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THE BAKING STRENGTH OF ARIZONA EARLY BAART FLOUR

By

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* In coöperation with United States Department of Agriculture, Bureau of Plant Industry.

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By Margaret Cammack Smith

INTRODUCTION

According to Alsberg (1) the nation faces today a shortage of hard wheat. Definite limits to hard-wheat production are set by climate, and there are no large areas in this country with climates suitable for the growth of hard wheat, that are not already being planted to this crop. Therefore, it is not possible to increase the production of hard wheat to any great extent, other than by increasing the yields. With hard-wheat production almost at a standstill, the discrepancy already existing between demand and supply will become more apparent as population increases.

The situation with soft wheat, however, is different, for it can be grown almost anywhere in the milder regions of the country, including the great Southwest. Thus it is evident that soft-wheat production can be greatly increased, and will be, if there are sufficient inducements.

At the present time, soft-wheat flour is preferred for the manufacture of crackers, cake, and pastries, but for breadmaking, the baker and the housewife alike demand the stronger hard-wheat flour with its higher gluten content. The fact that a higher bread yield can be obtained from the stronger flour, coupled with the fact that but a minimum amount of care and skill is required in the use of hard-wheat flour for breadmaking, makes it more desirable. This situation is responsible for the higher market price for hard wheats.

With limited hard-wheat production, one of the possible places of attack of this problem is to lower the demand for strong flours. This can best be done by the substitution of soft wheat for hard, and it is necessary to educate the baker and the housewife to the use of soft wheat for breadmaking. Before this can be done, methods of handling, and formulæ best adapted to the use of soft wheat for breadmaking must be developed.

Due to climatic and soil conditions, Arizona produces soft wheat almost entirely. While other varieties of soft wheat, such as Club, are grown to some extent in this State, the larger part (75 percent) is of the Early Baart variety.

Early Baart wheat, sometimes known as Columbia or Diener No. 18, was introduced into the United States from Australia in 1900 by the United States Department of Agriculture. Seed was distributed for experimental use to several parts of the country, including Arizona. By 1914, the Arizona Agricultural Experiment Station had established the growth of this wheat in Arizona, and it is now grown also in Washington, Idaho, and California. Bryan and Wood (1922) (2) reported this wheat to be especially well adapted to the irrigated lands in Arizona, and found it to be superior in yield, and of better milling quality than any other Arizona-grown wheat tested by the Arizona Agricultural Experiment Station.

Early Baart wheat flour has been selected, therefore, as a soft-wheat flour typical of Arizona, for scientific study. The purpose of this investigation was to study the physical and chemical properties of Early Baart wheat flour and to show any possible correlation between such properties and the baking-strength of the flour, the information obtained to be used in the subsequent development of a formula and a method of procedure best suited to its use for breadmaking purposes.

FACTORS AFFECTING THE BAKING STRENGTH OF ARIZONA EARLY BAART FLOUR

In order to understand the factors upon which the quality of the dough and the bread made from it depend, it is first necessray to realize the complexity of the raw materials. Chemical analysis of wheat or flour shows that it contains proteins, carbohydrates, fat, minerals, water, and enzymes. The nitrogenous fraction consists principally of two proteins, gliadin and glutenin, with edestin, leucosin, and protease present in small amounts. Approximately 75 percent of the flour is carbohydrate, chiefly starch, with a little sugar and cellulose. The ash is composed of many mineral elements, important among which from the nutritional standpoint, may be mentioned calcium, phosphorus, and iron. All are combined in a manner not clearly understood. The fat is principally in the form of phosphatides resembling lecithin, the concentration of which seems to vary with the grade of flour. Chief among the enzymes present in the flour are diastase which influences the rate of starch hydrolysis and the proteases which have an accelerating effect upon proteolysis.

When water is added to the flour, the glutenin and gliadin probably combine to form gluten; this forms the network in which the starch and other materials are enclosed, thus making a dough possible. The addition of yeast, sugar, salt, and fat makes the mixture even more complex, for the quality of the dough thus becomes dependent not only upon the flour, but also upon the nature of each addition and their relations and interactions. Many biochemical changes occur. Part of the starch is converted into dextrins and sugars by diastatic activity. Proteases bring about the hydrolysis of gluten proteins to some extent. Disaccharides such as sucrose and maltose are hydrolyzed to simple sugars, due to the catalyzing effect of yeast sucrase and maltase respectively; and these sugars subsequently undergo alcoholic fermentation. Most of the alcohol produced escapes, but the carbon dioxide is largely retained in the dough, making it light and porous. In addition to all these changes, there is an increase in acidity, due to the production of lactic, acetic, and carbonic acids, resulting from both bacterial and enzymatic action.

Whereas quality of dough depends upon all of the foregoing relationships and interactions, the part which the flour plays is perhaps first to be considered. One of the most important properties that flour possesses, and yet one of the most difficult to define, is that of strength. In a vague way, it is thought of as being the quality to produce a large, well-piled loaf of bread. At the present time there is no exact chemical method by means of which the strength or baking quality of a dough can be accurately measured. With so many variables involved, a test must either measure several factors at once, or else consist of a group of short tests each accounting for a single factor.

The relation between gluten content and flour strength has been noted from time to time. In 1920, Stockman (3) added dried gluten to flour and obtained an increase in loaf volume. Snyder (4) on the other hand reduced the gluten content of flour by adding corn flour and also by washing out some of the wheat starch, but found no change in the size or appearance of the loaf.

More recently the relation between total crude protein to flour strength has been studied. The ease of an accurate total protein determination makes duplication of results more probable. In 1913, Bailey (5) reported that loaf volume increased with increase in protein content, but not regularly. The addition of 1 percent protein to flour having a protein content between 9.5 and 10.5 percent effected a volume increase of 6.6 percent, whereas the same amount of protein added to a flour having a protein content within the range of 13.5 to 14.5 percent effected an increase of loaf volume of only 0.8 percent. Schollenberger (6) (1923) grouped flour samples on the basis of protein content and noted an increasing loaf volume with increasing protein content up to 15.9 percent crude protein. Further increases in protein content were accompanied by diminished loaf volume. With too high a protein content a condition occurs which is known as "gluten bound," a state in which so much gluten is present as to withstand distension of the gas liberated in the fermentation process.

Mangels and Sanderson (7) (1925), have also shown a positive correlation between protein content and baking quality, and again, Bailey and Sherwood (8) in 1926 demonstrated that "each increment of increase in percent of protein is progressively less effective in increasing the size of the loaf." However, differences in loaf volume and therefore probably of flour strength, paralleling increases in protein content were significant and today the protein test is the best single chemical test of flour strength.

Perhaps, however, even more significant than gluten or protein content is gluten quality. Efforts to find reasons for the seeming lack of correlation between gluten content and flour strength which was occasionally encountered, have led to investigation of the quality of gluten. It is strikingly evident that two flours of the same quantitative protein content may differ very decidely in baking-strength, as evidenced by volume of loaf.

Gluten quality, however, is a factor far more difficult to measure, as precise chemical methods for measuring and expressing it do not exist. Experienced bakers have long since made use of the general appearance and "feel" of the gluten washed from the flour, in judging its breadmaking possibilities. Such physical characteristics as elasticity, cohesion, toughness, softness, or stickiness, have meaning only for the experienced operator, however, and such grading depends solely upon his judgment and memory.

Cereal chemists have attempted to associate gluten quality with its gliadin content. Snyder (4) pointed out the relationship of gliadin content to the expansion of the gluten, to its physical properties, *i.e.*, softness and elasticity, and to the size of the loaf produced. He found that either excessive or small amounts of gliadin may cause a flour to have poor breadmaking qualities and the conclusion was reached, that in the best grades of flour 56 to 68 percent of the protein is in the form of gliadin.

Later work has placed greater emphasis upon the ratio of gliadin to glutenin. By finding the ratio for different flours and then changing the ratios by adding one of the proteins, Snyder comes to the conclusion that the optimum ratio is 65 percent gliadin to 35 percent glutenin. Other workers proposed that the gliadin-glutenin ratio be called the quality factor and be considered in addition to quantity of gluten in representing the baking-strength of a given flour. Later the gliadin-glutenin ratio fell into disrepute because of the recognized difficulty of actually determining the true proportions of gliadin and glutenin as they exist in flour. (9)

A method of measuring gluten quality which gives considerable promise is Sharp and Gortner's (10) well-known viscosimetric procedure.

This is based on the belief that other things being equal, strong glutens will have higher hydration capacities and also will imbibe water more rapidly than will weak glutens. The differences in hydration capacity are considered to reflect inherent colloidal differences in the glutens under study. In 1896, Gortner (10) presented data to show that glutenin is the protein most largely responsible for the water-absorbing capacity of a flour and more recent evidence strongly suggests that glutenin is the protein which is responsible for the variation in the colloidal properties of the flour.

However, the practical applications of this viscosity test so far, have not given satisfactory results, and belief has been expressed that such a test is not any more valuable and gives no more information than does a total protein determination.

It is now a widely accepted belief that flours may have good gluten quality as well as quantity and yet be weak because of low diastatic value. Wood (1907) (11) was perhaps first to call attention to the diastatic content of flour and its relation loaf volume. In 1922, Rumsey (12) stated that "flour showing the greater diastatic power should show the greater strength providing the relative quantity and quality of gluten is the same." The work of Collatz (13) (1922), indicated that superior bread resulted from the use of a small amount of malt extract. Recently, 1926, Sherwood and Bailey (14) found it possible to increase diastatic activity in flour by adding sprouted wheat, and increased diastatic activity improved the baking quality of the wheat.

Thus, it is evident that no single analytical factor suffices to measure the baking-strength of a flour and it accordingly becomes necessary to study the various factors which go to make up this property of flour-strength and their relationship. In order to obtain information regarding the relative inherent baking-strength of Arizona Early Baart flour a group of tests was made with it.

PHYSICAL AND CHEMICAL TESTS MADE WITH ARIZONA EARLY BAART FLOUR

MOISTURE

Results of analytical determinations made upon a flour or upon wheat have comparable significance only when calculated to a common moisture basis. The miller who buys his wheat on the basis of protein content only may be misled, due to the fact that differences in moisture content are not considered. Change in the moisture content of wheat is the most frequent cause of lack of uniformity of protein tests. Chemists on the Pacific Coast object to the custom of disregarding the percentage of moisture because grain from dry regions frequently arrives with a moisture content of 10 percent or less and consequently the protein test gives abnormally high results. On the other hand, wheat growers in dry regions object to a high moisture basis because it lowers the apparent protein content of their wheat. For some years, however, it has been the practice to report all analytical data on flours on the uniform basis of a flour containing 13.5 percent moisture. This basis was selected because, under the Pure Food and Drugs Act of the United States Government, flour cannot carry moisture in excess of 13.5 percent. More recently the standard of 15 percent moisture has been set.

The low moisture content of Arizona Early Baart flour (9.85 percent) which was obtained by drying the flour at 110° F. in a Freas electric oven has been used in calculating the chemical determinations that follow upon the recommended 15-percent moisture basis.

ASH

An ash determination is generally made to determine the relative grade of flour. A lower percentage of mineral elements is associated with greater refinement. This is due to the fact that the more highly milled flour contains less of the outen part of the wheat grain which is richest in mineral elements.

However, there has also been noted by some workers a class difference in ash content, soft wheats exhibiting lower ash contents than do the stronger, hard wheats. An ash content of .64 percent in Early Baart flour, is higher than that of most soft wheats, the ash content of which usually falls within the range of .35 to .57 percent in straight, grade flours. Though the ash content has been considered significant only in its relation to milling refinement and to have no bearing upon flour strength, it may be of significance because of the part it plays in the buffer action of the flour. This point will be referred to again.

TITRATABLE ACIDITY

"Acidity of flour" refers to the amount of water-soluble-free acid which can be neutralized by a base. The result is obtained by extractions of 18 grams of flour with 200 cc. of carbon-dioxide-free water for 1 hour with frequent shakings at regular intervals; 100 cc. of the filtrate are then titrated with N/20 sodium-hydroxide solution, phenolphthalein is used as the indicator, and the result is expressed in terms of percentage of lactic acid in the flour with a 15-percent moisture content.

The percentage of acidity decreases as does the ash content with increasing refinement and grade. An average acidity of various mill streams is as follows: First patents 0.100 percent acidity; straights 0.125 percent; first clears 0.175 percent; second clears 0.400 percent; and, low grades 0.500 percent.

Greater in its significance, however, is the relation of the acid content of flour to its soundness and keeping qualities, and it is in this connection that the determination of acidity percentage is of value. High acidity may indicate a lack of complete maturity of the wheat, or an unsound condition resulting from bacterially produced fermentation. The percentage of acidity of 0.098 of the Early Baart straight flour is low enough to indicate that sound wheat was used for this study and it is probably without further significance.

CRUDE PROTEIN

Total crude protein was determined by the Kjeldahl method, using potassium sulphate and mercury in the digestion process, the mercury being subsequently precipitated by the addition of a calculated amount of ammonium sulphide. The factor of 5.7 was used for the calculated conversion of the nitrogen obtained in wheat proteins.

Approximate Protein Content of Common-Wheat Classes

Wheat variety		Proteins* in wheat	Proteins in straight flour
Durum wheats		15.5	14.1
Hard Red Winter	Av	13.5	11.2
Hard Red Spring	Av	13.6	11.9
Soft Red Winter	Av	11.3	9.1
Soft White	Av	12.0	9.6

It is evident that Arizona Early Baart flour with its protein content of 9.84 percent belongs in the better class of soft wheats, if total protein content is to be the basis for judgment.

CRUDE GLUTEN

QUANTITY

The amount of crude gluten which a flour possesses has long since been correlated with its baking-strength. Whereas, the total protein test lends itself to more accurate determination, a flour analysis is yet not considered complete without actually separating out the gluten as such. As

* Data taken from U. S. Dept. of Agr. Bul. 1183

pointed out by Dill and Alsberg, several factors are subject to variation in the gluten-washing process. The inaccuracy of the procedure in general was reduced to a minimum by making 25 grams of flour into a dough ball using Dill and Alsberg's (15) recommended 0.1-percent, sodium-acid-phosphate solutions, allowing the dough to stand 1 hour in this solution after which the gluten was washed almost free from starch with the same solution. Controlling the time and kind of wash water rendered the process capable of quantitative duplication. The dispersion of gluten which accompanies the use of distilled water and the use of tap water of variable composition was thus avoided.

The " wet gluten " obtained was dried to constant weight and weighed as dry gluten. The result expressed in percentage of dry, crude gluten on the basis of original flour with a moisture content of 15 percent shows the Arizona Early Baart flour to contain 11.2 percent gluten. This fact again brings this flour into the class of semi-hard wheats. The gluten separated in this way contains but 75 to 80 percent protein, the remainder being starch, lipoids, and ash constituents, which are not subject to complete removal by the washing process. This fact accounts for a gluten content which is higher than the total protein percentage.

QUALITY

The simplest method of evaluating gluten quality is by the " feel " and general appearance of the hand-washed gluten. Whereas, Marquis, a typical spring wheat, gives a gluten that is granular, short, and tough; and Turkey Red, a typical hard, red, winter wheat has a gluten which is smooth, elastic, and with varying degrees of toughness, the gluten in Arizona Early Baart wheat is creamy in color, smooth, elastic, but rather soft and lacking in toughness. It is quite superior, however, to the grayish, soft, sticky, non-cohesive type of gluten which can be separated but with difficulty from the weaker flours of such varieties as Sonora and Club wheats. Soft glutens usually lack ability to spring and do not stand a long fermentation.

HYDRATION CAPACITY

The ability of dry gluten to absorb water is known as the hydration capacity. Strong glutens become hydrated to a greater degree and also more quickly than do weak glutens. A study of the absorbing power of gluten proteins is best made by the use of viscosity measurements. In this investigation the lack of facilities rendered such a measurement impossible. The ratio of dry to wet gluten, however, indicated that the Early Baart dry gluten absorbed 2⅓ times its weight in water. A strong gluten absorbs water anywhere from 2¼ to 2½ times its dry weight.

GLIADIN-GLUTENIN RATIO

This determination was first made by extraction of a 6-gram sample of flour by boiling 50-percent alcohol by volume under a reflux condenser according to the official method. Ninety-three percent of the nitrogen determined in an aliquot portion of the extract was considered to be gliadin nitrogen. By this method, 67 percent of the total protein was found to be gliadin. This value is not appreciably higher than is the 65 percent of gliadin which was thought by Snyder (4) to be correlated with flour of good strength.

Though no direct relation between the concentration of such forms of protein as edestin, leucosin, and protease and flour strength has been noted, a determination of these salt-soluble proteins was made incidental to the estimation of glutenin by difference. The extraction was made with a 5-percent potassium-sulphate solution in the cold and the nitrogen determined in an aliquot portion of the extract as before. Calculation of the potassium-sulphate-soluble proteins following the official method and using the conversion factor 5.7, gave Early Baart flour a salt-soluble, protein content of 1.64 percent.

A glutenin content of 1.54 percent determined by finding the difference between the sum of gliadin and the salt-soluble protein and the total crude protein resulted in a gliadin-glutenin ratio of approximately 80 to 20.

Since more modern methods of measuring the percentage of the various protein fractions have been recently developed, this work was repeated so as to obtain more accurate results.

The proteins soluble in a 5-percent, potassium-sulphate solution were first determined by the following method of Grewe and Bailey's (16). Six grams of flour were suspended in 75 cc. of the sulphate solution, shaken in a mechanical shaker for 30 minutes, and centrifuged at a high rate of revolution for 20 minutes. The supernatant liquid was decanted, and the process repeated with two additional 75-cc. portions of the sulphate solution. The percentage of nitrogen in the combined extracts was determined by the Kjeldahl method as previously used.

The gliadin percentage was obtained by extracting the residue from the sulphate extractions with 70-percent ethyl alcohol in the same way, and the three extracts again combined for determination of their nitrogen content.

The insoluble residue remaining after the extraction of the salt-soluble protein fraction and gliadin was then used for the determination of its nitrogen content. The result multiplied again by 5.7 gave the glutenin content according to the method of Sharp and Gortner (17).

Making use of the results obtained from the foregoing methods of extraction of gliadin, salt-soluble proteins, and glutenin, the ratios of the various protein fractions in Arizona Early Baart flour to each other were computed. The ratio of the protein extracted by a 5-percent, potassium-sulphate solution to the total crude protein was thus found to be 0.204. Upon analysis of 17 flours of widely different character, Bailey (16) found the ratio to vary from 0.15 to 0.223 percent with the lowest ratio found in a Pacific Coast, soft-wheat flour. The ratio of glutenin to the crude protein in the Early Baart flour was found to be 0.406. This is not appreciably higher than the highest ratio observed in Bailey's reported range from 0.36 to 0.40. Again, the ratio of glutenin to the true gluten, *i.e.*, to the sum of the gliadin and glutenin in the Early Baart flour, was found to be 0.439. This falls within the range reported by Bailey of 0.44 to 0.49 which led him to conclude that the difference between flours is too small to justify a conclusion that there is a substantial variation in the proportion of gliadin and glutenin in flours of differing types.

DIASTATIC ACTIVITY

As has been pointed out, gluten is often considered the cause for poor quality in bread, when in reality the yeast is unable to produce the desired loaf volume because of inadequate concentration of the enzyme which accelerated the hydrolysis of starch in the formation of sugar upon which the yeast zymase can act. A simple, purely qualitative test, was made for extent of diastatic activity with Early Baart flour by baking a dough without sugar or salt. The brown color which resulted indicated that the flour was fairly well provided with the diastatic ferment. The light crust resulting from the same test on Sonora flour was striking in comparison.

For a more nearly quantitative estimation of diastatic activity, the rate of production of sugar from starch in a flour-suspension was measured, using Rumsey's (1922) (2) method. In this test, 10 grams of flour were digested with distilled water in a 27° C. thermostat for exactly 1 hour. At the end of this period, the suspension was clarified by the addition of 3 cc. of a 15-percent sodium-tungstate solution, and then acidulated with sulphuric acid. Thus the enzymatic activity was stopped and further change in sugar content ceased. The concentration of reducing sugars in an aliquot, was then determined by the Quisumbing-Thomas (18) method. The results computed as equivalents of maltose in mg. per 100 grams of flour, gave the Early Baart flour a value of 180 mg. maltose.

Bailey's (16) reported analyses of 17 different flours showed a range from 90 mg. maltose in the soft wheat from the Pacific Coast, Indiana, and Ohio, to 290 mg. maltose obtained from certain hard, spring-wheat flours.

The original work of Rumsey (12) showed a range from 34.8 mg. maltose to 308.1 mg. of maltose per 10 gm. of flour. As a positive correlation is known to exist between diastatic activity and the baking-strength of a flour, the comparatively high rate of maltose-production in Early Baart flour is indicative of its probable worth as a breadmaking flour.

ABSORPTION

By absorption is meant the amount of water which a flour will take up in the production of a dough of desired stiffness. t is expressed in terms of percentage of water-absorption of a flour containing 15 percent moisture, thus representing the weight relationship of the water absorbed to the weight of the flour used.

From the commercial standpoint, percentage of absorption is very important, for other things being equal, the more water that can be worked into a given amount of flour, the greater will be the weight of the bread produced. To the baker, the bread yield, *i.e.*, number of pound loaves per barrel of flour, is an important measure of flour quality and commercial value. Some of the water is lost during baking, the extent of this loss probably being dependent to a considerable degree upon the quality of the gluten. However, there is a fairly well-defined relation between the weight of the loaf of bread produced and the water-absorption of the flour.

Hard wheats as a class absorb more water than do soft wheats, the percentage of absorption of the former ranging from 55 to 68 percent, whereas the latter show much lower percentage absorptions, usually lying within the range of 45 to 56 percent.

The percentage of absorption of the Early Baart flour was determined by the method recommended by the Inter-Bureau Committee of the United States Department of Agriculture on the Standardization of Bread Making Test for Hard Wheat Flours. Distilled water was incorporated in a 25-gram sample of flour until the resulting dough was of such consistency as "to just adhere to a glass surface when pressed firmly and perpendicularly" against it. By means of such a method of procedure which is accurate to 1 percent, the Early Baart flour was found to absorb water equal to 58 percent of its weight. This indicates that Early Baart flour has an exceptionally high absorption for a soft wheat, which fact will serve to enhance its commercial value, because of the probable yield in 1-pound loaves of bread per barrel.

Though none of the foregoing physical and chemical tests measure in themselves the strength of Early Baart flour, nevertheless, each made some contribution, and collectively they showed that this flour ranks high as a soft-wheat flour, and perhaps may better be classed as a semi-hard wheat flour. Compared with the best hard wheats, Early Baart is lower in percentage of gluten and total protein. The gluten has fairly good quality but lacks toughness. The gliadin content and gliadin-glutenin ratio lie within the range which deprives them of special significance. Its relaively high diastatic value for soft wheats is decidedly an advantage. A hydration capacity of degree high for soft wheats enhances its value for commercial usage.

The final proof of the breadmaking value of Early Baart flour, however, lies in the baking-test. This is considered by most experimental laboratories as the only "reliable quality index," and it is used as the final test in judging and grading wheat flours as to their inherent strength.

COLLOIDAL NATURE OF BREAD DOUGH

Whereas the factors which determine "strength" or "quality" are to a large extent pre-existent in the flour, nevertheless the baker can modify this quality to a considerable extent by his control over the environment of the flour particles. The extent of his control over their environment is a measure of the extent to which he is able to influence the breadmaking quality of the flour.

Dough forms a most complex colloidal system, each substance in the dough existing in colloidal condition. Swanson (19) pictures the complex colloidal dough in the following simple manner. The dough is a mass of starch and protein particles covered by films of water. The surface-tension forces inherent in these films of water bind the starch particles together and the protein particles form chains or strands which have a rubbery elasticity. Quality is determined in the first place by the number of particles present which form the strands, *i.e.*, the amount of protein or gluten in the flour. If too few in number, the gluten meshes will not be strong. This is the condition in a flour of low total protein content, even though the quality is good.

Quality of dough depends in the second place upon the structure of the protein particles and the manner in which they unite to form strands or chains. If the structure is weak, the network will be weak, no matter what the quantity. The number of particles is obviously related to the quantity of protein in the flour, and their structure is related to the quality. These two are determined when the wheat grain is formed.

A weak structure also results, however, if the environment is such that the protein particles cannot make strong contacts. The presence or absence of any substance or condition which would cause the protein particles to adhere more or less firmly in forming strands, will affect the quality of the dough. Herein lies the baker's power, for by proper handling of the dough, and changing the formulæ he can control the environment of the colloidal particles.

Among the environmental conditions affecting colloidal behavior may be mentioned H-ion concentration, the presence or absence of electrolytes, and enzyme activity (protein) which modifies the structure of the protein. Environmental conditions such as temperature and H-ion concentration are also factors affecting enzyme activity. For example, the rate of diastatic activity is controlled by temperature, H-ion concentration, and the concentration of the substratum, the gas which is formed being retained because of the colloidal structure of the dough.

The change produced in gluten during the fermentation process is known as "ripening." The physical or chemical changes in the dough which are correlated with this "ripening" or "maturing" process are not definitely known, but most of the evidence at hand indicates that change in H-ion concentration is involved, and is perhaps of prime importance.

Jessen-Hansen (1911) (20) was probably the first to indicate the importance of H-ion concentration in breadmaking. He stated that "for the dough of any wheat flour there exists a definite concentration of H-ions with which the production of bread from this flour will be most successful." He found that the largest loaf-volume was generally obtained at an H-ion concentration represented by a pH of 5. If this H-ion concentration was not reached by production of acids during normal fermentation, the addition of acids to the dough would usually result in increased loaf-volume.

Sherwood and Bailey (21) showed that the H-ion concentration increased at a fairly uniform rate in bread dough fermented under fixed conditions.

The chemical nature of the acid-reacting materials accumulating in bread dough during fermentation has been studied by Johnson (1925) (22). Carbon dioxide was found to be the most important single factor affecting its H-ion concentration. The organic acids present were shown to be lactic and acetic acids, with lactic acid predominating.

The significance of H-ion increase is manifold. The rate of yeast fermentation reaches a maximum at an approximate pH of 5. Rope-producing organisms are almost inactivated at this pH. Flour and malt diastase show their greatest activity in a medium of pH of 4.7.

Hendersen, Fehn, and Cohen (23) found that the viscosity of the dough passes through a minimum at a pH a little below 5. They associate low viscosity of dough with high bread quality.

BUFFER ACTION IN DOUGH

Thus, the desirability of reaching a pH of approximately 5 in a dough as a result of fermentation is quite evident. As flours have an original pH ranging from 6 to 6.5, with flours bleached by chlorine exhibiting somewhat lower pH's, the reacting of the pH usually associated with good bread production involves a considerable increase of H-ion concentration during fermentation. The rate at which a flour changes in H-ion concentration varies with the flour. Some flours never reach the optimum pH in a normal fermentation period, and others reach it but slowly. The resistance which a flour offers to change in acidity depends upon the degree to which the flour is buffered.

Bailey and Sherwood (21) have shown that low-grade flours are more highly buffered than are higher grade flours, due to their higher ash content.

Foster (24) in his studies of the chemistry of New Zealand wheats and flours shows that loaf-volume was correlated with the degree of buffering of the flour, in flours of the same protein content. He found evidence of only a slight relationship between the degree of buffering and the percentage of ash, and no relationship to the initial pH of the flour, absorption of water, or ratio of wet to dry gluten.

The pH of a 1 to 10 suspension of Early Baart flour as determined electrometrically, using a type K, Leeds and Northrup potentiometer with a calomel half-cell and a Bailey hydrogen electrode, was 6.07.

For measuring the relative degree of buffering the number of cc. of $\frac{N}{50}$ hydrochloric-acid solution required to bring a 1 to 10 flour-suspension to a pH of 5 was determined in the same electrometric manner. Eight and one-half cc. of the acid solution were required to lower the pH of 100 cc. of this suspension to a pH of 5, thus giving Early Baart flour a so-called buffer value of 8.5 which is notably higher than that of other soft wheats of the same approximate protein content. That the comparatively high buffer value of this flour may be due in part to the fact that its ash content is substantially higher than that of soft wheats of corresponding milling-grade and protein content, has been indicated by unpublished data of the author's through a study of 50 samples of straight flours milled from Arizona wheats. A longer fermentation period is thus indicated.

BAKING EXPERIMENTS WITH ARIZONA EARLY BAART FLOUR

INTRODUCTION

Though soft wheats have been in disrepute for breadmaking, from time to time attempts have been made to popularize their use for this purpose. Most of the work has been done in states which grow soft wheats, with the purpose of encouraging the use of the local wheat for breadmaking.

Williard and Swanson (25), in 1919, in making a study of Kansas hard wheats which included some work with soft wheat, came to the conclusion that soft-wheat flour gave the best results if a stiff dough and short fermentation period were used.

Jago, (26) (1911) advised the use of more yeast with soft-wheat flours.

Some work with soft, winter-wheat flour was done in 1911 at the University of Illinois under the direction of Dr. Bevier (27). The recommended procedure for handling soft-wheat flour indicated the use of a straight dough, three rising periods instead of two, and also that the dough should be allowed to finish proofing in the oven.

In 1912, Olsen (28) of the Washington State Experiment Station, studied the use of soft wheats for breadmaking. He attributes most failures in the use of soft-wheat flour to too stiff a dough and to non-active yeast, and recommended gentle mixing and kneading, because of the less destructive effect on yeast activity.

Harcourt and Purdy (29) report in 1922 their work done in the Ontario Department of Agriculture. The conclusion is reached that soft-flour doughs cannot stand a long fermentation, and they recommend a short, quick, straight-dough method, and suggest the inadvisability of using the sponge process.

The Department of Home Economics of Purdue University did some successful work in 1923 with making bread from Indiana soft wheat, in an attempt to encourage the use of their home product.

In 1923 work was started at the University of Missouri by Miss Laurel Davis (31) with the local, soft wheat, and the conclusion reached (1924) was that their soft-wheat flour required a slacker dough, more yeast and sugar, and a shorter fermentation time than the usual recommendations for hard wheats. A later report of Davis and Cline (1926) (32) gives the results of extending their studies to the use of dried yeast, liquid yeast, potato water, and buttermilk with the resulting production of light bread from Missouri soft-wheat flour.

The Bureau of Home Economics, United States Department of Agriculture, undertook the study of the baking qualities of 11 different varieties of soft, red, winter wheats in 1925. The findings of Dr. Denton were, that with the use of appropriate methods, good home-made bread could be made from the stronger of the soft-wheat flours and a fair quality bread from many of the weaker soft-wheat flours. A three-rising period, straight-dough method, with a formula containing 4½ percent yeast and 6 percent sugar gave the best results.

Weaver and Glodtrap (33) published the results of their studies on the baking-strength of various flours. They were able to produce a loaf of good quality from their soft-wheat flours by using a shorter fermentation period. Their conclusion is that when the flour is started with the proper absorption and the correct fermentation period is used, all flours whether from soft or hard wheat, will produce large, well-piled loaves of bread.

In Bread Facts, a publication of the Ward Baking Company, suggestion is made that if soft-wheat flours are used, less mixing, more yeast, and a shorter period of fermentation will be less destructive to the weaker gluten, and better bread will result.

The consensus of opinion regarding the use of soft-wheat flours seems to be that any flour will produce "a quality loaf" of a certain volume if properly handled. It seems to be a question of finding the right absorption and correct fermentation time. In most cases a slack dough, short fermentation period, and a limited amount of kneading and mixing with larger amounts of yeast and sugar are recommended.

MATERIALS USED

For the initial work, the Early Baart flour used was a straight, unbleached flour milled from Early Baart wheat which was grown on the Salt River Valley Experiment Farm near Mesa, Arizona. Many of the later experiments were repeated using a 100-percent Early Baart, patent, bleached flour which was the product of a local mill, sold to the bakers as pastry flour.

Distilled water was used, unless otherwise stated, in amounts as indicated by a predetermination of the absorption of the flour. Compressed yeast obtained fresh each day in 1-pound cakes from a local Fleishmann agent was used. Any discoloration on the outer surface of the cake was removed and only the fresh, inner part used. The weighed amount was dispersed in part of the water at the time of its use. A commercial salt was used which had not been adulterated with a filler for salt-shaker purposes. Swift's Silver Leaf lard served as shortening.

BAKING PROCESSES AND EQUIPMENT

MEASURING THE INGREDIENTS OF DOUGH

All the ingredients, with the exception of the water, which were used in making the bread dough, were weighed on a torsion balance accurate to .1 gram. The water was measured in a glass cylinder graduated in cc. Three hundred twenty-five grams of flour were used for each loaf of bread, and the amount of each of the other ingredients used was expressed in terms of percent of this weight of flour.

MIXING

Mixing of the ingredients was done by means of an electric mixonette manufactured by the Read Machinery Company. A special dough-hook attachment was used. Unless otherwise indicated, a uniform distribution of the various materials was accomplished by a 10-minute mixing period at a low speed of 46 revolutions per minute. The gluten conditioning effect of high speed was made a special study. By means of calculations involving the temperature of the room and the flour, water of the temperature which would permit the dough to come out of the mixing machine at 82° F. was added.

FERMENTATION

The dough taken from the mixer was put into Chidlow expansion jars calibrated to 50-cc. intervals, and allowed to ferment in a Despatch electrically-heated fermentation cabinet at 82° F. The temperature was kept constant by means of a thermostatic regulator. A flat pan of water kept in the cabinet at all times served for humidity control.

POUNDING

When the dough had reached the desired increase in volume it was pounded. This served to free some of the air and carbon dioxide, and distributed more uniformly that which remained. The removal of products of the yeast activity permitted also a more rapid subsequent action. This pounding takes the place of the kneading done in the home. Preliminary experiments in this laboratory showed that 10 to 15 minutes kneading of each loaf of bread did not produce a grain superior to that resulting from pounding the dough against a hard marble slab surface ten times. As the expenditure of effort and time in the pounding was much less, that method of pounding was used in all of the experimental work.

BENCH-PROOFING

Bench-proofing is the rest period for the dough. Experiments have shown that dough benefits by a rest period before a change in manipulation is made. Accordingly, in the experimental work which follows, the dough was allowed to stand for 15 minutes after pounding before it was molded and put into the pan to be proofed.

PROOFING

After the rest period, the dough was placed in baking pans of tinned sheet-iron having the following approximate inside dimensions: Top, 10x24 cm. (4x9½ inches), bottom 8x22 cm. (3¼x8½ inches), height 7.5 cm. (3 inches). Pans of these dimensions were recommended for 325 gms. of flour in the report of the Federal Bureau of Home Economics. The dough was well flattened into the corners of the pan and the desired extent of volume increase was marked on the side of the pan. The proofing cabinet was also a Despatch electrically-heated cabinet with thermostatic control, maintained at a temperature of 92° F. Here also a pan of water served to prevent the drying of the surfaces of the dough. In no cases were the dough surfaces greased.

BAKING

The bread was baked in an evenly-heated Despatch electric oven with thermostatic control, always with a humidity control present. It was baked at an initial temperature of 375° F. for 10 minutes and the temperature then raised to 410° F. for 25 additional minutes, at which time it was removed from the oven and placed upon racks to cool.

WEIGHING AND MEASURING

After cooling the bread was kept in ventilated tin bread boxes for 24 hours. It was then weighed and measured before being cut and scored on its internal characteristics. The loaf-volume measuring device used was the hour-glass type, the volume of a loaf being measured by the displacement of a known amount of rape seed which is read directly on the scale.

SCORING

Whereas loaf-volume is considered to be the best evidence of good baking-strength in flour, nevertheless a large-sized loaf is often obtained as a result of overproofing, in which case evidence of oven-spring is lacking, and the large volume is obtained at a sacrifice of other desirable qualities in bread. Accordingly in the results of the following experimental work, the volume of the bread produced is given and also its so-called "texture score." This latter measure is obtained by using the following basis for scoring, which is a modification of that used by the Federal Home Economics Bureau.

BREAD QUALITY SCORE CARD

External appearance		10
Symmetry	2.5	
Shape of top	2.5	
Smoothness of top	2.5	
Break and shred	2.5	
Crust		15
Depth	5.0	
Color	5.0	
Texture	5.0	
Crumb		35
Color	10.0	
Grain	10.0	
Texture	15.0	

Flavor and odor	30
Keeping quality	10
Total	100

MEASUREMENT OF THE H-ION CHANGE DURING FERMENTATION

Data concerning rapidity and extent of acid development in the bread were sought so as to gain some information relative to optimum fermentation period for Early Baart flour. Accordingly an H-ion measurement of a 1 to 10 suspension of each loaf was made electrometrically at the time it was cut and scored. In a few cases the H-ion change was followed throughout the various steps of the breadmaking process.

All the pH values and loaf volumes recorded in the following tabulations are averages of from two to six loaves. In a few cases in which the results were sharply conclusive, a duplicate experiment was considered adequate.

EXPERIMENTS USING THE STRAIGHT-DOUGH METHOD

VARIATION OF PROPORTION OF WATER

Most workers experimenting with soft-wheat flours have recommended a slacker dough than is customarily used when handling hard-wheat flours. In Table I, the results of varying the proportion of water used with Early Baart flour between the limits of 50 and 66 percent are tabulated.

TABLE I.— VARIATION IN THE PROPORTIONS OF WATER USED.

Absorption	Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Percent	Minutes	cc.	Percent	pH
50	200	1,860	82	5.28
54	180	1,890	85	5.28
56	160	1,910	86	5.28
58	150	1,940	89	5.27
60	150	1,960	87	5.26
62	140	1,960	85	5.26
66	135	1,850	75	5.23

With the Early Baart flour used in this work, an absorption of 58 percent produced the best bread. The use of 2 to 4 percent more water resulted in loaves of somewhat larger volume, but this advantage was offset by an accompanying lower texture score.

Further increases resulted in a dough too sticky to be handled comfortably. The volume of the resulting loaf was smaller because the dough was too slack to retain the gas. A light-colored crust, flat top, coarse, uneven grain, and rather damp, heavy texture were accompanying characteristics.

With the stiffer doughs, the loaf volumes were lower and the grain fine and cake-like. A cracked, shell top resulted from the use of too small amounts of water, showing too great a resistance being offered to the expanding gases when placed in the oven. The use of a slack dough with this Early Baart wheat flour overcame the close, cake-like grain usually reported as characteristic of soft-wheat bread, but the substitution of the too open, porous, uneven grain which accompanied the use of a greater proportion of water is not to be desired, even for the sake of its greater volume and lightness.

It may be noted that the time of fermentation, which in this case, was the time required to reach a certain volume in the Chidlow expansion cylinder and in the pan, decreased as the dough became more slack, due to the increase in speed of reactions involved in gas production. The advantage of the soft dough in handling this soft-wheat flour probably lay in the more vigorous fermentation that followed.

VARIATION OF THE PERCENTAGES OF YEAST AND SUGAR

The use of large amounts of yeast and sugar has been advocated in formulæ best suited to the production of good bread from soft wheats. In order to determine the proportion of yeast and sugar which is best adapted to good bread production from Arizona Early Baart flour, the percentages were varied within rather wide limits. In all cases the other constituents of the formula were used in constant amounts, namely 2 percent salt, 2 percent lard, and water as calculated from absorption.

In the first series of loaves in which the percentages of yeast and sugar were varied, the method recommended by Davis and Cline (32) for the handling of Missouri soft wheat was followed. It consisted of a short fermentation period in which the dough was allowed to double its volume once before proofing to treble its bulk in the pan.

Interpretation of the results tabulated in Table II was rendered somewhat obscure, due to the fact that all of the loaves showed such characteristics of overproofing, as coarse grain, harsh and crumbly texture, and flat top and little oven-spring. The low texture scores are to be accounted for by this fact. The experiment was, therefore, repeated changing only the extent of volume increase in the pan.

TABLE II.— VARIATION IN THE PERCENTAGES OF YEAST AND SUGAR USED IN THE FORMULA. A. DOUGH DOUBLED BULK IN JAR AND TREBLE IN PAN.

Formula		Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Yeast	Sugar				
Percent	Percent	Minutes	cc.	Percent	pH
2	3	145	1,800	75	5.35
3	3	130	1,850	78	5.33
3	4	120	1,870	78	5.30
4	3	115	1,870	76	5.27
4	4	110	1,870	80	5.27
4	6	100	1,900	80	5.26
6	4	90	1,935	75	5.20
6	6	90	1,960	70	5.23

B. DOUGH DOUBLED BULK*IN JAR AND PROOFED 2½ TIMES BULK IN PAN.

Formula		Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Yeast	Sugar				
Percent	Percent	Minutes	cc.	Percent	pH
2	3	135	1,785	80	5.41
3	3	125	1,795	80	5.40
3	4	115	1,820	84	5.36
4	3	105	1,810	83	5.32
4	4	105	1,820	86	5.30
4	6	90	1,880	88	5.29
6	4	90	1,900	84	5.28
6	6	80	1,925	82	5.25

TABLE II—(Continued) C. DOUGH DOUBLED BULK TWICE IN JAR, AND PROOFED 2½ TIMES BULK IN PAN.

Formula		Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Yeast	Sugar				
Percent	Percent	Minutes	cc	Percent	pH
2	3	195	1,820	85	5.30
3	3	165	1,895	87	5.28
3	4	150	1,940	89	5 26
4	3	145	1,960	89	5.24
4	4	155	1,960	89	5.22
4	6	150	1,980	91	5.22
6	4	125	2,020	90	5.20
6	6	120	1,980	83	5.23

Though the volumes recorded here are all smaller than are those recorded in Section A, the texture scores indicate better bread. The increase in volume of bread with increasing percentages of yeast and sugar was quite apparent. With the exception of the very rich formula, *i.e.*, high percentages of yeast and sugar, a corresponding ascending texture score made it evident that the larger volumes were not obtained at a sacrifice of other desirable bread qualities. This was not the case, however, with the bread in which the very rich formulæ were used. The lower texture scores of these loaves were partly due to their over-light characteristics. This condition may have been due in part to the fact that, with the increased yeast and sugar, the doughs were inclined to be rather sticky and harder to handle. The effect produced was similar to that of over-slackness due to the use of too much water. Reducing the liquid by 2 percent with formulæ containing 6 percent sugar did much to overcome these undesirable characteristics. All the high-sugar loaves had also a decidedly sweet taste of residual sugar, which had its adverse influence upon the bread score. Increasing the percentage of yeast without a corresponding increase of the food material upon which it was to act did not result in a corresponding improvement in bread quality.

That the fermentation rate became much more vigorous as the percentages of yeast and its substrate, sugar, were increased in the formula, was evidenced by the lessened time required to reach the given volume.

The more vigorous fermentation resulting from the use of more yeast and sugar was accompanied by a greater development of acidity, in spite of the shorter time of fermentation necessary for the production of enough carbon dioxide to raise the dough to the desired volume. The explanation of this fact probably lay in the continued increased speed of action after the bread was placed in the oven.

In no case, however, had the pH reading reached the value of approximately 5, which is the pH usually associated with the best bread production from a given flour. A greater increase in H-ion concentration was apparently necessary to overcome the natural buffers of the flour which a previous measurement showed to be comparatively great. This fact, coupled with the observation of a yellow crumb color associated with underfermentation, led to a repetition of the experiment using the same formula variation but extending the fermentation period by allowing the dough to double its bulk twice before being proofed.

The comparative effect of the variation in percentages of yeast and sugar in the formula was the same here as with the shorter fermentation method, namely, an increase in volume, and improvement in accompanying bread characteristics up to the limit of 4-percent yeast and 6-percent sugar.

In Table III a comparison of the three procedures given in Table II, Parts A, B, and C, is recorded. The effect upon loaf volume of increasing percentages of yeast and sugar seems to be the same regardless of the method used. With the longer fermentation period, namely, allowing the dough to double its bulk twice before pan-proofing, the sweet taste of residual sugar which lowered the scores of the shorter-time doughs was not apparent.

VARIATION OF THE TIME OF FERMENTATION

The results of a more extended study of the relation of fermentation time to bread qualtiy using again the straight-dough method, are given in Table IV. The rising period was extended from allowing no rise in the expansion cylinder to permitting the dough to expand to its maximum volume twice before pan-proofing. Maximum volume was considered to be reached when the dough receded upon a light imprint of a finger.

Shortening the fermentation period by eliminating all rising periods before proofing in the pan, resulted in bread of very low volume, thick cell walls, harsh texture, and yellow crumb characteristic of underfermentation. Extending the panary fermentation to a treble bulk increase did not result in any improvement, since the volume increase was offset by the accompanying coarse grain and crumbly nature of the bread crumb. In all cases, regardless of the pre-panary fermentation, trebling of dough bulk in the pan gave inferior bread. On the other hand, allowing but a 100-percent increase in volume in the pan produced loaves of smaller volume with a fine grain and firm texture which were lacking in desired lightness.

TABLE III.—COMPARISON OF PROCEDURES IN TABLE II, PARTS A, B, AND C.

Formula		Volume increase in expansion jar		Volume increase in pan	Volume of loaf	Texture score	H ion concentration in bread
Yeast	Sugar						
Percent	Percent	1st rising	2nd rising		cc	Percent	pH
2	3	Double		3x	1,800	75	5.35
2	3	Double		3½x	1,785	80	5.41
2	3	Double	Double	2½x	1,820	85	5.30
3	3	Double		3x	1,850	78	5.33
3	3	Double		2½x	1,795	80	5.40
3	3	Double	Double	2½x	1,895	87	5.28
3	4	Double		3x	1,870	78	5.30
3	4	Double		2½x	1,820	84	5.30
3	4	Double	Double	2½x	1,940	89	5.26
4	3	Double		3x	1,870	76	5.27
4	3	Double		2½x	1,810	83	5.32
4	3	Double	Double	2½x	1,960	89	5.24

TABLE III.—(Continued) COMPARISON OF PROCEDURES IN TABLE II, PARTS A, B, AND C

Formula		Volume increase in expansion jar		Volume increase in pan	Volume of loaf	Texture score	H-ion concentration in bread
Yeast	Sugar						
Percent	Percent	1st rising	2nd rising		cc.	Percent	pH
4	4	Double		3x	1,870	80	5.27
4	4	Double		2½x	1,820	86	5.30
4	4	Double	Double	2½x	1,970	89	5.22
4	6	Double		3x	1,900	80	5.26
4	6	Double		2½x	1,880	88	5.29
4	6	Double	Double	2½x	1,980	91	5.22
6	4	Double		3x	1,935	75	5.20
6	4	Double		2½x	1,900	84	5.28
6	4	Double	Double	2½x	2,020	90	5.20
6	6	Double		3x	1,960	70	5.23
6	6	Double		2½x	1,925	82	5.25
6	6	Double	Double	2½x	1,980	83	5.23

TABLE IV.— VARIATION IN THE NUMBER AND EXTENT OF FERMENTATION PERIODS
(Formula — 3 percent yeast, 4 percent sugar. Method — Straight dough.)

Number of rising periods	Volume increase in expansion jar			Volume increase in pan	Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	1st rising	2nd rising	3rd rising		Minutes	cc.	Percent	pH
1				2½x	80	1,620	70	5.43
1				3x	90	1,690	65	5.38
2	Double			2x	110	1,740	80	5.38
2	Double			2½x	120	1,820	84	5.36
2	Double			3x	115	1,870	76	5.30
3	Double	Double		2x	140	1,870	83	5.30
3	Double	Double		2½x	150	1,940	89	5.26
3	Double	Double		3x	155	2,000	78	5.20
2	Maximum			2x	140	1,870	85	5.31
2	Maximum			2½x	150	1,950	88	5.26
2	Maximum			3x	155	1,990	78	5.22
3	Double	Maximum		2x	205	1,790	82	5.28
3	Double	Maximum		2½x	220	1,900	86	5.21

TABLE IV—(Continued) VARIATION IN THE NUMBER AND EXTENT OF FERMENTATION PERIODS

Number of rising periods	Volume increase in expansion jar			Volume increase in pan	Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	1st rising	2nd rising	3rd rising		Minutes	cc	Percent	pH
3	Double	Maximum		3x	230	1,930	80	5.18
3	Maximum	Maximum		2x	275	1,790	76	5.20
3	Maximum	Maximum		2½x	250	1,800	82	5.16
3	Maximum	Maximum	Double	3x	260	1,850	74	5.10
4	Double	Double	Double	2x	210	1,740	76	5.24
4	Double	Double	Double	2½x	225	1,850	85	5.20
4	Double	Double		3x	240	1,850	72	5.16

Though a short fermentation period was not found to be optimum, it was also quite apparent that prolonging the fermentation to the extent of allowing the dough to expand to twice its maximum volume, or increase in volume three times, thereby increasing the fermentation time from 1½ to 4 hours, again produced bread of inferior volume and quality.

It is evident that the H-ion concentration steadily increased as fermentation time was prolonged and yet it had not been carried beyond a pH of 5 even with the longest fermentation periods. This would indicate that a factor other than attainment of a certain H-ion concentration is involved in good bread production. Repetition of this work, using both a richer and a leaner formula gave further evidence on this point.

In every case, regardless of the time of fermentation, the use of a larger proportion of yeast and sugar resulted in better bread than that produced under conditions comparable with the leaner formula.

The H-ion concentration was increased somewhat further when the richer formula was used but this increase was but slight. The advantage which was derived from the use of the high sugar and yeast formula cannot be explained on the basis of greater acidity development, since the same or lower pH values were reached by longer fermentation when leaner formulæ were used, and yet the bread volume and quality were inferior.

It may be noted that the falling off in volume which accompanied the lengthening of the fermentation time beyond that which permitted the dough to double in bulk twice before pan-proofing was less marked when the richer formula, 4 percent yeast, 6 percent sugar, was used.

Good loaf-volume is known to be dependent upon gas production as well as upon gas retention. It would seem as though the more rapid falling off in volume with prolonged fermentation when the leaner formula was used, might be due to a partial exhaustion in the last stages of the fermentation of the yeast food, sugar. In such a case, lack of sufficient carbon dioxide to effect the desired volume increase would result.

Rumsey (12) has pointed out that the sugar added at the beginning of the breadmaking process stimulates the yeast activity by supplying the food for the early fermentation, but in the last stages of the fermentation process, the yeast becomes dependent largely upon the sugars produced by diastatic activity. It would seem, therefore, that a method of handling the flour which would promote the hydrolysis of starch to maltose, *i.e.*, promote diastatic activity, would result in better æration of the dough in the proofing period, and correspondingly greater oven-spring and superior bread quality.

TABLE V — RELATION OF FORMULA AND FERMENTATION TIME TO QUALITY OF BREAD.

(A. Formula — 4 percent yeast, 6 percent sugar. Method — Straight dough)

Number of rising periods	Volume increase in expansion jar			Volume increase in pan	Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	1st rising	2nd rising	3rd rising		Minutes	cc	Percent	pH
1				2½x	75	1,690	74	5.36
2	Double			2½x	110	1,880	88	5.29
3	Double	Double		2½x	150	1,980	91	5.22
2	Maximum			2½x	155	1,985	90	5.23
3	Double	Maximum		2½x	215	1,960	90	5.13
4	Double	Double	Double	2½x	210	1,960	88	5.13
(B. Formula — 2 percent yeast, 3 percent sugar. Method — Straight dough)								
1				2½x	90	1,580	68	5.46
2	Double			2½x	135	1,785	80	5.41
3	Double	Double		2½x	195	1,820	85	5.30
2	Maximum			2½x	190	1,830	84	5.31
3	Double	Maximum		2½x	250	1,760	82	5.21
4	Double	Double	Double	2½x	240	1,760	80	5.19

Maximum activity of flour diastase is dependent upon at least three factors, temperature, H-ion concentration, and time. The optimum pH for flour diastase as determined by Rumsey and others is 4.7, a value so low as never to be reached during the fermentation of a normal straight dough. An increase in temperature from 27° to 35° C., increases the diastatic activity nearly 30 percent. Thus it is that the increased temperature of the dough at proofing, and the increased H-ion concentrations, combine to make the effect of diastase most significant during the later stages of fermentation.

Rumsey (12) has also demonstrated "that maximum activity of flour diastase in a dough at any given temperature of pH, is not reached at once because of insufficient water." It seems probable, therefore, that the sponge method of handling flour in which only a part of the flour is mixed with all of the water and yeast in a pre-fermentation period, would tend to provide the condition necessary for more rapid increase in H-ion concentration and consequently of diastatic activity and gluten ripening as well as yeast growth. Accordingly, experiments were carried out using Early Baart flour in which the sponge method was followed.

EXPERIMENTS USING THE SPONGE METHOD

EFFECT OF VARIATION OF THE SPONGE TIME UPON THE CHANGE IN H-ION CONCENTRATION

In order to determine the rapidity of increase in H-ion concentration in sponge doughs, using Early Baart flour, an experiment was carried out in which the sponge time was increased from 30 minutes (½ hour) to 720 minutes (12 hours). As stated above one-half of the flour was mixed with all of the liquid and yeast and the mixture allowed to stand at 82° F. in the fermentation cabinet for the varying periods of time. At the end of the sponge period, the pH value of a 1 to 10 suspension of the sponge was taken. After mixing in the remainder of the flour, sugar, salt, and lard, the stiff dough was allowed to double its bulk before pan-proofing. The H-ion concentration in the bread at the time of cutting and scoring was also recorded.

A gradual but pronounced increase in acidity shown by the decreasing pH readings of the sponges, accompanied the lengthening of the sponge time. A parallel increase in H-ion concentration in the resulting bread may be noted.

In Table VII are recorded more complete histories of the changes in H-ion concentration in a limited number of cases. A detailed study of the change in acidity resulting from each step in the procedure is given.

TABLE VI.—VARIATION IN ACIDITY WITH SPONGE TIME.

Formula			H-ion concentration of sponge	H-ion concentration of bread	Volume of loaf
Yeast	Sugar	Sponge			
Percent	Percent	Minutes	pH	pH	cc.
3	4	30	5.54	5.23	1,870
3	4	60	5.43	5.18	1,905
3	4	120	5.33	5.12	2,010
3	4	180	5.27	5.10	2,010
3	4	240	5.23	5.06	2,090
3	4	300	5.17	5.03	2,040
3	4	480	4.91	4.99	2,150
3	4	600	4.86	4.97	2,090
3	4	720	4.79	4.88	2,080
4	6	30	5.53	5.21	2,020
4	6	60	5.42	5.15	2,045
4	6	120	5.32	5.12	2,050
4	6	180	5.29	5.10	2,060
4	6	240	5.25	5.10	2,070
4	6	300	5.13	5.04	2,100
4	6	480	5.03	4.90	2,240
4	6	600	4.87	4.84	2,110
4	6	720	4.78	4.74	2,090

It is evident that a lower pH may result in the sponge than appears in the final bread, for upon incorporating the remainder of the raw flour with its initial acidity of pH 6.3, the pH value of the mixture takes a decided jump upward. Whether or not the final pH value is ever as low as that of the sponge depends upon the time of the sponge period and the extent of the fermentation permitted after sponging. At any rate, the high acidity produced in the sponge had probably resulted in increased rate of enzyme action in the sponge, and even though diluted upon mixing, it undoubtedly had influenced the final result.

In the stiff dough the most rapid increase in acidity occurred in the proofing period and probably in the early, baking period, stimulated by the increased temperature. Due to the loss of carbon dioxide, the 24-hour bread exhibited a lesser number of H-ions than did the bread at the time of removal from the oven.

Referring again to Table VI, the loaf volume is seen to increase with sponge time up to 8 hours. With even longer sponge times, the loaf volumes again decreased. However, they were larger than those reported for the very short sponge times. The destructive effect of prolonged proteolosis began to take effect as the darken color of the resulting bread showed. The bread product was coarse in grain, uneven and crumbly in texture, and poor in flavor.

TABLE VII.— HYDROGEN-ION CHANGES DURING BREADMAKING IN CERTAIN ISOLATED CASES.

Formula: Yeast	Formula: Sugar	Method	Volume increase in expansion jar: Risings 1st	Volume increase in expansion jar: Risings 2nd	pH after sponging	pH after mixing	pH after 1st rising	pH after 2nd rising	pH after proofing	pH of hot bread	pH of 24 minute bread
Percent	Percent										
3	4	30 min. sponge	Double	Double	5.42	5.67	5.58	5.35	5.25	5.11	5.16
3	4	60 min. sponge	Maximum		5.35	5.64	5.42		5.22	5.09	5.12
3	4	120 min. sponge	Double	Double	5.32	5.60	5.38	5.31	5.19	5.04	5.10
3	4	180 min. sponge	Maximum		5.29	5.44	5.22		5.11	5.00	5.06
3	4	240 min. sponge	Maximum		5.27	5.62	5.18			5.10	4.98
3	4	360 min. sponge	Maximum		5.31	5.50	5.19		5.00	4.98	5.06
3	4	Straight dough	Double	Maximum		5.82	4.61	5.42	5.31	5.21	5.28
4	6	60 min. sponge	Double	Double							

TABLE VIII.— VARIATION IN TIME OF SPONGING.
(A. Formula — 3 percent yeast, 4 percent sugar.)

Time sponging	Volume increase in expansion jars Risings			Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	1st	2nd	3rd				
Minutes				Minutes	cc.	Percent	pH
30				70	1,730	74	5.33
60				95	1,750	76	5.31
90				125	1,780	75	5.30
120				155	1,780	78	5.28
30	Double			140	1,870	87	5.23
60	Double			160	1,905	89	5.18
90	Double			185	1,960	90	5.14
120	Double			220	2,010	92	5.12
30	Double	Double		180	1,960	91	5.16
60	Double	Double		215	2,005	94	5.12
90	Double	Double		235	2,010	96	5.11
120	Double	Double		275	2,040	97	5.10
30	Maximum			190	1,970	90	5.13
60	Maximum			215	2,000	93	5.10
90	Maximum			240	2,020	94	5.09
120	Maximum			275	2,050	95	5.08
30	Double	Maximum		225	1,885	85	5.09
60	Double	Maximum		255	1,930	86	5.06
90	Double	Maximum		285	1,920	86	5.05
120	Double	Maximum		315	1,960	84	5.04
30	Double	Double	Double	220	1,860	84	5.10
60	Double	Double	Double	260	1,900	86	5.04
90	Double	Double	Double	290	1,900	86	5.04
120	Double	Double	Double	325	1,920	88	5.02

Table VIII.—(Continued.) (B. Formula — 3 percent yeast, 3 percent sugar.)

Time sponging	Volume increase in expansion jars — Risings			Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Minutes	1st	2nd	3rd	Minutes	cc.	Percent	pH
30				75	1,700	70	5.36
60				95	1,710	71	5.34
90				130	1,710	71	5.33
120				160	1,740	73	5.30
30	Double			155	1,800	83	5.25
60	Double			180	1,830	85	5.22
90	Double			205	1,845	86	5.20
120	Double			265	1,860	88	5.19
30	Maximum			220	1,850	86	5.21
60	Maximum			240	1,860	86	5.16
90	Maximum			275	1,870	87	5.15
120	Maximum			300	1,895	88	5.13
30	Double	Double		200	1,840	87	5.19
60	Double	Double		225	1,850	89	5.17
90	Double	Double		275	1,860	89	5.15
120	Double	Double		300	1,890	91	5.14
30	Double	Maximum		275	1,800	85	5.12
60	Double	Maximum		305	1,825	86	5.10
90	Double	Maximum		340	1,830	85	5.09
120	Double	Maximum		360	1,845	82	5.06
30	Double	Double	Double	275	1,780	85	5.11
60	Double	Double	Double	300	1,800	83	5.09
90	Double	Double	Double	340	1,830	84	5.08
120	Double	Double	Double	350	1,825	85	5.06

Table VIII.—(Continued) (C. Formula — 4 percent yeast, 6 percent sugar.)

Time sponging	Volume increase in expansion jars: Risings			Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Minutes	1st	2nd	3rd	Minutes	cc.	Percent	pH
30	Double			135	2,020	91	5.21
60	Double			165	2,045	93	5.15
90	Double			190	2,050	93	5.14
120	Double			215	2,070	94	5.12
30	Double	Double		165	2,030	93	5.15
60	Double	Double		210	2,080	95	5.08
90	Double	Double		240	2,080	96	5.06
120	Double	Double		290	2,110	98	5.04
30	Maximum			185	2,070	92	5.12
60	Maximum			200	2,080	94	5.08
90	Maximum			245	2,080	94	5.05
120	Maximum			270	2,155	97	5.04
30	Double	Maximum		225	1,970	91	5.07
60	Double	Maximum		245	2,050	93	5.06
90	Double	Maximum		280	2,040	92	5.04
120	Double	Maximum		315	2,070	92	4.99
30	Double	Double	Double	210	1,970	90	5.05
60	Double	Double	Double	250	2,000	92	5.03
90	Double	Double	Double	290	2,030	92	5.03
120	Double	Double	Double	310	2,065	93	5.00

An objection to prolonged fermentation other than the effect upon crumb-color and other bread characteristics, is the greater loss of dry material which means a reduction in yield of loaves of bread per barrel of flour.

VARIATION IN THE SPONGE TIME UPON QUALITY OF BREAD

To study the effect upon bread quality of varying the sponge time within narrower limits, thereby lessening the possibility of the proteoclastic enzymes having a disastrous effect, as well as minimizing the loss of dry material, the preliminary sponge time was varied from 30 to 120 minutes.

Regardless of the formula or method of procedure following the sponge period, the increase in volume and improvement in accompanying bread quality with increasing sponge time from ½ to 2 hours was quite evident.

VARIATION OF THE EXTENT OF FERMENTATION

Data obtained upon the effect of varying the extent of fermentation after sponge periods of different lengths appear in Table IX.

As the number or length of fermentation periods increased, the pH values of the bread steadily but slowly dropped. The bread volume and texture scores, however, reached their maximum value when the dough had been allowed to double its bulk twice. Further fermentation, in spite of the accumulation of H-ions, caused the loaf to have less oven-spring and a correspondingly smaller volume. This was less apparent with the longer sponge period and the higher sugar formula.

Regarding fermentation time, loaf-volume, or pH value of bread, it may be noted that but little difference occurred between a dough-volume expansion of double bulk twice and maximum bulk once. The same may be said of allowing the dough to expand to double its volume, followed by a maximum expansion and permitting three successive expansions of double-the-dough volume. One maximum expansion period had a slight advantage in volume of loaf over the twice doubling in bulk, but a somewhat coarser grain lowered the texture score. Frequent removal of a portion of the enclosed gas by pounding the dough, resulted in a more even distribution of the gas pockets. In the case of allowing the dough to double its volume three successive times, there appeared to be a reduction in volume as a result of the third pounding. This may have been due to a mechanical effect upon the finely divided gluten strands.

VARIATION OF THE PERCENTAGES OF YEAST AND SUGAR

Data of a detailed formula variation of the same order as that carried out in a previously described experiment using the straight-dough method appear in Table X. The optimum sponge method of allowing the dough to double its bulk twice after a preliminary 2-hour sponge period was selected as a basis for this study of formula variation.

TABLE IX.—VARIATION IN EXTENT OF FERMENTATION.

I. After 30-minute Sponge Period. (A. Formula — 3 percent yeast, 4 percent sugar.)

Time of sponging	Volume increase in expansion jar: Risings 1st	2nd	3rd	Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Minutes				Minutes	cc.	Percent	pH
30	Double			140	1,870	87	5.23
30	Double	Maximum		180	1,960	91	5.16
30	Maximum			190	1,970	90	5.13
30	Double	Maximum		250	1,930	86	5.06
30	Double	Double	Double	260	1,860	84	5.04
(B. Formula — 4 percent yeast, 6 percent sugar.)							
30	Double			135	2,020	91	5.21
30	Double	Double		165	2,030	93	5.15
30	Maximum			185	2,070	92	5.12
30	Double	Maximum		225	1,970	91	5.07
30	Double	Double	Double	210	1,970	90	5.05
II. After 60-minute Sponge Period. (A. Formula — 3 percent yeast, 4 percent sugar.)							
60	Double			160	1,905	89	5.18
60	Double	Double		215	2,005	94	5.12
60	Maximum			215	2,000	93	5.10
60	Double	Maximum		255	1,930	88	5.06
60	Double	Double	Double	260	1,900	86	5.04

Table IX.—(Continued.) (B. Formula — 3 percent yeast, 4 percent sugar.)

Time of sponging	Volume increase in expansion jar			Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	Risings						
Minutes	1st	2nd	3rd	Minutes	cc.	Percent	pH
60	Double			135	2,045	93	5.15
60	Double	Double		210	2,080	95	5.08
60	Maximum			200	2,080	94	5.08
60	Double	Maximum		245	2,050	93	5.06
60	Double	Double	Double	255	2,000	92	5.03
III. After 120-minute Sponge Period. (A. Formula — 3 percent yeast, 4 percent sugar.)							
120	Double			220	2,010	92	5.12
120	Double	Double		275	2,040	96	5.10
120	Maximum			275	2,050	95	5.08
120	Double	Maximum		315	1,960	88	5.04
120	Double	Double	Double	325	1,920	88	5.02
(B. Formula — 3 percent yyeast, 4 percent sugar.)							
120	Double			215	2,050	94	5.12
120	Double	Double		290	2,095	98	5.04
120	Maximum			270	2,155	96	5.04
120	Double	Maximum		315	2,070	92	4.99
120	Double	Double	Double	310	2,065	90	5.00

TABLE X.—VARIATION IN PERCENTAGES OF YEAST AND SUGAR IN THE FORMULA.

(Method: 120-minute sponge dough allowed to double bulk twice before proofing.)

Formula		Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Yeast Percent	Sugar Percent	Minutes	cc.	Percent	pH
2	3	300	1,870	90	5.13
3	3	260	1,960	92	5.11
3	4	275	2,010	96	5.10
4	3	260	2,045	95	5.09
4	4	255	2,050	97	5.07
4	6	290	2,095	98	5.02
6	4	255	2,080	96	5.00
6	6	230	2,120	92	4.98

Inspection of the foregoing tabulation shows again an increase in volume paralleling increased percentages of yeast and sugar. Here, also, increases in yeast without a corresponding addition of sugar did not result in material improvement. The large volume of the 6-percent yeast and 6-percent sugar loaves was again obtained at a sacrifice of grain and texture.

The result of formula variation under different conditions of sponge time and number and length of fermentation periods after sponging appear in Table XI.

It is quite evident that differences in bread quality resulting from formula variations are far more striking than differences resulting from a variation of sponge time or of the extent of the subsequent rising period. Regardless of the time of sponging, the higher yeast and sugar formula resulted in the best bread production. The same may be said of the extent of fermentation permitted after the preliminary sponge period. Regardless of differences of method of this kind, the 4-percent yeast and 6-percent sugar formula produced superior bread.

Assembling the data of the previously described experimental work serves to bring out more clearly a comparison of the straight-dough and sponge methods of procedure for handling Early Baart flour.

COMPARISON OF STRAIGHT-DOUGH AND SPONGE METHODS

That the sponge method is superior to the straight-dough method for Early Baart flour was strikingly evident. Not only were larger loaves of bread obtained from the same amount of material, but the loaves were better piled as well, the sponge-process bread being notably softer and silkier in texture, finer and more even in grain, than was the harsher, thicker cell-walled, straight-dough product. Thus, in every case in which the extent of rising in the expansion jar and the formula were similar, the sponge bread was superior.

TABLE XI.—VARIATION OF PERCENTAGES OF YEAST AND SUGAR IN THE FORMULA.

(A. Using 30-minute Sponge Method.)

Formula: Yeast	Formula: Sugar	Volume increase in expansion jar: Risings: 1st	2nd	3rd	Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
Percent	Percent				Minutes	cc	Percent	pH
2	3	Double			155	1,800	83	5.25
3	4	Double			140	1,870	87	5.18
4	6	Double			135	2,020	91	5.21
2	3	Double	Double		200	1,840	87	5.19
3	4	Double	Double		180	1,960	91	5.16
4	6	Double	Double		165	2,030	93	5.15
2	3	Maximum			220	1,850	86	5.21
3	4	Maximum			190	1,970	90	5.13
4	6	Maximum			185	2,070	92	5.12
2	3	Double	Maximum		275	1,800	85	5.12
3	4	Double	Maximum		250	1,930	88	5.06
4	6	Double	Maximum		225	1,970	91	5.07
2	3	Double	Double	Double	275	1,780	83	5.11
3	4	Double	Double	Double	220	1,860	84	5.10
4	6	Double	Double	Double	210	1,970	90	5.05

(B. Using 60-minute Sponge Method.)

Formula: Yeast	Formula: Sugar	Volume increase in expansion jar: Risings: 1st	2nd	3rd	Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
2	3	Double			180	1,800	85	5.22
3	4	Double			160	1,905	89	5.18
4	6	Double			135	2,030	91	5.21
2	3	Double	Double		235	1,825	89	5.17
3	4	Double	Double		215	2,005	94	5.12
4	6	Double	Double		210	2,080	95	5.08

TABLE XI—(Continued) VARIATION OF PERCENTAGES OF YEAST AND SUGAR IN THE FORMULA

2	3	Maximum			240	1,860	90	5.16
3	4	Maximum			215	2,000	93	5.10
4	6	Maximum			200	2,080	94	5.05
2	3	Double	Maximum		305	1,825	86	5.10
3	4	Double	Maximum		255	1,930	88	5.06
4	6	Double	Maximum		245	2,050	93	5.06
2	3	Double	Double	Double	300	1,800	83	5.09
3	4	Double	Double	Double	260	1,900	86	5.04
4	6	Double	Double	Double	255	2,000	92	5.03
(C Using 120-minute Sponge Method.)								
2	3	Double			265	1,860	88	5.19
3	4	Double			220	2,010	92	5.12
4	6	Double			215	2,050	94	5.12
2	3	Double	Double		300	1,890	91	5.14
3	4	Double	Double		275	2,040	96	5.10
4	6	Double	Double		290	2,095	98	5.04
2	3	Maximum			300	1,895	88	5.13
3	4	Maximum			275	2,050	95	5.08
4	6	Maximum			270	2,155	96	5.04
2	3	Double	Maximum		360	1,845	82	5.06
3	4	Double	Maximum		315	1,960	88	5.04
4	6	Double	Maximum		315	2,070	92	4.99
2	3	Double	Double	Double	350	1,825	85	5.06
3	4	Double	Double	Double	325	1,920	88	5.02
4	6	Double	Double	Double	310	2,005	93	5.00

TABLE XII.—SUMMARY OF THE COMPARISON OF STRAIGHT DOUGH AND SPONGE METHODS.

(A. Formula — 2 percent yeast, 3 percent sugar.)

Method	Volume increase in expansion jar			Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	Risings						
	1st	2nd	3rd	Minutes	cc.	Percent	pH
Straight-dough	Double			135	1,785	80	5.41
30-minute sponge	Double			150	1,800	83	5.25
60-minute sponge	Double			180	1,830	85	5.22
120-minute sponge	Double			265	1,860	88	5.19
Straight-dough	Double	Double		195	1,820	85	5.30
30-minute sponge	Double	Double		200	1,840	87	5.19
60-minute sponge	Double	Double		235	1,850	89	5.17
120-minute sponge	Double	Double		300	1,890	91	5.14
Straight-dough	Double	Double	Double	240	1,740	80	5.19
30-minute sponge	Double	Double	Double	275	1,780	85	5.12
60-minute sponge	Double	Double	Double	300	1,800	83	5.10
120-minute sponge	Double	Double	Double	350	1,825	85	5.06
(B. Formula — 3 percent yeast, 4 percent sugar.)							
Straight-dough	Double			120	1,820	84	5.36
30-minute sponge	Double			140	1,870	87	5.23
60-minute sponge	Double			160	1,905	89	5.18
120-minute sponge	Double			220	2,010	92	5.12
Straight-dough	Double	Double		150	1,940	89	5.26
30-minute sponge	Double	Double		180	1,960	91	5.16
60-minute sponge	Double	Double		215	2,005	94	5.12
120-minute sponge	Double	Double		275	2,040	97	5.10

TABLE XII.—(Continued) SUMMARY OF THE COMPARISON OF STRAIGHT DOUGH AND SPONGE METHODS

Method	Volume increase in expansion jar			Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	Risings						
	1st	2nd	3rd	Minutes	cc	Percent	pH
Straight-dough	Double	Double	Double	225	1,820	84	5.20
30-minute sponge	Double	Double	Double	220	1,860	86	5.09
60-minute sponge	Double	Double	Double	260	1,900	86	5.06
120-minute sponge	Double	Double	Double	325	1,920	88	5.04
(C. Formula — 4 percent yeast, 6 percent sugar)							
Straight-dough	Double			110	1,880	88	5.29
30-minute sponge	Double			135	2,020	91	5.21
60-minute sponge	Double			165	2,045	93	5.15
120-minute sponge	Double			215	2,070	94	5.12
Straight-dough	Double	Double		150	1,980	91	5.22
30-minute sponge	Double	Double		165	2,030	93	5.15
60-minute sponge	Double	Double		210	2,080	95	5.08
120-minute sponge	Double	Double		290	2,190	98	5.04
Straight-dough	Double	Double	Double	210	1,960	88	5.13
30-minute sponge	Double	Double	Double	210	1,970	90	5.07
60-minute sponge	Double	Double	Double	255	2,000	92	5.06
120-minute sponge	Double	Double	Double	310	2,065	93	4.91

TABLE XIII.—EFFECT OF SPONGING IN THE PRESENCE OF ADDED SUGAR

Formula		Time of addition of sugar	Time of sponging	Volume increase in expansion jar		Total fermentation time	Volume of loaf	H-ion concentration of sponge	H-ion concentration of bread
Yeast	Sugar			Risings					
Percent	Percent		Minutes	1st	2nd	Minutes	cc.	Percent	Percent
3	4	After sponging	60	Double	Double	215	2,005	5.40	5.18
3	4	Before sponging	60	Double	Double	205	1,950	5.43	5.18
3	4	After sponging	120	Double	Double	275	2,040	5.40	5.10
3	4	Before sponging	120	Double	Double	325	1,690	5.17	5.09
4	6	After sponging	60	Double	Double	210	2,080	5.34	5.08
4	6	Before sponging	60	Double	Double	185	2,020	5.38	5.09
4	6	After sponging	120	Double	Double	290	2,110	5.31	5.04
4	6	Before sponging	120	Double	Double	290	1,810	5.16	5.03

A glance at the comparative pH values bears out the theory that the slack nature of the sponge was conducive to more rapid acid development, since lower pH values and, therefore, higher concentration of H-ions were encountered in the sponge doughs. The supposed gluten-ripening effect of the H-ions is not clearly understood.

That the expansive power of Early Baart flour dough was increased as the ripening process proceeded was evident from an experiment in which the dough was allowed to expand to its maximum volume twice. The second volume of maximum expansion was greater by 300 cc. than was the first. By allowing doughs to reach their maximum volume after sponge periods varying in length from 30 to 480 minutes, an increased attenuation of the gluten strands, probably resulting from acids produced in the fermentation was evidenced by the increasing volume of maximum expansion obtained after sponging.

The neutral point of gluten protein which corresponds to the isoelectric point of a pure substance is in the neighborhood of a pH of 6. Increase in acidity during fermentation would, therefore, carry the gluten farther away from its isoelectric point, which would result in greater solubility and dispersion of the gluten-protein particles. The network of gluten strands would become more attenuated and, therefore, less tough and resistant to distension by the expanding gas. This may possibly explain the apparent greater expansive power of the dough as fermentation progressed and account for the better oven-spring obtained. Thinner cell walls would follow the greater degree of gluten dispersion and an improved bread-crumb texture would be obtained.

Without question, however, there is a factor involved in good bread production from Early Baart flour other than the reaching of an optimum concentration of H-ions for "gluten ripening." Attempts to correlate increases in acidity with loaf-volume show this fact very plainly. The differences resulting from a formula variation throw light on this subject. Without the presence of fermentable material or in the absence of a sufficient supply, gas production cannot proceed at an optimum rate or extent.

That the sponge process results in greater diastatic activity with the resulting production of sugar available as a yeast food may be noted by the fact that with the longer sponge time the falling-off in volume with prolonged time of fermentation is less pronounced than with the shorter sponge time or straight dough. The sugar formed in this way partially compensated for the exhaustion of the added sugar before the last stages of a long fermentation were reached. Additional evidence upon this point was obtained by studying the effect of adding the sugar to the flour before sponging. In this procedure, the best sponge methods, namely, the 60- and 120-minute sponge times followed by a twice doubling of bulk in the expansion cylinder, were selected. Both a 3-percent yeast-4-percent sugar and the richer 4-percent yeast-6-percent sugar formulæ were used. The pH measurements of the sponges were taken as well as the final pH measurements of the 24-hour bread.

The presence of sugar during the sponging process resulted in a marked reduction in volume of loaf. The bread was also inferior in color of crumb, grain, and especially in flavor. The crust was pale and uneven in appearance and the loaves were flat-topped and lacked oven-spring. The results were somewhat less disastrous with the shorter time (60 minute) sponges.

Without sugar in the sponge, the change in pH which follows an increase in sponge time from 60 to 120 minutes is small, whereas the presence of sugar in the sponge seems to effect a marked increase in acidity with extension of sponge time. This difference is not as noticeable in the final bread for the effect is partially erased as a result of incorporation of the raw flour. In the fermentation period following the sponge time, the H-ion change is slower in the former and proceeds at a more rapid rate upon the addition of sugar in the latter case.

Probably the effect of adding the sugar before sponging was to promote a most vigorous yeast activity. The dough was rather quickly saturated with carbon dioxide, the slack condition of the sponge lessening CO_2 retention and the excess gas escaped. The added sugar is, therefore, rather quickly used up, and insufficient residual sugar resulted in diminished rate of CO_2 production in the last steps of the fermentation process. As might be expected, the effect was less pronounced when either the shorter fermentation period or richer formula was used.

Thus it may be that the obvious advantage of the sponge process over the straight-dough method lies in this more rapid increase in H-ion concentration in the sponge which results in a more rapid maturing of the gluten and at the same time approaches a more nearly optimum medium for diastatic activity which is accordingly stimulated. This results in the production of larger amounts of maltose which become available in the last stages of the fermentation process.

FURTHER EXPERIMENTS

COMPARISON OF THE USE OF TAP WATER AND DISTILLED WATER

Distilled water was used in all of the previous experimental work so as to eliminate a possible variable in the experimental procedure and make possible the duplication of results in different localities. For practical purposes, tap water of course must be resorted to. Table XIV gives the data resulting from a substitution of tap water for the previously used distilled water. The tap water used was obtained from the local supply of the University of Arizona with the following reported analysis:

Analysis of University of Arizona Tap Water

Calcium	7.5	parts per million
Magnesium	11.25	parts per million
Sodium	92.0	parts per million
Chlorine	14.0	parts per million
Carbonates	None	parts per million
Sulphate	95.0	parts per million
Bicarbonates	176.0	parts per million
Total soluble salts	395.75	parts per million

A pH value of 7.92 shows the tap water to be on the alkaline side of neutrality.

The best formulæ and methods were selected as bases for the comparison, the value of the water being the only variable.

A smaller loaf-volume was consistently obtained with the use of tap water. It may also be noted that the pH values of the bread showed a definite difference, the tap-water bread always possessing the lower acidity. Herein, no doubt, lies the cause of the observed differences in volumes, for as has already been pointed out within limits, higher acidity results in greater expansive power of the gluten as well as in heightened diastatic activity.

THE USE OF FLOUR IMPROVERS

The use of flour-improving agents is becoming general. Some are acids or acid salts which increase the initial H-ion concentration of the dough, thus enabling it to maintain a higher acdity level throughout than would otherwise be possible. Others are mineral salts which act as yeast foods, thereby stimulating yeast activity.

A few experiments in which lactic acid was added to Early Baart flour showed a resulting improvement in bread volume. Again, however, with the longer fermentation, lack of residual sugar was a limiting factor. It seemed also as though the addition of acid in this manner was less effective than were the acids produced in the usual course of fermentation.

A more extended study was made of the use of a mixture of the mineral salts, ammonium chloride, and calcium sulphate with small amounts of potassium bromate, sold commercially under the name of Arkady. The effect of its use upon the bread quality is recorded in Table XV.

Not only were larger volumes obtained when Arkady was used, but the resulting bread was also of finer texture and color, thereby possessing a higher texture score. The oven-spring was greater and the shredded appearance of the bread gave evidence of an improvement in gluten strength.

TABLE XIV.— COMPARISON OF EFFECT OF USE OF TAP AND DISTILLED WATER UPON BREAD QUALITY.

Kind of water	Formula		Time of sponging	Volume increase in expansion jar		Volume of loaf	Texture score	H-ion concentration in bread
	Yeast	Sugar		Risings				
				1st	2nd			
	Percent	Percent	Minutes			cc.	Percent	pH
Tap	3	4	60	Double	Double	1,950	87	5.22
Distilled	3	4	60	Double	Double	2,005	89	5.18
Tap	4	6	60	Double	Double	1,990	93	5.11
Distilled	4	6	60	Double	Double	2,080	95	5.08
Tap	3	4	120	Double	Double	1,970	96	5.15
Distilled	3	4	120	Double	Double	2,040	97	5.10
Tap	4	6	120	Double	Double	2,030	96	5.08
Distilled	4	6	120	Double	Double	2,110	98	5.04

TABLE XV.— EFFECT OF ADDITION OF ARKADY UPON BREAD QUALITY.

Formula: Yeast	Formula: Sugar	Method	Volume increase in expansion jar: Risings 1st	Volume increase in expansion jar: Risings 2nd	Volume of loaf: With Arkady	Volume of loaf: Without Arkady	Texture score: With Arkady	Texture score: Without Arkady
Percent	Percent				cc.	cc.	Percent	Percent
3	4	Straight-dough	Double		1,960	1,825	88	84
3	4	Straight-dough	Double	Double	2,010	1,940	95	89
3	4	Straight-dough	Double	Maximum	1,960	1,820	86	84
3	4	30-minute sponge			2,050	1,740	76	74
3	4	30-minute sponge	Double			1,870	93	87
3	4	30-minute sponge	Double	Double	2,020	1,960	89	91
3	4	30-minute sponge	Double	Maximum	1,760	1,860	78	86
3	4	60-minute sponge				1,788	78	76
3	4	60-minute sponge	Double		2,000	1,985	91	89
3	4	60-minute sponge	Double	Double	1,980	2,005	87	94
3	4	60-minute sponge	Double	Maximum	1,870	1,900	80	86
3	4	120-minute sponge				1,840	80	78
3	4	120-minute sponge	Double		1,970	2,110	82	92
3	4	120-minute sponge	Double	Double	1,920	2,040	75	97
3	4	120-minute sponge	Double	Maximum	1,750	1,920	70	88
4	6	Straight-dough	Double		2,010	1,880	95	88
4	6	Straight-dough	Double	Double	2,040	1,980	96	91
4	6	Straight-dough	Double	Maximum	2,070	1,960	97	88

TABLE XVI.—EFFECT OF ADDITION OF ARKADY UPON BREAD ACIDITY

Formula		Method	Volume increase in expansion jar		H-ion concentration in sponge		H-ion concentration in bread	
Yeast	Sugar		Risings		With Arkady	Without Arkady	With Arkady	Without Arkady
Percent	Percent		1st	2nd	pH	pH	pH	pH
3	4	Straight-dough	Double				5.17	5.36
3	4	30-minute sponge	Double		5.38	5.54	4.93	5.23
3	4	60-minute sponge	Double		5.15	5.43	4.91	5.28
3	4	120-minute sponge	Double		5.14	5.33	4.86	5.12
3	4	Straight-dough	Double	Double			5.10	5.26
3	4	30-minute sponge	Double	Double	5.38	5.54	4.85	5.16
3	4	60-minute sponge	Double	Double	5.35	5.43	4.78	5.12
3	4	120-minute sponge	Double	Double	5.14	5.33	4.74	5.10
3	4	180-minute sponge	Double	Double	5.13	5.27	4.74	5.06
3	4	240-minute sponge	Double	Double	5.07	5.23	4.82	5.03
3	4	Straight-dough	Double	Maximum			4.95	5.21
3	4	30-minute sponge	Double	Maximum	5.38	5.54	4.80	5.09
3	4	60-minute sponge	Double	Maximum	5.35	5.43	4.70	5.06
3	4	120-minute sponge	Double	Maximum	5.14	5.33	4.72	5.04

These advantages in the use of Arkady, however, only hold true in shorter fermentation doughs. It is evident from the data presented in Table XV that the presence of Arkady with the longer sponge periods had a deleterious effect, for the resulting loaf was smaller in volume, darker in color, and possessed the "characteristics of age."

The effect of the use of Arkady upon the rapidity of acid development may be seen by inspection of Table XVI.

The initial acidity of the dough was not increased but a more rapid development of acidity followed which had a beneficial effect upon the colloidal behavior of gluten as well as diastatic activity. Accordingly, the gluten-aging process proceeded more rapidly in the presence of Arkady and the optimum fermentation time was thereby lessened. Undoubtedly an intelligent use of Arkady has a great advantage, however, the fermentation period must be carefully controlled or "old" bread will result. The range of good bread production is materially decreased and the danger of extending the fermentation period too far is great.

THE EFFECT OF HIGH-SPEED MIXING

Recent work of Swanson (34) has shown that "it is so possible to modify dough by mechanical means that light bread can be baked using only the fermentation in the pan." By means of a high-speed mixer with the "pack-squeeze-pull-tear" type of motion, the gluten strands have been separated, elongated, and have lost some of the toughness with an increase in the elastic limit. This work suggested that such a mechanical development might be used successfully with Early Baart flour to assist the maturing action of the increasing H-ions resulting from yeast fermentation. The fermentation time might then be definitely reduced as the dough would bcome more easily expanded and, therefore, reach the desired volume more quickly. With the use of Arkady to further the increase in acidity with its beneficial effect on both the colloidal behavior of gluten and upon diastatic activity, it would seem as though the marked advantage which the sponge method possesses over the straight dough, might be offset.

By increasing the speed of mixing from 46 to 152 revolutions per minute, using a mixing paddle with a movement more nearly like that described by Swanson (34) than was obtained by the dough hook used in the foregoing experiment, the effect of mechanical action upon the gluten of Early Baart flour was investigated. Arkady used as a yeast food was added to the two basic formulæ represented in Table XVII.

The dough was mixed for 2 minutes at the lower speed to prevent the flour from being thrown out of the mixer. When the dough ball was formed, the speed of the mixer was increased for 8 minutes. When the dough came from the mixer it was like cake batter in appearance, very sticky and stringy and difficult to handle. After having doubled its bulk, however, it had lost all of its initial stickiness and was stiffer than the dough which had been mixed at low speed. The use of a higher proportion of water was then indicated and by experiment it was found that increasing the absorption by 2 percent when the dough was mixed at high speed gave results comparable to those resulting from the use of low-speed mixing.

Inspection of Table XVII gives proof of the advantages resulting from high-speed mixing. The volume of the bread was somewhat greater, the texture was silkier, the crumb was whiter. The resulting bread compared favorably with the best sponge bread, as had been expected. The time required to reach the desired volumes in the expansion jar and in the pan was materially less. A reduction of time is a matter of commercial importance both from the standpoint of labor charge and through saving of dough material. The latter fact coupled with the higher absorption that can be used with high-speed mixing means a greater yield in 1-pound loaves per barrel.

The pH values accompanying low-speed mixing, however, seemed to be lower, so much lower as to be hard to explain on the basis of the 5-minute longer fermentation time. It may be that the time of mixing at the high rate of speed was prolonged to such an extent that the severe mechanical action injured some of the delicate yeast plants. That this might be the case was suggested in a preliminary experiment in which a mixing-time of 10 minutes at high speed resulted disastrously, the dough doubling its bulk only after a 2-hour fermentation period. The fact that the gluten strands had become less resistant to the expanding gas may have resulted in the volumes obtained here even with lessened yeast activity. Prolonged mechanical action as well as too great a dispersion of the gluten-protein by H-ions would both carry the attenuation process too far and result disastrously. This experiment might have given even more pronounced results if the time of the high-speed mixing was reduced.

COMMERCIAL BAKING WITH EARLY BAART FLOUR

As the treatment afforded a bread dough in an experimental baking laboratory is of necessity different from that in commercial bakeries, the question of applicability of the results obtained under laboratory conditions with Early Baart flour to commercial practices was still unsolved. Accordingly, baking of the Early Baart flour on a large scale under the commercial conditions of a local bakery was tried.

TABLE XVII.—EFFECT OF MIXING AT HIGH SPEED UPON BREAD QUALITY

Speed of mixing	Formula		Volume increase in expansion jar		Total fermentation time	Volume of loaf	Texture score	H-ion concentration in bread
	Yeast	Sugar	Risings					
			1st	2nd				
	Percent	Percent			Minutes	cc.	Percent	pH
Low	3	4	Double		130	1,960	88	5.17
High	3	4	Double		120	1,980	90	5.19
Low	3	4	Double	Double	170	2,010	95	5.10
High	3	4	Double	Double	160	2,020	96	5.10
Low	3	4	Double	Maximum	205	1,960	86	4.95
High	3	4	Double	Maximum	200	1,980	85	4.82
Low	4	6	Double		125	2,010	95	5.17
High	4	6	Double		120	2,080	96	5.18
Low	4	6	Double	Double	160	2,040	96	4.96
High	4	6	Double	Double	155	2,100	98	4.97
Low	4	6	Double	Maximum	200	2,070	96	4.92
High	4	6	Double	Maximum	195	2,080	97	4.85

In the first trial, the 2-hour sponge method with 4 percent yeast and 6 percent sugar in the formula was followed, the stiff dough being allowed to double its bulk twice before the proofing period. In the second trial the straight-dough method which is perhaps better suited to commercial practice was used. Arkady was used to hasten the development, the formula and method of procedure being otherwise identical with the foregoing. Both lots of dough were subjected to the usual commercial machinery. mixing machine, divider, and similar equipment, and were handled in the usual manner.

Loaves of excellent quality were obtained with a bread-yield of 2?? 1-pound loaves per barrel of flour. The success of the experiment assured the practicability of Early Baart flour for breadmaking under commercial conditions. The mixer used was a low-speed mixer of the old type and it is to be expected that the results with high-speed mixing will prove even more satisfactory, both from the standpoint of bread-quality and bread-yield.

SUMMARY AND CONCLUSIONS

For the purpose of gaining information as to the inherent baking-strength of flour milled from Arizona Early Baart wheat, a group of physical and chemical tests, each measuring a different factor, was made.

A moisture content of 9.85 percent, as determined by the official method, gave the basis for the calculation of the other constituents upon a moisture basis of 15 percent, which is the moisture content of flour permitted by the United States Pure Foods and Drugs Act.

The ash content, again determined by the official method, was found to be high for a soft-wheat flour of the same milling grade.

A total crude protein content of 9.84 percent obtained by the Gunning-Arnold-Dyer modification of the Kjeldahl method using the conversion factor of 5.7 for wheat protein, places Early Baart in the better class of soft wheats, or perhaps as a semi-hard wheat.

Upon separation of the crude gluten using Dill and Alsberg's .1 percent sodium-phosphate solution to wash out the starch, a creamy colored, elastic, soft, but not sticky, gluten was obtained which was somewhat lacking in desired toughness.

The ratio of the wet gluten to the material dried to constant weight in a Freas electric oven, evidenced a relatively high hydration capacity.

Separation of the protein, *i.e.*, glutenin, gliadin, and salt-soluble protein by the methods of Bailey, and Sharp and Gordner indicated a resulting gliadin-glutenin ratio of 0.402, a ratio which is probably lacking in special significance.

A quantitative determination of the reducing sugars present in Early Baart flour and its diastatic activity by the method of Rumsey, with a subsequent determination of the reducing sugars by the method of Quisumbing and Thomas, giving a value of 180 mg. of maltose per 10 grams of flour, indicated the presence of but a fair amount of the diastatic ferment.

Eight and one-half cc. of N/50 HCl being required to lower the pH of 100 cc. of a 1 to 10 suspension of the flour measured electrometrically by means of a Leeds and Northrup potentiometer from pH 6.07 to a pH of 5 indicated a relatively high buffer value for Early Baart wheat flour, and predicted the necessity of a longer fermentation period before realization of optimum acidity conditions.

With the indications from chemical and physical tests that Early Baart flour could be satisfactorily used for breadmaking, baking experiments were carried out with the idea of finding a formula and method of procedure best suited to the handling of this flour in breadmaking. Use was made of well-standardized equipment and each procedure was carefully controlled. As a guide to correct fermentation period, the pH value of the bread was taken and in some cases the changes in H-ion concentration were followed throughout the whole process.

In a study of the straight-dough method, the number and extent of fermentation periods were varied. A short fermentation of one rising period before proofing in the pan frequently recommended for soft wheat, gave results markedly inferior to a longer fermentation period, for apparently optimum acidity conditions are not reached in this rather highly buffered flour in a short fermentation period. On the other hand, a still longer fermentation period resulted in reduced loaf volume even though it was apparent that the increase in H-ion concentration had not been carried beyond the optimum point.

Variation of the yeast and sugar in the formula within rather wide limits resulted in an increase in volume and improvement of bread quality with increase in yeast and sugar up to 4 percent yeast and 6 percent sugar. Further increases were accompanied by larger loaf volumes with lower texture scores.

A study of the relation of formula to fermentation time showing a less decrease in loaf-volume with prolongation of fermentation time when the higher sugar formula was used suggested that the accounting factor was a lack of sufficient gas production in the last stages of the fermentation period.

The sponge method of procedure was found to give bread superior to that produced by the straight-dough method in which the same formula was used. The quality of the bread produced improved with the time of the preliminary sponge period up to 120 minutes. Hydrogen-ion determinations showed a more rapid increase in acidity in the sponge dough which would result in more rapid gluten ripening and diastatic activity. The silkier, softer texture, and whiter color of crumb of the sponge bread and its larger volume may be due to the greater attenuation of the tough gluten strands which followed the greater dispersion of the colloidal gluten resulting from an increase in number of H-ions which carried the gluten further away from its isoelectric point. The thinner cell walls in the bread network were more easily distended by the CO_2 gas which was liberated by the action of yeast upon the added sugar as well as upon that formed in the dough by the accelerated diastatic activity.

Variation in the time of sponging, length of the fermentation periods after the preliminary sponge periods, and in the formula, were carried out, and the conclusion was reached that a 2-hour sponge period, followed by allowing the dough to double its bulk twice in the expansion cylinder resulted in an excellent bread from Early Baart flour. A vigorous fermentation resulting from the use of a formula containing 4 percent yeast and 6 percent sugar gave the best results, though a leaner formula produced bread of fine quality.

Adding the sugar to the flour before sponging was found to give loaves of poor volume, color, texture, and flavor, probably due to the exhaustion of the yeast food before the last stages of the fermentation process.

Tap water obtained from the University of Arizona well with its pH value of 7.9 resisted the increase in H-ion concentration and produced somewhat inferior bread than that in which distilled water was used.

A mineral-salt mixture (Arkady) when added to the basic formula, stimulated yeast activity, resulting in a more rapid increase in the concentrations of H-ions as was evidenced by a lower pH value of the baked product. A marked improvement in loaf volume and bread quality followed the use of 5/16 of 1 percent. Danger of too rapid increase in bread age can be avoided by shortening the fermentation period.

High-speed mixing (152 revolutions per minute) mechanically modified the gluten of Early Baart flour, thereby aiding the action of the H-ions in attenuation of the gluten network. Greater loaf volume accompanied by an improved bread texture was obtained upon the substitution of high-speed mixing for the low-speed mixing used in all of the other experimental work. The water-absorbing capacity of the flour was increased 1 to 2 percent, thereby increasing the bread yield. There was some indication that a mixing time of 4 minutes with this high speed had a destructive effect upon the yeast, the gluten, or both.

The addition of Arkady to the basic formula with mixing at a high rate of speed served to make possible the production by the straight-dough method, bread which was comparable in quality if not superior to that produced by the sponge method. With 4 percent yeast and 6 percent sugar in the formula, the use of 5/16 percent of Arkady in addition to high-speed mixing made a satisfactory substitute for a preliminary sponge period of 2 hours and had the advantage of higher bread yield due to less loss of flour-constituents and to the higher water absorption.

That Early Baart flour is a good bread flour for commercial usage was proved by putting it to the test of commercial handling with a resulting high-quality bread yield of 293 1-pound loaves per barrel of flour using a low-speed mixer.

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