material. This discharges into drag conveyors which carry it to dewatering screens. This method is the least costly and most satisfactory of the three.

None of the pomace-handling methods discussed is completely satisfactory. All involve fermentation of the pomace with its attendant problems. The ultimate in efficient processing would be the elimination of the pomace from the fermenting cellar. In the production of standard wines (some 90% of all those produced) this goal is now obtainable. Using the continuous must heater, it is no longer necessary to ferment the juice with the skins to effect color release and dissolution. The must of red grapes, following passage through the continuous heater, and the must of white grapes directly from the crusher can be screened and the sugar remaining in the screened pomace removed by conveying through the continuous washing system. With this system only juice and wash would enter the fermenting cellar. The savings in this method and the advantages offered are so great that it must be seriously considered by the wine industry.

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PANARY FERMENTATION

Current Status of Problems

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Current problems and trends with respect to fermentation in the production of yeast-leavened baked goods, principally bread, are more concerned with dough conditioning during the fermentation period and early stages of baking than with the actual production of leavening gas. Recent advances in knowledge concerning the action of amylases and proteinases on flour components during fermentation and baking have stimulated a rapidly increasing use of fungal enzymes in bread production. Judicious use of fungal enzymes in addition to the traditional diastatic agents derived from malted cereals permits efficient adaptation of a wider selection of flours to particular shop conditions.

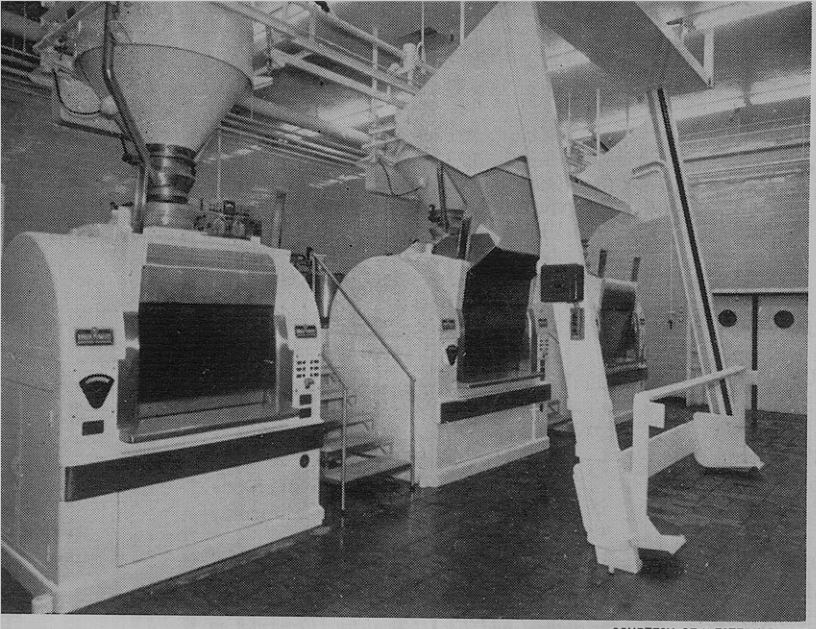
PANARY FERMENTATION differs from most industrial fermentations in several respects, perhaps the most notable of which is that the gas produced is the most important product, although other products have an important function. The principal products of the fermentation are largely the means to an end, as only small amounts of the substances themselves are retained in the final product. The environment of the fermentation is somewhat unusual, in that free liquid content is held to a minimum, and the chief substrate, potentially at least, is present in great excess but is desirably utilized to only a small extent.

Much has been learned in recent years about mechanisms that are important in panary fermentation. Scientific experiment has disclosed the nature of fundamental processes by which sugars are converted by yeast into carbon dioxide (the leavening agent in all light breads) and into acids and alcohols which modify properties of the doughs and contribute to the flavor of finished products (*28*). The nutrient requirements of yeast appear to be well understood (*1*). Knowledge has been gained regarding the chemical and physical nature of the starch which, after enzymatic breakdown, becomes a principal substrate for the actively metabolizing yeast cells (*19*). The identity of the amylases and their mode of action on starch and its derivatives have been revealed (*8, 15*).

Although production of leavening gas and proper retention of the gas may be the most important general considerations in the manufacture of bread, economic pressures for more efficient bakery production increasingly emphasize the importance of proper conditioning of doughs. With high-speed machinery and accelerated shop schedules, it is essential that suitable handling properties of doughs be realized. Treatments or formula additions which promote optimal gas production may sometimes have an adverse effect on gas retention or dough properties, and vice versa. It might be easy to establish adequate gas production under given circumstances, if that were the only consideration, but other features of the over-all process may limit the means by which this gas production can feasibly be established. It is this complexity and interrelatedness which require discussion of associated problems under the topic of panary fermentation.

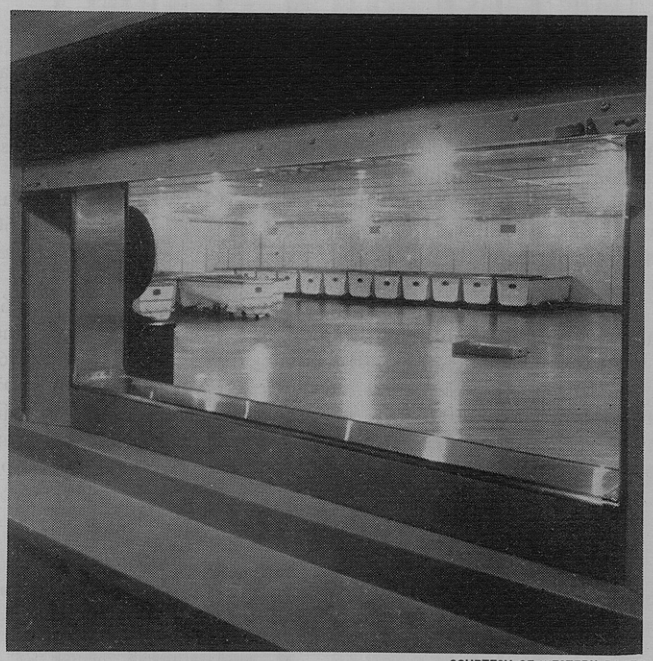
General Features of Bread Production

The major product of commercial bread manufacture in this country is ordinary, white pan bread made by the sponge and dough process. The following discussion is concerned primarily with this product and process, although most of the material also applies to the straight dough method and production of other types of bread.



COURTESY OF WESTERN BAKER

Figure 1. Modern, high-speed dough mixers. Hoist at center machine is for dough troughs. Fermentation room behind doors at right



COURTESY OF WESTERN BAKER

Figure 2. Fermentation room of large bakery showing dough troughs. Double-paned window illustrates care taken to ensure controlled temperature and humidity of fermentation room

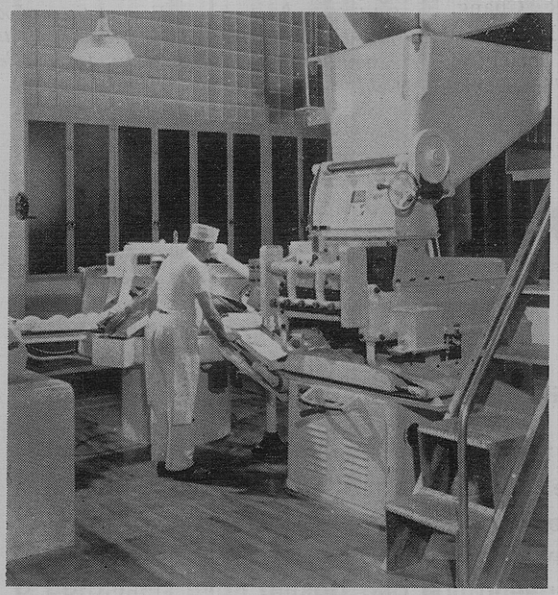


Figure 3. Divider and rounder. Five pieces of dough of predetermined weight are simultaneously extruded onto moving canvas belt by divider at right. After rounding, dough pieces pass into overhead proof box at left

COURTESY OF WESTERN BAKER

In the straight dough process, all the ingredients are made into a dough at one time. In the sponge and dough method, only a part (usually 60 to 70%) of the flour and water, together with the yeast and flour improvers, is mixed into a dough called the sponge; after a period of fermentation, which lasts from 4 to 5 hours, the remainder of the bread ingredients are mixed into the sponge, which now becomes the dough proper. These ingredients include the remaining flour and water, the salt, sugar, shortening, and milk solids. The formulas used and details of the operations vary widely. After mixing, the doughs are allowed a rest period (30 to 60 minutes), spoken of as the floor time. The doughs are then divided into small pieces of suitable weight for single loaves, rounded up, and again allowed to rest for a few minutes (10 to 20). They are next molded into loaves, placed in pans, and fermented (proofed) until the pieces have expanded to a suitable volume, and then are baked. In all but small shops, machinery is used for all steps in bread production (see Figures 1 to 5). A large modern bakery may produce as many as 5000 loaves of bread per hour.

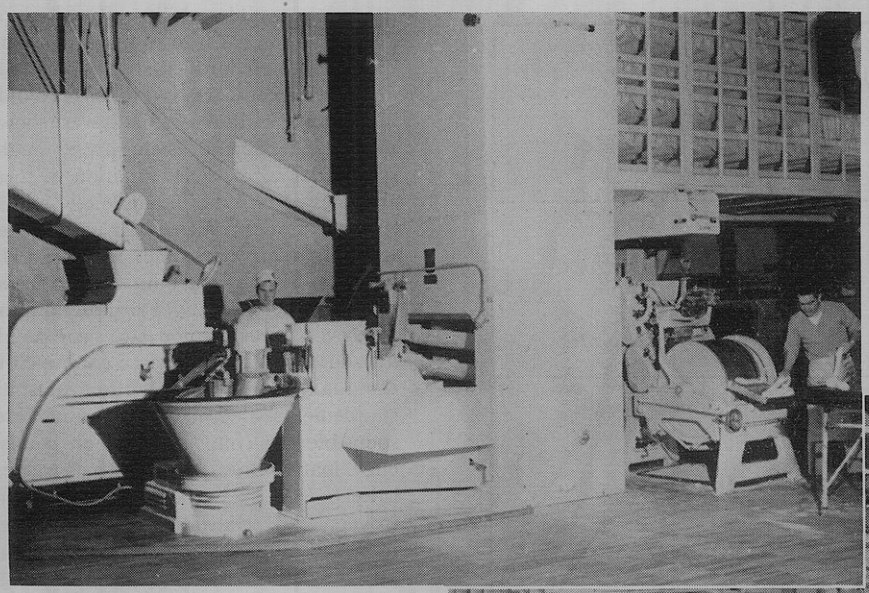
Care is taken to prevent undue loss of moisture from the doughs during processing, by control of the relative humidity in areas in which the doughs are fermented. Sponges and doughs are usually fermented near 80° to 86° F., but the loaves are more often proofed at temperatures near 95° F. The bread is usually baked for 25 to 30 minutes at about 430° F.

Dough properties which are of particular importance include consistency, pliability, and stickiness. Consistency may be considered as being most closely related to water content, which is spoken of as absorption. Pliability reflects the plastic and elastic properties of doughs during machining and is primarily a function of the colloidal properties of protein components of the flour; starch components of doughs influence pliability to a lesser extent. The stickiness of doughs may be significantly influenced by either the protein or starchy components of flour, depending upon specific conditions.

Color, flavor, volume, and crumb grain and texture of the finished bread are features of major importance. Crust color is directly influenced by the fermentation process, since caramelization of residual sugars is responsible for much of the external color of the finished loaf. Flavor of the crumb is greatly influenced by chemical changes occurring in the crust at the time of baking (*2*, *3*), but yeast, sugars, and acids and alcohols produced during fermentation are very important in producing the pleasing, characteristic taste and aroma of fresh bread. The softness, volume, and crumb grain and texture are perhaps more closely related to properties of the protein components of doughs, although starchy components, as modified during fermentation, are also very important.

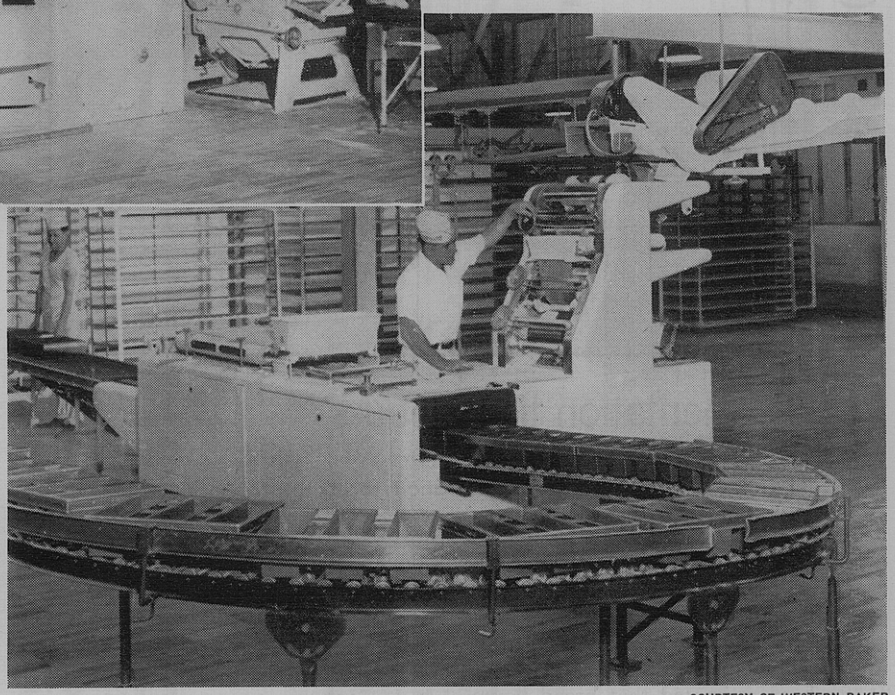
Factors Affecting Gas Production in Bread Doughs

Dough has been described as a favorable, though not always ideal, environment for alcoholic fermentation by living yeast (*1*). In a dough, yeast is suspended in an aqueous medium which



COURTESY OF WESTERN BAKER

Figure 4. View of rounding machine. Dough pieces are deposited in individual canvas pockets on endless conveyor shown through windows of overhead proofer at upper right. Operator at right is panning loaves by hand after molding operation



COURTESY OF WESTERN BAKER

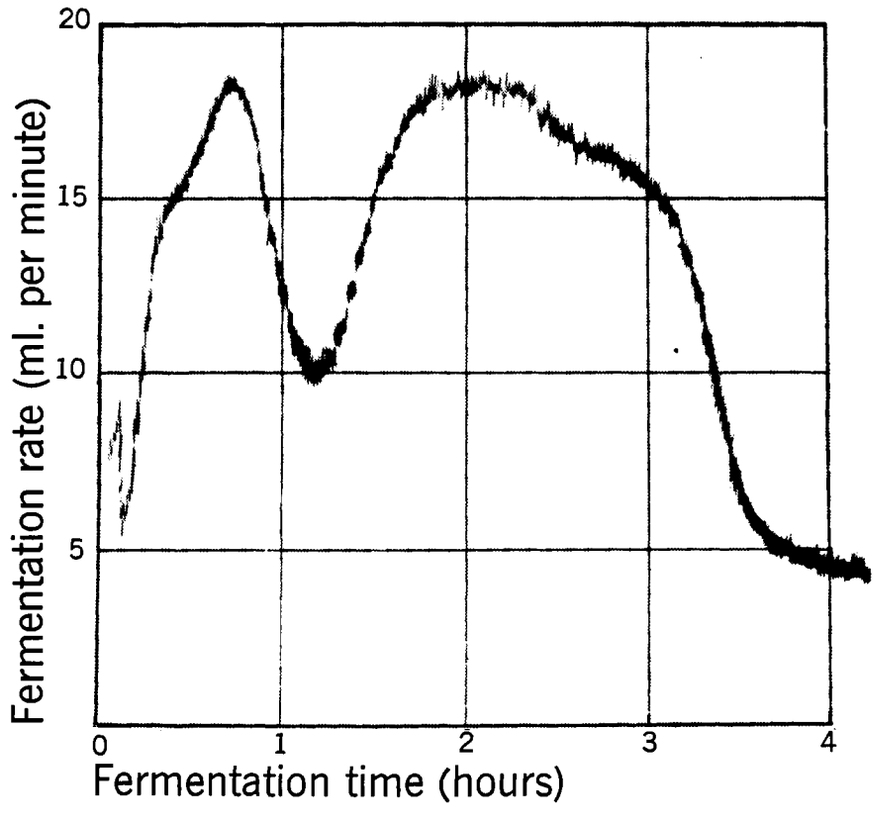
Figure 5. Automatic molding and panning machine. Dough pieces come in from upper right, pans from lower left. Sheeting rolls flatten dough pieces (center), which are then rolled into loaf form under compression

contains fermentable sugars, available nitrogen, phosphates, sulfates, magnesium ion, potassium ion, thiamine, and pyridoxine, all of which appear to be essential for optimum fermentation (*1*). Under practical dough conditions, gradual exhaustion of any of the essential fermentation factors may severely limit the rate of gas production. The two factors that most frequently become deficient are fermentable sugar and available nitrogen (*1*, *8*). For instance, the rate of gas production during fermentation of a sponge dough is characterized by the appearance of two maxima as shown in Figure 6. The occurrence of the first maximum is caused by exhaustion of the limited supply of readily fermentable sugar in this type of dough, and the second by the long induction period in the fermentation of maltose by baker's yeast (*1*). Flour normally contains only about 1% of fermentable sugar (*4*, *24*), whereas maltose is produced in larger amounts by amylases present in the dough (*16*). The addition of readily fermentable sugar to a sponge causes a progressive delay in the appearance of the first maximum until at about 5% of added sugar, only one maximum in the rate is observed (*18*). The final decline in gas production is usually caused by a deficiency of available nitrogen or fermentable sugar.

Most dough improvers or yeast foods contain mixtures of various salts which include ammonium compounds that furnish ample available nitrogen during the later stages of dough fermentation. It is common practice in the industry to add such dough improvers at the sponge stage. In doughs to which insufficient sugar has been added, the decline in gas production is caused by an inadequate production of maltose. The latter condition may arise from an exhaustion of the supply of readily susceptible starch or to an inadequate level of α-amylase activity. Fermentation ultimately proceeds at a low level, sometimes called the diastatic level, which means the rate of fermentation is controlled solely by the amount of sugar produced by the amylases of the dough from intact starch granules.

When a dough has finally been molded, panned, and placed in the proof box, it must be fermenting at a relatively rapid rate, and bread must be made from this dough before gas production becomes a limiting factor. In the oven, the temperature rises rather rapidly, and all the enzymatic processes are greatly accelerated for a brief period. The enzyme reactions gradually cease as the rising temperature penetrates the loaf, and the dough is finally coagulated. During the period in the oven, a great increase in volume of the dough occurs. Part of the increase in volume is caused by the thermal expansion of gases contained in the dough, but a very significant part is due to fermentation, which continues until a critical temperature (ca. 60° C.) is reached (*1*).

Flours milled from sound wheat normally contain a relative abundance of β-amylase but only small amounts of α-amylase, so that in unsupplemented doughs, saccharification (maltose production) is limited to that caused by β-amylase on the small amounts of susceptible starch present in ordinary bread flours. The susceptibility of starch to



COURTESY Q. LANDIS, C. N. FREY, AND EDITOR OF CEREAL CHEMISTRY

Figure 6. Sponge-type fermentation for high-protein flour (*17*)

rapid enzyme attack seems to be governed by the extent of damage to the granules during milling (*15*). This damage to the starch granule, in turn, is influenced by the hardness of the wheat. It has been estimated that bread flours contain 3 to 4% of damaged starch (*15*).

The normal amylase activity of flour is usually supplemented by the addition of malted wheat flour during the milling process and by the inclusion of diastatic agents in the baking formula. Flours are usually malted during milling to a level slightly below that required for adequate gas production under average baking conditions. This small margin reduces the danger of overdiastating, since bakers almost always add at least small amounts of malt during baking. The α-amylase contained in the supplements vigorously attacks available starch and provides new points of attack for β-amylase, so that under the combined influence of the two enzymes, rapid saccharification occurs. Alpha-amylase, or an enzyme associated with it, is capable of slow attack on undamaged starch granules (*15*), causing the so-called diastatic level of fermentation mentioned above.

In recent years, α-amylase supplements derived from fungal or bacterial sources have become of considerable interest in the baking industry, in addition to the traditional cereal amylases. These supplements produce much the same effects on the gas production of doughs as do the cereal enzymes. At the present time, the regulations of the Food and Drug Administration permit only the cereal enzymes to be added to flour, but both cereal and fungal enzymes may be used in bread production (*7*).

Factors Affecting Gas Retention And Handling Properties of Doughs

Fermentation Products During fermentation, the pH of dough normally decreases by approximately 0.5 pH unit (*1*, *8*), depending upon specific conditions. Besides the carbon dioxide, appreciable amounts of acetic and lactic acids are formed (*11*). A portion of the acetic acid is probably formed by the yeast, but bacterial contaminants of flour are probably responsible for the lactic acid and the remainder of the acetic acid. The total and relative amounts of these acids influence the flavor of bread to an important extent. The acid conditions prevailing during fermentation also affect colloidal properties of the flour proteins. Gluten is known to swell greatly and to increase in hydration capacity as the pH of its environment is lowered. This effect is offset, however, by the presence of salts, which have a toughening effect on gluten. The baker strives to achieve a balance among these factors and others, which will produce the most desirable flavor and best dough properties.

Enzymatic Effects The ability of malted cereals to impart desirable characteristics to bread has long been recognized, but it has been only in recent years that the effects were shown to be due to enzyme systems present in the sprouted grains. The function of these enzymes is still not completely understood, although much progress has been made in their control in baking. The increase in sugar production with the resulting increase in gas production and improved crust color are commonly attributed to the α-amylase contained in the malted cereals and other diastatic supplements. The components responsible for changes in dough consistency, loaf volume, and crumb characteristics, however, have been a subject of controversy (*14*). Diastatic supplements used in bread making usually contain proteinases in addition to amylases. Although it has long been known that proteinases can significantly affect dough properties (*10*), lack of fundamental information concerning the proteinases as well as the proteins of flour themselves has hampered understanding of the relative importance of these two types of enzymes in bread making.

α-Amylases It was formerly believed that the softening of bread doughs caused by the addition of malt was due to α-amylase (*1*, *8*, *15*) and that an excess of this enzyme was the cause of soft, sticky doughs producing bread with a sticky, gummy crumb and poor loaf volume. However, results obtained more recently (*12*, *13*) have shown that only part of these effects are due to α-amylase. It was demonstrated that the softening effect of α-amylase, freed from proteinase, on bread doughs was limited by the amount of susceptible starch present (*12*). Excessive amounts of this enzyme caused no further change in the properties of the doughs themselves, but during the baking period, excess α-amylase caused the bread to have a sticky, gummy crumb, although the loaf volume itself was good (*13*).

The susceptibility of starch to rapid enzyme attack seems to be governed by the extent of damage to the granules during milling (*15*). Starch granules that are ruptured mechanically are able to disperse in cold water and absorb greater amounts of water than intact granules. As this soluble starch is broken down into simpler products by enzymes, the water released causes a definite softening or decrease in consistency of the dough. As the average bread flour contains only about 4% of damaged starch granules, the softening effect of α-amylase is thereby limited by the amount of available substrate.

During baking, considerable swelling and gelatinization of the starch granules occur (60° to 65° C.) before the enzymes are completely inactivated; and at

elevated temperatures, enzymatic degradation of the starch occurs very rapidly. The resulting dextrins with their impaired water-retaining capacity and gelatinous consistency have a very important effect on the texture of bread crumb. Small amounts of these substances are desirable, but larger amounts are responsible for the sticky, gummy characteristics of bread produced from overdiastated doughs. The inactivation temperature of fungal α-amylase (ca. 70° C.) (*23*) is sufficiently lower than that of the cereal enzyme that much higher levels of activity of the former can be used before excessive dextrinization of starch occurs during the baking process. The higher critical temperature of bacterial enzymes (80° to 90° C.) (*27*), on the other hand, allows them to be used at only very low levels of activity.

It has recently been observed that the staling of bread can be significantly retarded by using very small amounts of bacterial amylases to dextrinize a slightly greater than normal portion of the starch that is gelatinized during baking (*25, 27*). Despite the current interest in antistaling agents, however, it seems doubtful that bacterial enzymes will be widely used for this purpose, even if they were allowable in bread. The sensitivity of crumb characteristics to the degree of dextrinization of the starch and the great care necessary to obtain the optimal amount of this action under shop conditions would deter their acceptance by many bakers.

Proteinases It is now known that much of the damage to dough properties caused by overmalting is due to the proteinase content of the malt supplements (*13, 20*). Although the mechanisms remain obscure, the effect was clearly demonstrated with diastatic supplements which had been freed of amylase activity (*21*). The softening effects seemed to occur chiefly during the sponge stage, because the salt added at the dough stage was found to decrease the proteinase activity of the supplements by about 60% (*20*). The low inactivation temperature (55° to 60° C.) (*21*) of the proteinase further reduced the possibility of extensive proteolysis during baking. Excess proteinase activity caused the doughs to become progressively more sticky and slack. The softening of doughs by proteolysis was found to be additive to that caused by α-amylase. Doughs in which excessive softening had been caused by proteolysis produced bread with coarse grain and texture and impaired loaf volume (*12*).

Although malted wheat flour is customarily added to domestic bread flours in order to provide an adequate potential for gas production during baking, great benefit is also realized from the mellowing effect the proteinase components of such supplements have on doughs which are difficult to handle in make-up machinery. It is common practice for bakers to add diastatic supplements to doughs for this purpose, in addition to the amounts already contained in the flour as it comes from the miller. With the advent of purified and standardized concentrates of fungal enzymes having various ratios of amylase and proteinase activity, the up-to-date baker is furnished tools which permit him greater latitude in the selection of flours to fit particular baking conditions and practices. Enzyme concentrates are available in a variety of potencies and types of activity (*23*) and are finding a rapidly increasing use in the trade (*22, 26*).

Among advantages attributed to the use of fungal enzymes on a commercial scale (*5, 22*) can be mentioned improvement with respect to grain and texture, external characteristics, and loaf volume. Improvement in grain—that is, a finer cell structure—also seems to give the appearance of a whiter color. Advantages from the standpoint of manufacturing include reduction in mixing time and better extensibility of the dough. A recent investigation of the effect of high levels of proteinase supplementation on the mixing requirements of dough (*6*) showed that the progressive softening induced could effectively substitute for a large part of the mixing development normally required by flours.

It has been suggested (*9, 22*) that it would be desirable to add fungal amylase supplements at the mill, with or without the addition of malted flours, and that fungal proteinase supplementation should be left up to the individual baker, because proper dough conditioning and bread quality react sensitively to slight variations in proteolysis, depending upon differences in shop practices.

Each flour may need a different combination of proteinase and α-amylase for best results in a given shop. Malted cereals provide a combination of enzymes which is suitable for most flours under average conditions, and benefit from the addition of fungal proteinase may not be obtained. In some instances adverse effects may occur. Nevertheless, fungal enzymes provide opportunity for selective supplementation to give the baker greater control over the properties of his doughs under specific shop conditions.

It is anticipated that as greater knowledge is gained of the mechanisms which occur in the tremendously complex system that bread dough constitutes, substantial, and perhaps dramatic, advances will be made in bread technology in coming years. It may eventually be possible to separate the various processes to the extent that they may be treated somewhat more as unit processes.

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