (sec.)	Optimum Water Absorption (%)	Mixing Time (min)
A37	13.1	10.2	0.45	390	52.5	3.00
A32	12.6	10.6	0.50	338	54.0	3.00
B30	13.5	10.2	0.48	372	54.5	3.00
Good quality	13.8	13.8	0.55	363	65.0	3.25
Poor quality	13.8	12.0	0.54	358	63.0	3.50

[a] Results are expressed on 14% moisture basis.

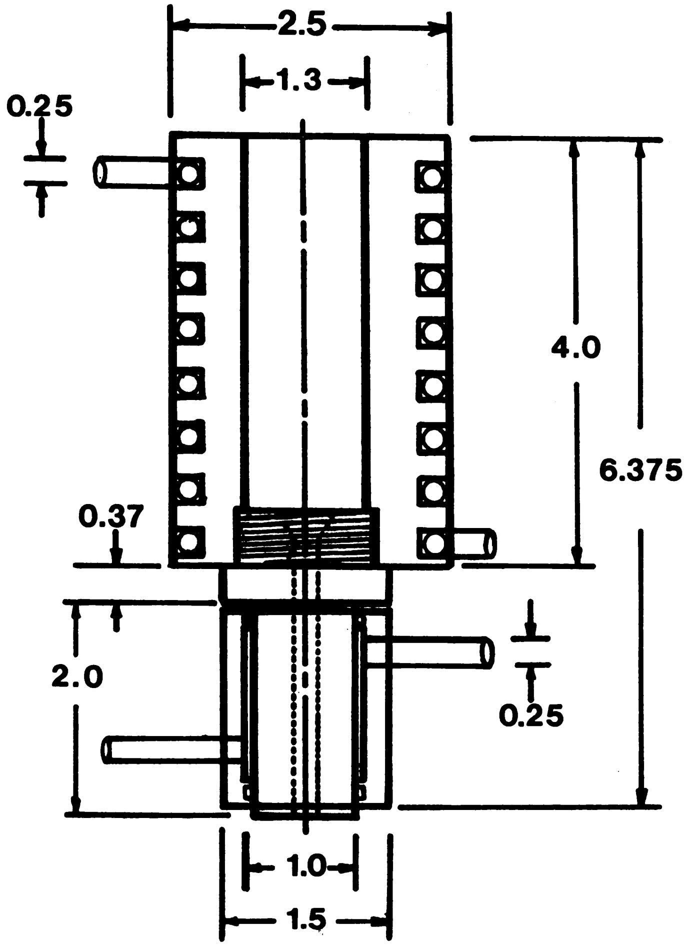

Fig. 1. Piston extruder assembly consisting of a dough chamber with copper tubing for temperature control, cylindrical or slit die and die water jacket. Dimensions are in centimeters.

Mixed dough was rolled manually into a cylinder, then transferred to the extruder dough chamber. To reduce surface drying, the piston was lowered immediately to cover the surface of the dough, and the loaded dough was allowed to rest ~3.0 min to re-equilibrate to the target temperature before extrusion. The actual rest time was determined by inserting a thermocouple in the center of the dough piece. After resting, the dough piece was formed by being forced through the extruder die using the Carver Press to apply force to the piston. From the circular die, the extruded dough was a solid rope, whereas from the slit die, the extruded dough was a flat strip 1.78 cm wide and 0.32 cm thick. In either case, the extruded dough was cut at right angles to the direction of extrusion into 1.27- or 2.54-cm pieces before further processing.

Drying

Extruded dough pieces were transferred to a metal screen that was placed immediately in a laboratory air oven (Precision Scientific, model 28, Fisher Scientific, NJ) at 40°C. Drying times varied from 15 min to 16 hr. After drying, the dough was placed in tightly capped glass jars and allowed to equilibrate for 24 hr at ambient temperature.

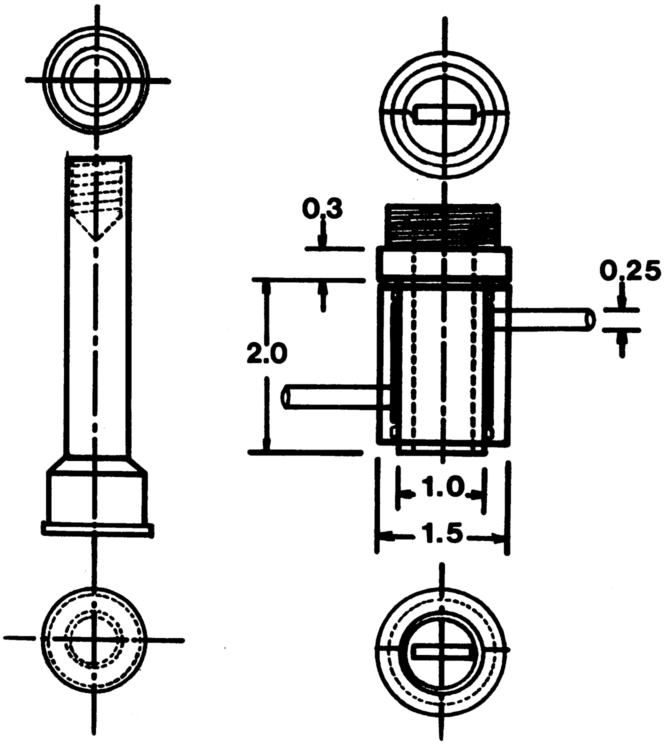

Fig. 2. Schematic diagrams of the extruder piston and slit die. Slit die lengths were 1.27, 5.08, or 10.16 cm. Slit dimensions were constant at 1.90 × 0.32 cm. Dimensions are in centimeters.

TABLE II
Control Dough Formula

Ingredient	% FWB
Flour	100.00
Water	42.00
Premix	12.00
Soybean oil	7.55
Sodium sulfite	0.006

Steaming

Dough was steamed either immediately after extrusion or after air-oven drying. Extruded or extruded and dried dough was placed on a metal screen in a large roaster containing water and heated by a laboratory hot plate. The screen held the product above the boiling water.

Baking

Time and temperature of baking (usually 150° C) were adjusted to assure that no doughy core remained in the product. After baking, the product was cooled to room temperature and stored in plastic (Zip-Lock) bags. Baked products were evaluated for structure (microstructural alignment) and texture (breaking strength). In all cases, products for analysis were made from a minimum of two dough batches (10–15 pieces/batch). Means and standard deviations are reported.

Texture Analysis

A universal testing machine (UTM) (Instron model 1130-C4) was used in the compression mode to measure the force required to break the product in the axis parallel to its extrusion. A 50-kg load cell was used at a crosshead speed of 5 cm/min, a chart speed of 25 cm/min, and full-scale chart deflection of 10 kg.

The breaking force test was a three-point break test in which the bridge sides (1.90 cm high, 2.54 cm wide, 2.54 cm long) supporting the test piece were placed ~1.27 cm apart. An individual baked sample spanned the bridge. The UTM crosshead, carrying the sharp-bladed probe destined to break the sample was positioned immediately above the sample at midpoint and then lowered until the sample failed along the axis parallel to extrusion. Force versus distance curves were recorded for each piece. Breaking force was expressed as peak force (in kilograms). Typical curves recorded for puffed and crisp, extruded, baked snacks are presented in Figure 3.

Dough Moisture Content

The moisture content of the dough before and after drying and the moisture content of the product after baking were determined in duplicate for all samples using AACC methods 44-15A and 44-18, respectively (AACC 1983).

Density Measurement

Volumes of individual extrusion-formed, baked, snack pieces, each of known weight, were measured by the dwarf rapeseed displacement method (VanHamel et al 1991). Bulk density of the pieces was calculated as g/cm^3.

Scanning Electron Microscopy

After baking and cooling, individual pieces were broken in the plane parallel to extrusion. Broken samples were mounted, fractured face exposed, on scanning electron microscopy (SEM) specimen stubs with silver paste and vacuum-coated with carbon and then with gold-palladium. Samples were viewed with an ETEC U-1 AutoScan scanning electron microscope operating at an accelerating voltage of 5 kV. Images were photographed on Polaroid film, type 55.

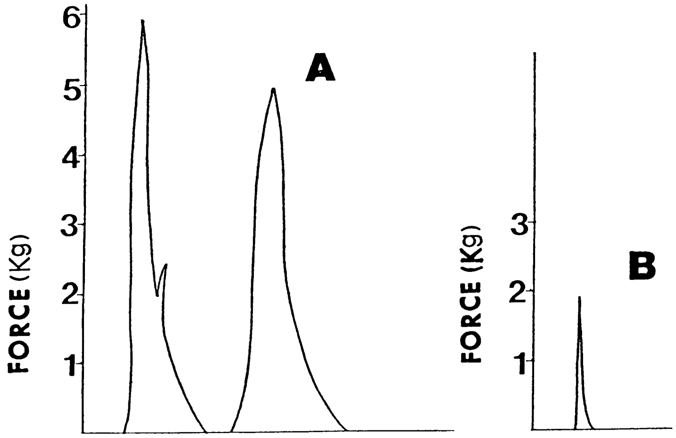

Fig. 3. Typical force versus distance curves from the analysis of extrusion-formed and baked products: A, curve types obtained for puffed products; B, typical curve for a crisp, nonpuffed product.

RESULTS AND DISCUSSION

Effect of Die Geometry

The products produced by extruding full-formula doughs through the 1.27-cm circular die puffed during baking. Inspection of these products under low magnification failed to find any orientation or alignment of their microstructure. The products were physically strong, resisting uniform fracture in either direction. From these observations, we concluded that the dough was passing through the extruder as plug flow and underwent little shear with this die configuration.

To increase shear, the diameter of the circular die was reduced (sequentially) to 0.95, 0.64, and 0.32 cm. The products made using the two smallest dies (0.64 and 0.32 cm) showed a small degree of structural alignment at their outer edges. Regardless of die size, the cylindrical shape of the product and its nonuniform cross section (resulting from uncontrolled puffing) combined to make it impossible to measure breaking strength accurately.

Because of the described problems, a 5.08 cm long slit die (1.78 × 0.32-cm opening) was constructed and substituted for the circular die. Although the internal structure of the product produced by the slit die was aligned in the direction of extrusion, the products still puffed during baking. When it was tested using the three-point break test, breaking force of these products showed no significant improvement over the cylindrical product in terms of variation both within and between replicates. Thus, the uncontrolled product puffing obscured any differences in the measured characteristics.

Puffing results in the light, open cell structure deemed desirable in some but not all snacks (Sanderhude 1969). However, uncontrolled puffing makes it impossible to investigate the variables responsible for product structure and texture. This suggested that an understanding of puffing and what controls it was necessary.

Control of Puffing

Heating rate. When full-formula, slit-extruded dough pieces were baked at various temperatures (65, 120, 150, and 190°C) and for various times (40, 25, 17, and 10 min), all of the products puffed. After baking for 40 min at 65°C, the dough pieces had a doughy core and appeared to have been dried rather than baked. Thus, lowering the temperature to reduce heating rate was not sufficient to stop product expansion during baking.

Dough moisture content. Because puffing is attributed to the gaseous expansion of water in the product, the second variable investigated was drying of the dough pieces at low temperature to reduce their moisture content before baking. Results showed that, even though drying times at 40°C were varied from 6 to 16 hr, if baked immediately after the drying step, all products still puffed. This can be explained by the surface of the product drying excessively, resulting in a gradient of moisture. During

TABLE III
Effect of Drying on Product Characteristics[a]

Drying Time (hr)	Moisture After Drying (%)	Breaking Force[b] (kg)	Puffing
6	15.1	10 (3.5)	Present
8	13.8	8 (3.0)	Present
10	12.0	8 (3.0)	Present
12	11.2	10 (2.5)	Present
14	10.1	8 (2.0)	Present
16	9.1	3 (0.5)	Absent

[a] Flour A37.

[b] Standard deviation in parenthesis.

baking, as the product's internal temperature increased, the water in the interior would vaporize, causing puffing.

In another attempt to eliminate or reduce moisture gradients, products were dried 6–16 hr, and then equilibrated for 24 hr in sealed jars. Upon baking, the products dried for 14 hr or less still puffed, but puffing was much less than the nonequilibrated controls.

Significantly, the product equilibrated after 16 hr of drying did not puff. Thus, it appeared that extended drying time at low temperature, coupled with equilibration brought moisture content and distribution to a point at which the product's structure was fixed, or at least incapable of expanding during baking.

Breaking forces of the products dried for less than 14 hr (Table III) were inconsistent, most likely because of the puffing. Products dried for 16 hr and equilibrated were very weak, requiring only 3 ± 0.54 kg to fracture. Thus, although drying and equilibration stopped puffing effectively, it also changed the product's texture, reducing its strength and causing it to become brittle. This suggested that simply reducing product moisture content by extended drying was not a satisfactory approach to control product puffing.

Steam treatment. The previous data suggested that simply removing moisture from the dough was an inappropriate method to control puffing. Therefore, a method was needed to "fix" or "set" the dough so that it would resist puffing during baking. At the same time, the dough should contain sufficient moisture during baking to provide a good texture to the final baked product. Steam treatment after extrusion was investigated as a means to set or fix the dough while retaining sufficient moisture to obtain a crisp texture upon baking.

Products steamed >2 min did not puff during baking. Bulk density measurements (Table V) confirmed that steamed products were, in fact, more dense than their unsteamed counterparts. When different times of steam treatment were compared, product properties appeared to improve up to ~10 min of steaming. Steaming times >20 min caused the baked products to be unacceptably dark.

As had been hoped, the products produced from steamed dough were not weak. In fact, 2.54-cm baked pieces had breaking strengths in excess of 10 kg. To reduce breaking strengths, a test piece size was reduced to 1.27 cm. When the smaller pieces were steamed (10 min), the resulting products still resisted puffing (Table V). They possessed a strong yet crisp texture as indicated by their 6-kg breaking strength (Table IV).

Dough drying plus steam treatment. Comparisons of the strengths of dried and baked products (Table III) with steamed and baked products (Table IV) suggested that the amount of moisture in the product when it was baked controlled its final textural strength. To investigate this further, doughs were dried for increasing times before steaming and baking.

Product breaking strength and dough moisture content as a function of drying time are presented in Figures 4 and 5. As anticipated, breaking strength decreased as moisture content in product decreased. With extended (10 hr) drying, breaking force decreased to 3–4 kg, compared to 10 kg for products that had received no drying, further supporting a model in which moisture content during baking controls product strength.

Effect of Dough Properties on End Product Quality

Die length. Variations in conditions used to extrude the dough (specifically the length of the slit die) were studied to test the hypothesis that extrusion resulted in alignment of the dough structure which, in turn, resulted in baked products weak in the plane parallel to their extrusion. Subjective evaluation of the product's die swell and handling characteristics as it exited the die indicated that, as the die length was increased from 1.27 to 10.16 cm, the extruded dough was more elastic and less extensible. The dough exiting the 10.16-cm die showed characteristic lateral

TABLE IV
Effect of Steam Treatment on Breaking Force[a]

Steam Time (min)	Breaking Force[b] (kg)	Number
4	6.3 (0.5)	29
8	7.3 (0.8)	28
16	5.7 (0.4)	30
32	5.7 (0.3)	35

[a] Flour used was A37.

[b] Breaking force is mean ± standard deviation (in parenthesis) of two replicates (n = 14–18 duplicates per replicate) for each treatment.

TABLE V
Effect of Steaming on Density and Puffing

Sample Treatment	Product Appearance	Mean Density (g/cm^2)[a]
Baked immediately after extrusion	Puffed	0.507 (0.008)
1 min of steam after extrusion and then baked	Less puffed	0.619 (0.016)
2 min of steam after extrusion and then baked	Not puffed	0.621 (0.006)
10 min of steam after extrusion and then baked	Not puffed	0.529 (0.004)

[a] Standard deviation (±) in parenthesis.

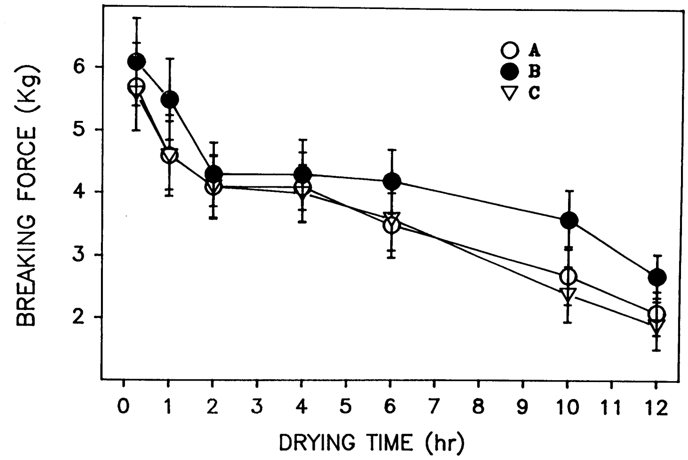

Fig. 4. Effect of dough drying time on baked product breaking force. Flours tested were A37, B30, and A32 (A–C, respectively). Error bars represent mean ± standard deviation for at least two doughs with 10–15 duplicates per dough.

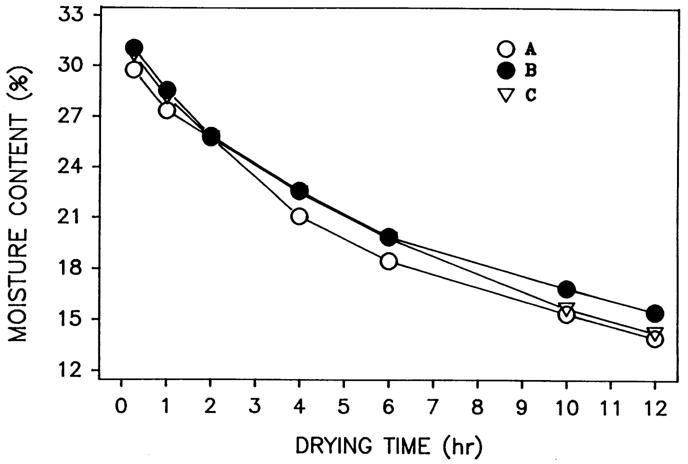

Fig. 5. Effect of drying time on dough moisture content before baking. Flours tested were A37, B30, and A32 (A–C, respectively). Error bars represent mean ± standard deviation for at least two doughs with 10–15 duplicates per dough.

striations on its surface. Rossen and Miller (1973) found similar striations and concluded that they resulted when shear in the extruder exceeded the cohesive strength of the dough.

The protein matrix of products made using short dies appeared to have some structural alignment, whereas, the product from the long (10.16 cm) die was more dense with a fine, but poorly aligned structure. To use the terminology applied to the mixing characteristics of bread dough systems, doughs extruded through the long dies were more developed than those processed through short dies.

The breaking strength of doughs dried for various times and baked (Fig. 6), with up to 2 hr of drying, show that differences in die length did not affect product breaking strength. However, with increased drying time, dough moisture content decreased (Fig. 7) as expected, and the extrusion die length affected final product strength. The products made from dough extruded through the longer dies were stronger than those processed through shorter dies. Regardless of die length, extended drying times (>6 hr) caused the product to become weak during baking.

Longer dies produced more elastic and less extensible doughs, while extrusion through short dies resulted in products with more extensive structural alignment. Thus, sufficient dough extensibility appears to be necessary at the extrusion step to allow the creation of an aligned structure.

To test this model, the short (1.27 cm) die was used to create dough which, after relaxation, was stretched manually to twice its original length in the direction parallel to extrusion. As a consequence of being stretched, the width and thickness of the dough strip decreased slightly. Significantly, this treatment resulted in a significant increase in structural alignment (orientation) and a crisp texture. These results are consistent with the above hypothesis.

Effect of mixing time. To assess the effect of dough properties at the end of mixing on subsequent product properties, preliminary studies were performed on doughs from a single flour (A37) that had been mixed for increasing lengths of time (data not shown). When the final products were evaluated for their structural alignment, increased mixing time appeared to increase the amount of alignment. To confirm and extend the preliminary observations, five flours with differing final product properties (A37, B30, commercial poor, good, and bread flours) were mixed for 5 and 20 min and the resulting products studied by SEM.

Micrographs of the products made from those doughs are shown in Figures 8 and 9. Clearly, the flours did not respond equivalently to extended mixing. When mixed for the short time (5 min), A37, B30, and the poor commercial flour produced products with more internal puffing than when mixing was extended to 20 min. In addition, as mixing time increased past 5 min, internal cell structure became smaller and the product structures became more aligned (Fig. 8a,c,e vs. 8b,d,f). In contrast, the good commercial and bread flour doughs behaved differently. In these cases, extended mixing time resulted in little or no orientation or alignment of product microstructure (Fig. 9a,c), even though doughs mixed only 5 min produced products with uniform cell structure and little internal puffing.

For three out of the five flours tested, mixing time affected the structure of their final products, while, for the remaining two flours, extended mixing had little or no effect. The former

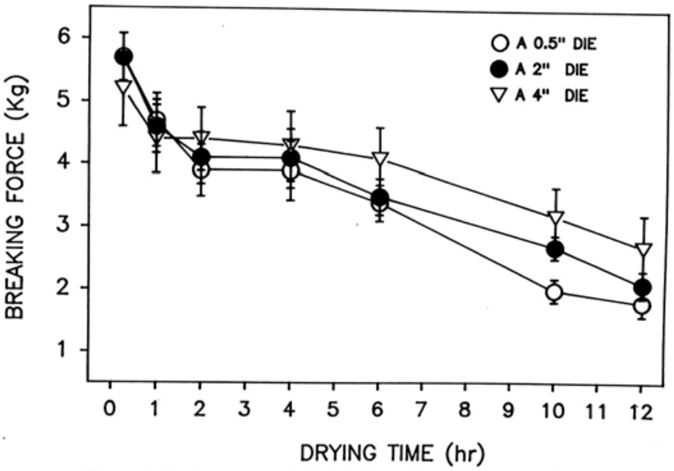

Fig. 6. Effect of die length and dough drying time on product strength for A37 flour.

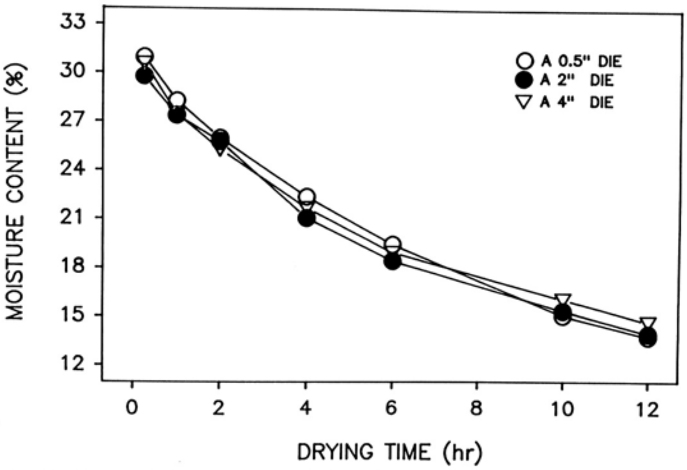

Fig. 7. Effect of die length and drying time on dough moisture content before baking for A37 flour.

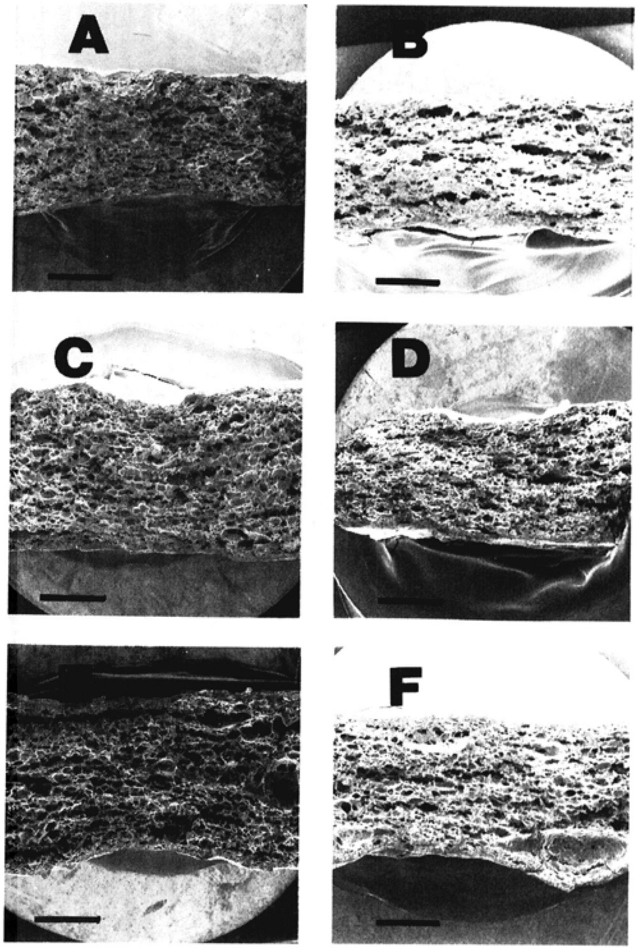

Fig. 8. Microstructure of extrusion-formed, baked snacks as affected by flour type and mixing time. Left column: 5 min of mixing. Right column: 20 min of mixing. **A** and **B**, good quality snack flour. **C** and **D**, commercial bread flour. **E** and **F**, low quality snack flour. Bar = 2 mm.

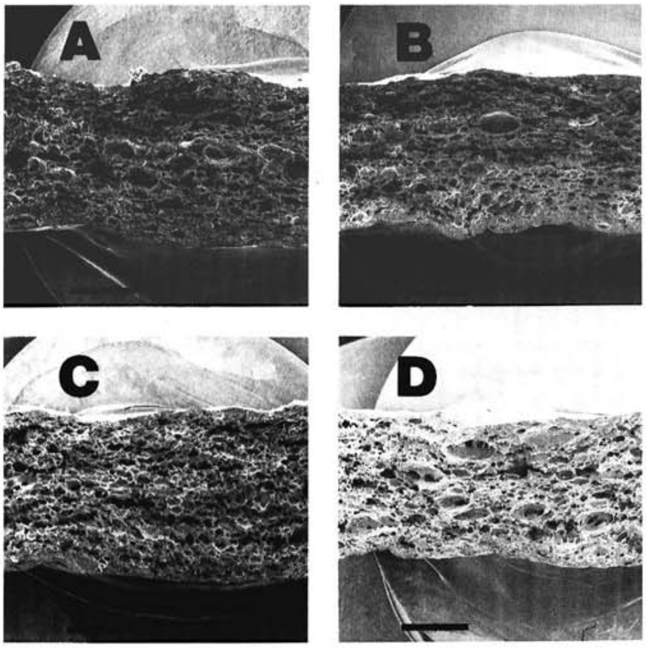

Fig. 9. Microstructure of extrusion-formed, baked snacks as affected by flour type and mixing time. Left column: 5 min of mixing. Right column: 20 min of mixing. **A** and **B**, good quality snack flour. **C** and **D**, commercial bread flour (13.5% mc, 11.4% protein [N × 5.7], and 0.53% ash [14%, mb]).

TABLE VI
Effect of Orientation on Breaking Force[a]

Mixing Time (min)	Parallel (kg)	Perpendicular	
		(kg)	Corrected to 1.47-cm Size Product Piece
5	0.78 (0.15)	1.15 (0.04)	1.92
20	0.35 (0.08)	1.12 (0.12)	1.87

[a] Flour used was A37.

samples allowed analysis of the effect of structural alignment on product texture. The products, made from doughs mixed 5 and 20 min, were broken both parallel and perpendicular to the direction of extrusion. The data (Table VI) show that the force required to fracture in the plane parallel to extrusion was less than that required to break across the plane of extrusion. A structural change (alignment) brought about by extruding the dough made the baked product weak in that same plane.

SUMMARY

Dough that was formed by extruding and then baked, puffed during baking. Although puffing is often desirable, it is not always wanted. A number of things were tried to control puffing. Reducing baking temperature was not successful. Reduced moisture in the product before baking (predrying) also was not successful when the product was baked immediately after drying. If the product was equilibrated (tempered) after drying, the product did not puff with sufficiently long drying time. However, the breaking strength of the product was low.

Steam treatment was successful in controlling puffing. The treatment appeared to set the product. Thus, puffing could be controlled (stopped), and the texture of the product could still be varied.

The die length of a slit die was varied. Increasing die length gave a dough that was more elastic and less extensible. Thus, the dough appeared more developed when using the longer die. On the other hand, the product appeared to be more aligned with the shorter die (i.e., less-developed dough). The alignment of the dough was important in determining the product's breaking strength. Thus, as shown in Figure 6 (at 10 hr), products extruded through a short die were more aligned and produced weaker products, while those extruded through the longer die were both less-aligned and texturally stronger.

For three of the five flours tested, extended mixing (longer than 5 min) gave increased protein alignment in the final product. For the other two flours, extended mixing had no effect.

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