Extrusion Cooking of a High-Fiber Cereal Product with Crispbread Character

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ABSTRACT

High-fiber products with crispbread character were prepared by extrusion cooking of dry mixtures of wheat bran, secondary starch, and gluten in a twin-screw extruder. Product density decreased from 700 to 260 g/dm^3 when the ratio between analyzed starch and dietary fiber contents was raised from 1.1:1.0 (a mixture of 50% bran, 40% secondary starch, and 10% gluten) to 4.1:1.0 (a mixture of 10% bran, 80% secondary starch, and 10% gluten). Increasing the screw speed resulted in a more expanded, less hard product, whereas changing the amount of added water had no effect. During extrusion, the total sugar content was reduced by 70–80%. Decreasing screw speed or addition of more water tended to increase the breakdown of glucose, whereas omitting gluten had the opposite effect. The phytate content, closely related to the bran level in the mixtures, decreased by 13–35%. A product with the character of Swedish crispbread in structure, texture, and taste was obtained when a mixture of 30% bran, 60% secondary starch, and 10% gluten was extruded. The extruded product contained only 6–7% water, and the amount of dietary fiber was calculated as 20.4%, which is about 75% more than the most fiber-rich crispbread varieties usually contain.

Nutritional studies indicate that a low dietary fiber intake may contribute to a number of noninfectious "diseases of civilization." Dietary fiber acts as a bulking agent normalizing intestinal motility and preventing diverticular disease (Burkitt et al 1974). Some types of dietary fiber may also be important in reducing colonic cancer, in lowering serum cholesterol levels, and in preventing hyperglycemia in diabetic patients (Walker 1974). However, some fibers, especially those rich in phytic acid, interfere with the absorption of minerals, such as zinc, iron, and calcium, which, in turn, leads to deficiency diseases (Reinhold et al 1973).

To increase dietary fiber consumption, several high-fiber products have been introduced on the retail market (McCormick 1976). Most interest has been concentrated on the use of bran from wheat, rice, corn, soy, etc. and of microcrystalline celluloses in baked products. Bread volume did not change by addition of up to 7% wheat bran to wheat flour (Pomeranz et al 1977), whereas spread, color, tenderness, and crispiness in sugar-snap cookies were influenced by addition of 30% wheat bran (Vratanina and Zabik 1978). Replacement of 30% of the wheat flour with wheat bran still gave acceptable white layer cakes (Springsteen et al 1977, Shafer and Zabik 1978).

In Europe, different types of crispbread with a high dietary fiber content (about 12%) are produced. The bread contains approximately 7% moisture, has a crispy texture, and can be stored for several months at room temperature (Haenel and Tunger 1976).

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The consumption of crispbread in Sweden exceeded 6 kg per person in 1978 (Anonymous 1979). The conventional crispbread process requires the steps of dough production, forming, cutting, baking, cooling, and packing (Bressler 1979). The baking steps, in particular, are energy intensive because considerable quantities of added water must be removed.

In Central Europe, several companies have developed processes based on extrusion cooking for the production of crispbread (Vincent 1980). Extrusion cooking is a high-pressure, high-temperature, short-time process that offers a substantial improvement over conventional baking processes; in particular, reductions occur in specific energy consumption, in the space required for equipment, and in capital investment. Investigations by Breen et al (1977) and Seiler and Seibel (1978) on high-fiber products produced by extrusion have been published. Knowledge on how this process changes the components (eg, carbohydrates, proteins, fats, and vitamins) is still very limited, however.

The purpose of this investigation was to determine the influence of formula (different wheat bran, starch, and gluten levels) and of processing conditions on chemical, physical, and sensory properties of an extruded product similar to a Swedish crispbread.

MATERIALS AND METHODS

Materials

Wheat bran (Kruskakli) was obtained from Kungsörnen Mill, Sweden. Wheat gluten (Universal Vital) and wheat starch (Raisio, secondary starch) were obtained from the Raisio Factories, Finland.

Before extrusion, the ingredients were thoroughly mixed in a double-ribbon blender (Palmia FB 70.2, Palmiaverken, Sweden) in 10-kg batches. The composition of the four formulas is shown in Table I.

Extrusion Cooking

Extrusion was done in a Creusot-Loire BC 45 extruder (Firminy, France) with corotating double screws having the following configuration: transport, low pressure, medium pressure, high pressure, and reverse screw elements. No external heat was transferred to the barrel or the screws during extrusion. On the contrary, the barrel was cooled with a specially designed air-cooling device. Mass temperature and pressure were measured with a Dynisco probe in the compression chamber just before the dies.

To obtain a crispbread type of product, rectangular dies (2 × 20 mm) with a land thickness of 27 mm were used. The feed rate of material was kept constant at 400 g/min, and two screw speeds, 150 and 200 rpm, were chosen. During extrusion, water was added directly to the material in the extrusion barrel at three different levels (25, 54, and 78 ml/kg).

Analysis

Moisture and Kjeldahl nitrogen were analyzed according to AOAC (1975) standard methods 14.058 and 14.063, respectively.

Starch content was determined as the difference in glucose before and after digestion of the sample with amyloglycosidase.

Dietary fiber was analyzed according to a method outlined by Hellendoorn et al (1975). The sample was suspended in water, boiled for 15 min, and digested with pepsin and pancreatin. The insoluble fiber fraction was obtained after filtering the suspension and drying. The soluble fiber fraction was precipitated with ethanol, filtered, dried, and weighed.

Monosaccharides and disaccharides were analyzed by liquid chromatography according to Hedlund and Marvik (1980). Ten grams of a finely ground sample was extracted with 50 ml of 80% aqueous ethanol for 3 hr at 60°C. The extract was cooled and filtered through a Munktell 00R ash-free filter. The clear filtrate was subjected to analysis.

Phytate was determined according to Oberleas (1971). Two grams of ground sample was extracted with 0.3*M* HCl. The extracted phytic acid was precipitated as ferric phytate. After ashing, the phosphorus content was determined spectrophotometrically at 660 nm, according to Lindberg and Ernster (1956).

The density of the extruded products was determined according to Hwang and Hayakawa (1980).

The sensory characteristics of the extruded products were screened by a four-member expert panel that was well aware of the purpose of the investigation. The panel members individually evaluated appearance, taste, and texture of the products. Then, under the supervision of the panel leader, common conclusions were drawn regarding the characteristics.

RESULTS

Composition of Ingredient Mixtures

The chemical properties of the ingredients are presented in Table II. Bran contained 47.3% dietary fiber, gluten contained 13.5%, and starch 8.0%. The protein content in the gluten preparation was 74.3%, whereas the bran and the starch contained smaller amounts of protein, 14.0 and 5.4%, respectively.

The calculated amounts of moisture, protein, starch, and dietary fiber in the four ingredient mixtures (formulas I–IV) are shown in Table III. The dietary fiber and protein content were highest in formula I; formulas III and IV contained the lowest amounts of dietary fiber and protein, respectively. All mixtures contained 8–9% moisture.

Extrusion Conditions

Extrusion temperature and pressure were measured in the material flow close to the die inside the barrel (Table IV). An increase in bran content caused a decrease in extrusion temperature (from 150 to 142°C) as well as in extrusion pressure (from 17 to 6 MPa). Shifting the screw speed from 150 to 200 rpm resulted in a 2–3 MPa decrease in extrusion pressure but no difference in extrusion temperature, as shown for formula II in Table IV.

Moisture. For any given extrusion condition, the highest water content was found in formula I, which had the highest bran content and also the highest water content in the ingredient mixture (Fig. 1). Addition of water during extrusion caused an increase in moisture of the extruded products. Changing the water addition from 25 to 54 ml/kg resulted in an average increase in moisture of 1.3% in the extruded products. However, a further increase in water addition, from 54 to 78 ml/kg, led to an increase in moisture of only

TABLE I
Composition of Formulas for Extrusion of Products with Crispbread Character

Formula	Ingredient, % (w/w)		
	Bran	Starch	Gluten
I	50	40	10
II	30	60	10
III	10	80	10
IV	30	70	···

TABLE II
Chemical Composition (%) of Ingredients Used in Extrusion Experiments

Ingredient	Moisture	Protein[a]	Starch	Dietary Fiber
Bran	10.2	14.0	9.7	47.3
Starch	8.3	5.4	63.1	8.0
Gluten	4.6	74.3	6.8	13.5

[a]N × 5.7.

TABLE III
Calculated Chemical Composition (%) of Ingredient Mixtures

Formula	Moisture	Protein[a]	Starch	Dietary Fiber
I	8.9 (9.2)[b]	16.6	30.8	28.3
II	8.5 (8.5)	14.9	41.5	20.4
III	8.1 (8.0)	13.2	52.2	12.5
IV	8.9 (8.8)	8.0	47.1	19.8

[a]N × 5.7.
[b]Moisture values in parentheses were experimentally obtained.

0.6%.

Increasing the screw speed from 150 to 200 rpm caused a decrease in moisture in the product.

Product Density. The product density varied from 85 to 650 g/dm^3 (Fig. 2). The ratio (w/w) between starch and fiber greatly influenced the density of the product. Highly expanded products with low density were obtained with high-starch/low-bran mixtures and compact products with low-starch/high-bran mixtures (Fig. 3).

Shifting the screw speed from 200 to 150 rpm caused an increase in density of 20–80%, whereas changing the amount of water added from 25 to 78 ml/kg did not influence the density of the product.

Sugars. The total amount of glucose, fructose, and sucrose in the unextruded mixture of ingredients decreased (Fig. 4) from 53 mg/g (formula I) to 15 mg/g (formula III). During extrusion, the sugar content was reduced by 80% for formulas I–III and 72% for formula IV.

The glucose and fructose content tended to decrease when the addition of water was increased. The reduction in monosaccharide content was somewhat lower when the higher screw speed was used.

In addition to glucose and fructose, the ingredients also contained some arabinose and xylose. After extrusion, neither arabinose nor xylose could be detected in any product.

Phytate. The phytate content, determined as phytic phosphorus, was closely related to the amount of bran in the formulas (Fig. 5). The reduction in phytate during extrusion was between 13 and 35%. No influence of formula or processing conditions on decrease in phytate content was noticed.

Sensory Screening. The results from the sensory screening of the extruded products are summarized in Table V. A product similar to Swedish crispbread in structure, texture, and taste was obtained from extrusion of formula II with a water addition of 78 ml/kg. The sensory characteristics were most influenced by changing the proportions between bran and starch, whereas exclusion of gluten from the formula only had small effects. At very high bran contents, the extruded product showed properties similar to a Swedish bread known as thin-bread. An increase in water addition resulted in a less hard product with open structure and good taste.

DISCUSSION

To evaluate the influence of different components on the chemical, physical, and sensory properties of an extruded high-fiber cereal product with crispbread character, four mixtures of ingredients containing different amounts of dietary fiber, starch, and protein in the ranges 12.5–28.3%, 30.8–52.2%, and 8.0–16.6%, respectively, were processed. The bran fraction "kruskakli" was chosen for its very high dietary fiber content, 47.3%, and gluten was added as a protein source as well as a functional ingredient to stabilize the cell structure of the expanded product. Secondary

TABLE IV
Effect of Process and Formula on Extrusion Temperature and Pressure

Process	Formula	Extrusion Conditions: Added Water (ml/kg)	Screw Speed (rpm)	Temperature[a] (°C)	Pressure[a] (MPa)
Standard	I	54	150	142	6
	II	54	150	150	10
	III	54	150	150	17
	IV	54	150	145	11
Varied	II	25	150	155	8
			200	155	6
		54	150	150	10
			200	150	7
		78	150	144	10
			200	142	8

[a] Extrusion temperature and pressure were measured in the material flow close to the die inside the barrel.

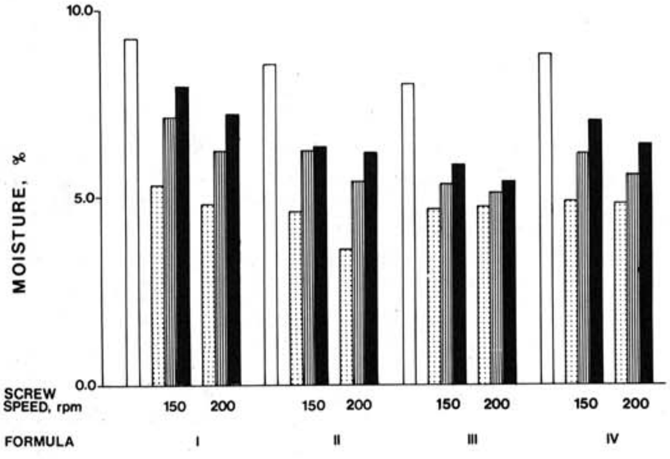

Fig. 1. Effect of extrusion on moisture. □ = Ingredient mixture; extruded product made with added water level: ▨ = 25 ml/kg, ▥ = 54 ml/kg, ■ = 78 ml/kg. Mean of duplicate determinations. Coefficient of variation: <1.0% of analytical values.

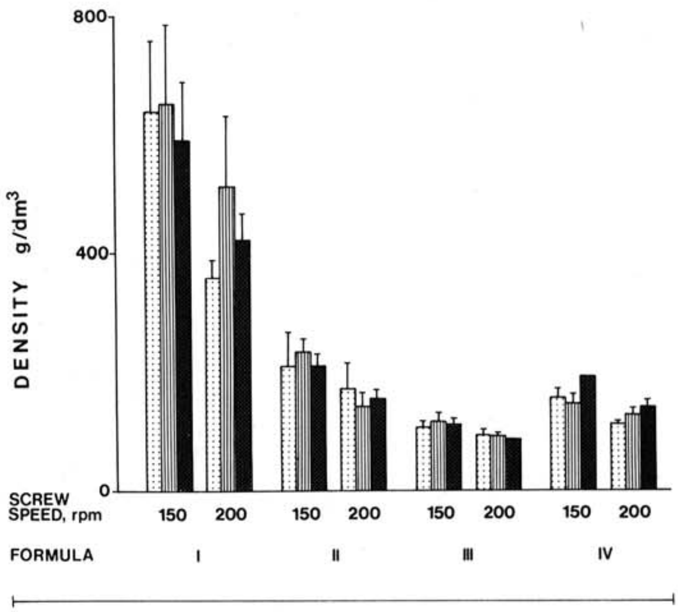

Fig. 2. Effect of extrusion on product density. Extruded product made with added water level: ▨ = 25 ml/kg, ▥ = 54 ml/kg, ■ = 78 ml/kg. Mean of duplicate determinations including range.

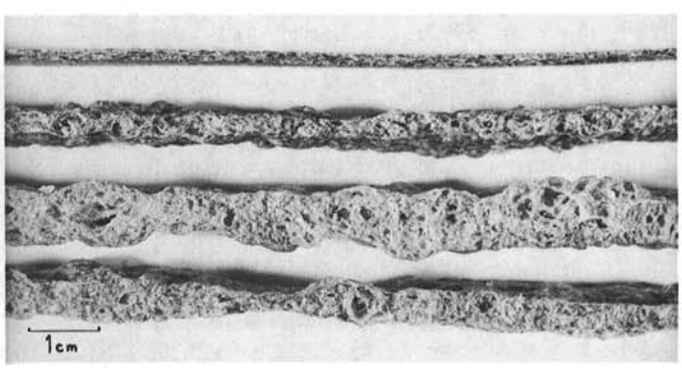

Fig. 3. Extruded products, transverse cut. From top to bottom: formulas I, II, III, IV. Extrusion conditions: screw speed 150 rpm, added water 54 ml/kg.

starch was selected because of its lower viscosity, compared to that of primary starch, in the pseudo-plastic melt of material within the extruder.

The expansion of cereal-based products (measured as product density or expansion ratio) is greatly influenced by type and amount of starch, moisture content, extrusion temperature, screw speed, etc (de la Guérivière 1976, Harper 1979, Mercier and Feillet 1975). Our study showed that the product density greatly decreased when the ratio between analyzed starch and dietary fiber contents was raised from 1.1/1.0 to 4.2/1.0; for example, the density decreased from about 700 to about 260 g/dm^3 for products produced with a screw speed of 150 rpm. High-fiber/low-starch ingredient mixtures resulted in compact products with the character of Swedish thin-bread, whereas the products with lower contents of dietary fiber had structures similar to Swedish crispbread (Fig. 3). Earlier, Seiler and Seibel (1978) reported similar results for an extruded wheat starch/bran product. They showed that the bulk density decreased from about 320 to 190 g/dm^3 when the ratio between starch and dietary fiber increased from about 1.2/1.0 to 3.0/1.0. We have also shown that shifting the screw speed from 150 to 200 rpm resulted in a more expanded, less hard product, in spite of the fact that the pressure measured in the compression chamber was lower for the higher screw speed (Table IV). Normally, a lower pressure should have given a less expanded, harder product. This result may be explained by a decrease in viscosity of the pseudo-plastic melt within the extruder caused by the higher shear rates at the higher screw speed (Remsen and Clark 1978). The viscosity decrease could change the heat transfer to and the heat transport within the mass, leading to chemical modifications of starch and/or changes in product characteristics. Increasing the amount of added water from 25 to 78 ml/kg did not influence the density in any clear direction. Mercier and Feillet (1975) observed no change in expansion of the product until the moisture content exceeded 22% (w/w), which was considerably higher than those used in our study.

A high-temperature extrusion process causes chemical degradation of the starch material (Wells 1976). According to Mercier and Feillet (1975), extruded starch is solubilized without any formation of maltodextrin. The solubilization is dependent on temperature, moisture content of starch before extrusion, and the amylose-amylopectin ratio. They also noticed a decrease in ethanol-soluble carbohydrate content, indicating a decrease in the amount of oligosaccharides.

During extrusion, the total sugar content was reduced by 70–80% (Fig. 4). Glucose was most sensitive; only minor amounts, approximately 0.1%, were found in extruded products from formulas I–III. Exclusion of gluten in the products (formula IV) resulted in considerably higher levels of glucose and fructose compared to those in products from the other formulas. This indicates a sugar degradation reaction of the Maillard type, leading to lower biological availability of lysine in the mixtures containing gluten (Adrian 1974, Beaufrand et al 1978). However, the reduction of sugars seems to be too large to be accounted for by Maillard or caramelization reactions only. Possibly, the sugars are physically bound in the product, causing a poor recovery of the sugars in the aqueous-ethanolic extraction. This phenomenon will be studied in more detail in future investigations.

Whole-grain cereals such as wheat and rice contain approximately 1% phytate, which is concentrated in specific subcellular particles (protein bodies) in the germ and aleurone

TABLE V
Sensory Properties of the Extruded Products

Variation	Result: Appearance	Result: Taste	Result: Texture
Increasing starch, decreasing fiber	More open structure Larger cells Lighter brown color	Increase in bitter taste Decrease in cereal-like taste	Decrease in hardness Increase in gluiness Material falls apart
Increasing screw speed	No difference	Increase in burnt taste Decrease in cereal-like taste	No difference in hardness and gluiness
Increasing water addition	More open structure More like Swedish crispbread	Decrease in bitter and burnt taste	Increase in hardness
Exclusion of gluten	More open structure Lighter brown color	No difference	Some decrease in hardness Some increase in gluiness

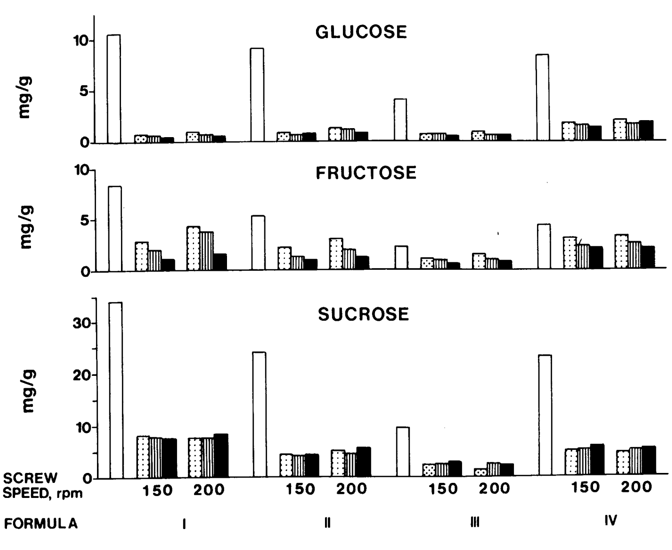

Fig. 4. Effect of extrusion on sugar content. ☐ = Ingredient mixture; extruded product made with added water level: ▨ = 25 ml/kg, ▥ = 54 ml/kg, ■ = 78 ml/kg. Mean of triplicate determinations. Coefficient of variation: <0.5% of analytical values.

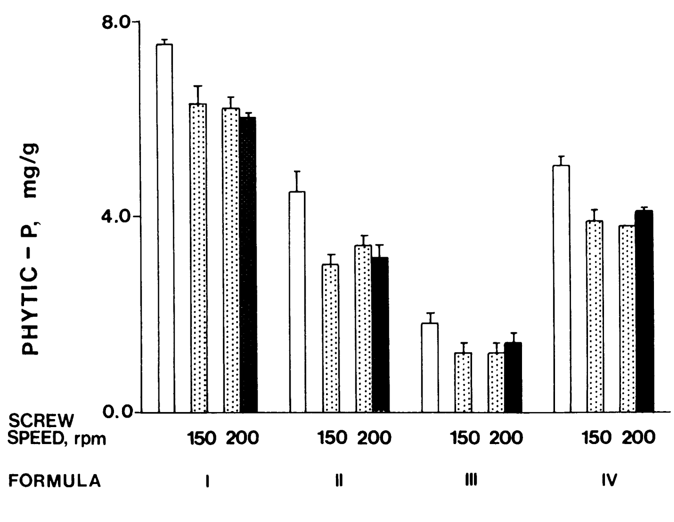

Fig. 5. Effect of extrusion on phytic-P content. ☐ = Ingredient mixture; extruded product made with added water level: ▨ = 25 ml/kg, ■ = 78 ml/kg. Mean of duplicate determinations including range.

layers of the kernel cells and in bran or hull (Erdman 1979). The phytate is rather thermostable, and heat treatment of a wheat slurry with added phytic acid for 4 hr at 115°C resulted in destruction of only 15% of the acid (de Boland et al 1975). In the present investigation, between 13 and 35% of the phytate was lost when dry mixtures of different wheat components were extruded at approximately 150°C. The main phytate reduction was probably caused by hydrolysis. However, heat treatment also denatures the protein components within and around the protein bodies, consequently reducing the extractability of the phytate. Because a reduction in phytate content of less than 40% is supposed to have only minor effects on the metal ion complexing capacity of bran, the extrusion conditions used in this study are not suitable as a phytate-reducing process.

A product with the character of Swedish crispbread in structure, texture, and taste was obtained from extrusion of a mixture of 30% bran, 60% secondary starch, and 10% gluten with a water addition of 78 ml H_2O/kg. The water content in the mixture before expansion was about 16%, whereas the extruded product contained only 6–7% water, quite similar to the level in Swedish crispbread. The amount of dietary fiber in this product was calculated as 20.4%, which is about 75% more than the most fiber-rich crispbread varieties usually contain. A further increase in bran content resulted in extruded products with thin-bread character.

A process to make extruded, hard, breadlike products has been patented by Müller (1978). The patent includes a mixture preferably containing wholemeal wheat or rye with a water content of 18–25%, which is extruded into strips that are cooled, dried, and cut into slices. Seiler and Seibel (1978) extruded a wheat bran/starch mixture with a water content of 20–28%, resulting in product moisture levels of 13–21%. In our study, ingredient mixtures containing 11–17% water (including water added during the extrusion process) were extruded into products having ideally low water contents (4–7%) without a product drying step.

Consumption of 10 g of the extruded product containing 30% bran will result in a dietary fiber intake of 2 g, an amount proposed by Painter et al (1972) for preventing diverticular disease. However, whether dietary fibers heat-treated at higher temperatures (in this case around 150°C) will have the same physiological effects as fibers not heat-treated is not known. The nutritional consequences of extrusion cooking as a food preparing process are still not fully elucidated.

CONCLUSIONS

Extrusion cooking is a suitable process for making breadlike high-fiber products that, after cutting, are ready for packaging and distribution. For such products, different types of bran can be used as the fiber-contributing ingredient. However, because natural components in most brans decrease the biological availability of minerals as zinc, iron, and calcium, dietary fibers without this disadvantage are needed. Studies are now in progress in which mixtures of potato and/or carrot fibers, starch, and protein are extruded into breadlike products.

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