RHEOLOGICAL CHANGES IN CRACKER SPONGES DURING FERMENTATION AND A CRACKER TEST BAKING PROCEDURE

by

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Dedicated to the author's father and mother for their support and understanding throughout his education.

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INTRODUCTION

Crackers are an exceptional baked product having a peculiar texture. This texture and a relatively low moisture content makes crackers storable for comparatively long periods of time without significant changes in desirability. The production of saltine crackers is one of the most challenging operations in the entire baking industry.

The production of the crackers is not generally considered to be an integral part of the baking industry, largely because of the highly specialized equipment used in cracker baking. The mixers, dough sheeters, ovens and packaging machines all vary in design from their corresponding counterparts in a typical bread bakery. On the other hand, cracker bakers utilize essentially the same ingredients as do bread bakers, their production procedures are at many points similar, and their quality control problems often identical.

Perhaps the most striking difference between bread production and cracker production is the brevity of the make up and baking process. Five minutes after beginning to feed dough to the sheeter, the dough is entering the oven. Two and one half minutes later, the golden brown crackers emerge from the oven and begin their trip down the cooling conveyor and into packages. Within a time lapse of 20 minutes, from the time the dough is fed into the machine, packaged crackers are being stocked in the warehouse for shipment to stores. However, the work that made these crackers possible had begun 24 hours earlier when sponge mixing started (1).

Conventionally, cracker doughs are prepared by a sponge and dough process covering a period of approximately 24 hours. It is generally believed that the prolonged sponge fermentation is required to bring about the many changes responsible for the unique textural and eating properties which characterize saltine crackers. The cracker sponge fermentation is important but this process is very long covering a period of 18 hours, or approximately 75 per cent of cracker production time.

The saltine cracker formula has not been standardized. However, Matz (2) summarized 6 published formulas for soda crackers and presented an average and range for each ingredient used in the formulation. In reviewing the basic principles of saltine cracker production, Pieper (3) outlined a typical formula for cracker production. Other information has been reported by Heppner (1) and others (4, 5).

The chemistry of cracker doughs is very complex and is not completely understood. Although many attempts have been made to deal with the subject in a practical way, few references are found in the literature dealing with the problem in a scientific manner. Analytical data is helpful in determining the usefulness of a particular flour for cracker production. However, analytical data is not sufficient and cannot be totally relied upon to pick flours to give a quality finished product. Attempts to develop a procedure for production of experimental crackers has led to the conclusion that satisfactory saltine crackers cannot be produced under laboratory conditions.

The purpose of the present investigation was to study physical changes occurring during saltine cracker sponge fermentation and to establish a procedure to produce saltine cracker under laboratory conditions.

REVIEW OF LITERATURE

Cracker Ingredients

In general, the simplest typical cracker formula consist of soft wheat flour, yeast, shortening, soda, salt and water. Malt and enzyme supplements may also be used (3).

Flour. Soft wheat flour is the principal ingredient of crackers. Consequently, it plays a big role in determining the texture and eating qualities of crackers. The stronger flours are used in the sponge and are generally found in the range of 8.5 to 10.5 per cent protein, 0.38 to 0.42 per cent ash, and 60° to 90°M viscosity (1, 5). Weaker flours in the range of 8.0 to 9.0 per cent protein, 0.38 to 0.42 per cent ash, and 40° to 60°M viscosity are used in dough stage (1-4, 6). Whatever the flour used in these ranges, the fermentation process must be adjusted to the individual flour, and, thus, a precise procedure cannot be described, but must be experimentally obtained.

Testing flour performance in cracker-making is one problem that has received much attention in the literature (7-20). Dunn (7) in an attempt to develop a procedure for production of experimental crackers for testing flour, found that different crackers from the same batch varied in quality over a wide range. He felt that commercial crackers could not be produced under laboratory conditions. Many other approaches to the problem have been tried. It is generally recognized that analytical data are helpful in determining the use of a particular flour for cracker production. However, analytical data are not sufficient and cannot be relied upon to select flours to produce quality finished crackers. Baking small loaves of bread (pup loaves) was found of value in testing flours for cracker use, especially when combined with acidulated viscosity test. The viscosity test was found more indicative of flour strength than was the baking test (8, 10-12, 14, 15). However, Brown (13) and Micka (20) did not confirm the value of viscosity in selecting cracker flours. Micka (20) investigated the usefulness of different laboratory baking tests in evaluating cracker flour. He found a positive relationship between bread volume and the volume of commercial soda crackers. In selecting and blending cracker flours, emphasis has been placed on what is called "relative quantity of protein" (21). The ratio of sponge-to-dough flours was also considered of vital importance in cracker production. Micka (22) studied the effect of flour aging on the quality of soda crackers and showed decreases in volume, tenderness, and bloom of crackers as flour aged. He also concluded that bloom of crackers was an important factor in evaluating the quality of crackers.

Occasionally, cracker and biscuit manufacturers use white or light rye flour in their blends (2, 23). Besides its lower cost, relative to wheat flour, rye is used to dilute strong flours and consequently to improve the quality of finished crackers. However, rye flour has a distinct flavor that is undesirable in crackers when it is used in higher levels. According to Kerr (24) and Hahn (25) starch has also been used in the biscuit and cracker industry to modify textural properties of the flour. Both raw and gelatinized starches have been used in cracker production (24, 25). The listed beneficial effects of adding starch, raw or pregelatinized, to cracker doughs were as follows: to dilute the flour-protein to a desirable level, to improve machinability of the dough, to produce a more tender cracker with good flavor and eating quality, and to reduce requirements for higher levels of certain ingredients, i.e., shortening. It was also claimed that, when the flour is "very strong", addition of a gelatinized starch will enhance fermentation and give a smooth-running dough and produce cracker with good baking properties (24). Starch has also been used as a dusting agent (24) during the machining of dough to prevent sticking.

Water. Water is the second largest ingredient by weight and is important as a solvent to facilitate biochemical reactions. As a rule, the water in a batch will approximate 29.5 to 34 per cent of the total flour weight (2). The actual amount will be determined by the strength of flour, its characteristic absorption, the temperatures of process, and the desired consistency of dough.

In cracker production, most water that is considered suitable for drinking purposes is also acceptable for cracker use (2, 6). Some of the variations in cracker quality have been attributed, in part, to variations in water quality. Water influences many physical properties of the dough, usually described by such terms as consistency, pliability, extensibility, stickiness, mobility, starchiness, wetness and springyness (26, 27). It seems logical then to assume that water could affect the quality of the finished baked product in several ways.

Minerals in the water supply differ in their effect on finished product characteristics. Bayfield et al. (28) studied the effect of calcium and magnesium ions and concluded that these ions have a beneficial effect on both fermentation and baking properties of bread. On the other hand, the presence of bicarbonate and hydroxide ions cause an increase in pH to levels above the optimum for gas production.

Besides being a solvent for solid materials and a wetting agent for flour, water has been shown by Wolfmeyer and Hellman (29) to enhance fermentation in cracker sponges. The rate and total gas produced was increased significantly by increasing absorption level by as little as 2 per cent.

Yeast. The primary functions of yeast in cracker-making are: leavening agent, enzymes supplier, bacteria source, and flavor enhancer. The amount of yeast used varies, but it is seldom more than 0.3 per cent, and generally less. Compressed yeast is preferred.

The leavening action contributed by yeast in soda cracker is essentially none because the carbon dioxide formed during fermentation is lost during rolling, sheeting, and cutting. Johnson and Bailey (5) found that only 10 per cent of the carbon dioxide formed during sponge fermentation was dissolved in the sponge solution and an additional 10 per cent of the gas remained in the sponge to affect its volume, while the remaining 80 per cent of the gas escaped to the atmosphere. It was also suggested that the role of carbon dioxide in the final acidity of a cracker sponge was small (5, 30). Organic acids, produced by yeast or other organisms present in the sponge media, are the major factor in determining the final acidity of the cracker sponge (30-32). Because of its enzymatic activity and ability to produce an acidic medium, yeast was believed to have a vital role in conditioning dough by mellowing and softening the gluten protein. This mellowing is essential for handling dough in the machinery used in cracker production. Yeast, also produces other substances, besides carbon dioxide and alcohol, that are believed to contribute to flavor and aroma of baked goods.

Shortening. In cracker-making, shortening contributes to the tenderness and crispness of the finished crackers and improve the "oven spring" and flavor of the baked crackers (1, 2, 6). Shortening also makes dough less sticky (33), a property that is important in commercial cracker manufacturing. High levels of shortening in dough may help control "checking" of the baked product (33, 34) also a great concern in cracker production. However, Dunn and Bailey (33) studied "checking" in biscuits and found that biscuits containing sugar and whose shortening content ranges from 5 to 20 per cent, which includes the level usually encountered in cracker production, are most susceptible to "checking."

Rancidity during storage is another problem associated, at least in part, with high levels of shortening in crackers. Triebold and Bailey (35) studied rancidity extensively as it related to shortenings and crackers. Those workers concluded that the keeping quality of crackers was correlated with the type of shortening used. An interesting observation reported in their studies was that shortenings of poor keeping quality may be used to produce crackers of good keeping quality. This suggests that shortening is best evaluated by studying the storage of crackers. Bohn and Bailey (36) studied the effect of shortening on physical properties of doughs and suggested that shortening action was physical. They believed that shortening acted as a lubricating agent to both gluten strands and starch particles in the dough.

Shortenings are normally melted and used as a liquid which aids in obtaining an excellent dispersion during the short mixing time that is characteristic of cracker doughs. Shortening may be introduced either in the sponge or in the dough. Those who put it in the sponge claim better dispersion of the shortening, and those who put it in the dough claim better sponge fermentation (1).

Sodium Chloride (Salt). Salt is used both as a dough ingredient and as a topping for crackers, however, there is a small quantity of crackers made with no salt. Thus salt is not essential to the process other than for flavor improvement. In going from salted to unsalted doughs, there has to be adjustment made, usually a reduction in the amount of water (1). Besides its seasoning action, salt exhibits a depressing effect on dough fermentation (37, 38). It was found that salt altered gas production in fermented dough in almost the opposite direction of that of yeast (38). Miller and Johnson (39) found that salt also acts as a proteolytic inhibitor when added to sponge doughs. In this respect, salt can be used to control the deleterious effects of proteolytic enzymes in malt supplements when these are employed in relatively high concentrations. Salt also has a direct effect on gluten (40). This function of salt imparts maximum absorption and improves gas retention of the gluten and consequently the baked product improves in the volume and texture (41). The strengthening or toughening effect of salt on the gluten has been demonstrated by Bohn and Bailey (36). These workers found that salt markedly increased stress readings and increased the width of the farinograph curve. Salt was reported to decrease dough consistency (26, 42). Bennett and Coppock (26) emphasized the importance of interpreting the farinograph results. These workers stated that "farinograph consistency appears slacker with each addition of salt because the salted doughs, being less sticky, offer less resistance to mixing."

In addition to the dough salt which is added at the dough stage, topping salt is required for saltine cracker production to provide crackers with a quickly sensed salty flavor and to impart a desirable appearance to the product (6, 41). For this reason, topping salt has some unique properties which are not required for dough salt. These properties were discussed in detail by Page (41) and Strong (43). A flake-type salt that is sufficiently coarse, reasonably pure, and has optimum dissolving property meets the requirement for topping use in crackers.

Sodium Bicarbonate (Soda). Soda is added at the dough stage to neutralize the acids produced by the sponge, and to extablish the pH of the finished product. One can find a variety of pH in crackers, but in general a pH of 7.5 to 8.0 is considered ideal for maximum flavor characteristics (1). It was noted that dark crackers were produced from too alkaline doughs, while acid crackers were pale in color (44).

Many of the variations in cracker quality, either within the same plant or between different plants, have been attributed to variation in pH of the finished cracker or variation in the amount of soda added to the dough (1-6, 21). The amount of soda required is affected by numerous factors. These factors are related to ingredients, processing conditions, or even to climatic conditions (21). Practically, any factor that affects the acidity of cracker doughs and pH of crackers may contribute to variation in soda requirement. The amount of acid can be altered by ingredients that are introduced in cracker sponge or dough and by sponge and dough fermentation (6). In turn, sponge acidity as well as dough acidity can be influenced by a variety of internal and external factors including type of flour, length of fermentation, temperature, type and amount of yeast and many others. It is also recognized by cracker bakers that soda requirement varies with the age of the dough (2, 3, 6, 31, 32).

In cracker production, soda can react with dough ingredients that are acidic in nature. The general principle involves reaction of sodium bicarbonate with acids or acid salts (45). Late in the baking process soda alone can partially decompose, releasing part of its carbon dioxide (46). The decomposition of soda takes place only at relatively high temperatures (21), therefore, considering the short baking period of crackers and the fact that the temperature inside crackers is below the baking temperature, it seems logical to assume that soda decomposition has no significant role in cracker-leavening.

Malt. Malted wheat, barley flour, or diastatic malt syrup has been used to supplement the diastatic activity of flour. Malt syrup is frequently added at the dough stage as a sugar source, to aid in securing proper color and flavor of crackers (1). Buckheit (47) suggested the use of malt powders in commercial cracker production because they are suitable for automatic measuring and feeder equipment. Blish et al. (48) studied the effect of malt flour and extracts on flours and soluble starch substrates, respectively, and concluded that the immediate effect of adding malt was to improve alpha-amylase activity. The improving effect of optimum malt supplements on dough and finished baked product is generally agreed upon by several investigators (29, 38, 47-56). Sandstedt et al. (56) working with synthetic doughs concluded that starch and not gluten is responsible for the improving effects of malt on flour doughs. The amount of damaged starch in flours appears to be the undesirable fraction removed by malt. It has been demonstrated that proteolytic enzymes, when present in excessive amounts, in a malt supplement may cause detrimental effects (39, 54). However, most authors believe that excessive amounts of alpha-amylase in the malt preparation is the main cause of detrimental effects (52, 53, 57).

In cracker production, malt supplements are usually added at the dough stages (1-4, 6). However, malt may also be added to the cracker sponge (2, 4, 29). When added to the dough, malt has been reported to enhance fermentation and to compensate for sugars lost during the prolonged fermentation of sponge (6). This in turn contributes to bloom, color, and flavor of the finished crackers (2, 4, 6, 29). However, Bohn (4) pointed out that diastatic activity in cracker dough is not important because diastatic enzyme activity is not favored by the alkaline condition of the dough. The purpose of malt added to the cracker sponges is to adjust the diastatic activity of the flour (1, 2, 4-6, 29). Johnson and Bailey (5) found that flours varied considerably in diastatic activity and suggested that the failure of certain cracker sponges to rise properly in the trough might be attributed to this variation. However, it was pointed out that neither high diastatic nor medium diastatic malt supplements are desirable in cracker production and the low diastatic type is more welcomed in the cracker industry (6).

<u>Enzyme Supplements</u>. Amylases and proteases are the most important enzymes in baking. In cracker production, both cereal and fungal amylase supplements have been employed (1-4, 6, 29). Today, fungal and bacterial enzymes are in general use and have enabled more precise control of machinability and cracker texture (1-4, 6, 29).

Protease is also used in cracker doughs (3, 58, 59). Morimoto (59) has reported an increase in free amino acids content of baked cracker when protease was added to cracker sponge. Protease has been reported to improve the physical characteristics of both dough and finished crackers (58). Cracker doughs containing added protease were more pliable and easy to rool out and the finished crackers became more uniform in shape and more tender.

Protease, through its action on gluten can reduce dough consistency (60). Alpha-amylase also was found to cause a decrease in dough consistency (61). However, while the damaged starch substrate of alpha-amylase is a limiting factor in reducing dough consistency, it has been shown that the protein substrate of protease is not a limiting factor.

Cracker Processing

Commercially, crackers are prepared by the sponge and dough process which involves a total fermentation period of approximately 24 hr. It is generally believed that the prolonged sponge fermentation is required to bring about many changes which may be responsible for the unique textural and eating properties which characterize commercial crackers. Flakiness, crispness, tenderness, bloom, spring, and natural flavor are all required in very delicate and exact magnitudes in any cracker intended for commercial use.

Mixing and Mixing Factors. In the sponge and dough process, part of the flour, usually 60 to 70 per cent, is mixed with yeast and water for 1 to 4 min. to make the sponge. In some cases the shortening is also included in the sponge. The sponge is set at 70-72°F and fermented for 18-20 hr. (1-3, 6) at 78-84°F and 70-80 per cent relative humidity (6). The dough is prepared by mixing the remainder of the flour and other ingredients with the sponge for 3 to 7 min.

Whatever exact formulation is worked out for a particular flour and end product, it is essential that the procedure to be followed batch by batch, day by day, as exactly as can be accomplished. A difference of a degree or two in the setting of a sponge can affect machining of the dough and will definitely detract from the quality of the cracker. The mixing speed, temperature, and the proof time must be rigidly adhered to. A uniform method of scraping down troughs day by day must be established. Yeast and enzyme supplements must be thoroughly dissolved before adding to the mix. Soda must be carefully calculated for each dough from the pH of the sponge, or, once a base has been established, by increasing or decreasing the soda a fixed amount per degree of sponge temperature variation from a standard. Dry ingredients to be added at dough mixing should be thoroughly distributed and stirred into the flour before the mix to assure full dispersion and to avoid streaking.

Dough Mixer. The most common mixer for crackers is termed a vertical spindle mixer. The mixing arms, 3 or 4 in number, are attached at the right angles to a vertical shaft, and spaced equally from the bottom to the maximum planned height of the dough in the trough. Mixers have 3 such spindles for a 10 hundredweight batch. The dough trough is placed into the mixer frame and the spindles lowered into the trough for actual mixing. When mixing is completed, the spindles are raised and the trough removed. The arms of the mixer are shaped and pitched so as to give a maximum of blending and a minimum of mechanical development to the dough. The speed of the mixers is in the neighborhood of 20 revolutions per minute.

A proof room or fermentation room operated at 80°F, and 70 per cent relative humidity, will give excellent results (1).

Machining the Doughs. When the dough is ready, it is brought to the sheeting machine and dumped into a hopper. At the bottom of the hopper are feed rolls which form the bulk dough into a thick continuous sheet. This sheet then passes through a series of rolls which reduce the dough sheet in stages from its original thickness of perhaps 2 and 1/2 inches to about 1/4 inch. The thin sheet is then folded back on itself by a section of the machine called a lapper. The number of folds vary, but commonly 5-7 layers of dough are stacked cross grain to the original direction of travel. This stacked sheet is then reduced by further sheeting and finally passes through a set of rolls, called the gauging rolls, which sets the required thickness of the sheet to produce crackers of a given count per pound. The sheeting of dough must be guided by the equipment available to do the job. The principles to keep in mind are: avoid stress in the dough caused by stretching or crowding it at the point of contact with the rolls, make use of all sheeting rolls equally to avoid punishment of the dough by rapid reduction at any one set of rolls. If the number of sheeting rolls is inadequate, make the first reduction the largest. Keep the lap even and use dusting flour sparingly.

When the dough sheet comes from the gauging rolls, it is passed under a cutting head which docks the sheet and stamps the outline of the cracker. In most cases, the traveling sheet is scored deeper about every 20 rows, so that when shrinkage occurs in the oven it will pull apart evenly at this cut, rather than pulling itself apart in odd places and thus distorting the crackers. After going under the cutting head, the sheet is salted by a sprinkle device and then goes into the oven. The principles to be observed in the cutting section: keep the sheet clean of dusting flour, keep only enough tension on the sheet as it leaves the gauge rolls to avoid wrinkling, cut the sheet only hard enough to seal the edges of the cracker outline, but not hard enough, to cut cleanly through the dough. Crackers are baked in sheets and then broken to size on the score lines after coming out of the oven. If the cut is too deep, the sheet will shrink apart at these points and distort the cracker edges. It is necessary that the cutter be designed to allow sufficient pressure to seal the edges of the crackers but not separate the sheet. If insufficient pressure is applied, then the edges of the cracker will pop open in the oven producing what is called "fish-mouth." If the cutting apron which carries the dough sheet is unduly worn, or the bad under the apron which absorbs the impact of the cutter has lost its resilience, it will be impossible to get an even cut.

The Cracker Oven. The oven in most common use is the band oven. The dough sheet passes from the cutting machine on to a continuous baking surface which is the form of a metal conveyor running through the baking chamber. The baking surface most desirable for crackers is closely woven wire mesh conveyor. However, many forms of conveyor are in use. A 38-inch width is becoming standard for the oven conveyor. The conveyor length will be governed by the length of baking chamber which in turn determines the baking capacity of the oven. In practice, these ovens run from one to several hundred feet in length.

The cracker dough contains about 34 per cent water contributed by ingredient moisture and added water. The baked cracker contains 3 per cent moisture. Thus, one finds that cracker ovens must have an elaborate exhaust system to remove the water.

The ovens may be fired by any of the common fuel. The majority are directly fired by open flame burners above and below the baking surface. The direct fired oven is thought to improve oven spring and bloom of cracker. The bulk of the burners are concentrated in the first half of the oven since this is the area of maximum heat absorption. The second half of the oven will have fewer total burners and more burners over than under the baking surface. Full control of the top heat and bottom heat, individually, is supplied in all cracker ovens.

Many of the eating characteristics of the cracker come from increasing its volume several times shortly after it enters the oven (1). This is termed the "oven spring." This calls for high heat in the initial stage of the oven to vaporize the alcohol and release the carbon dioxide from the aqueous solution which causes the initial spring. Almost immediately the water changes to steam maintaining the volume until the structure is set by the heat. Too high a heat will seal the surface before oven spring is complete, thus hampering the release of the water. Too low a heat will lessen the spring and prevent proper color development of the cracker later. It is almost impossible to discuss temperatures to be used because of the wide variety of ovens, baking surfaces, and temperature indicating devices. Suffice us to say that the full volume of the cracker has to be reached early in the bake, and be maintained by adequate heat through the first half of the oven, but that no browning should occur in this section. The proper balance between top heat and bottom heat is essential in the first section to prevent cupping of the crackers. An excess of top heat in relation to bottom heat will pull the sheet up, cupping the cracker edges down, while a similar excess of bottom heat will cup the edges upward. In general, a slight excess of top heat, in the neighborhood of 50°F, is used (1).

The second half of the oven requires much less fuel pressure to maintain temperatures. Bottom heat is tapered off rapidly while the top is maintained at a high level to insure proper color development. Baking time varies from as low as 1 and 1/2 min. to 3 min. The time should be as short as is consistent with oven characteristics in obtaining the proper spring, dryness, and browning.

A cracker, regardless of manufacturer and ignoring individual preferences in flavor, color, and thickness, should be tender and crisp. These qualities should come from a dry, well opened, even texture, and not as the fragile character of a piece that is flinty and uneven. Next in importance are uniform shape, well sealed edges, uniform pH, flat bottoms, flourless tops and bottoms, clean breaking on score lines, absence of shelling (breaking of paper thin blisters on cracker surface with slightest pressure), even browning, proper count and volume.

Cooling and Packaging. As the crackers emerge from the oven and begin the trip down the cooling conveyor towards the packaging equipment, one rates the quality of the product, detects flaws and relates them to the process so as to determine the point of variation. If flaws are detected, it requires immediate attention, for back in mixing room, tomorrow's crackers are under way today.

In cracker packages, paper, cellulose film, or other films can be used to perform any packaging function; as the container itself (bags), as inner liners for grease protection, as outer wrappers for moisture protection (waxed glassine, cellophane), as outer wrappings for printing the design (opaque waxed, lithographed labels), and for bundling (kraft).

All packages containing crackers should have a grease-proof surface where crackers touch the package. This can be accomplished by a grease-proof surface on the carton on through a grease-proof liner. Except for boats or trays for visible packages, or with other special packages where a separate paper liner is not feasible, grease-proofing is usually accomplished by some type of paper liner. The papers usually considered for inner liners are: a) dry waxed draft, b) dry waxed sulfite and c) waxed glassine (3). Thus one can say that after attaining a moisture content of about 3 per cent, crackers are stacked and packaged in moisture-proof packages.

MATERIALS AND METHODS

A brief description of the ingredients and equipments used in this study is given below.

Ingredients

Two types of flour were used throughout of the experiments. Soft wheat flour (SWF) with 9.2% protein and 0.44% ash, from Acme-Evans Co., Division of General Grain, Inc., 902 W. Washington Ave., Indianapolis, Ind. 46204, and hard wheat flour (HWF) with 11.6% protein and 0.40% ash, milled on the K.S.U. pilot mill. Compressed, fresh, "Budweiser Yeast" produced by Anheuser-Busch, Inc., St. Louis, Mo. 63118 was used. Two types of shortening were tested. "Crisco" pure vegetable shortening made from hydrogenated vegetable oil by Procter & Gamble, Cincinnati, Ohio, and Swift's "Silverleaf" lard made from lard and partially hydrogenated lard with BHA, BHT added to help protect flavor. Other chemicals used were reagent grade.

Equipment

The mixer used was a pin mixer with 1 lb mixing bowl from National Mfg. Co., Lincoln, Nebr. Fermentation cabinet was also from National Mfg. Co., Lincoln, Nebr. An electrically heated reel-type oven from National Mfg. Co., Lincoln, Nebr. was used. The sheeter used was a "Anets" pie-crust roller model MDR-4S from Anetsberger Bros., Inc., Northbrook. Ill. Physical tests on cracker sponge were performed with Brabender Extensigraph from C. W. Brabender Instruments, Inc., 50 East Wesley St., South Hackensack, N.J. A hand-cutter equipped with docking pins and having 21 cells (7 x 3) of 2" x 2 3/16" were used for cutting-docking. Measurement equipment used were a Vernier height gage with Vernier reading 1/1000" or 1/50 mm and range 10" or 250 mm, made in Japan by Mitutoyo Mfg. Co., Ltd and a specially constructed ruler graduated in 1 mm to measure the length of 10 crackers. The baking surface used was a specially designed 8 1/2" x 17" rectangular shaped 1/4" flattened expanded metal plate (gauge 20 - 22) weighting 444.06 g and measuring 1 mm (0.040") in thickness with adjustable legs for the required height. Normally it was used a 3" height leg.

Cracker Formula

The cracker formula used in this study was based on that used by Araghi (62) and is given in Table 1.

Table 1. Cracker formula[a/]

Ingredients	Sponge (%)	Dough (%)
Flour[b/]	65	35
Water	25	--
Yeast	0.4	--
Shortening	--	11
Salt	--	1.8
Soda	--	0.45

[a/] Ingredients based on flour weight.

[b/] 100% soft wheat flour, or replacement with 10, 20, 30, or 100% hard wheat flour.

Baking Procedure

Crackers were made on a laboratory scale employing a sponge and dough procedure. All ingredients were scaled on the basis of 500 g flour. All ingredients were used at room temperature. Yeast was weighed and dispersed, immediately before use, in the amount of tap water called for in the formula. Sponge temperature was controlled by placing the mixing bowl in a freezer for 7 to 10 min. This procedure gave a sponge temperature of approximately 73°F (23°C).

The sponge ingredients were mixed in a low speed pin mixer (32 r.p.m.) using a 500 g mixing bowl. After 2 min. of mixing, the mixer was stopped and adhering pieces were scraped from the side of the bowl and mixing continued for an additional minute. After a total of 3 min. mixing the sponge was transferred to a 2000 ml beaker covered with a plastic bag previously soaked in hot water. The sponge was fermented for 18 hrs at 86°F (30°C). With this procedure a relative humidity of about 90% was maintained and after fermentation the sponge had a relatively wet surface with no skin formation.

To facilitate mixing at the dough stage, shortening was the first ingredient placed into the mixing bowl followed by the previous hand mixed dry ingredients and the fermented sponge. The dough was mixed for 4 min. at 32 r.p.m. in a modified pin mixer. The mixer was then stopped to scrape adhering dough pieces from the side of the bowl and mixing continued for 1 min.

After a total of 5 min. mixing, the dough was hand-packed tightly and evenly in a 2000 ml beaker and allowed to ferment for 6 hrs at 30°C and 90% R.H.

After fermentation the dough was flattened by hand into a rectangularly shaped frame to give a uniform piece of dough with the following dimensions: 3 1/2" x 11" x 1"; width, length, and thickness, respectively. With this procedure it was possible to control the width and have a more uniform edges on the sheeted dough, besides facilitating the first passage through the sheeter. Dough was sheeted in steps by passing 12 times through the sheeter and going from initial thickness of 1" (25 mm) to the final one of 0.023" (0.58 mm). During the first 6 passages dough was gradually reduced from 1" (25 mm) to 0.050" (1.25 mm) by passing through the following sheeter openings: 0.635" (16.12 mm), 0.485" (12.30 mm), 0.375" (9.50 mm), 0.225" (5.65 mm), 0.114" (2.88 mm), and 0.050" (1.25 mm), respectively. The next 3 passages were with a 0.050" gap. After each of these 3 passages dough was folded on itself once, consequently after 3 passages it had 2^3 or 8 layers. The dough now having the 8 layers was sheeted 3 more times through the following openings: 0.035" (0.89 mm), 0.025" (0.64 mm), and 0.023" (0.58 mm), respectively. The final reduction 0.023" (0.58 mm) is one of the factors involved with the final thickness of finished crackers. In order to have better control over the spread the first 8 sheetings were in one direction and the last 4 at a right angle to the first direction. Once dough was sheeted, it was cut with an especially designed hand-cutter-docker. The cutter-docker indents and partially seals the edges of cracker dough without cutting through. Cutting-docking was accomplished by placing the dough sheet on a belting cloth laid on a heavy board. This arrangement forms a bed for the dough sheet which is neither too soft (causes distortion) nor too hard (causes inefficient cutting). After cutting the dough sheet was protected from moisture loss by keeping it covered with wax paper until immediately before baking. Crackers were baked for 4 min. and 20 sec. at 510°F (265°C) on the specially designed rack. It was found necessary to leave a protective edge of about 1/2" of dough around the cut cracker plate to protect cracker edges from overbaking. Without this precaution, the edges of the crackers bloom faster than the middle area and become darker in color than the body of crackers. The oven door was opened during the last 20 sec. of baking period. This procedure gave crackers with a better developed color.

After baking, the crackers were placed on a rack at room temperature and allowed to cool for approximately 30 min. The baked cracker plate was then broken into individual crackers. From a total of 21 pieces 10 pieces were chosen at random and placed in pressure sealed plastic bags and stored for later measurements. Approximately 24 hrs after baking, weight, height, and length (in two directions) were measured for each sample (composed of the 10 pieces). Each sample was measured twice for each attribute and each 500 g dough generated 3 samples.

Extensigraph

The extensigraph was used to measure changes in the rheology of cracker sponges. Three test pieces of 150 g were scaled off from an approximately 500 g sponge prepared in a low speed pin mixer (32 r.p.m.). The test pieces were given 20 revolutions in the extensigraph rounder, rolled into a cylindrical shape on the shaping unit and clamped in lightly greased dough holders. The test pieces in the holders were stored in a humidified chamber for 45 min. before stretching on the extensigraph. The instrument records load extension (resistance to extension) and extensibility.

pH Determination

The hydrogen ion activity of cracker sponges were determined according to method outlined by ITT Continental Baking Co., Inc., (63). Fifteen grams of sponge were placed in an 8 ounce, wide mouth glass jar, containing 80 ml of distilled water. Ten drops of formaldehyde was added to stop fermentation. The jar was sealed and shaken for 30 min. at high speed (200 r.p.m.) in an "Eberbach" reciprocating shaker. If necessary, additional shaking was used until the sponge sample had been completely dispersed. The sample was transferred to a 250 ml beaker with 20 ml of distilled water. The hydrogen ion activity was determined with a Beckman Expandomatic IV pH Meter.

RESULTS AND DISCUSSION

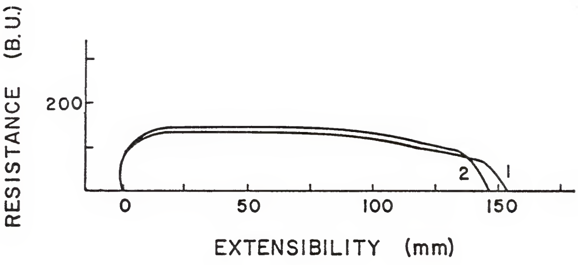
Rheological Changes in Cracker Sponges During Fermentation

Preliminary studies showed that both the mixograph and extensigraph were inadequated to measure the rheological changes in cracker doughs. The doughs were too tough. Al-Zubaydi (44) reported a similar problem when he tried to use a farinograph with cracker doughs. That author (44) overcame the problem by softening the cracker dough with added water (approximately 12% on flour basis). However, when water was added to the cracker dough the water to flour ratio was changed to essentially the ratio found in cracker sponges. Thus, based on the results reported by Al-Zubaydi and on our own experience we concluded that the common physical dough instruments (farinograph, mixograph, and extensigraph) could not be used to measure the physical changes in cracker doughs.

There appeared to be two alternatives to follow, either to work with cracker sponges or to work with cracker doughs at cracker sponge water to flour ratios. Since most of the reactions take place during sponge fermentation, in this study we decided to work with cracker sponges. When dough ingredients were added the dough flour was always left out, consequently the cracker sponge water to flour ratio was kept constant. After preliminary experiments, the Brabender extensigraph was selected to measure the changes in physical characteristics of cracker sponges. The extensigraph gave much larger difference in the physical properties of doughs as a result of fermentation than did either the mixograph or farinograph. Five hundred gram sponges were prepared in the low speed pin mixer (32 r.p.m.) and sponges fermented in a proof box at 86°F (30°C). The effect of fermentation time, soda, salt, yeast, mixing time, and pH were evaluated alone and in certain combinations. Mixing by itself has a great effect on rheological properties of doughs and shortening was considered an indespensable ingredient that had considerable effect on physical characteristics of doughs. In this study cracker sponges were remixed at the end of the fermentation period when shortening was added. All cracker sponges were mixed for a total of 8 min. (3 min. mixing sponge and 5 min. after fermentation) and contained shortening. Consequently, the effects of dough mixing and shortening were present in all cracker sponges evaluated.

The effect of adding shortening either at the sponge or dough mixing steps (before and after 18 hrs of fermentation) was evaluated (Fig. 1). The extensigrams obtained were very similar showing that when the shortening was added was not a critical factor. Addition of shortening at the sponge mixing did not have any apparent detrimental effect on fermentation. The pH was essentially the same whether the sponge contained shortening or not. Bohn and Bailey (36) suggested that the effect of shortening on physical properties of doughs was a physical one (lubricating). In this study, shortening was always added at the dough mixing stage. The shortening facilitated incorporation of dry ingredients added in the second mixing. The effect of certain mixing times on the extensigrams of cracker sponges (Fig. 2) showed that as mixing time increased extensibility increased and resistance to extension decreased. The effect was the same either in presence of soda and salt or in their absence. It was clear that mixing had a large effect on the extensigram properties of cracker sponges. Excess mixing was detrimental causing stickness which gave doughs that were difficult to handle.

Figure 1. Effect of adding shortening at 0 hr (extensigram 1) or after 18 hrs of fermentation (extensigram 2) on the extensigram properties of cracker sponges. Both soda and salt were added at dough mixing. Both doughs had 18 hrs of fermentation and had a pH of 6.90.



RESISTANCE (B.U.)
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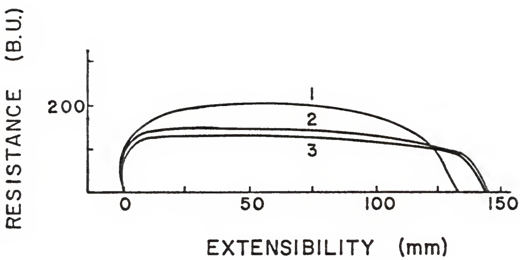
EXTENSIBILITY (mm)

Figure 2. Effect of dough mixing time on the extensigram properties of cracker sponges (18 hrs of fermentation). Both soda and salt were added at dough mixing. Doughs giving extensigrams 1, 2, and 3 were obtained with 4, 5, and 6 min. mixing time, respectively. All doughs had a pH of 6.90.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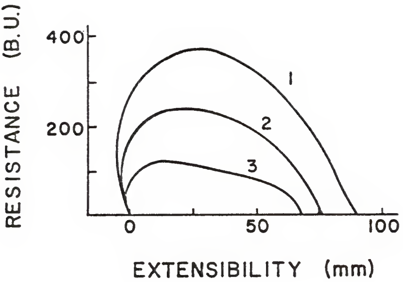
Effect of fermentation. The effect of fermentation time was studied (Fig. 3). Extensigrams showed that as fermentation time increased the strength of cracker sponges decreased. After fermentation the extensigrams had less resistance to extension and less extensibility, consequently less area or strength. The weakening of cracker sponge could be attributed to many factors, for example, the production of organic compounds, mainly acids during fermentation. During fermentation the pH of the dough dropped from 5.35 without fermentation to 4.15 after 18 hrs of fermentation. The mechanism by which acid would weaken a cracker sponge is uncertain. However, it is generally believed that acid disrupts gluten structure. The breakdown of protein has been postulated to be caused by the cleavage of protein salt linkages by the action of either the hydrogen ion or the anionic acid residue (64, 65).

Effect of Soda and Salt. Soda and salt are normal ingredients in crackers. Soda is added at the dough stage to neutralize acids produced during sponge fermentation and establish the pH of the finished product. Product too light or too dark in color is due to lack or excess of soda, respectively. Salt is also added at the dough stage and besides its seasoning action, controls yeast fermentation and had a direct effect on dough rheology. The effect of soda or salt and their combination on extensigrams was evaluated (Fig. 4). The results showed that soda increased the extensibility while salt mainly increased resistance to extension of cracker sponges. The effect of salt is thought to be because of changes in gluten hydration. Bushuk and Hlynka (66) explained the phenomenon by using the concept of "free" and "bound" water. When salt is present in a dough system, it increases the amount of free or mobile

Figure 3. Effect of fermentation time on the extensigram properties of cracker sponges. No soda or salt was added. Doughs giving extensigrams 1, 2, and 3 were obtained with fermentation times of 0, 9, and 18 hrs and had pH values of 5.35, 4.90, and 4.15, respectively.


RESISTANCE (B.U.)
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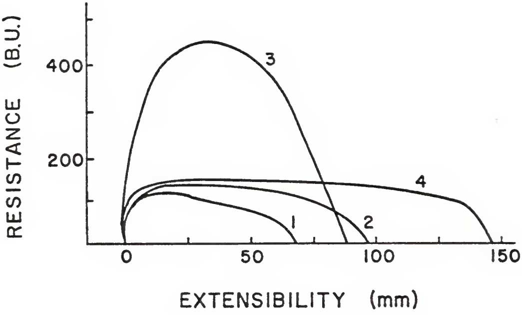
EXTENSIBILITY (mm)

Figure 4. Effect of addition of soda (extensigram 2, pH 6.90) and salt (extensigram 3, pH 4.30) alone and in combination (extensigram 4, pH 6.90) on the extensigram properties of cracker sponge fermented for 18 hrs. Extensigram 1 was the control with no soda or salt and with a pH of 4.15.



RESISTANCE (B.U.)
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EXTENSIBILITY (mm)

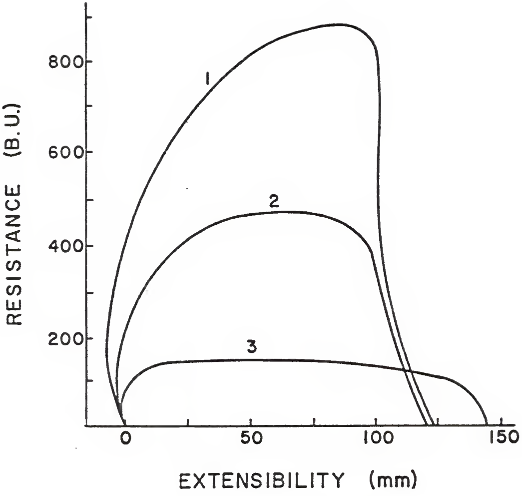
water in the system by altering the gluten in such a way that salt occupies the sites once occupied by the bound water. Thus, the theory explains the toughening or strengthening effect of salt.

The effect of salt at low pH has been studied by Galal et al. (67). According to their theory, at low pH the repulsive forces between the positively like-charged side chains, causes the coiled part of the protein molecule to unfold. Salt, on the other hand, suppresses the intermolecular repulsions, particularly in the unfolded part of the protein molecule, and in so doing would lower water absorption by tightening and aggregating the protein molecules. Thus, salt enhances protein aggregation, but does not reverse changes in conformation caused by low pH. Acid increases the number of positively charged sites available for interactions with salt ions, as well as exposing more hydrophobic groups. In addition, because salt suppresses the intermolecular ionic repulsions, the exposed hydrophobic groups would be freed to interact, and that in turn would result in a further strengthening of the protein structure. Such increased hydrophobic interaction would not exist if acid or salt were present separately. Eventually, the extremely insoluble protein would increase the tendency to form compact aggregates. These reactions would explain the synergistic effects observed when organic acid and salt were combined. When soda and salt were added to the sponge a large increase in extensibility was found (Fig. 4). In addition, the resistance to extension decreased when compared with the addition of salt alone. Addition of soda had a marked effect on the final dough pH while salt did not affect pH. In general, soda and salt strengthened cracker sponges.

The effect of fermentation time on the extensigram properties determined in the presence of both soda and salt was evaluated. Extensigrams (Fig. 5) showed that as fermentation time increased strength (area) of cracker sponges decreased. Comparison of the extensigrams presented in Figure 3 and 5 shows that cracker sponges with the same fermentation time were always stronger when the extensigrams were determined in the presence of both soda and salt. The effect of different soda levels on the extensigrams of cracker sponge (Fig. 6) was slight, when measured in the presence of the normal level of salt. A small increase in extensibility was observed as soda content increased. Extensigrams in Figure 7 show that increased levels of salt, with soda held constant, strengthened cracker sponges giving extensigrams with more extensibility and more resistance to extension.

Effect of pH. Extensigrams of cracker sponges prepared with normal level of yeast and with twice the normal level were similar (Fig. 8). However, extensigrams of cracker sponges made with no yeast had a much greater resistance to extension compared to extensigrams obtained from cracker sponges containing a normal level of yeast. However, the cracker sponge containing no yeast but with an 18 hr "fermentation" (extensigram 1, Fig. 8) showed a large reduction in resistance to extension and a considerable increase in extensibility in relation to a cracker sponge containing no fermentation time (extensigram 1, Fig. 5). Because the pH of the cracker sponge containing no yeast remain constant at 5.35 it was presumed that the effect was due to action of native proteolytic enzymes from flour working on the cracker sponge. Although the effect of that proteolytic

Figure 5. Effect of fermentation time on the extensigram properties of cracker sponges. Both soda and salt were added at dough mixing. Extensigrams 1, 2, and 3 were obtained with 0, 9, and 18 hrs of fermentation and had pH values of 7.10, 7.10, and 6.90, respectively.



RESISTANCE (B.U.)
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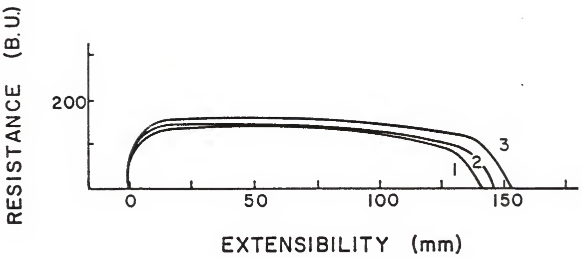
EXTENSIBILITY (mm)

Figure 6. Effect of adding different levels of soda after 18 hrs of fermentation on the extensigram properties of cracker sponges. Each dough contained the normal level of salt. Extensigram 1 was obtained with 50 per cent less soda than the normal level (pH 6.15), extensigram 2 was obtained with normal level of soda (pH 6.90), and extensigram 3 was obtained with 50 per cent more soda than the normal level (pH 7.35).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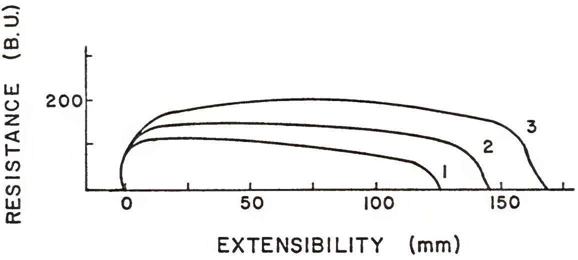
EXTENSIBILITY (mm)

Figure 7. Effect of adding different levels of salt after 18 hrs of fermentation on the extensigram properties of cracker sponges. Each dough contained the normal level of soda. Extensigram 1 was obtained with 50 per cent less salt than the normal level, extensigram 2 was obtained with normal level of salt, and extensigram 3 was obtained with 50 per cent more salt than the normal level. All doughs had a pH of 6.90.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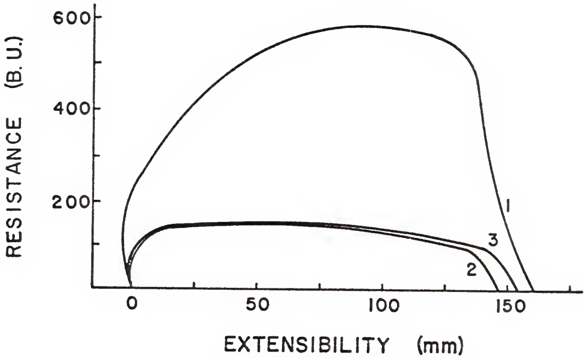
EXTENSIBILITY (mm)

Figure 8. Effect of different levels of yeast after 18 hrs fermentation on the extensigram properties of cracker sponges. Each dough contained both soda and salt. The dough giving extensigram 1 contained no yeast, extensigram 2 the normal level of yeast, and extensigram 3 twice the normal level of yeast. The doughs had pH's of 7.30, 6.90, and 6.90, respectively.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EXTENSIBILITY (mm)
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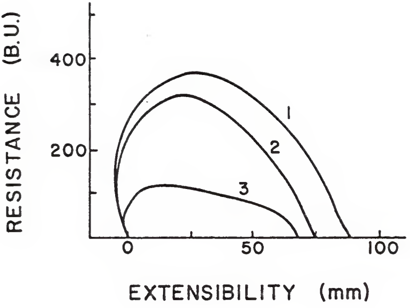
enzyme on cracker sponge rheology was considerable, its effect was much less than that obtained when yeast was present. Elkassabany (68) has reported evidence of proteolytic enzyme activity in flour with a pH optimum of 5.2.

Because of the low pH produced in cracker sponges, the effect of lactic acid was studied. Adjusting the pH of cracker sponges to 4.15 by addition of lactic acid gave extensigrams (Fig. 9) that showed that the final pH was not the only factor responsible for the changes in the extensigram properties. The addition of lactic acid decreased the resistance to extension and extensibility slightly. At the same pH (4.15) extensigram 2 had much stronger rheological properties than did the normal cracker sponge fermented for 18 hrs (extensigram 3). Consequently, some other factor(s) are working on the cracker sponge.

The effect of lowering the pH to 4.15 and giving the cracker sponge prepared without yeast an 18 hr "fermentation" period is shown in Figure 10. The "fermentation" time at pH 4.15 had a large effect on the extensigram properties. This is shown by comparing extensigram 2, Figure 9 with extensigram 2, Figure 10. This suggested that the lower pH, created by the action of yeast, brought the pH of the sponge to the optimum pH (4.15) of the native proteolytic enzymes of flour which were then responsible for the rheological changes in cracker sponges. Because the rheological changes were greater at pH 4.15 than with a yeasted system, the next step was to evaluate how long a "fermentation" time was necessary to match the properties of normal sponges. Extensigrams presented in Figure 11 showed that as "fermentation" time increased the strength of the cracker sponge decreased up to 15 hrs. After that period of time

Figure 9. Effect of pH on the extensigram properties of cracker sponges. Each dough contained no soda or salt. Extensigram 1 was obtained with normal cracker sponge with 0 hr of fermentation (pH 5.35). Extensigram 2 was obtained with cracker sponge with 0 hr of fermentation, but with the pH adjusted to 4.15 with lactic acid. Extensigram 3 was obtained with normal cracker sponge with 18 hrs of fermentation and had pH of 4.15 after fermentation.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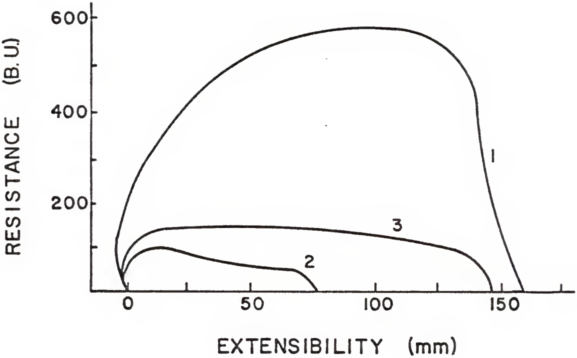
EXTENSIBILITY (mm)

Figure 10. Effect of pH on the extensigram properties of cracker sponges after 18 hrs of fermentation. Each dough contained both soda and salt. Extensigram 1 was obtained with cracker sponges containing no yeast (sponge pH 5.35, dough pH 7.30). Cracker sponges (no yeast) used in extensigram 2 had the pH adjusted to 4.15 with lactic acid, the dough pH was 7.10. The sponge used in extensigram 3 contained yeast (control).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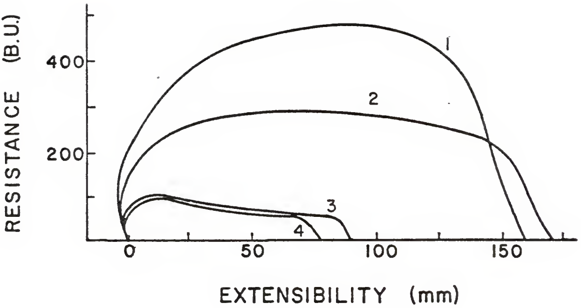
EXTENSIBILITY (mm)

Figure 11. Effect of "fermentation" time on the extensigram properties of cracker sponges. Each sponge contained no yeast and had sufficient lactic acid added to give a pH of 4.15. Extensigrams 1, 2, 3, and 4 were obtained with 9, 12, 15, and 18 hrs of "fermentation", respectively. Each dough contained both soda and salt and had a pH of 7.10.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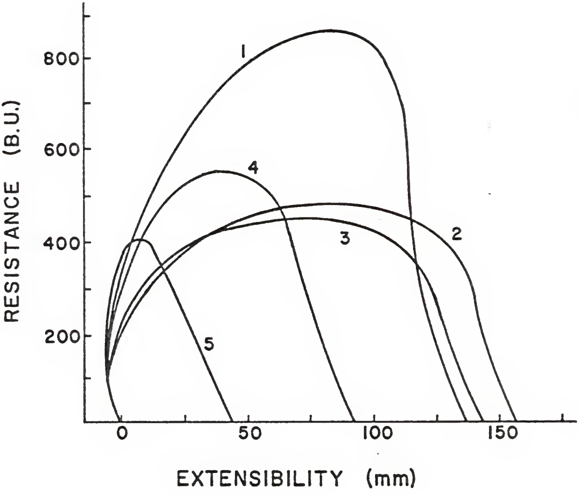
EXTENSIBILITY (mm)

there was a considerable reduction in resistance to extension. On the other hand, extensibility stayed essentially constant during this time period. However, between 12 and 15 hrs of "fermentation" time resistance to extension and extensibility both were reduced to a large extent.

The final step in this study was an attempt to evaluate the optimum pH for the presumed proteolytic enzyme activity. Extensigrams presented in Figure 12 show that sponges with different pH values had different extensigram properties. If we assume that the most important function of pH was on proteolytic enzyme activity, then the optimum pH is between 3.85 and 4.15. That pH agrees well with the pH of normal cracker sponges, and with the literature (69) which shows pH 4.00 as the optimum for native flour proteolytic enzymes. The effect of pH 3.00 on the properties of cracker sponges appears to be more in terms of acidic action than in terms of proteolytic enzyme action. Experiments showed that the effect occurred immediately after mixing cracker sponges and no "fermentation" time was required. Addition of soda raising the pH did not reverse the action of high level of acid even when it was added immediately after mixing without any "fermentation" time. Also salt did not strengthen the cracker sponge, again showing that acidic action was not reversible.

From this study it is concluded that strength of cracker sponges decreases as fermentation time increases. As fermentation time increases pH of cracker sponges decreases. Consequently, strength of cracker sponge decreases as pH decreases. Yeast is required and appears to be responsible for the lowering of pH by the production of organic acids during fermentation. The lower pH's are optimum for native flour proteolytic enzymes. There is possibly a second proteolytic enzyme with a pH optimum around

Figure 12. Effect of 9 hrs of "fermentation" at different pH values. Each dough contained no yeast, and both soda and salt were added at dough mixing. Extensigram 1, 2, 3, 4, and 5 were obtained with cracker sponge having pH values of 4.45, 4.15, 3.85, 3.50, and 3.00, respectively. Doughs had final pH values of 7.35, 7.05, 7.05, 6.45, and 3.90 respectively.


RESISTANCE (B.U.)
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5.2. However, its action is not enough to mellow the cracker sponge in 18 hrs. Salt has a marked effect strengthening cracker sponge by increasing resistance to extension to a great extent. Soda appears to increase extensibility. Mixing has a considerable effect on sponge rheology by increasing extensibility and decreasing resistance to extension up to certain limits. However, excessive mixing is detrimental to cracker sponge causing stickness. Salt plus soda has a synergistic effect increasing extensibility considerably and strengthening the cracker sponge. However, salt alone strengthens cracker sponge to a greater extent than does salt plus soda.

Development of an Experimental Cracker Baking Procedure

There is not a standard procedure for production of crackers on a laboratory scale. Consequently, this exploratory work was undertaken in an attempt to develop an appropriate experimental cracker procedure. During this work major attention was given to the following factors: type of mixer, mixing time, fermentation time, type of sheeter, sheeting procedure, the cutter-docker, oven, type of baking surface, baking temperature, baking time, and cooling conditions. Each of these factors was studied in an effort to define conditions for experimental cracker production. A brief description of each factor along with pertinent observations are given below.

Mixer. A Hobart Model-A-200 was studied first. This mixer was not satisfactory for 2 reasons. First, the mixing bowl was considered too large for experimental purposes, requiring at least 500 g flour for reasonable mixing. Second, its lowest speed appeared to be too fast and there was no easy way to reduce the speed. Thus, another mixer was chosen. A special 1 lb bread dough mixer (National Mfg.) was selected. The mixer is a pin mixer similar in design to the mixograph. The pin mixer bowl would accomodate 500 g of flour, but its speed was much too high, around 130 r.p.m. However, by changing pulley sizes the original speed was reduced to 32 r.p.m. This mixer proved to be satisfactory and was used throughout this work.

Mixing Time. Once the mixer was selected, tests were performed in order to find suitable mixing times. Usually cracker sponges are mixed for a period just long enough to uniformly hydrate the ingredients. Sponges mixed from all flours tested appeared to be hydrated within 3 min. Overmixing cracker sponges can lead to gluten development which constitutes a negative factor in cracker production. In the dough mixing step 4 min. was enough to incorporate dough ingredients, but 5 min. gave dough which handled better through the processing steps. Thus, a 3 min. sponge mixing and 5 min. dough mixing was used in this study.

Fermentation. Cracker sponges were mixed at 23°C (73-74°F), the temperature was achieved by placing the mixing bowl in a freezer for 7-10 min. before mixing. The sponges were fermented at 30°C (86°F) for 18 hrs. Experiments showed that by covering the cracker sponges with a plastic bag, previously soaked in water, it was possible to control the relative humidity (around 90%) and produce cracker sponges without skin formation after fermentation. This procedure was helpful because incorporation of dry ingredients at the dough stage was easier when no skin was present on the cracker sponge. Cracker dough was fermented under the same conditions at the cracker sponge, but for 6 hrs.

Sheeter. Two different type of sheeters were tested. The first, a "Rondo" autoreverse with manual and automatic gap adjustment, appeared to have too high a speed, the cracker dough sheet was often torn. The second sheeter tested was "Anets" pie-crust roller, model MDR-4S. Although this sheeter was not as easy to operate as was the Rondo, it did a good job and dough could be sheeted with excellent results. Thus, the Anets sheeter was selected and used throughout this study.

Sheeting Procedure. Several sheeting procedures were tested. One important aspect of sheeting was the initial shape of the dough. To obtain a rectangular dough piece suitable for cutting, it was essential that the original dough piece also be rectangular. Wood frames were constructed to aid in forming the dough in the desired shape. Frames measuring 4" x 12", 3 3/4" x 12", and 3 1/2" x 11" were tested with the latter size giving the best results. The wood pieces used for construction of the frames had a rectangular cross section 1" x 1/2" and they were nailed together in such a way that the frames had a 1" height, consequently the doughs had a 1" thickness (Fig. 13). Doughs were sheeted in steps by passing 12 times through the sheeter and going from the initial thickness of approximately 1" (25 mm) to the final one of 0.023" (0.58 mm). The final thickness of the sheeted dough was tested by setting the sheeter with the following openings: 0.013" (0.33 mm), 0.015" (0.38 mm), 0.018" (0.45 mm), 0.020" (0.51 mm), 0.023" (0.58 mm), 0.025" (0.64 mm), 0.027" (0.68 mm), and 0.030" (0.76 mm), respectively. A sheeter setting of 0.023" (0.58 mm) was selected because it gave crackers with weights and heights very close to commercial crackers. During the first 6 sheetings the dough was

Figure 13. Wood frame used to pre-mold the dough with dough inside.

gradually reduced from approximately 1" (25 mm) to 0.050" (1.25 mm) by passing through the following sheeter openings: 0.635" (16.12 mm), 0.485" (12.30 mm), 0.375" (9.50 mm), 0.225" (5.65 mm), 0.114" (2.88 mm), and 0.050" (1.25 mm), respectively. The next 3 passages were with the same 0.050" gap. In each of these 3 passages dough was folded on itself once, consequently after 3 passages it had 2^3 or 8 layers. After layering, the dough sheet was given 3 more reductions through the following openings: 0.035" (0.89 mm), 0.025" (0.64 mm), and 0.023" (0.58 mm) respectively. In order to have better control of the spread of the dough and also to improve texture of the baked crackers the following combinations of sheetings were tested: 9 + 3, 8 + 4, 7 + 5, and 6 + 6. In all cases there was a total of 12 passes through the sheeter. The best results were obtained with 8 + 4 which means that dough was sheeted for the first 8 sheetings in one direction and then turned 90° for the last 4 sheetings. This combination (8 + 4) gave better control of the spread of the dough and improved considerably the cracker texture. Crackers had better oven spring during baking and were more uniform with less blisters and compact areas.

Cutting-Docking. A critical point in the cutting-docking step was the surface on which the dough was cut. It should be neither too hard (causes inefficient cutting) nor too soft (causes distortion). A belting cloth laid on a heavy board gave excellent results (Fig. 14). A specially designed hand-cutter-docker having 21 cells (7 x 3) of 2" x 2 3/16" was used (Fig. 15). This cutter-docker indented and partially sealed the edges of cracker dough without cutting through (Fig. 16).

Figure 14. Cutting bed formed by a heavy board together with a belting cloth, and a sheeted dough.

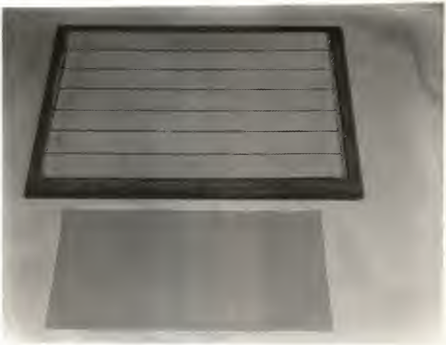

Figure 15. Cutting operation: cutter and bed used as a support for cutting.

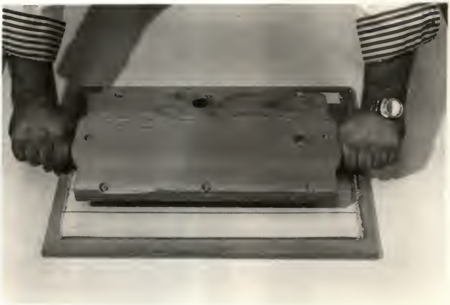

Figure 16. A plate of sheeted dough after cutting-docking.

Oven. The most common oven for crackers is a band oven with open flame burners above and below the baking surface. The control of top and bottom heat is thought to improve oven spring and bloom. However, a band oven cannot be used on a laboratory scale. Consequently, an electrically heated reel type laboratory oven was selected. Baking was carried out with the reel stopped and set in such a way that from a total of 4 shelves, 2 of them were at the same level and exactly in the middle of the other 2 shelves.

Baking Surface. Baking surface is one of the most important factors in the experimental cracker production. The baking surface most desirable for crackers is a closely woven wire mesh used in band ovens. However, it cannot be used at laboratory scale and consequently, another baking surface had to be found. In this study four different types of racks were tested. All of them had the same overall size 8 1/2" x 17". Two of them were made with a 3/32" diameter wire spaced 1/4" and 3/32" respectively. The other two were made of 1/4" and 1/2" flattened expanded metal. The best results was obtained with the 1/4" flattened expanded metal which was selected for further tests (Fig. 17). Although this surface was the best found and it gave satisfactory results, it should not be considered ideal.

The major problem with the baking surfaces appeared to be a heat transfer problem. Because the rack is at room temperature before going to the oven, part of the oven heat is absorbed by the rack. Consequently, the bottom of the dough sheet receives less heat for a period of time. Pre-heating of the racks created more problems than it solved. Racks with

Figure 17. Baking rack with a plate of molded crackers before baking.

more mass, of course, required more oven heat to warm them to oven temperature and thus the bottom of the cracker stayed cool longer. The heat transfer problem was more pronounced with heavier racks. It appeared that mass of the baking surface had to be balanced with the weight of the cracker piece to obtain the desired baked product.

Baking Temperature. Three baking temperatures were tested; 470°F, 510°F, and 550°F. Crackers baked at 470°F were light in color even with increased baking time. On the other hand, with 550°F crackers were darker and had more blisters. Thus a baking temperature of 510°F was used.

Baking Time. Baking time appeared to be a function of the dough thickness, baking temperature, and baking surface. When the conditions were established at 0.58 mm as the dough thickness, 510°F as the baking temperature, and 1/4" flattened expanded metal as the baking surface, the best baking time was determined to be 4 min. and 20 sec.

Cooling. Crackers should be cooled on an open mesh so heat and moisture can be lost on both sides at the same time. This allows the crackers to cool without cupping or curling. The cooling surface should be at room temperature. A cooled surface will cause cracks and too hot a surface will cause curling. A 1/2" flattened expanded metal rack was used as a cooling surface with good results throughout this study.

Baking Results. Baking tests were performed using 100% SWF as control When HWF was used it was identified. Pictures of a baked cracker plate together with the cutter and baking rack and a close-up of baked crackers are shown in Figures 18 and 19.

Figure 18. Cutter-docker, plate of baked crackers, and baking rack.

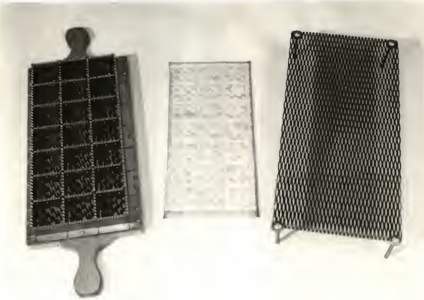

Figure 19. Close-up of baked crackers and a cracker cross-section showing the internal structure.

Data in Table 2 show that the characteristics of baked crackers were affected considerably by fermentation time. In general, the H/W ratio decreased and shrinkage decreased (both sides A and B), as fermentation time decreased. Doughs which were fermented longer were more pliable and had better machinability. Doughs with less fermentation time were more elastic and thus required more pressure to be sheeted. The elastic character caused the dough to contract after sheeting and before cutting. Thus, the cracker is thicker which is responsible for the increased weight and height of cracker with reduced fermentation time. Because the contraction occurs rapidily (before cutting) it probably also explains the reduced shrinkage. The increased height obtained with less fermentation were mainly due to blisters and do not represent better oven spring. Oven spring was more uniform as fermentation time increased. Increased fermentation time also gave crackers with better texture, less blisters, and with less compact areas.

Results in Table 3 show that when part, or all, of the SWF was replaced with HWF there was a trend of decreasing shrinkage in relation to side A (the direction of the last sheeting) as the level of HWF increased. Side B shrinkage was inconsistent as it increased with 10 and 20%, and decreased with 30, and 100%. The weight of baked crackers decreased as SWF was substituted. This gave lighter crackers than obtained with straight SWF, except for 100% HWF which were slightly heavier than the control. There was a general tendency of increasing height and H/W ratio as the level of HWF was increased. Hard wheat flour had a mellowing effect on the dough which improved its machinability. Oven spring was also improved by addition of HWF and this resulted in crackers with better texture.

Table 2. Effect of cracker sponge fermentation on the physical characteristics of baked crackers. Data is for 10 crackers.

Sponge Fermentation	Shrinkage[a/] (cm)		Weight (gram)	Height (cm)	Ratio H/W
	Side A	Side B			
18 hrs (Control)	3.385	4.037	29.729	6.983	0.235
15 hrs	3.167	3.866	31.157	6.864	0.220
12 hrs	2.900	3.550	33.337	7.326	0.220
9 hrs	2.767	3.375	34.457	7.508	0.218
6 hrs	3.000	3.375	34.483	7.459	0.216

[a/] The difference between 10 x the theoretical length (cutter dimensions) and the length of 10 crackers.

Table 3. Effect of replacement of SWF by HWF[a] on the physical characteristics of baked crackers. Data is for 10 crackers.

Samples	Shrinkage[b] (cm) Side A	Shrinkage[b] (cm) Side B	Weight (gram)	Height (cm)	Ratio H/W
100% SWF (Control)	3.385	4.037	29.729	6.983	0.235
90[c] + 10[d]	3.275	4.175	28.940	7.172	0.248
80[c] + 20[d]	3.208	4.241	27.813	7.080	0.255
70[c] + 30[d]	3.125	3.775	28.067	7.161	0.255
100% HWF	2.542	3.525	30.283	8.205	0.271

[a] When HWF was added, the percentage was calculated on the basis of all the flour (both sponge & dough). The HWF was all used in the sponge, however at 100% HWF there was no SWF used either in the sponge or dough.

[b] The difference between 10 x the theoretical length (cutter dimensions) and the length of 10 crackers.

[c] Percentage of SWF

[d] Percentage of HWF

A comparison of cracker quality of 2 SWF and 2 HWF is given in Table 4. The crackers from the SWF were lighter in weight and had more shrinkage than those prepared from HWF. However, the lower shrinkage obtained with HWF was probably due to a fast contraction of the sheeted dough before cutting. Consequently, most of the contraction took place before cutting and in so doing decreased the amount of shrinkage in the baked crackers. There was no consistent relation of H/W ratio to flour type. Oven spring of crackers prepared with HWF were considerably higher than those with SWF. This is reflected by the height values. In general the HWF gave crackers of good quality.

When lactic acid was added to cracker sponges (pH 4.15), it gave a mellowing effect on the sponge and extensigrams with low extensibility and low resistance to extension (Fig. 11). Cracker doughs prepared in absence of yeast but with lactic acid added to adjust the sponge pH to 4.15 were very soft. This softness increased with "fermentation" time. In general, the doughs were excellent for machining with the exception of the 6 hr "fermentation." However, crackers prepared with those doughs had no oven spring at all. The difference in height values (Table 5) were due to blisters which were in greater number as "fermentation" time decreased. Also as "fermentation" time decreased there was a general decrease in shrinkage. On the other hand, weight, height, and H/W ratio increased as "fermentation" time decreased. These crackers were completely different in texture and taste from normal crackers. These results make it clear that yeast is a fundamental ingredient in crackers and show that besides its role in adjusting pH to allow enzymatic conditioning the dough, yeast has a very important effect on both texture and flavor.

Table 4. Physical characteristics of baked cracker prepared with SWF and prepared with HWF. Data is for 10 crackers.

Flour Type	Shrinkage[a/] (cm) Side A	Shrinkage[a/] (cm) Side B	Weight (gram)	Height (cm)	Ratio H/W
SWF A (Control)	3.385	4.037	29.729	6.983	0.235
SWF B	3.217	4.183	27.660	6.884	0.249
HWF A	2.542	3.525	30.283	8.205	0.271
HWF B	2.392	3.450	33.083	7.696	0.233

[a/] The difference between 10 x the theoretical length (cutter dimensions) and the length of 10 crackers.

Table 5. Effect of "fermentation" time on the physical characteristics of baked crackers when in presence of lactic acid (L.A.). Data is for 10 crackers.

"Fermentation" Time	Shrinkage[a/] (cm) Side A	Side B	Weight (gram)	Height (cm)	Ratio H/W
18 hrs (Control)[b/]	3.385	4.037	29.729	6.983	0.235
18 hrs + L.A.	2.608	3.066	27.657	5.387	0.195
15 hrs + L.A.	2.408	2.925	28.573	5.802	0.203
12 hrs + L.A.	2.358	2.908	29.090	5.942	0.204
9 hrs + L.A.	2.325	2.933	30.073	6.156	0.205
6 hrs + L.A.	2.283	2.550	33.393	7.012	0.210

[a/] The difference between 10 x the theoretical length (cutter dimensions) and the length of 10 crackers.

[b/] Yeasted dough.

Data in Table 6 show means and standard deviations (SD) for the different attributes measured. From the baking results it is concluded that fermentation time has an important role in conditioning cracker sponges. Cracker doughs prepared from sponges fermented longer were more pliable and had better machinability. Crackers obtained from those doughs had more uniform oven spring and better texture, less blisters and less compact areas. Replacement of SWF by HWF up to certain limits (30%) had a beneficial effect, improving machinability by mellowing the dough. Oven spring was also improved by addition of HWF and this resulted in crackers with better texture. Normally the weight of baked crackers decreased as HWF increased up to 30 per cent. In general, crackers obtained from straight HWF had good quality, giving an excellent oven spring. However, they were heavier than crackers obtained from straight SWF. Crackers obtained from doughs mellowed by addition of lactic acid had no oven spring at all, and they were completely different in texture and taste from normal crackers. These results make it clear that yeast is a fundamental ingredient in crackers that not only adjusts the pH to allow enzymatic conditioning of the dough, but also improves both texture and flavor of the finished crackers.

Table 6. Mean and standard deviation for the control working with 12 samples on 4 different days.

Control	Shrinkage[a] (cm)		Weight	Height	Ratio
	Side A	Side B	(gram)	(cm)	H/W
Mean	3.385	4.037	29.729	6.983	0.235
SD	0.313	0.260	0.676	0.182	0.007

[a] The difference between 10 x the theoretical length (cutter dimensions) and the length of 10 crackers.

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RHEOLOGICAL CHANGES IN CRACKER SPONGES DURING FERMENTATION AND A CRACKER TEST BAKING PROCEDURE

by

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ABSTRACT

Rheological changes in cracker sponges as a result of fermentation were studied using the Brabender Extensigraph. The effect of soda, salt, mixing time, and pH were evaluated alone and in certain combinations. The results showed that the strength of the dough decreased as fermentation time increased. Salt increased dough resistance to extension, while soda and mixing time tended to increase extensibility. Yeast was responsible for the drop in pH during fermentation. The lower pH appeared to be necessary for proteolytic enzyme action. Addition of lactic acid to create sponges having different pH values showed that the decrease in resistance to extension during fermentation was pH dependent. The pH value around 4.0 was optimum for the presumed proteolytic enzyme action.

A cracker test baking procedure was developed. Baking results showed that fermentation time of the sponge had an important role in conditioning cracker doughs. Cracker doughs prepared from sponges fermented longer, besides machining better, had more uniform oven spring and a better texture with less blisters and less compact areas. Replacement of SWF by HWF up to 30% had a beneficial effect on machinability by mellowing the dough. Oven spring was also improved by addition of HWF and this resulted in crackers with better texture. Normally, the weight of baked crackers decreased as HWF increased up to 30%. In general, crackers obtained from straight HWF were of good quality, with an excellent oven spring. However, they were heavier than crackers obtained from straight SWF. Crackers obtained from doughs in which the sponges were mellowed by addition of lactic acid had no oven spring at all, and they were completely different in texture and taste from normal crackers. These results make it clear that yeast is a

fundamental ingredient in crackers. Yeast not only adjusts pH to allow enzymatic conditioning of the dough, but also improves both texture and flavor of the finished crackers.