BAKERY PROCESSES, YEAST-RAISED PRODUCTS

1. Introduction

Bread and other yeast-raised bakery foods are widely consumed and desired, in part, because of their appealing flavor and light, porous texture, properties which depend largely on yeast fermentation. Leavening by the action of yeast was known to the Egyptians as early as 2000 BC; mummified yeast-raised loaves have been found in early Egyptian tombs as well as in the Roman ruins of Pompeii (1,2). The Hebrews also understood the art of leavening, presumably by yeast, because laws concerning the use of both leavened and unleavened bread are given in the book of Exodus in the Bible.

The role of baker's yeast (*Saccharomyces cerevisiae*) in producing leavened bread depends on two factors: the ability of yeast to generate carbon dioxide and alcohol through the breakdown of simple sugars, and the unique ability of wheat flour proteins to form films in dough that trap evolved gases. Basic bread is made with flour, water, salt, and yeast. Product variety is achieved by incorporating varying amounts of additional ingredients; by altering the breadmaking process; by shaping or cutting or putting toppings on the dough prior to baking; or by the method of baking. Each of these practices may be utilized alone or in combination to produce a virtually limitless number of yeast-raised products. Thus raisin bread is made from a white-type bread dough with the addition of raisins and possibly spice. French bread is made from a lean white dough, shaped into a cylinder and baked on the hearth of a steam-filled oven. Pita bread is also made from a lean white dough, but it is shaped into thin, round pieces before baking in a very hot (400°C) oven, to achieve the typical pocket formation. Sweet roll doughs are made with relatively high levels of sugar, fat, eggs, and yeast, compared to ordinary bread dough, and are shaped in various ways, with additional fillings and toppings to obtain the desired product.

Many other products belong to the category of yeast-raised bakery foods. Some that may be cited include various kinds of specialty breads, coffee cakes and danish pastries, bagels, croissants, yeast-raised doughnuts, some types of crackers, English muffins, and rolls.

2. Ingredients

A great many ingredients may be utilized in the production of innumerable bakery foods. The following discussion is limited to a relatively few key ingredients.

2.1. Flour. The primary ingredient of most bakery foods is wheat flour (3–6). This is especially true in breadmaking, where flour may comprise up to 95% of the ingredients, excluding water, in a lean bread dough. When the flour comes in contact with water in the dough, and mixing energy is applied, some of the proteins form elastic, gas-retaining films known as gluten (7). It is now widely accepted that gluten proteins are responsible for variations in baking quality. In particular, it is the insoluble fraction of the high molecular weight glutenin polymer which is best related to the differences in dough strength and baking quality among the various wheat varieties (8). Mixing the dough is a critical processing step since it not only serves to distribute ingredients homogeneously, but also develops the gluten protein strands to a proper balance of viscoelastic properties that have the unique ability to retain fermentation gases in numerous small gas cells. During fermentation, the dough, which is tough and relatively elastic after mixing, mellows and becomes more extensible so that it is readily manipulated and shaped by appropriate machines and then baked into foods of good volume and quality.

The quality of flour used in the production of yeast-raised products depends on several factors, including the quality and characteristics of the wheat variety, the environmental conditions under which the wheat was grown, the skill of the miller in separating the endosperm of the wheat kernel from the germ and bran, and the proper treatment of the flour in the mill.

Flour quality analyses performed by the producer and user of flour include moisture, protein, ash, enzymatic activity, physical dough properties, and baking tests, all of which evaluate flour for specific end uses. The ash content of flour serves as an index of refinement. Enzymatic activity tests, which indirectly measure the effects of alpha-amylase on the hot-paste viscosity of flour suspensions, are estimated chiefly with the amylograph or Falling Number methods (9); optimum alpha-amylase activity in bread flour is important for overall quality and staling properties of bread. Physical properties of dough are generally evaluated by means of either the farinograph or mixograph. These instruments are small recording mixers which measure work input during mixing, and provide information such as mixing time, amount of water required (absorption) to yield a dough of appropriate consistency, mixing stability, and overall gluten strength.

Bread flours are primarily milled from hard red winter wheats grown in the Great Plains and hard red spring wheats grown in the north central region of the United States. Most white pan breads are made with flour having a protein content of 11.0–12.5% (14% moisture basis). Certain products, such as mixed-grain or high fiber breads, or crusty hard rolls, may require stronger bread flours having about 1–2% higher protein. Clear flours, which are darker in color than typical bread flours but have a protein content of 13% or higher, are often used to bolster flour strength in nonwhite rye or wheat bread doughs.

Cake flours are produced from soft red or white wheats. Good quality cake flours are more highly refined than bread flours, and have lower ash and protein contents. Cake flours are usually treated with low concentrations of chlorine, which bleaches the flour and improves its baking performance such that higher amounts of sugar, shortening, and liquid may be used in formulations. The resulting “high ratio” cakes, which contain more sugar than flour, have good volumes, a fine grain, and tender, moist-eating properties. Soft wheat flours, less refined than cake flours, are used in the manufacture of biscuits, crackers, pies, and certain pastries. These flours are occasionally treated with chlorine gas in order to reduce spreading of certain cookies during production.

2.2. Yeast. Most of the yeast (3,10,11) used by wholesale bakers is available in the form of fresh compressed yeast, granular, or as cream yeast (a slurry). Fresh or creamed yeasts are delivered at frequent intervals and refrigerated until used. Yeast fermentation leads to gas production which, in turn, leads to leavened dough and bread as well as the development of fermentation flavors.

The quantity of yeast added to dough is directly related to the time required for fermentation. Currently, most bread doughs are made with 2–3% fresh compressed yeast, based on flour. This amount varies depending on the form of yeast utilized. High sugar levels in sweet yeast-raised doughs tend to inhibit yeast activity through increased osmotic pressure and higher yeast levels are necessary to compensate.

Active dry yeasts of improved quality have been available for many years, and more recently instant active dry yeast has been introduced (6,12). This instant yeast exhibits more activity than regular active dry yeast due to improved drying techniques, and can replace compressed yeast at a rate of 33–40%. Dried yeasts, which are stable for long periods of time at room temperature, are of interest to bakers because of the high distribution cost of fresh compressed yeast. This is especially true for those away from distribution centers and for smaller bakers whose usage rate of yeast is low.

2.3. Yeast Foods. The so-called yeast foods are universally employed by wholesale bakers in quantities ranging from about 0.25–0.50% based on flour. Yeast foods are multifunctional proprietary materials, containing principally an ammonium salt, a calcium salt, and an oxidant. The only food in yeast foods is the ammonium ion, which serves as a source of nitrogen for the yeast. The bivalent calcium ion has a beneficial strengthening effect on the colloidal structure of the gluten, and the oxidizing agent has an improving action in dough through some largely unknown mechanism. A widely used yeast food is composed of 30% calcium sulfate, 9.4% ammonium chloride, 0.3% potassium bromate, 35% sodium chloride, and 25.3% starch or flour added as a filler.

2.4. Sugar. Sugar usage in white pan bread has increased over the years to a present concentration of about 8%, based on flour. Sugar is utilized to modify flavor, to help support yeast fermentation, and as a contributor to crust color and toasting properties through browning and caramelization reactions (3,6,13). High fructose corn syrups are predominantly used in bread production, although sucrose (cane or beet sugar) and corn syrups see some usage in breadmaking. In products requiring greater sweetness, sucrose is preferred. For frostings and fillings sucrose in the form of powdered sugars or fondant is the sweetener of choice because of its contribution to structure and its solubility properties. For cakemaking, sucrose is also preferred; replacement of sucrose in cake systems with high fructose corn syrup is limited because the latter causes flour starch to swell differently in a baking cake (14) and it also leads to excessive browning.

2.5. Shortening. Animal and vegetable fats and oils are used in many bakery foods to produce tenderness and to perform many other specific functions in the finished product (3,6). In breadmaking, fat addition yields a 20% volume increase besides improving keeping properties and tenderness. Fat usage has undergone considerable changes over the years; lard gave way to hydrogenated vegetable shortenings some years ago, and now liquid oils are mostly employed by wholesale bakers. Liquid soybean oil, used in conjunction with dough-strengthening surfactant systems (15), is economical, easily handled in bulk systems, and is desirable from a nutritional perspective. Fats in bread doughs have decreased from about 3–4% to 2–2.5%. Many cakes, icings, and fillings are made with specialty plasticized shortenings; however, wholesale snack cake bakers now widely use liquid soybean oil, which can make good quality cakes when employed with emulsifiers tending to form alpha crystals (16). Fluid shortenings, made with a base oil stock and small quantities of crystalline fat and surfactants, are also readily handled in bulk systems and are reported to yield superior quality bakery foods (15).

Butter is used in some, usually more expensive, bakery foods, and is prized for its flavor contribution. Fats are used in some products such as pie crust, croissants, or puff pastry, up to 60%, based on flour. Stability of fats and oils in perishable items such as breads, cakes, or pastries is of no consequence because shelf life is so limited that rancidity does not occur. In cookies and crackers, however, stable fats must be used in the formula since prolonged shelf life could lead to product deterioration with fats that develop rancidity.

Baking shortenings generally contain 30% trans fats. Animal products such as butter contain about 3%. Health concerns over the possible connection between heart disease and the intake of trans fats have caused some health outhorities around the world to recommend the intake of trace amounts of trans fats (17). Trans fats from partially hydrogenated oil seem to be more of a health risk than those occurring naturally. Some food chains have removed trans fats from their products, some voluntarily and others not.

A trend in the baking industry is to produce bakery foods with either no or reduced fat, to achieve perceived nutritional benefits (18). The functions of fat are achieved, to a degree, with materials such as maltodextrins and modified starches in combination with gums and emulsifiers. In response to consumer demands for low calorie or calorie-free fats, a wide array of fat replacers have been developed. Fat replacers are substances that contribute a similar mouthfeel, texture, or flavor to a food product as normal fat. There are three major fat-replacement ingredient categories: carbohydrate, protein, and fat based. (see Fat Replacers).

2.6. Surfactants. Surfactants are widely used in bread and other bakery foods (3,6,19). In breadmaking, surfactants perform as crumb softeners or dough strengtheners, and they apparently do so by forming complexes. Monoglycerides, for example, complex with starch during baking to minimize subsequent retrogradation and staling, while ethoxylated monoglycerides complex with gluten proteins to provide strength. Other surfactants utilized in baking include sodium or calcium salts of fatty acids and lactic acid, polysorbates, succinylated monoglycerides, and diacetyl tartaric acid esters of monoglycerides. Surfactants are incorporated in cakes, icings, and fillings to promote emulsion stability, and to aid air incorporation and fat dispersion.

2.7. Milk and Milk Replacers. White pan bread was long made with about 3–4% nonfat dry milk (NFDM) in the United States, for reasons of enhanced nutrition, increased dough absorption, improved crust color, fermentation buffering, and better flavor. For some years, however, sharply increased milk prices have led to a decline in its use in breadmaking. Many bakers have turned to the use of milk replacers to control the costs of their products, and these ingredients are now commonly utilized. Milk replacers were designed to duplicate some of the functions and nutrition of milk. These blends may contain soy flour or cereals, with whey, buttermilk solids, sodium or calcium caseinate, or NFDM. Milk replacers or NFDM used in bread dough amount to about 1–2%, based on flour.

NFDM and whey constitute the most important dairy ingredients, but whole dry milk, fluid milk, condensed or evaporated milks, buttermilk, and cream cheese are employed to lesser extents in the production of specialty bakery items. For use in yeast-leavened products, milk must first be specially heat treated to inactivate some unknown factor or factors that would otherwise adversely affect dough handling properties and cause the production of poor bread quality. Milk is used in many cakes, where it is quite functional in terms of stabilizing the batter and improving structure of the baked cake; it is generally more difficult to replace the functions of milk in cakemaking than it is in breadmaking.

2.8. Eggs. Eggs are not used much in breadmaking, except for specialty egg breads. Egg whites are occasionally used on the surface of hard rolls to impart a crispy crust. Yeast-leavened sweet doughs or danish doughs often contain egg, up to 20%, based on flour, to achieve richness and to influence color and flavor. Some bakery foods, eg, sweet goods, croissants, and puff pastry, are often washed with egg wash (a mixture of egg and water or milk) prior to baking to obtain a rich, golden brown color in the finished product.

Eggs are employed in most cakes, at levels of 35–100%, based on flour, where they are functionally important (3,6). Unique properties of whippability, heat coagulation, and emulsification are critical factors in many bakery foods. Films of proteins surrounding gas bubbles in batter, provided by egg, are important in the leavening process and ultimately to the cellular structure of the finished cake. Egg whites are used to make white and angel food cakes; for other cakes, and for sweet yeast-raised goods, whole eggs, whole eggs fortified with yolks, or occasionally yolks alone, are used.

Bakers may use egg products in liquid, dried, or frozen forms. Liquid eggs, which have been churned, filtered, and pasteurized by the egg producer, are available in refrigerated tank cars to the large wholesale bakeries. The quality of dried egg products have been immensely improved in recent years, and many types of dried eggs are widely used by U.S. bakers in their production of bakery foods. Frozen egg products have lost ground to dried eggs because the former require careful thawing, a tedious, labor-intensive, and sometimes uncertain process.

2.9. Salt. Virtually all bakery foods contain salt (sodium chloride), except for a small number of products made for individuals on low sodium diets. Salt is quite functional in yeast-leavened bakery products. In breadmaking, salt, used at roughly 2% based on flour, provides flavor, moderates yeast fermentation by increasing the osmotic pressure in dough, and toughens gluten proteins. Crystal size and solubility are important quality factors in salt. Many bakery foods are best made with fine-flaked salt that dissolves readily; on the other hand, pretzels, and some hard rolls and bread sticks, require salt crystals of a larger size as a topping for purposes of appearance and flavor. For long shelf life foods such as crackers, it is important to use salt that is refined to minimize trace levels of iron and copper, since these tend to promote fat oxidation.

2.10. Water. The components of yeast-raised doughs and chemically leavened batters are dispersed in water. Water for dough mixing is generally not softened because the minerals in hard water may be beneficial, tending to strengthen gluten proteins. Sulfide waters have a deleterious action because the gluten protein is weakened by the sulfhydryl groups. Alkaline water, especially well-buffered alkaline water, also adversely affects bread quality since it interferes with the normal acidity development in dough, a necessary factor for flavor and overall bread quality (20).

2.11. Enzymes. Adequate amylolytic enzymes must be present in dough for several reasons. They break down available starch into fermentable sugars that constitute the energy source for yeast and degrade some of the starch to simpler structures during the early stages of gelatinization in baking to improve volume, texture, and keeping properties (19). Most wheats harvested in the United States are deficient in alpha-amylase, and flours milled from these wheats may be supplemented with enzymatic preparations. This is most typically done with the addition of malted barley flour. Fungal amylase preparations derived from *Aspergillus oryzae* are also permitted by the U.S. standards of identity for use in flour or bread, but fungal amylases are more often added at the bakery rather than the mill level. The amylase from *B. subtilis*, which is relatively heat stable and partly survives the baking process for further starch modifications, is utilized by some wholesale bakers to slow down the firming of bread.

Proteolytic enzymes, also derived from *A. oryzae*, may be used in yeast-raised dough production to reduce mixing time of dough or to make doughs more pliable. These functional effects are achieved through selective hydrolysis of gluten protein bonds, thus modifying dough and causing it to be more extensible.

2.12. Mold Inhibitors (Antimycotics). Antimycotics play an important role in extending the shelf life of many bakery foods (21). Calcium propionate [4075-81-4] is the most widely used antimycotic in breadmaking. It is often utilized at about 0.2%, flour basis; higher concentrations lead to flavor problems and begin to inhibit yeast fermentation. Sodium propionate [137-40-6] and potassium sorbate [590-00-1] are used to inhibit mold growth in chemically leavened products. Potassium sorbate suspensions may be used to spray the surface of yeast-leavened bakery foods for antimycotic protection; the sorbates cannot be used in doughs because of a strong yeast-inhibiting effect. Other agents sometimes used to control microbiological growth in bakery foods include vinegar, sodium diacetate [126-96-5], monocalcium phosphate monohydrate [10031-30-8], and lactic acid. Proprietary materials based on the fermentation of whey are also now available for antimycotic purposes; such materials are apparently effective on the basis of propionic acid that is formed during fermentation of the whey.

2.13. Flavorings. Various spices are employed to provide distinctive flavors in many bakery foods. Similarly, flavors and colors, both natural and artificial, are used to enhance bakery products in terms of both eating properties and appearance (3,6). Cocoa, chocolate, and many varieties of fruit, as well as some vegetables, (fresh, frozen, canned, and dried) are used in the food product or in fillings or icings.

2.14. Enriching Ingredients. Most commercially produced white breads are enriched with added thiamin, riboflavin, and iron. When breads or rolls are labeled enriched, these nutrients must be present in amounts prescribed by federal standards of identity (22). In g/kg product these are thiamin 4.0, iboflavin 2.4, niacin 33, and iron 27.5. Calcium may optionally be added at 1.3 g/kg. Although federal regulations relate to interstate commerce, most states also require enrichment of white bread and rolls. Enrichment nutrients may be added by the baker to the dough in the form of tablets, as a mixture of powdered nutrients in water-soluble pouches, or as a proprietary salt-enrichment blend. Alternatively, many bakers prefer to purchase flour that has been enriched to prescribed levels during the flour milling operation. Products labeled as enriched must also carry a nutritional label. Typically, a serving of one slice, approximately 1 oz (28 g), of enriched bread provides the following percentages of the U.S. Recommended Daily Allowance: thiamin 8.0%, riboflavin 4.0%, niacin 6.0%, iron 4.0%, and calcium 4.0%.

2.15. Chemical Leavening Agents. Chemical leavening agents are utilized in cakes, cookies, some crackers, refrigerated dough, and quick bread manufacture. Practically all leavening agents used in industry today are of the phosphate type. Both yeast and chemical leavenings are used in some products, eg, certain frozen dough. Sales of frozen dough and batters have increased rapidly in recent years. This trend is due to increased refrigeration and freezer capacities in stores and the development of new products (23–26).

3. Procedures and Equipment

3.1. Bulk Ingredient Handling. Mills ship flour in bulk directly to large commercial bakeries via specially designed railroad cars or trucks. Upon receipt, this flour is transferred pneumatically from the cars or trucks to bins in the plant, from which it is conveyed (also pneumatically) to the mixing process as required. Smaller plants may instead use a tote bin system of bulk handling. In this system, several bins, each holding about 1360 kg of flour, are carried on a flatbed truck. When unloaded at the bakery these serve as storage bins and are eventually returned to the mill for refilling. Flour used in small quantities, or flour used by bakers with no bulk handling facilities, is delivered in multiwalled paper bags and is handled on skids with forklift trucks.

Most of the sugar used by commercial bread bakers is in syrup form; high fructose corn syrup is primarily used. Following shipment in tank cars, it is piped into bakery storage tanks from where it is metered into mixers upon demand.

Shortening and oil can also be handled in bulk. If the shortening is plastic, it is melted so that it can be pumped through pipes. These pipes must be heated throughout the plant to prevent the shortening from congealing.

Yeast (compressed and cream), and other perishable ingredients, are stored under refrigeration; freezers are required for frozen eggs and fruits. Yeast may be suspended into a slurry and stored under refrigeration for short-time intervals to expedite its transport and metering into mixers. Water is metered into mixers rather than weighed. Minor ingredients may be weighed directly from their containers or they may be suspended in water slurries which are subsequently metered into mixers (1,2,27,28).

Dough Processes for Bread Production. Principal process categories used in the manufacture of yeast-raised products include the sponge and dough method, the straight dough method, and highly accelerated short-time methods that include frozen dough processing, continuous mix, and liquid ferment processes. Considerable variation exists among commercial bakeries within each of these categories. Rolls, buns, and sweet yeast-raised products are produced in ways analogous to those described for bread production. Principal differences are that special makeup machinery is required to produce the various shapes, and finishing equipment is required to fill and ice sweet roll and coffee cake units.

3.2. Sponge and Dough System: Conventional Breadmaking. - Most domestically produced bread is manufactured by the two-mixing stage sponge and dough process (Fig. 1) (3, 29–32).

Mixing and Fermentation of the Sponge. Extensive work on dough mixing has shown that mixing speed and energy must be above a certain value to develop the gluten network and to produce satisfactory bread. An optimum work input has been related to breadmaking performance and depends on the mixer type, flour composition, and ingredients (33). Overmixing tends to damage the dough and can cause dough difficult to handle. The strong role mixing has in the breadmaking process has led to a number of commercial mixers, such as the Farinograph and the Mixograph (34,35).

Sifted flour is pneumatically conveyed to a weighing hopper (scale) above a horizontal mixer. About 60−80% of the total flour required for a batch is used in mixing the sponge. Yeast, the yeast food, and the enrichment ingredients, usually presuspended in water slurries, are metered on top of the flour. The proper amount of water is metered into the bowl, and these ingredients are mixed into a sponge. The sponge may also include enzymes used as flour supplements and a fraction of the formula salt. Mixing of the sponge is intended to produce a homogeneous mass, but is not intended to produce full mechanical development of the wheat gluten. The sponge is dumped from the mixer into greased troughs which are transferred to a fermentation room. The fermentation room provides an optimum environment for sponge bulk fermentation of about 27°C and 75−80% rh. In practice, sponge fermentation time ranges from 2.5 to 6.0 hours, with best results usually found using 3.5−4.5 hours. As fermentation proceeds, the sponge volume increases dramatically until it reaches such extension that it drops spontaneously. This drop point is used as a reference indicating completion of 66−70% of total sponge fermentation. This bulk fermentation not only generates gas, but also generates fermentation by-products that contribute to final product flavor, develops the viscoelastic properties of dough that improve its gas retention capabilities, and reduces pH to a range that is optimum for final breadbaking results.

After the sponge has fermented sufficiently, it is returned to the mixer. The remaining flour and water, plus sugar, salt, shortening, nonfat dry milk (or milk replacer), and any other minor ingredients are added to the sponge and the final dough is mixed. Dough stage mixing is intended both to produce a homogeneous mass and also to mechanically develop the hydrated wheat gluten by repeated stretching and folding. This mixing to full development improves loaf volume, grain, and texture of the resultant loaf. There is a definite optimum mixing time range; deviation too far off the optimum in either direction harms end product quality. Mixers are jacketed so that temperatures of sponges and doughs may be partially controlled either by circulating refrigerant or brine in the jacket, or using direct-expansion coils. The properly developed dough, with a temperature of about 27°C, is ejected from the mixer into a greased trough where it is permitted a rest period (floor time) of 15–45 min before makeup.

Makeup. Following the floor time, the trough is hoisted and dumped to transfer the dough to the hopper of a divider. Several types of dividers are used, depending on dough consistency at this processing stage. A common type consists of pistons of adjustable size and/or “throw” which operate in cylinders. Piston movement draws dough into a cylinder, the cylinder door closes to cut off the piece of dough, and the cut dough piece is forced out of the chamber onto a conveyor belt. Ejected pieces are checkweighed frequently, and the size of the piston throw is adjusted accordingly.

The conveyor belt moves the rough, ragged dough pieces to a rounder, where they are converted to smooth, spherical shapes with consequent further mechanical development of the gluten network from the stretching and folding encountered. The rounder consists of a large rotating cone and a pressure board. Dough pieces are rolled and compressed as they are forced to travel up the pressure board by the rotating cone. Rounded dough pieces are transferred to an overhead or intermediate proofer, which is a large enclosed chamber through which the dough pieces are carried on trays suspended on a chain drive. The trip through the overhead proofer takes 7–15 min. The gluten network, which was tightened by the previous mechanical manipulation, relaxes during this period so that the dough pieces become pliable enough to successfully undergo sheeting and molding.

Dough pieces are conveyed out of the overhead proofer to a molder, usually of the cross-grain variety. In the molder, a series of reduction rollers sheet the relaxed ball-shaped dough pieces to thin flattened ovals. The resulting sheets pass through a chain curler to be formed into loosely formed cylinders. Each cylinder is tightened by passage under a compression plate. Cross-grain molders sheet each dough unit in two axes at right angles to each other, creating mechanically elongated and strengthened air cells that culminate in improved interior grain of the final baked bread loaves. At the end of the molder, these dough cylinders are automatically deposited into baking pans that are joined together in straps of four to six by means of cross pieces. Strapping facilitates handling and alignment through the next stages in the process.

Proofing. The panned dough cylinders are allowed to rise a final time in a controlled environment proof room or proofer at 35–43°C, 85–95% rh. Proofing is usually designed to take about one hour. During this period, the dough piece expands to approximately six times its original volume. Proofing may be accomplished by continuously conveying the pans through a proofer or alternatively, pans may be manually loaded onto racks which are transferred into a proofer.

Baking. If a continuous proofer was used, pans of proofed dough are mechanically conveyed into the oven. If proofing was done on racks, strapped pans are transferred to the oven by hand. Most large-scale bakeries use traveling tunnel or lap ovens in which bread pans are loaded at one end and the baked loaves exit the other. Such ovens generally consist of several chambers at different temperatures. One pound (0.45 kg) loaves generally bake at 215–225°C for 17–23 min, depending on formulation and desired end product. Smaller bakeries may use reel ovens, in which trays are rotated about a horizontal axis reel, or one of a number of ovens using heated air blown at high speed including convection ovens, rotating rack ovens, and air-jet impingement ovens (3, 36–38). Within the first few minutes of baking, the volume of the dough increases rapidly and reaches the maximum size of the loaf (called oven rise or oven spring) (39).

Cooling, Slicing, and Wrapping. Baked bread is depanned automatically and conveyed through a cooler to lower loaf interior temperature to 40.5°C. Loaves are conveyed to a slicer where they are sliced by bandsaw blades. Sliced bread loaves are then bagged in plastic bags, or less frequently today, in waxed paper or transparent film. Packages are twist-tied or plastic clipped, or alternately heat sealed.

The sponge and dough process is used to manufacture a wide variety of yeast-leavened products that extend beyond the scope of the pan bread manufacturing process discussed here. To illustrate, sweet roll doughs often utilize the sponge and dough process. Such sweet doughs are characterized by their richer formulas, the equipment used to create their specific shapes, and equipment used to fill, ice, and package these products.

3.3. Straight Dough Method. The straight dough method differs from the sponge and dough method in that all ingredients are mixed in a single mixing stage to full development. Following mixing, the dough undergoes a bulk fermentation period of about two hours at 27°C. Fermentation is followed by a "punch" in which the risen dough is folded over on itself in its trough. The punch deflates the dough, expelling excess carbon dioxide gas and contributing to the strength (elasticity) of the maturing dough via the mechanical manipulation of the gluten network. A floor time of about 30 min follows, after which the dough is divided into desired unit pieces, rounded and rested briefly, then molded into loaves or other desired shapes. Subsequent processing is identical to that described in the sponge and dough method. Domestically, the straight dough method is used primarily in smaller retail-scale bakeries. It is sometimes used in larger commercial bakeries for short production runs of specialty products. In general, straight dough processes are more sensitive (less tolerant) to deviations in the processing steps than sponge and dough versions utilizing the same formula.

A variation on the straight dough method is the category of remixed straight doughs in which most or all ingredients are mixed to homogeneity, bulk fermented, then remixed to full development, given a short floor time, and subsequently processed as normal. In a sense, a remixed straight dough can also be considered a 100% flour sponge and dough system. Such methods are useful in smaller bakeries desiring maximum flexibility with respect to production scheduling.

3.4. No-Time Doughs. No-time or short-time dough processes are a special subset of the straight dough method. Increased amounts of yeast and such fast-acting oxidants as ascorbic acid and azodicarbonamide [123-77-3] (ADA) enable the elimination of most of the normal straight dough bulk fermentation period. Though attractive from an economic and production planning viewpoint, products of these processes tend to have open grain, less flavor, and shorter shelf lives. No-time processes are used advantageously in the production of short-lived hard-crusted hearth breads in smaller bakeries, and in the larger-scale production of frozen dough products.

3.5. Frozen Dough Products. Frozen dough products have found increasing acceptance as the numbers of skilled baker/artisans available to small bakeries have declined. End users of frozen dough products are typified by the growing number of grocery store in-store bakeries.

Doughs intended for frozen dough production usually include reduced water percentages and increased amounts of water-binding ingredients to minimize the amount of free water available for ice crystallization. No-time dough processes are generally used for frozen dough in order to minimize yeast activation prior to freezing. With minimized activation, yeast cells appear to be less damaged by the ice crystallization that occurs in frozen storage. The no-time dough process is thought to yield dough products that are least damaged by freezing and by frozen storage relative to gas production and gas retention capability. Dough strengthener additives, such as SSL and DATEM, are used to partially counter the structure weakening effect of glutathione leached from yeast cells that have been damaged during freezing. Frozen doughs that are produced from no-time doughs necessarily include high concentrations of oxidants including ascorbic acid, azodicarbonamide, and to a lesser degree, potassium bromate (40–43).

After mixing, doughs are immediately divided and rounded, rested briefly, then molded. Molded units are rapidly frozen in blast (or other) freezers until reaching a core temperature of about -7 to -5°C. Units are boxed and stored at -18°C, then shipped to end users. End users slowly thaw these products in 2°C retarders over 16–18 h, proof, and bake the products as needed (40–43).

3.6. Continuous-Mix Breadmaking Process. Continuous breadmaking uses equipment which continuously mixes and deposits dough in pans. This manufacturing method differs markedly from the conventional sponge and dough method discussed above, and produces loaves with characteristics substantially different from the bread produced by the conventional methods (6,30,31). Early versions of the continuous-mix process accomplished fermentation in a liquid water brew containing water, yeast, sugar, yeast food, and enrichment nutrients. Subsequent continuous-mix methods featured the use of some percentages of the total flour (up to 70%) in the brew. Proponents of flour usage in brews claimed improvements in bread flour and overall bread quality. The fermented brew is metered into a premixer along with flour, shortening, additional sugar, a dairy ingredient, other optional ingredients, and an oxidizing agent solution of potassium bromate and azodicarbonamide (ADA, 1,1′1-azobisformamide) to form a more or less homogeneous dough. This is pumped into a continuous developer where rapidly rotating agitators mechanically develop the dough. The developed dough is extruded under pressure as a ribbon which is automatically cut into properly sized pieces. These drop into pans and are subsequently proofed and baked.

Continuous-mix bread processes are economically attractive alternatives to conventional batch breadmaking processes. Because of this it is estimated that continuous-mix plants accounted for nearly 40% of domestic white pan bread production in the late 1960s and early 1970s. However, the end product lacks the grain and bite that the market expects of its bread, as well as the subtle yet complex flavor of breads produced from doughs that have undergone bulk fermentation. Some continuous-mix bakeries, as noted above, found that improved bread flavor could be obtained by including a percentage of the formula flour in the fermenting brew, but grain remained unchanged. Consumer preference has pulled most manufacturers back to more conventional breadmaking processes, and continuous-mix bread today accounts for perhaps only 5% of domestic bread production.

3.7. Liquid Ferment Processes. The second most prevalent commercial dough making process today is the liquid ferment category, accounting for about 20% of domestic bread production and nearly all bun production. Liquid ferment processes use either a water brew, or more commonly today, a fermented flour-containing brew, or liquid sponge, in conjunction with a batch-mixing process using conventional horizontal mixers. After mixing, dough pieces are divided, rounded, rested, and molded as in the conventional breadmaking process.

The higher the percentage of flour included in the fermenting brew, the more improved is final product flavor, and the lower the oxidant addition requirements. It is possible to use as high as 70% of formula flour in a brew, but this requires all of the formula water to still have a pumpable slurry. In practice, most bakeries use flour brews that include about 40% of formula flour.

Flour brews are usually mixed and fermented in batches. Alternatively, these brews may be mixed and fermented on a continuous basis in which the flour brew, or liquid sponge, is moved progressively through a fermentator tank system. Depending on the equipment design and the consistency of the brew system used, movement through the fermentator tank is accomplished either by means of brew density changes through time or by rotors (3,29,32).

4. Other Yeast-Leavened Product Categories

Many other products are included in the category (3,23,44,45).

4.1. Buns and Rolls. Hamburger and hot dog buns and rolls may be processed in a manner directly analogous to those used for bread production. Almost all domestically produced bun products are produced by a batch liquid ferment process. After mixing, doughs are immediately divided and rounded to small unit-sized balls. Following a brief rest, these are given their final shape, proofed, baked, cooled, and packaged.

4.2. Sweet Yeast Goods. Sweet roll and coffee cake production is likewise directly analogous to bread-production methods. Chief differences are in makeup equipment used to produce the specific shapes and sizes of units. Also, following baking and cooling, sweet goods are “finished,” ie, iced and/or filled prior to packaging.

4.3. English Muffins. English muffins are fairly tough, chewy, and honey-combed with holes and have a somewhat sour flavor. Typically made by the sponge and dough method, the final dough of English muffins has a comparatively high water content which makes the dough soft enough to flow. These soft dough units flow to fill griddle cups into which they have been deposited. Units are baked in these covered griddle cups on a highly automated line (19).

4.4. Bagels and Pretzels. Though their production processes are not necessarily typical of other yeast-leavened products, the principal distinguishing feature of these products is that they are both cooked briefly in a boiling water bath just before transfer to the hearth of an oven. The boiling water bath gelatinizes starch on the surface of the units, yielding a glossy crisp surface on the finished product (5).

4.5. Croissants and Danish. Both product categories are produced from laminated doughs. Croissant dough consists of a white bread straight dough into which butter is folded to create 27–54 layers. Similarly, Danish doughs are lean sweet roll doughs laminated with butter and/or other solid fats. In the Scandinavian countries, the weight of roll-in butter is generally about half the total weight of the dough being laminated. Following the lamination process, these doughs are retarded to facilitate subsequent sheeting and makeup. After makeup and proofing, these laminated dough units additionally puff gently upon oven heating, creating a crisp, friable, flaky, and buttery texture to the final product.

4.6. Raised Doughnuts. Mixing and fermentation of raised doughnut doughs, like that of sweet roll doughs, is virtually identical to processes used in bread manufacture and sweet roll dough production. The only significant difference is that the proofed units are fried instead of baked for approximately 1 min per side in 191°C fat. Fried units are cooled and drained briefly, then glazed or finished as desired.

4.7. Crackers and Cookies. These products have long shelf lives and so may be distributed over wide geographic areas. For this reason, cracker and biscuit plants are generally larger than those producing bread and cake products. This large volume from a single plant warrants more expensive and intricate mechanical equipment, and these plants are the most highly automated in the baking industry. Their products are generally produced from soft wheat flours, usually straight grade; saltine crackers may be made with some hard wheat flour to provide strength during dough processing (24–26,31,46,47).

Saltine cracker manufacture begins with mixing of a sponge consisting of 65% of the formula flour (10% protein), a small amount of yeast, and 27% water, considerably less than is used in a sponge for bread production, plus a lactobacillus inoculum provided by a portion of an old dough "starter." The sponge is fermented for 18 h. By the end of sponge fermentation, sponge pH has reached 4.0, activating the proteolytic enzymes naturally found in flour to yield greatly increased extensibility. The remaining 35% flour (8.5–9% protein), fat, salt, plus sufficient sodium bicarbonate to raise final dough pH to 7.5 are added at the dough mixing stage. This dough is allowed to ferment for 6 h. The dough is sheeted and laminated, then sheeted and scored into the shapes and sizes desired. Crackers are baked on a moving steel band in a tunnel oven (26,48).

Snack crackers are made from nonfermented straight doughs that obtain required extensibility via chemical or enzymatic means. They have harder, denser, and less friable texture than saltines, and obtain their flavor mostly from artificial flavors incorporated in the dough or sprayed onto the surface of baked crackers. Cookies are also made from a nonfermented dough. Cookie doughs contain eggs, sugar, flour, shortening, milk, salt, leavening agent, flavoring, and possibly fruits and nuts. Shapes are obtained by extrusion or by passing the sheeted dough under rollers with appropriate dies, and these are likewise baked in a band oven.

4.8. Nutritionally Modified Yeast-Leavened Products. Current growth segments in bakery foods markets include products with formula modifications that provide high fiber, reduced food calories, reduced total and saturated fats, and/or reduced cholesterol (49–51). The potential for percentage calorie reduction in bread products is somewhat limited by their relatively low fat and sugar content and their relatively low total caloric value. The need for high fiber foods in diets is today widely recognized (51). High fiber breads are often reduced in calories; this reduction is largely achieved through the use of various nondigestible fibers and increased water in the formula (49,52). In richer dough products, ingredients may be replaced with materials that attempt to simulate the function of fats. This substitution may be either in the dough itself, as with reduced fat sweet dough items and low fat crackers, or in the roll-in fat of laminated doughs, as with reduced fat Danish products. Some typical fat replacers include modified food starches, gums, emulsifiers, polydextrose, microparticulate protein, and β-glucan fiber (49,50). High fiber ingredients with low calorie content may be used as bulking agents to replace higher calorie ingredients (sugar, flour), but mostly these are nonfunctional "dead weight." High intensity sweeteners such as sugar substitutes will be increasingly useful as workable bulking agents are developed (49).

5. Economic Aspects

The U.S. baking industry comprises an important portion of the food industry. The industry is diverse in both products and size of production units. Large manufacturing complexes have increased, but much production takes place in relatively small plants since distribution of highly perishable bakery goods to the consumer is feasible only within a limited area around the manufacturing facility.

U. S. bakery products are produced in bakeries around the country. Most of these facilities are made up of retail and in-store bakeries where products are typically baked and sold to the consumer. Many companies involved in wholesale bakery production operate a single plant; many national companies operate more than one bakery usually located in large population centers. Bakeries have become more automated and computerized.

Another source of bakery products is the food service industry, which includes hospitals, restaurants, and prisons.

Differentiated from quickly perishable foods are the dry bakery products such as cookies, crackers, pretzels, and ice cream cones. These items have a longer shelf life and can be distributed over a wider area from the manufacturing site.

In 2002, commercial bakeries reported shipments worth $\$21.4 \times 10^9$ and retail bakeries reported shipments worth $\$2.4 \times 10^9$ (53). Table 1 gives data on the average annual per person food expenditures of all households on bakery products in the U.S. in 2004 (54).

5.1. Imports on the Rise. The rapid growth of U.S. agricultural imports relative to exports in recent years has come as a surprise to many because the U.S. is still the world's leading exporter of farm products. American consumers, buoyed with larger spending budgets, also purchased imported processed foods. Of total U.S. agricultural imports of $\$46 \times 10^9$ in 2003, processed food, feed products, and beverages accounted for 28×10^9 (62%) of this total. Bakery products are included among the processed foods making the largest gains. Processed food imports increased by an average of 7% each year from 1994 to 2003, for a total of 96% over ten years. This increase does not reflect the larger share of processed foods manufactured by foreign firms with U.S.-based affiliates (55).

Table 2 gives data on the U.S. trade balance in bakery products from 1995–2001 (56).

6. Standards of Identity for Bakery Foods

Federal standards of identity exist for white bread, enriched bread, milk bread, raisin bread, and whole wheat bread that move in interstate commerce (22). Many states have adopted the federal standards or have promulgated nearly identical laws. Most bakery foods sold in the United States are produced by large commercial bakeries engaged in interstate commerce. As a result, nearly all bread and rolls necessarily conform to the federal standards. The FDA has taken the position that if an ingredient or packaging material has crossed state boundaries, then products containing that ingredient or wrapped in that packaging material are covered under regulations pertaining to interstate commerce. Most specialty breads, such as rye, multigrain, pita, and French, are not covered by standards of identity. All ingredients permitted in standardized bakery foods are considered optional ingredients and therefore must be declared in ingredient legends on bread wrappers. Since 1975, the FDA has required that all enriched bread-type products bear nutrition labeling.

Effective January 1, 2006, FDA regulations require nutritional labeling to include trans fat data (57).

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Fig. 1. Conventional dough process. (Courtesy of Union Machinery Division. American Machine & Foundry Co.)

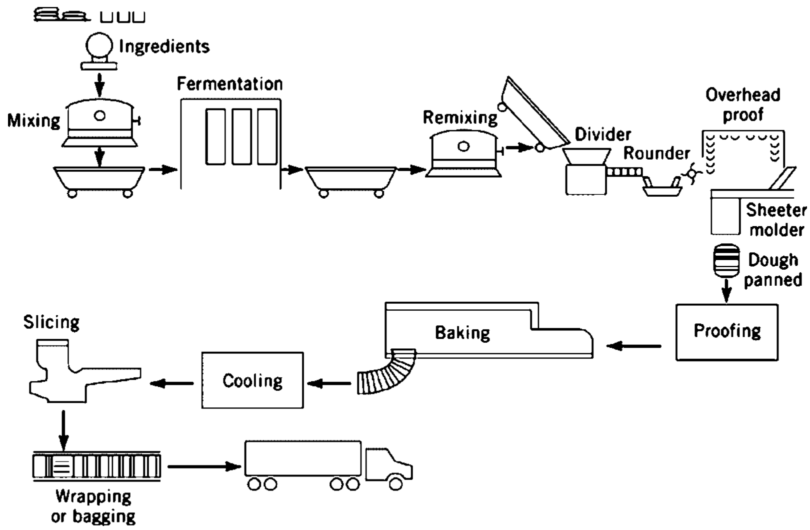

Table 1. **Average Annual per Person Food Expenditures in Bakery Products of all U.S. Households, $[a]**

Item	All	Urban	Rural
white bread	14.12	13.91	15.50
other bread	21.17	21.63	18.03
fresh biscuits, rolls, and muffins	16.95	17.18	15.33
cakes and cupcakes	15.83	16.00	14.70
cookies	18.71	19.00	16.70
crackers	9.89	9.99	9.21
bread and cracker products	1.31	1.27	1.56
doughnuts and sweetrolls	9.53	9.63	8.86
frozen and refrigerated bakery products	10.59	10.62	10.38
fresh pies, tarts, and turnovers	5.60	5.77	4.49
Total	*123.69*	*125.00*	*114.77*

[a]Ref. 54.

Table 2. **U.S. Trade Balance in Bakery Products, × times; 10^3 $**[a]

	1995	1996	1997	1998	1999	2000	2001
bread, cake, and related products	−131	−131	−117	−67	−115	−154	−163
cookies and crackers	−82	−108	−132	−233	−270	−298	−291
frozen bakery products	−7	−15	−17	−39	−80	−115	−181
Bakery products, Total	*−221*	*−253*	*−265*	*−340*	*−465*	*−566*	*−635*

[a] Ref. 56.