Wheat, Wheat-Rye, and Rye Dough and Bread Studied by Scanning Electron Microscopy[1]

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ABSTRACT

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Three types of bread (100% white wheat flour, 60% wheat–40% rye flours, and 90% rye meal–10% rye flour) were examined by scanning electron microscopy along with appropriate samples drawn during dough mixing, various stages of sourdough production and fermentation, and baking. In white wheat flour doughs, structure was based primarily on formation of a protein matrix. Large starch granules and especially "stringing" of small starch granules contribute to dough structure in white wheat flour systems. In the bread, interaction occurs between protein and swollen starch (mainly large granules). Much of the starch is modified, but in some "protected" crumb and crust areas (inside vacuoles), little modification, especially of small starch granules, was observed. In the mixed wheat–rye system, some contribution is from gumlike substances and from modifications of gluten and starch by organic acids. In rye meal systems, gum materials facilitate stringing of small starch granules and their adherence to large granules. Whereas in white wheat or mixed wheat–rye systems, pericarp-aleurone particles are part of the problem, in the rye meal system they are part of the solution of providing a coherent and continuous dough or bread structure. The major contributor to rye meal bread structure is modified starch. The rye meal bread crust, unlike the crust of wheat and mixed wheat–rye flour bread, is coarse and affected by the presence of particles rich in aleurone-pericarp.

The structure of the crumb in panned white wheat bread has been the subject of numerous studies. Some earlier studies were reviewed elsewhere (Pomeranz 1976). Some recent studies that employed light, transmission electron, and, particularly, scanning electron microscopy (SEM), were conducted by Moss (1974), Marston and Wannan (1976), Hoseney et al (1977, 1978), Khoo et al (1975), Varriano-Marston (1977, 1981), Bechtel et al (1978), Chabot et al (1979), and Vassileva et al (1981).

By light and transmission electron microscopy, Bechtel et al (1978) found that protein strands provided a matrix network in a mixed dough; matrix formation required adequate mixing and fermentation-produced gas vacuoles. Protein strands were thin and had small vacuoles after oven spring. Starch granules in the bottom center of a loaf varied widely in degree of gelatinization, with gelatinization of starch beginning in the interior of the granules. In the baked bread, most of the starch was gelatinized into fibrous strands that were in contact with thin protein strands.

Modification of starch during baking is of particular interest in relation to the role of starch in wheat and rye breads. According to Kulp and Lorenz (1981), functionality of wheat starch as a bread ingredient remains elusive. Integrity of the wheat starch granule is essential for their optimal performance in both bread and cake systems. Mechanical, chemical, or biochemical disruptions of the native granule have adverse effects on bread-forming properties of wheat starch. The effect of excessive mechanical starch damage is further aggravated by abnormally high levels of α-amylase from malt or sprouted grain. Yasunaga et al (1968), Derby et al (1975), and Lineback and Wongsrikasem (1980) postulated that degree of gelatinization depended mainly on the available moisture but also on the temperature during baking.

Information on the structure of rye breads is limited. Using SEM, Wassermann and Dorfner (1974) compared structures of white, mixed, and rye bread crumbs. Rye bread is of significance for several reasons. First, it is a nutritious staple in several parts of the world. Second, it has good shelf life. Third, its structure is based, to a limited extent, on a gluten matrix. And fourth, findings based on structure of rye bread could be applied in the production of acceptable baked goods from nonwheat products.

Methods of rye bread production were reviewed recently by Stephan (1982). According to Drews and Seibel (1974), water-imbibing and swelling substances (proteins and pentosans) and amounts and properties of starch are of major significance in making rye bread. Under conditions of baking, wheat starch is less susceptible to enzymic attack and gelatinizes at higher temperatures (above 70° C) than rye starch (above 50° C). Wheat products can be baked in relatively neutral media and may require light acidification, only if produced from highly sprouted grain. Similarly, the significance of starch in white wheat bread is much smaller than in rye bread (Drews and Seibel 1974). Most of the attention is directed to the contribution of gluten quality and quantity. Gluten can exert its unique viscoelastic properties more distinctly in the relatively neutral wheat dough than in the acidic rye dough. In addition, wheat breads are predominantly baked from white flours that contain relatively small amounts of pentosans, which are concentrated in the outer kernel layers. Those pentosans absorb water and swell but produce only with difficulty porous and well-leavened baked products. Those pentosans may be a strain on the whole system.

In wheat bread, the well-leavened gluten system is reinforced during baking by the gelatinized starch (Bechtel et al 1978). The protein components cannot realize their full potential in the acidic, highly viscous rye dough (Drews and Seibel 1974, Stephan 1982). Consequently, the degree of leavening of rye bread is reduced. Starch is a major structural component, rather than a reinforcing contributor, in rye bread. The role exerted by the starch is affected by the pH of the system, dough composition and formulation, enzymic activities, and extent of starch degradation (mechanical or enzymic).

Use of a coarse meal, rather than a flour, is especially important in the production of bread from highly sprouted rye. In the meal, surface area, starch damage, and effective enzymic activities are reduced, dough acidification is enhanced, and excessively high, stress-effecting levels of water are eliminated. In some parts of Central Europe, ripe grain has some degree of sprout damage. Starch damage in rye breadmaking, unlike in wheat breadmaking, is highly undesirable. Interestingly, it is rather difficult to damage rye starch mechanically during milling (unlike in wheat), probably because of the relatively high content of gum materials in rye. Similarly, the tendency to use finely milled flour in wheat bread production (to accelerate processes, produce more uniform products, and increase water absorption and starch damage) is a disadvantage in rye processing. Practice has also shown that some deficiencies in rye bread production, caused by raw material of somewhat inferior quality, can be mitigated by the use of coarse meals rather than flours (Drews and Seibel 1974).

The objective of this study was to use SEM to follow changes that occur during dough mixing, sour production, fermentation, and

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[1] Mention of firm names or trade products does not constitute endorsement by the U.S. Department of Agriculture over others not mentioned.

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TABLE I
Description of Flours

									Farinograph (14% m.b.)		
Flour	Type	Moisture (%)	Ash (%, d.b.)	Reducing Sugars (maltose, %, d.b.)	Falling No. (sec)	Sedimentation Value	Protein (%, d.b.)	Gluten Wet (%, as is basis)	Absorption (%)	Dough Development Time (min)	Consistency Fall (BU)[a]
Wheat (treated)[b]	550	14.2	0.54	2.2	272	35	12.1	27.2	59.7	3.0	95
Wheat (treated)[b]	1050	11.6	1.04	2.1	262	24	13.2	23.2	60.9	5.0	75
Rye	997	13.4	0.92	2.4	163	...	9.4	...	...	...	...

[a] Brabender units.
[b] 20 ppm ascorbic acid.

TABLE II
Sieve Analyses: Alpine Air-jet Sieve

Flour	Sieve Openings (μm)	Percent Retained
Wheat		
Type 550	75	38.0
Type 1050	75	35.0
Rye, type 997	75	29.5
Rye meal	1,400	46.0
Type 1800	710	32.0
	250	12.0
	(pan)	10.0

TABLE III
Formulation for the Production of Breads

Component (g)	Wheat Bread	Wheat-Mixed Bread	Rye Bread
Wheat flour 550	100	...	...
Wheat flour 1050	...	60	...
Rye flour 997	...	40	10
Rye meal	...	...	90
Sugar	1.0	...	...
Fat	1.0	...	...
Commercial improver (baking aid)	1.0	...	...
Yeast	4.0	1.9	1.0
Salt	2.0	1.9	2.0
Water	60.5	65.0	75.0

baking, and to compare the structure of wheat, mixed wheat–rye, and rye doughs and breads.

MATERIALS AND METHODS

Flours and Rye Meal

Three flours and a rye meal used in this study are described in Table I. Determinations were made according to Standard Methoden fur Getreide, Mehl und Brot (Arbeitsgemeinschaft Getreideforschung 1978). Ash, maltose, and protein (N × 5.7 in wheat, N × 6.25 in rye) are expressed on a moisture-free basis; sedimentation value and farinograph data (water absorption, dough development, and consistency fall) on a 14% moisture basis; and falling number and wet gluten on an as-is moisture basis. The rye meal (medium particle size) and rye flour were milled from the same product to different granulations. The whole rye had an ash content of 1.6% and protein content (N × 6.25) of 9.7% (both on a dry basis). The falling number was 106 (as-is basis), and the maximum amylograph viscosity at 63° C was 445 Brabender units (BU). In sieve analyses (Alpine air-jet sieve) amounts given in Table II were retained.

The amylograph data (80 g, 14% m.b.) of the rye flour were: 85 BU beginning viscosity, 465 BU maximum viscosity, and 62.5° C temperature of maximum viscosity. When the flour was baked by the lactic acid baking test, the volume was 315 cc, and the bread was of satisfactory crumb grain, texture, and overall quality.

TABLE IV
Procedures for Bread Production

					Baking	
Bread	Mixing (min)	Dough Temperature (° C)	Fermentation (min)	Final Proof (min)	Time (min)	Temperature (° C)
Wheat	1 (high-speed)	26	10 + 15	45	30	240
Wheat-mixed	2 (Diosna)	27	15	65	55	250–210
Rye	10 (Diosna)	29	30	60	120	200–180

TABLE V
Baking Results

	Wheat Bread	Wheat Bread	MixedRye Bread
Bread yield (%)	137.2	147.6	150.0
Baking loss (%)	18.9	12.1	15.8
Loaf volume (ml/100 g of flour or meal)	557	369	210

Doughs and Bread

The wheat bread (free-standing longitudinal loaves) was baked from 100% white wheat flour, the mixed bread from 60% wheat and 40% rye flours of high milling extraction, and the rye bread from 90% whole grain of medium particle size and 10% high-extraction rye flour.

For the production of the wheat bread, we used the formulation in Table III. Wheat flour (type 550), and the other ingredients are used in standard West German white bread. The dough was mixed with a Stephan high-speed mixer and fermented and baked as described in Table IV. The baking results are summarized in Table V. From 100 g of wheat flour (14% moisture basis), we received 137.2 g of bread. The loaf volume of 557 ml indicates a wheat flour of medium baking strength.

Tables III and IV and Fig. 1 also describe formulations and dough-handling details for the mixed wheat–rye and rye meal breads. Doughs for those breads were mixed with a Diosna mixer at about 100 rpm. For the wheat–rye mixed bread, 20% of the total flour (including 50% of the rye flour) was used in a sourdough. In the Detmold two-stage sourdough process (Fig. 1), we start with 1 kg of starter (Anstellgut), which corresponds to the basic sour at the end of stage 1. By adding rye flour and water, we obtain 24 kg of basic sour after 18 hr. This sour is used for stage 2. We again add rye flour and water, and after 3 hr we obtain 72 kg of full sour. During the whole two-stage process, we obtain, from 1 kg starter sour (Anstellgut) after the two stages within 21 hr, 72 kg of full sour that can be used directly as part of the formulation for the production of mixed wheat–rye bread. From 100 g of flour (60% wheat and 40% rye) we obtained 147.6 g of bread (Table V).

The yield of rye bread, which is higher than that of white wheat bread, results from the higher moisture content of the bread crumb. The main acids formed during the sourdough process are lactic and acetic. *Lactobacillus plantarum* produces lactic acid only, whereas

L. brevis produces both acetic and lactic acids. The ratio of the two fermentation acids may be varied with the sourdough conditions (dough yield, time, and temperature).

For the production of rye meal bread, we used 90% whole rye meal and 10% rye flour type 997 (Table III). A whole rye meal bread must be baked from a formulation that contains a minimum of 90% whole rye meal. We used 35% of the meal as sourdough (Fig. 1). Mixing time and fermentation length are considerably longer than in mixed wheat–rye bread (Table IV). In addition, meal breads are baked longer and at lower temperatures than flour breads. For the rye meal bread, we used sourdough from a single-stage sourdough process (Fig. 1). Within 16–18 hr we obtained from 1.0 kg of starter sour (Anstellgut) 76 kg of full sour. The yield of the rye meal bread is 150 g per 100 g of meal and flour, and the loaf volume decreases further to 210 ml (Table V).

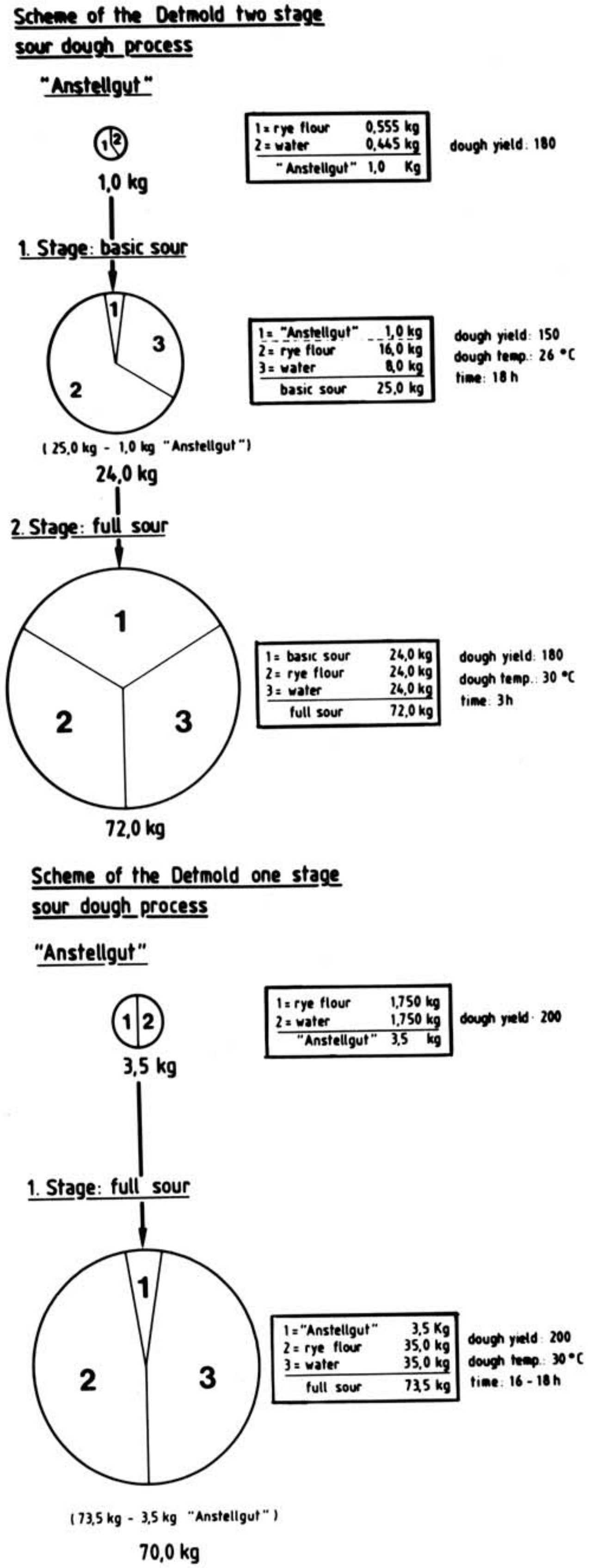


Fig. 1. Diagrammatic descriptions of methods to produce mixed wheat–rye (Detmold two-stage sourdough process) and rye meal (Detmold one-stage sourdough process) bread.

Microscopic Examinations

Flours and meals were placed on double-stick adhesive tape. Small pieces (about 1 cm in diameter) of dough or bread crumb (from the center of a freshly baked bread) were cut with a pair of sharp scissors with minimum distortion from smooth, freshly

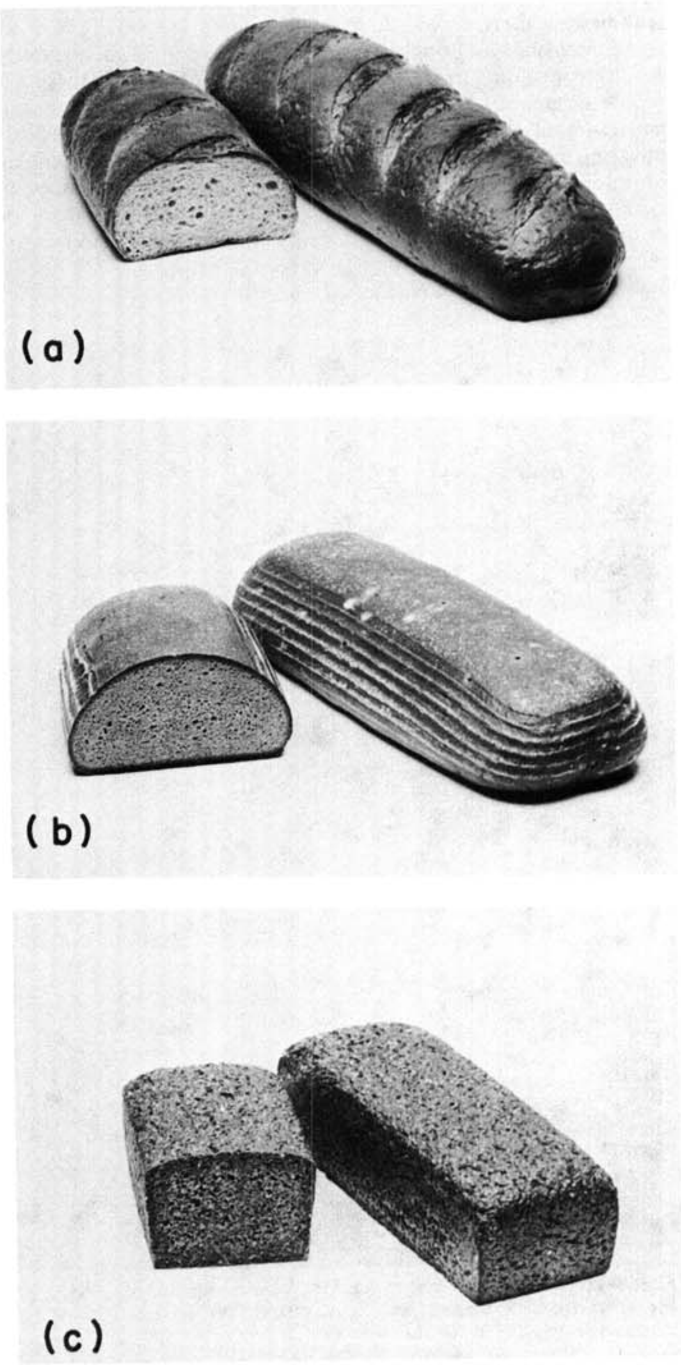


Fig. 2. Loaves and cut loaves of breads baked from **(a)** 100% wheat flour, **(b)** 60% wheat–40% rye flour, and **(c)** 90% rye meal (medium) and 10% rye flour.

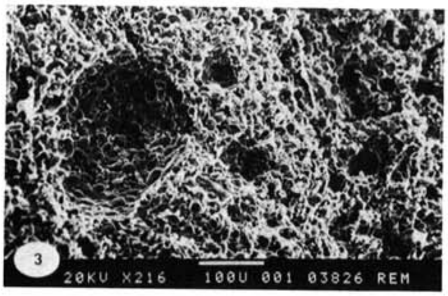
exposed surfaces. Small pieces of dough, bread crumbs, and crust (cut immediately after baking) were air-frozen at −20° C and freeze-dried. The freeze-dried pieces were fractured to expose interior surfaces, mounted on specimen holders coated with a special glue (Leit C), and sputter-coated with gold. The preparations were viewed and photographed in a Leitz AMR 1 600 T scanning electron microscope at an accelerating voltage of 20 kV.

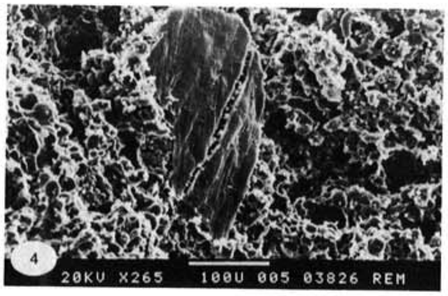
RESULTS

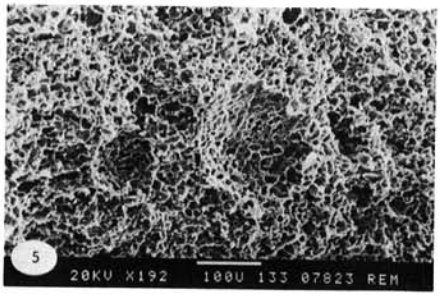
Loaves and cut loaves of breads baked from 100% wheat flour, 60% wheat–40% rye flour, and 90% rye meal (medium)–10% rye flour are shown in Fig. 2.

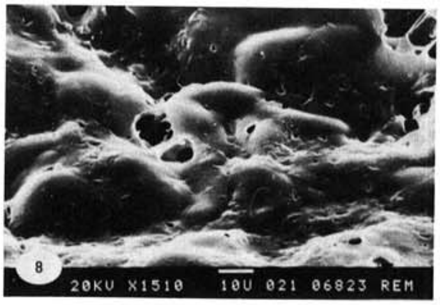
Scanning electron micrographs of samples from various stages of wheat bread production are shown in Figs. 3–11. Figure 3 is an overview at low magnification of freshly mixed dough. A bran particle (in Fig. 4) forms a foreign body, which may interrupt continuity of the matrix and damage it mechanically. The structure is somewhat more developed in the fermented dough (Fig. 5) than in the freshly mixed dough (compare Figs. 3 and 5). Some structure results from gluing small starch granules (Fig. 6) together to form a strung-out matrix. The structure and cell walls in the bread crumb can be seen in Fig. 7. The structure involves a protein matrix covering expanded starch granules (Fig. 8). Small starch granules appear little modified, and the larger granules expand and interact with the protein matrix in formation of the bread crumb (Fig. 9). Outlines of starch granules (especially small ones) were well recognized in the outside crust layer (not shown). Cross section, at low magnification, of the crust shows a porous system with relatively large gas vacuoles (Fig. 10). Inside the vacuoles, especially in areas close to the outside crust, starch granules are less expanded (Fig. 11), unlike starch granules in crumb (not shown). The difference may be related to availability of water for starch gelatinization; more is available in the area close to the crumb, and most is evaporated from the area immediately below the outside crust.

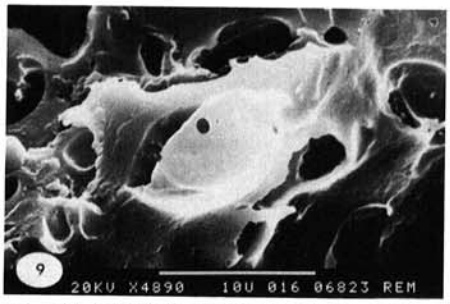
SEM of samples from various stages of mixed bread (wheat–rye) are shown in Figs. 12–20. Only a small number of figures have been selected from the three stages of mixed-bread sour fermentation (basic sour, full sour, and dough). Development of dough structuring increased from stage to stage and throughout each stage. Several elements appeared to comprise the structure of the basic sour. They included a protein-gum matrix, small starch granules strung together, and large individual starch granules (Fig. 12). Another element in the structure of the basic sour of the mixed bread is bran and aleurone layer particles, as shown in Fig. 13. A mixture of various structures, from a coarse and thick-walled cover (Fig. 14) to a very fine veil-like (Fig. 15) is shown in full sour. In Fig. 14, dough sour structure seems to involve participation of modified-distorted starch, even though the material has not undergone heat treatment. Some of the distortion might have been caused during sample preparation. The sour was produced from a mixture of wheat and rye flours, both of relatively high extractions, which contained bran. This is reflected in Fig. 16, an overview at low magnification of the final stage of the full sour. In that sour, a matrix—in part enmeshing starch granules (Fig. 17)—encompasses pericarp-aleurone particles (Fig. 18). In Fig. 18, bran cell walls appear to align and form part of the dough (or sour) structure. In











Figs. 3–11. Wheat dough and bread. **Fig. 3.** Scanning electron microscopic (SEM) overview of a wheat-flour dough. Note coarse structure and vacuoles. **Fig. 4.** Bran particle in coarse structure of mixed dough. **Fig. 5.** SEM overview of fermented wheat-flour dough. Note finer and more developed structure than in mixed dough. **Fig. 6.** SEM of wall and vacuole in fermented dough in which small amounts of proteinaceous membrane material cement together (string out) small starch granules. **Fig. 7.** SEM overview of fine structure of wheat-flour bread crumb. **Fig. 8.** Protein matrix covering expanded starch granules in bread crumb. **Fig. 9.** Swollen starch-protein matrix interaction in formation of bread crumb structure. Note small, seemingly unaltered starch granule. **Fig. 10.** Cross section through crust of wheat bread. Note thick layer close to outside and coarse vacuoles in layers towards the crumb. **Fig. 11.** Starch granules retained (in shape, size, and overall appearance) in vacuole of crust in area close to outside.

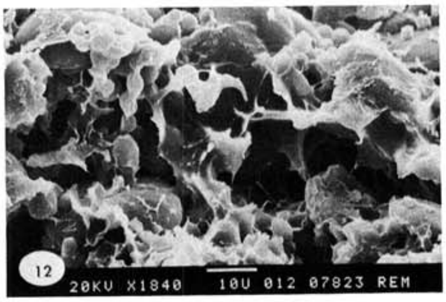
addition, limited starch modification may affect both elasticity and resilience of the dough during oven spring. Figures 19 and 20 show the crumb of mixed wheat–rye bread at various magnifications. The bread crumbs of wheat (Fig. 7) and of mixed wheat (Fig. 19) are comparable. The latter, however, is crumbly and appears weakened, presumably by the pericarp-aleurone particles. The somewhat weakened structure is also indicated in Fig. 20, in which numerous highly damaged starch granules and starch-protein interfaces are shown. The mixed-bread crumb was the most fragile (during preparation of fractured surfaces for freeze-drying) among the crumbs of the three bread types (wheat, mixed, and rye). The mixed-bread crust (not shown) was denser than the wheat bread crust and contained numerous starch granules that had apparently undergone little modification. The bread crumb close to the crust showed a fine structure and contained highly swollen starch granules. This may reflect the somewhat higher baking times and starting baking temperatures of the mixed wheat–rye than wheat bread.

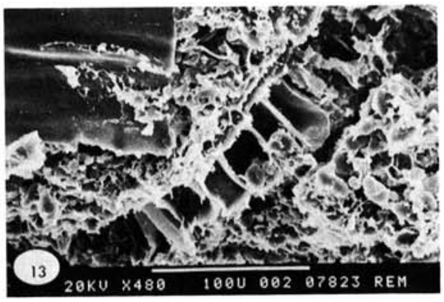
SEM of samples from various stages of rye meal bread production are shown in Figs. 21–29. The sour of the rye meal bread includes several elements: small starch granules and bran particles glued together, in addition to what appears to be gum material (Fig. 21). Some small starch granules seem to cluster around, or are glued to, large granules. The rye meal dough is composed of fine-textured gum materials that hold the starch granules (Fig. 22) and chunks of rye meal (Fig. 23). Cross and longitudinal pericarp cells are part of the rye chunk and form either the wall or the lining of a vacuole when glued together. This combined contribution is shown at higher magnification for the mixed dough (Fig. 24). The participation of aleurone and pericarp particles in the fermented dough before baking is shown in Fig. 25. The pericarp-aleurone contributed to a rodlike structure in some, and to a sheetlike structure in others.

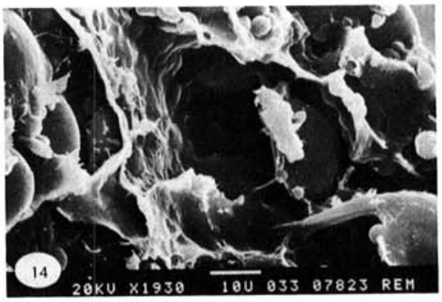
The diversity of contributions to bread structure is further demonstrated in the bread crumb. Figure 26 shows both fractured and vacuole areas. The contribution of starch-protein and bran regions is shown in Fig. 27. The bread crust was rugged, and despite the long baking time, outlines of starch granules could be identified. A cross section of the crust is shown in Fig. 28. Two features stand out, the "ruggedness" (large vacuoles) and the contribution of starchy and bran regions. Large starch granules in the vacuole and in the fractured area (Fig. 29) are expanded, but some small granules retain their sizes and shapes. The outside crumb, in proximity of the crust, showed considerable irregularity and relatively little of the fine structure shown by similar areas in the wheat and mixed (wheat–rye) bread.

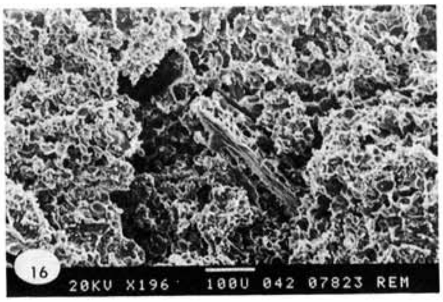
DISCUSSION

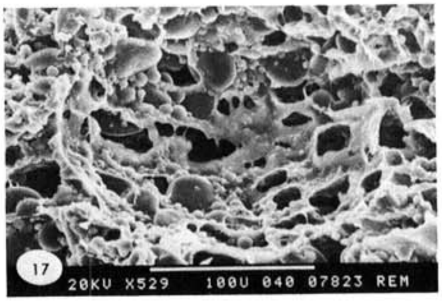
In white wheat bread, dough structure is formed by a protein matrix that becomes thinner, finer, and better distributed by fermentation and formation of small vacuoles. In the bread crumb, there is considerable interaction between proteins and swollen-modified starch. In dough formation, both immediately after

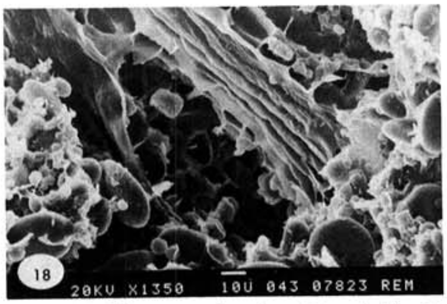


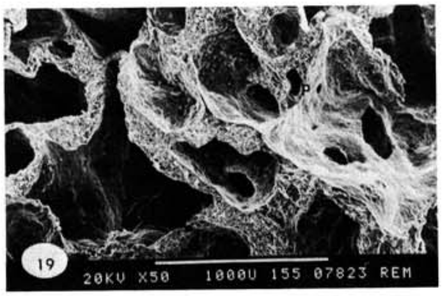










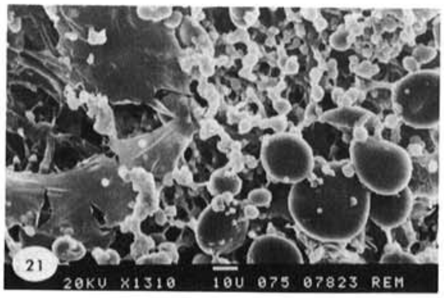


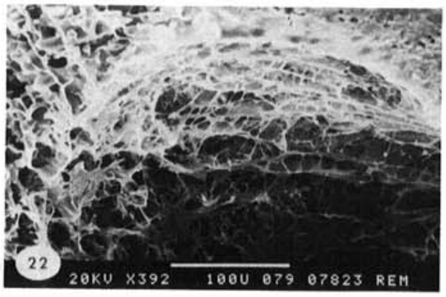
Figs. 12–20. Wheat-rye dough and bread. **Fig. 12.** Matrix covering starch granules in wheat-rye sour, beginning stage. **Fig. 13.** Bran and aleurone layer particles, along with starch-protein matrix, as elements in wheat-rye basic sour, beginning stage. **Fig. 14.** Coarse and thick-walled protein cover along with modified starch granules as part of structure in wheat-rye full sour, beginning stage. **Fig. 15.** Fine veil-like matrix covering starch granules in wheat-rye full sour, beginning stage. **Fig. 16.** Scanning electron microscopic (SEM) overview of various structural components in wheat-rye full sour, final stage. **Fig. 17.** Protein matrix (covering-imbedding-incorporating starch granules) as major structural components in vacuole of wheat-rye full sour, final stage. **Fig. 18.** Pericarp and aleurone particles as structural components of a wheat-rye full sour, final stage. **Fig. 19.** SEM overview of crumb of mixed wheat-rye bread. Note numerous vacuoles. **Fig. 20.** Crumb structure of mixed wheat-rye bread. Note highly perforated starch granules and overall crumbly structure, weakened in many places.

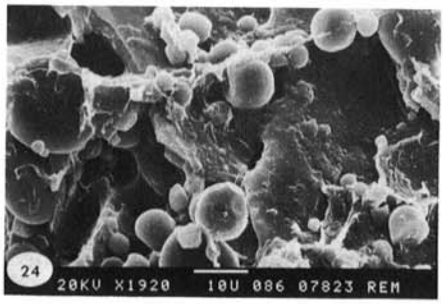
mixing and after fermentation, some structure formation involves "stringing" of small starch granules. In light of the high numbers of small starch granules, this contribution of starch to dough structure may be quite significant (Meuser and Klingler 1977). Evers and Lindley (1977) have shown that starch granules below 10 μm in diameter accounted for one third to one half of the total weight of wheat endosperm starch (Brocklehurst and Evers 1977). The large starch granules in the dough of white wheat bread probably contribute little to structure formation. As shown by SEM, the contribution of small starch granules in the baked bread is relatively smaller than that of large granules, which swell and interact with protein. Thus, in white wheat bread, the structure of the dough involves the gluten protein matrix and the strings of small starch granules glued together by gluten proteins. The structure of the baked wheat bread involves primarily interaction of denatured gluten-swollen starch (mainly large granules) and small starch granules that are strung together. Much of the starch in the crumb and crust is modified, but substantial amounts of starch granules, especially small ones, seem to retain their size and shape in "protected" areas inside the vacuoles. Starch in the area immediately beneath the outside crust is less modified than starch in the area next to the outside crumb. The difference seems to be related to water availability. The coherence and continuity of the protein matrix is weakened by small and disrupted by large amounts of bran particles.

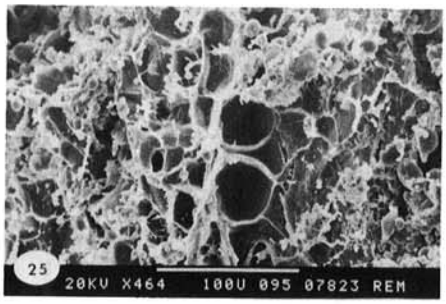
The mixed wheat–rye bread resembles the white wheat bread except that there is less organization, and some pieces appear to be glued together rather than spread uniformly over the starch to provide a uniform structure. Some contribution to dough structure seems derived from gumlike materials and protein and to a small extent from starch granules that are damaged mechanically or enzymatically. The higher bran-aleurone content (than in white wheat flour) may be disruptive, but those particles may be "anchored" by the various contributors to dough and bread structure. Whether dough acidification (sour) contributes to incorporation of bran aleurone particles in the dough and bread depends on several factors. Extent of starch-granule modification varied widely, probably reflecting differences in gelatinization of small and large granules, higher temperature of wheat starch than of rye starch gelatinization under baking conditions, and conditions in fractured areas or inside vacuoles. The crumb may be fine-textured and porous but relatively fragile and crumbly in part.

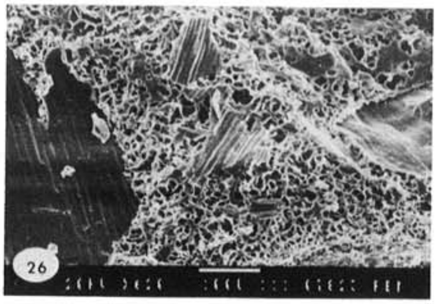
Rye meal samples (from sour through dough to bread) were much denser than white wheat flour or mixed wheat–rye samples. The rye meal dough is held together in part by gums and in part by a dense mass. The small starch granules are strung out and clustered (glued) to the large starch granules. Additional structural dough components include finely textured, gum components and rye meal pieces, thin-threaded in three dimensions. Whereas pericarp-aleurone particles are part of the problem in white wheat or mixed wheat–rye, in rye meal the chunks containing particles from the outer grain layers help to provide a coherent and continuous dough or bread structure. The major contributor to the structure of the rye bread is expanded starch. The structure of the rye meal bread crust is coarse, has large vacuoles, and is affected by bran and varied contributions of starch. Despite the long baking time, high water

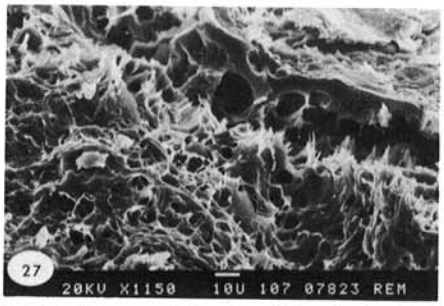


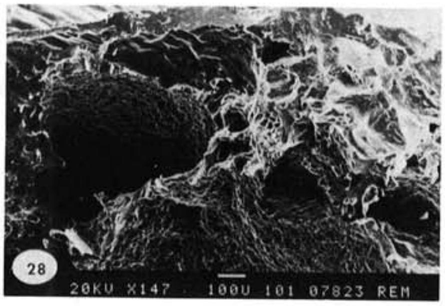












Figs. 21–29. Rye-meal dough and bread. **Fig. 21.** Structure of rye meal sourdough, beginning stage, comprised of small starch granules glued together, a platelet of gummy material, and bran particles. **Fig. 22.** Fine, three-dimensional, thread-like, structure of gum-type materials in the vacuole of rye meal sourdough, end stage. **Fig. 23.** Bran material in the structure of walls around vacuoles in rye-meal sourdough, end stage. **Fig. 24.** Starch granule threads and insoluble gum matrix in rye meal dough. **Fig. 25.** Empty aleurone and pericarp particles incorporated as part of rye meal dough before baking. **Fig. 26.** Scanning electron microscopic overview of fracture and vacuole areas in the crumb of rye meal bread. Note starch-protein and bran areas. **Fig. 27.** Interaction between pericarp-aleurone particles and a starch-protein matrix in the crumb of rye meal bread. **Fig. 28.** Overview of a cross section of the crust of rye meal bread. Note rugged uneven areas and large vacuoles. **Fig. 29.** Starch granules of various sizes in fractured areas of rye meal bread crust.

content, and lower gelatinization temperature of rye than of wheat starch, some small granules seem to retain much of their size and shape both in the crumb and the crust of rye meal bread. Starch has a much greater role in rye than in wheat bread, especially than in wheat bread baked from relatively high-protein flours. In the rye bread, the starch forms the sheetlike component. The gums, probably in cooperation with protein, form fibrils. The extensively expanded starch holds large pericarp-aleurone chunks together, binds large amounts of water, and makes it possible to produce a delectable bread of fine taste and flavor and of good shelf life.

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