THE RATIO OF LIQUID TO FLOUR IN YEAST BREAD
MADE FROM
VARIOUS GRADES OF FLOUR.

by

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THE RATIO OF LIQUID TO FLOUR IN YEAST BREAD MADE FROM VARIOUS GRADES OF FLOUR.

Flour, yeast, and water, the three necessary components of bread, have been the object of much study and experimentation because yeast bread has become such a common article in the diet. Such investigations received great stimulus during the war period when the quantity of all cereals, particularly of wheat, was limited, and when the quality of breads and similar products were unfavorably affected by the substitution of different cereal flours and meals. Commercial bakers and housewives alike were at a loss to know how to secure satisfactory results under the new conditions.

The art of bread making has been practised for years and unfortunately much of the experience which brought about the common methods used in the making of bread have been forgotten. At the same time bread making, as a science has been almost entirely neglected and until the recent organization of the bread industry little attention has been paid to the various problems of bread making, and no practical application of the greatly increased knowledge of physical and biological chemistry has been made.

The quality of bread depends largely upon the kind and condition of the ingredients used; upon the proportions...
in which these ingredients are combined; and upon the treatment of the dough during the bread making process.

It is with the second factor, i.e., the proportion of the ingredients, and especially the proportion of the liquid to the flour content of the dough, that this paper is concerned.

REVIEW OF LITERATURE.

FLOUR.

The character of the flour depends to a great extent upon the variety (2) of wheat from which the flour was milled, the kind of soil upon which it was grown, the fertilizer used, weather conditions, (1, 2) the stage of ripeness when harvested (3) and the method of milling.

Bread flour is made from the hard spring wheats grown in the Northwest, and from the hard winter wheat of the central and western states. The flour from this wheat is characterized as "strong" flour and is rather granular to the touch, has a higher percentage of gluten and its absorptive power is somewhat greater than is the case with soft flour. The color of the flour varies somewhat with the variety of wheat and also with the method of milling.

"A strong wheat," according to Jago & Jago, (4) who accept the definition of Humphries & Biffen (5), is one which yields a flour capable of making large well piled
loaves; and the strength of the flour is "determined by its capacity for producing a bold large-volumed, well risen loaf". The requisites (4) of a strong flour vary somewhat, according to the type of bread to be made from it, but in any case there must be, first, an abundance of sugar to be used as a source of food by the yeast organisms in the production of carbon dioxide, and second, "some substance present in the flour which shall be capable of retaining a sufficiency of the gas generated in the dough, and elastic enough to be evenly distributed by such gas". This substance is known as gluten, and is especially characteristic of flour made from wheat. Gluten is made up largely of the two proteins, gliadin and glutenin (6) which are insoluble in water. It constitutes about nine tenths of the protein of the flour. "There must be," say Jago & Jago, (4) "sufficient gluten present to adequately retain gas and confer elasticity. It must be highly elastic, yielding readily to distention without breaking and yet it must be sufficiently rigid to maintain a well upstanding bold shape."

It has long been known that a rather close relationship existed between the capacity of the flour to produce good bread and the gluten content of the flour. But since a large proportion of gluten does not always insure that the flour will produce good bread, strength must be dependent upon something more than an abundance of gluten. At
one time it was thought that the ratio of gliadin to glutenin in an individual gluten had much to do with the strength of that gluten. Fluerent (7), in 1896, after examining a number of flours, concluded that the most desirable proportion of glutenin to gliadin was 1:3 or 25% glutenin and 75% gliadin. In flour containing 1 part of glutenin to 4 parts of gliadin, he found that the dough collapsed during the baking process. When the ratio of glutenin to gliadin increased to 1:2, the bread did not expand sufficiently either during fermentation or baking.

In 1900 Guess (8) found that the elastic quality of the gluten was improved as the ratio of gliadin to glutenin increased, and he discovered no point beyond which the increase in gliadin produced any harmful effects.

Snyder (9) concludes that in order to produce good bread it is necessary to have a well balanced gluten, and he found the best proportion to be approximately 65% gliadin and 35% of glutenin. However more recent investigators find that there is little connection between the gliadin—glutenin ratio and the capacity of the flour for producing good bread. Wood (7) concludes that neither the percentage of total nitrogen nor of gliadin in the flour, nor the ratio of gliadin to glutenin can be taken as an absolute measure indicating the strength of the flour. Freeman (10) found that 7 out of 8 samples tested gave proportion of 43% glutenin and 56% gliadin. Some of these made very good bread, others made bread of very poor
quality. One flour, with 36% glutenin and 63% gliadin, almost the exact ratio recommended by Snyder, yielded a loaf of the smallest volume.

Wood (11, 12) in studying the water soluble constituents of various flours concluded that the acidity bore no relation to strength, but found that the greater the ratio of protein in a flour to the soluble ash, the greater the strength of the flour. Since he found some exceptions to this hypothesis, he thought that possibly the strength of a flour might be divided into two independent factors, one controlling the volume of the loaf, the other its shape. The shape of the loaf seemed to be governed by the ratio of the total protein to the soluble salts, a high ratio indicating a strong flour. The volume of the loaf depended upon the percentage of "sugars" present, and upon the ability of the flour to give off gas when fermented by yeast, especially during the later stages of the fermentation process. Following these suggestions he performed a series of experiments from the results of which he suggests "that the variations in coherence, elasticity, and water content, observed in gluten extracted from different flours are due rather to varying concentrations of acid and soluble salts in the natural surrounding of the gluten, than to any intrinsic difference in the compositions of the glutens themselves. These properties must undoubtedly have a direct
bearing on the power which some flours possess of making shapely loaves. He concluded that there was no difference in the composition of the glutens (gliadin and glutenin) of strong and weak flours.

A later report by Wood and Hardy (14) shows that wheat gluten, like all proteins that have been studied, belongs to the class of emulsoid colloids, and one of the typical reactions of this class of proteins is that they have a great affinity for water. The degree of this affinity may be altered by the addition of salts, acids, or alkalies, to the solution.

The colloidal swelling of gluten was next studied by Upson and Calvin (16) who, using Hofmeisters (18) method for the study of the swelling of animal proteins, found that the addition of salts to the solution decreased the amount of water absorbed by the gluten. In dilute acid solutions, the disks of gluten "puff up and take on an appearance somewhat resembling cotton balls, finally becoming transparent, soft, and gelatinous".

They found that by neutralizing the acid solution after the disks had puffed up, the water would actually be given off from the gluten, which would again resume its firm consistency.

Later, Upson & Calvin (17) arrive at the conclusion that "strength is related to soluble acid and salt content of the flour. Flours containing acids and salts in such combinations as to favor absorption will behave as 'weak'
flours, whereas these containing acids and salts in such combinations as inhibit water absorption will behave as 'strong' flours when baked'.

In 1918 Gortner & Doherty (19), assuming that the previous work on gluten had been done on the gluten obtained from a single flour and that usually a strong one, carried out a series of experiments using 5 glutens obtained from "strong" and "weak" types of flour. From their results they conclude that although the moist glutsens from these different flours differ greatly in quality and in physical properties, they are hydrated to almost the same extent. The rate at which the gluten becomes hydrated is however, much more rapid in the glutens which come from "strong" flours. The weak flour gluten has a much lower "maximum hydration capacity" than has gluten from a strong flour, and it changes from a gel to a sol at a much lower degree of hydration. They noticed that the curves representing the rate and degree of hydration of these glutens are of two types. In dilute hydrochloric and oxalic acid the water is rapidly absorbed, but in slightly stronger concentrations of these acids the wet gluten actually gives up water to the acid solution. In the case of dilute solutions of lactic, acetic, and phosphoric acids, the gluten strongly absorbs water, but increasing the concentration of the acid decreases only slightly the amount of water absorbed by the gluten.
These investigators think that the hydrogen ion concentration of acid is probably not the only factor controlling the absorption of water by gluten, and they point out that "the anion of the undissociated molecules, as well as their relative absorption by the protein must in all probability be taken into consideration.

On adding inorganic salts to the acid solutions, the relative absorption of the glutens was lowered but in this case they found that the different glutens reacted differently on the addition of the salts.

They conclude that the difference between strong and weak gluten is due to something other than the acid and salt content of the flour. There is, they think, some innate difference in these glutens, the physico-chemical properties of which are not identical and "would not be identical even if the flour had originally had the same acid and salt content".

From their experience with these different glutens they make the following conclusion:

"The difference between a strong and weak gluten is apparently that between a nearly perfect colloidal gel with highly pronounced physico-chemical properties, such as pertain to emulsoid, and that of a colloidal gel in which these properties are less marked."

These differences, they suggest "may be due to the size of the gluten particles and that at least a part of the particles comprising the weak gluten may lie near the
boundary between the colloidal and crystalloidal states of matter than is the case with the stronger glutens."

Cohn and Henderson (20) in "The Physical Chemistry of Bread Making" report that "the acidity of the dough at the time of baking seems to be the most important variable factor in bread making." By increasing the acidity, the production of carbon dioxide by the yeast organism is increased and the tenacity and the elasticity of the dough is controlled. This increase in acidity may be accomplished with much the same effect by the addition of such acids as lactic or acetic. However, the amount of acid which should be added varies with the flour used, with the amount of yeast, and with the length of the fermentation process.

Jessen-Hansen (21), and Henderson (22) et al., agree that the optimum hydrogenion concentration for breadmaking is about PH 5. A colorimetric method for quickly determining the acidity of bread is given by Cohn, Cathcart and Henderson (23). It is as follows: "The loaf is cut cleanly, and upon a point near the center of the loaf four drops of a 0.02 per cent solution of the indicator (methyl red) in 60 percent alcohol are allowed to fall. After waiting 5 minutes the color is observed. By comparison with a color chart, or with a loaf of bread of known acidity, the hydrogen ion concentration of a loaf of bread may be estimated."
Thus it appears that, although there is yet much to be learned before one can definitely say what factors are most important in determining the strength of a given flour, most investigators agree that the strength is due not to the ratio of gliadin to glutenin, in an individual gluten, but rather to the reactions, not yet thoroughly understood, between the proteins of the wheat and certain acids and salts which may be normally present in the wheat kernel or maybe added to the dough in the process of bread making.

**Yeast.**

Bread is leavened by the yeast organisms which ferment the sugars and to some extent part of the starch of the flour with the production of carbon dioxide which aerates the mass of the dough. The organisms are ordinarily added either in the form of compressed yeast or dry yeast cakes. Commercial bakers sometimes use brewers or distillers yeast.

Compressed yeast is made by cultivating pure strains of the yeast organism, which are especially adapted to the bread making process in suitable media after which the organisms are washed carefully, filtered, and compressed into cakes, sometimes with the addition of starch or some such binding material. Compressed yeast deteriorates quite rapidly, and so it must be used only when fresh and in good condition. According to Jago and Jago (4), compressed yeast should have the following characteristics, "it should
be very slightly moist, not sloppy to the touch, the color should be a creamy white; when broken it should show a fine fracture; when placed on the tongue it should melt readily in the mouth; it should have an odor of apples, not like that of cheese; neither should it have an acid odor or taste. Any cheesy odor shows that the yeast is stale, and that incipient decomposition has set in.

Dry yeast is prepared in much the same manner excepting that the organisms are mixed with corn meal or some other carrier, pressed into cakes and dried. The organisms are consequently in an inert state, and more time must necessarily be allowed for its use, but after it begins to grow it is equally as good as the compressed yeast. Dry yeast will keep almost indefinitely. (24)

The quantity of yeast used varies considerably with the method of making the bread, and the time which can be allowed for the completion of the process. Bevier (26) and Williams (33) state that as the amount of yeast increases the time of rising decreases, the texture becomes finer, the volume of the bread is greater, but an excess of yeast produces crumbliness and some loss of color in the crust.

Williams, however, finds that yeast in large quantities resulted in the loss of the delicate flavor of the bread. Results at the University of Kansas (39) show that an increased amount of yeast increases the volume of the bread and decreases the time factor, but the texture is
usually somewhat coarser. (39). As to the effect of yeast upon the flavor of the bread there seems to be a difference of opinion. Wardall (35), after studying 33 cultures of yeast, in pure cultures, thinks that the flavor is not affected by the yeast. Jago and Jago (4) think that the variety of yeast employed has much to do with the resulting flavor of the bread. Simmons (36) and Grossfeld (37) believe that any change in flavor which may occur in connection with the yeast is due to the products of fermentation and consequently a small amount of yeast allowed to ferment for a long period of time may produce greater changes in flavor than a larger amount acting for a shorter time.

The yeast organism is most active at a temperature of about 30°C. It is readily affected, not only by rather slight changes in the temperature, but also by variations in the dough. As has already been suggested the sugar content of the dough, either that which is normally present in the wheat (11), or that which may be added, has much to do with the volume of the loaf. This sugar the yeast uses as food, with the production of carbon dioxide and alcohol. The lack of sugar will greatly retard the activity of the yeast (20), while the use of added sugar up to 4% hastens the rate of fermentation, increases the volume of the bread, and produces a finer more even texture. (26) Salt retards the growth of the organism (26, 20, 34) and decreases the amount of carbon dioxide produced (20).
and Jago (4) find that up to 3\% the fermentation is not greatly retarded by the salt, but more than that amount decidedly diminishes the quantity of gas produced. This figure however, seems rather high and Bevier (26) records considerable retardation of fermentation when using 1.64\% of salt, and she recommends the use of a little less than 1\% salt.

The stimulating effect of potato and potato water upon the yeast has long been known and its use practiced by the housewife. Jago and Jago (4) state that boiled potato induces a "more rapid and copious evolution of gas", and that the use of potato water was almost as efficient as the potatoes themselves. These results are confirmed by a rather extended series of experiments at the University of Kansas (39), which show that the use of potato or potato water is of great value in increasing the quantity of carbon dioxide produced by the yeast organism and thus decreasing the time of fermentation and increasing the volume of bread. The time of fermentation was almost 50\% shorter when either potato or potato water was used.

During the process of fermentation there is a gradual increase in the acidity of the dough and this increase in acidity up to a certain point, stimulates the yeast organisms to greater activity with an accompanying increase in the rate at which the carbon dioxide is evolved. Thus the dough rises more rapidly as the process of fermentation proceeds.
During the last few years a good deal of investigational work has been carried on in an effort to discover other substances which will hasten fermentation and shorten the time of the bread making process. Dudley (34) finds that yeast grows faster when no potato is added to the water, but the addition of a little ginger hastens the reaction. Kohman and his collaborators (27) report that the addition of .015 part of potassium bromate or .005 part of potassium iodate to 1000 parts of the usual mixture of flour, yeast, etc., hastens the rate of fermentation, decreases the time, and the amount of yeast required. The addition of 0.06% ammonium chloride and 0.12% of calcium sulfate to the dough also decreases the time of fermentation or permits the use of less than the normal amount of yeast (23). The use of malt extract too, is recommended by Kohman (29). "The amounts that can be successfully used depend upon the strength of the flour and the diastatic activity of the extract." These same investigators (30) find that it is possible to use from 50 to 65% less than the ordinary amount of yeast by adding a small amount of ammonia and calcium, together with minute quantities of potassium bromide. The use of these substances also affects a saving of about 2% of the fermentable starches. Cheese and other nitrogenous substances such as amino acids from wheat gluten, bean or pea press cakes, so treated as to make their proteins soluble, and peptonized milk have been found (31) to serve as food for the yeast organisms...
and to hasten the rate of fermentation.

Hoffman (32) finds that ammonium chloride when added to the dough serves as food for the yeast and is used for building new yeast cells. By using \( \frac{1}{2} \) pound to 1000 pounds of flour 30\% less yeast may be used, and the quality of the bread at the same time is improved.

**LIQUID.**

In this connection there are two factors which must be considered; first, the kind, and second, the proportion of liquid. Water is the liquid which is generally used in ordinary bread making. From a series of experiments with hard and soft water Jago and Jago (4) conclude that there is very little difference in the character of the resulting bread, and such differences as do occur may easily be controlled by slight changes in the blend of the flour or the method of fermentation.

According to Bevier (26) there is no liquid better than water, at least as far as flavor of the bread is concerned. Many people, however, prefer the flavor of bread in which most of the water is replaced by milk (4, 39). In addition to modifying somewhat the flavor of the bread, milk improves the keeping quality of the bread, and contributes to the tenderness of the crumb, the color of the crust and the elasticity (26). According to some authorities (38, 3:9), however, the use of milk decreases the rate of fermentation thus increasing the time factor. This may be due to the fact that the use of milk instead of water decreases (40)
the acidity of the bread quite perceptibly, and that stim-
ulus to rapid fermentation is thus lacking. When using
20% of the substitute flours (corn or barley) the results
of investigations on yeast bread made in the Experimental
Kitchen of the United States Food Administration show an
increased rate of fermentation when water was replaced by
milk (40).

The beneficial influence of potato water upon the
growth of the yeast organism has already been mentioned.
In addition to this, the use of potato water is accom-
panied by a decided improvement in the texture and color
of the bread, in the color of the crust, in the tender-
ness of the crumb and in the elasticity or spring of the
baked loaf (26, 39).

The literature on bread offers very little definite
information concerning the proportion of liquid to flour
in bread making. Most recipe... call for one cup of liquid
to three cups of flour. Bevier (26) however, finds that a
somewhat stiffer dough, 1 cup of liquid to 3.6 cups of
flour (260 cc. of liquid to 440 g. flour) gives the most
satisfactory bread "as regards shape, size and general
characteristics of loaf." A slacker dough, she finds, is
quite likely to produce a loaf of poor shape with a ten-
dency to be clammy and coarse in texture. Stiffer doughs
make a loaf well rounded on top, of finer texture, and one
which shows a tendency to crack open during baking.
Williams (33) finds that soft doughs produce loaves somewhat flat on top, with coarse texture and dark color, and a tendency to be tough and clammy. However, they yield larger weights of bread in proportion to the flour used than do stiffer doughs.

This same investigator concludes that moderately stiff doughs give the most satisfactory results, and she finds the best proportion to be the same as that recommended by Bevier (26), i.e., 260 cc. of liquid to 440 g. of flour. Bread made from stiffer doughs is more rounded on top, has a tendency to crack open on the side, is finer in texture, the crumb is whiter and dryer, and the color richer. Moderately stiff doughs rise more in the oven and thus yield larger volumes than do either the very stiff or very slack doughs.

From a report made by the Home Conservation Division of the United States Food Administration (42) on "Factors Affecting the Quality of Yeast Breads Containing Wheat Flour Substitutes" it appears that much importance rests upon the proportion of the liquid to flour in the dough. In these breads it was found that doughs which were too soft often rose well, but fell considerably during the baking period, or if they did not fall, they were very coarse textured, often being filled with large cavities. When the doughs were too stiff they did not rise well, and the resulting loaves showed a tendency to crack. In breads con-
taining from 25 to 40% substitute the ratios of the weights of the liquids to the weight of the flour ranged from 1:1.47 to 1:1.68 with an average optimum ratio around 1:1.60. This ratio seemed to increase with the increase in substitute, and varied slightly with the kind of substitute used, but as a good general working principle upon which to begin the study of any flour, it appeared that the ratio of 1:1.6 was to be recommended.

REPORT OF EXPERIMENTS.

OBJECT.

These experiments were undertaken in order to determine if there is a relation between the weight of the flour and of the liquid which remains constant for high patent flours; and to see if this relationship varies with the grade (or brand) of flour.

FLOURS USED.

Throughout the experiments seven different flours were used. Two of these, A and B, were high patent flours; one, C, was a second or standard patent; two, D and E, were straight grade; and two, F and G, were low grade, F being what is called by the manufacturers, a fancy clear grade. All of these flours were made from hard winter wheat grown in Kansas, and with the exception of flour D, all were to be had in the public market. Flours A, D and E were manufactured by one mill, and B, C, F, and G by another.
The patent flours were both rather hard, dry, and of very fine granulation. The content and character of the gluten was good and both flours were slightly creamy in color, A somewhat more so than B which had a very faint bluish tinge.

Flour C, a second patent flour, was slightly less granular to the touch than the first patent flours and somewhat more creamy in color. It contained a very small percentage of tiny particles of bran.

The straight grade flours, D and E, were slightly yellow in color and contained more of the bran particles. The gluten was somewhat softer and less elastic, and the flavor of the wheat was more pronounced. Of these two flours, E seemed to contain a good deal more of the outer portion of the kernel than D and in handling it, it felt and acted more like a low grade flour. Flour D was made by combining 80% of the patent flour, A, with 20% of the low grade flour G, and its properties were such as would be expected from such a combination.

The low grade flours, F and G, were still less granular than the straight grade flours, G showing this characteristic to a greater extent than F. Both contained larger amounts of the bran particles and had a higher ash content. They were much more creamy being almost yellow in color, and had a very characteristic wheat flavor. Both flours showed a decided tendency to clamminess, i.e., when a handful of the flour was gripped firmly, and then released
and allowed to lie on the palm of the hand, the flour would stick together, holding the shape into which it was pressed.

The percentage composition of each of these flours, as determined by the company chemists was as follows:

<table>
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<th>Ash</th>
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<td>43</td>
<td>12.0</td>
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<tr>
<td>B</td>
<td>--</td>
<td>12.13</td>
<td></td>
<td>.33-.41</td>
<td>12.17</td>
</tr>
<tr>
<td>C</td>
<td>--</td>
<td>12-13</td>
<td></td>
<td>.40-.45</td>
<td>13</td>
</tr>
<tr>
<td>D</td>
<td>30.06</td>
<td>12.2</td>
<td></td>
<td>.43</td>
<td>11.6</td>
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<tr>
<td>E</td>
<td>--</td>
<td>12.5to</td>
<td></td>
<td>.47-.51</td>
<td>13</td>
</tr>
<tr>
<td>F</td>
<td>--</td>
<td>13-14</td>
<td></td>
<td>.59</td>
<td>13</td>
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<tr>
<td>G</td>
<td>46.04</td>
<td>14.07</td>
<td></td>
<td>.76</td>
<td>11.6</td>
</tr>
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</table>

**MATERIALS OTHER THAN FLOUR.**

**LIQUID**

Since in previous work it had been found that potato water hastened the rate of fermentation and produced a bread of good texture and flavor, it was decided to use it as the liquid throughout the experimental work. Occasionally milk and water were substituted for a part or all of the potato water.

In order that there might be as little variation as possible in the potato water it was always made as follows: Approximately one pound of potatoes, washed and pared, were sliced into one and one-half quarts of cold distilled water and cooked until done. The water was then drained from the potato and cooled to about 40°.
YEAST.

Fleischman's compressed yeast was invariably used. It was purchased daily, and as fresh as possible but there were some slight variations in quality from day to day. The quantity of yeast to be used in a day's experiments was crumbled into small bits and carefully mixed, to insure uniform quality in all loaves. Then the required amounts were accurately weighed.

SALT, SUGAR, AND FAT.

With only one or two exceptions, these ingredients were kept constant throughout the experiments. In every case they were measured instead of being weighed, and slight variations in measuring these ingredients undoubtedly help to account for part of the slight variation in weight among the individual doughs.

METHOD OF PROCEDURE.

In the first series of experiments a short sponge method with three risings, (including one after the dough was formed into a loaf), was used. Later because of the time required to complete the process, the long sponge method with only two risings was used.

SPONGE.

The potato water was cooled to about 40°C and to it was added the yeast, sugar and enough flour to make a batter. In case of the short sponge method, an hour was allowed for the process of fermentation. For the long sponge, fourteen hours were allowed. During this time the
sponge rose to two or three times its original volume, and then fell.

In both methods, the sponge was kept at a temperature of approximately 30°C. The temperatures recorded, however, represent that of the batter itself, and not of the air surrounding the bowls.

**MIXING.**

At the completion of the fermentation period for the sponge the remainder of the flour was added together with the salt and melted fat.

In the first series of experiments the mixing and kneading was done by hand, approximately ten minutes being required to mix each loaf.

The bread in the remaining experiments was mixed in an ordinary small sized bread mixer, driven by an electric motor of 1/6 horsepower. The mixer turned at the rate of 90 revolutions per minute and the time of mixing was two minutes excepting in those experiments where the effect of kneading was being tested.

**RISING.**

Each loaf was lightly greased and placed in a Tetlow Expansion jar to rise. Thus it was possible to tell quite accurately just when the bread had doubled in bulk.

For the first experiments the dough was kept in a well insulated fireless cooker oven which was warmed by the intermittent use of a small gas flame. An effort was made to keep the temperature at 30°C but this method was not very
satisfactory, and so throughout the later experiments a small, well insulated icebox, fitted with an electric bulb and a thermostat was used to maintain a constant temperature. This was quite successful, tho the temperature varied slightly from day to day.

The dough was allowed one or in some cases, two risings before being formed into a loaf. In the first series of experiments the dough was allowed to double in bulk, and was then kneaded or cut down twice and then formed into a loaf and when again double in bulk, was baked. In later experiments the dough was allowed to rise for an hour, when it was cut down, shaped into a loaf, allowed to rise for seventy minutes, and then baked.

This latter method was adopted because it was thought that greater uniformity could thus be secured and any differences in the character of the bread would be more conspicuous.

BAKING.

The bread was baked in gas ovens which were kept at a constant temperature by means of an ordinary chemical thermometer inserted through the top of each oven and held in place by a cork. Usually not more than two loaves were baked at the same time in each oven, thus allowing plenty of space for free circulation of the air.

The first two series of bread were baked at 225°C for 15 minutes after which the temperature was reduced to about 195°C. The remainder of the bread was baked at 210°C for
15 minutes and then reduced to 195°C for the remainder of the time.

Small loaves (using ½ cup liquid as a basis) were baked for 30 minutes and the larger loaves for 50 minutes.

The bread was baked in pans made of a medium weight tin. The pans for the smaller loaves measured 5 inches long by 3 inches deep and were 2½ inches in width at the bottom of the pan and 3 5/8 inches in width at the top. The larger loaves were baked in tins 7 ½ inches long, 2 5/8 inches deep, 3 ½ inches in width at the bottom and 4 ½ inches in width at the top.

**VOLUME.**

The volume of the bread was obtained by displacement. A large pan of the same general shape as the loaves of bread was filled level full with rape seed. Part of the seed were removed and the loaf to be measured was put in and the top leveled again. The seed which were displaced by this loaf were measured in a graduated cylinder and that number taken as the volume of the loaf.

**RESULTS AND DISCUSSION.**

Altogether forty-two series of loaves were made in most of which the ratio of the weight of the liquid to that of the flour ranged from 1: 1.3 to 1: 1.8, the weight of the flour being increased by one-tenth of the weight of the liquid for each succeeding loaf. From previous work done at the University it appears that the ratio of 1: 1.4
made a dough so slack that the resulting bread was quite undesirable from every standpoint. However, in order to be quite sure that the maximum amount of liquid was being used most of the series was begun with the ratio of 1: 1.3 and extended to 1: 1.9 in the majority cases, to 1: 1.9 occasionally. Every series was repeated at least twice, and usually three or more times for each of the flours used.

The ingredients, and the amount of each used, were as follows:

For the small loaves:
- potato water
- yeast
- salt
- sugar
- fat
- flour

For the larger loaves:
- potato water
- yeast
- salt
- sugar
- fat
- flour

FLOUR A.
Plate I illustrates the character of the resulting loaves. Those containing the larger proportions of liquid were coarse in texture, of small volume and of very poor shape and color. The dough itself was so slack that it was impossible to handle it and it had to be stirred rather than kneaded. When the ratio of 1 : 1.6 was reached the dough was just stiff enough to be handled without its sticking. The texture of the bread made from this dough was much finer, the shape of the loaf good and the color of the crust a golden brown. As the dough became stiffer, the texture of the resulting bread grew finer and somewhat more even, the volume of the loaf increased and the time of rising decreased. The yield of bread, as expressed by the ratio of the weight of the baked loaf to the weight of the flour used decreased from 1 : 1.5 when one part of liquid was used to 1.3 parts of flour, to 1 : 1.394 for one part of liquid to 1.8 parts of flour. The stiffer doughs also showed a marked tendency to crack during the baking process. This tendency was greatly aggravated by any uneveness in the temperature of various parts of the oven.

For the average taste the ratio of 1 : 1.7 seemed to be the most desirable from every standpoint. For those who preferred a coarser less compact loaf the ratio of 1 : 1.6 was considered best, and some chose as most desirable the rather close compact bread containing 1.8 parts of flour to 1 of liquid.
Plate I.

Yeast Bread made from High Grade Patent Flour using an Increasing Proportion of Flour to Liquid.

Flour - A
Grade - High Patent.

Ratio of liquid to flour.

\begin{align*}
1:1.3 & & 1:1.4 & & 1:1.5 & & 1:1.6 & & 1:1.7 & & 1:1.8
\end{align*}
Flour B.

This series is illustrated in plate II. The ratio of 1:1.2 was included in an effort to make a bread which would not be stiff enough to bear its own weight or to retain the carbon dioxide and would fall. As is shown in the illustration, this did not happen but the bread was of very poor quality in texture, shape, color, crumb and flavor. With the increase in flour content the loaf improved in shape until the ratio of 1:1.7 was reached. The texture became finer, the color of the crumb and crust was greatly improved, and the bread was most desirable in every respect.

Again the most desirable bread was made using the ratio of 1:1.7 parts of liquid to flour. As in the former case a few people chose the ratio of 1:1.8 as best but very few preferred the bread made from a slackier dough than that which contained 1 part of liquid to 1.6 parts of flour.

The volume of the loaves increased with the increase in the flour content, but the yield decreased from 1.57 to 1.42. The slack doughs required a longer period of fermentation in order to make a loaf of anyways near the same volume as that produced by the stiffer dough. When the loaves were allowed to rise to the same height before being baked the softest dough, ( 1 part of
Plate II.

Yeast Bread Made from a Fancy Patent Flour Using an Increasing Proportion of Flour to Liquid.

Flour - B
Grade - Fancy Patent.

1:1.2 1:1.3 1:1.4 1:1.5 1:1.6 1:1.7 1:1.8
Ratio of liquid to flour.
liquid to 1.2 parts of flour by weight) required 4 hours and 35 minutes for the total time of fermentation while the stiffest dough, (1 part of liquid to 1.8 parts of flour) required 3 hours and 49 minutes, excluding in both cases the time of baking.

Flour C.

This series ranged from 1: 1.2 to 1: 1.9 inclusive, and the resulting bread is illustrated in Plate III. As was the case with both of the patent flours the quality of bread again improved with the increase in the flour content. The ratio of 1: 1.9 produced a loaf of exceedingly close texture, too close to be desirable. Again the optimum ratio seems to be about 1: 1.7 with not a great deal of difference between it and the ratio of 1: 1.6, which in one case seemed best.

The volume of the bread increased considerably with the larger amounts of flour. The loaf containing 1.9 parts of flour was 46% larger than the one containing 1.2 parts. The ratio of 1: 1.7 increased the volume by 36%.

The flavor and color of the bread made from this flour was quite like that made from a high patent flour. The characteristic flavor of the wheat may have been slightly more pronounced.
Plate III.

Yeast Bread Made from Second or Standard Patent Flour Using an Increasing Proportion of Flour to Liquid.

Flour - C
Grade - Second or Standard Patent.

1:1.2 1:1.3 1:1.4 1:1.5 1:1.6 1:1.7 1:1.8 1:1.9
Ratio of Liquid to Flour.
Flour D.

This straight grade flour produced bread quite similar to that made from flour A. Since this flour was made by mixing 80% of flour A with 20% of flour B, one would scarcely have expected any very great differences.

The flavor of the bread was quite good, being somewhat more characteristic of the wheat than the standard flour but not as strong as that made from low grade flour and much less pronounced than the flavor of Graham or whole wheat flour bread.

The color of the bread, both crust and crumb was darker than that made from high patent flour.

The optimum ratio, in this case, seemed to be about 1:1.6. The texture was somewhat closer and more compact when a higher proportion of flour was used, but the loaves showed a decided tendency to crack.

The volume of the loaf which was made with 1.6 parts of flour to 1 of liquid was 30% larger than the one containing 1.3 parts of flour.

The yield as expressed by the ratio of the weight of the flour content to that of the baked loaf decreased from 1:1.54 to 1:1.38 as the flour content increased to 1.3 parts by weight for each part of liquid.
Flour II.

Plate IV illustrates the bread obtained in this series. As in the previous experiment the bread improved in quality as the ratio of liquid to flour decreased. The texture grew constantly finer and closer until when 1.0 parts of flour were used, the bread was quite solid and compact.

The shape of the loaves, with the exception of the two containing the larger ratios of water, was very good and with this flour there seemed to be less tendency for the loaves to crack on the sides.

The optimum ratio appeared to be 1:1.6 with a possibility of either 1:1.5 or 1:1.7, depending upon the character of the bread desired. The ratios of 1:1.8 and 1:1.9 were entirely too close and compact.

The volume of the loaves increased with the increase of the flour content. The ratio of 1:1.6 was 25% larger than that of 1:1.2.
Plate IV.

Yeast Bread made from a Straight Grade Flour Using an Increasing Proportion of Flour to Liquid.

Flour - E
Grade - Straight

1:1.2  1:1.3  1:1.4  1:1.5  1:1.6  1:1.7  1:1.8  1:1.9

Ratio of liquid to flour.
Flour F.

Plate V illustrates the results in this series. As before, the character of the bread improved as the proportion of the flour was increased. The slackest loaves were coarser in texture than the corresponding loaves in the better grade flours, but the shape of the loaves was better and improved more rapidly than was the case with the better grade flours. Again there seemed to be less tendency for the loaves to crack on the sides during the baking process.

The color of the bread was much darker, and the flavor much more pronounced than in the former series of loaves.

The optimum ratio was in the vicinity of 1 : 1.6 with 1 : 1.5 and 1 : 1.7 both producing desirable breads. The volume of the loaf made with 1.6 parts of flour was 32.5% larger than the one containing only 1.2 parts of flour to 1 part of liquid.
Plate V.

Yeast Bread made from Fancy Clear Grade Flour Using an Increasing proportion of Flour to Liquid.

Flour - F
Grade - Fancy Clear.

1:1.2  1:1.3  1:1.4  1:1.5  1:1.6  1:1.7  1:1.8  1:1.9
Ratio of liquid to flour.
Flour G.

This flour seemed to be of much poorer quality than F. The resulting bread was quite dark in color and the flavor rather strong. Probably the majority of people would object to using this flour for bread because of these facts. The color of the crust, however, was more desirable than in the patent flours.

Excepting for the differences in color and flavor, the characteristics of the bread as illustrated in plate VI, were much the same as were those of the other flours. The texture grew finer, the volume larger, the shape and color of crust and crumb better with the increase in the flour content.

The optimum ratio appeared to be 1 : 1.6 or even 1 : 1.5. The ratio of 1 : 1.7 seemed too stiff and the resulting bread too close and compact for most tastes at least.

These results agree quite closely with those obtained by Williams (33) who found that the most satisfactory breads were obtained from moderately stiff doughs. She states that the stiffer the dough, the finer the texture, the whiter and drier the crumb, the more rounded the top of the loaves and the greater the tendency of the loaves to crack. They yield larger volumes too, due she thinks to the fact that they rise more in the oven. She decides that the best proportion, when using bread flour
Plate VI.

Yeast Bread Made from Low Grade Flour Using an Increasing Proportion of Flour to Liquid.

Flour - G
Grade - Low
made from spring wheat, is 260 grams of water to 440 grams of flour or a ratio of 1 part of liquid to 1.69 parts of flour.

From the results of the experiments here reported the optimum ratio of liquid to high patent and standard patent flours, made from hard winter wheat was 1 : 1.7 or almost identical with Miss Williams' proportion. For lower grade flours, which absorb more water, the amount of flour necessary decreased considerably, and the ratio of 1 : 1.6 and in very low grade flour 1 : 1.5 seemed desirable.

In this connection it must be remembered that the moisture content of the flour itself varies considerably depending upon the humidity of the atmosphere in which it is kept. Bailey (43) finds that flour, the moisture content of which has come to equilibrium with the moisture of the air, may vary as much as 10 per cent in its water content. At a temperature of 25°C and the relative humidity at 30 per cent he found the flour to contain 5 percent moisture. When the relative humidity was 80 per cent the flour contained 15 per cent moisture. The rate at which this change is brought about depends largely upon the conditions of exposure.

Then too, the ability of the flour to absorb water changes slightly as the flour ages. Jago and Jago (4) found that flours which have been stored for 5 months generally show "signs of slight diminution in the water
absorbing power." Stockham, however, found that normal wheat flour increased in absorption capacity during storage. The average increase for 34 samples which had been stored for 8 months was 1.22 per cent.

Obviously these factors must be considered when working with flours the age and water content of which are unknown.

The color of both the crumb and the crust of the bread were improved with the increase in the flour content. The crust of the bread made from slack doughs was pale, unevenly browned and generally unattractive. As the flour content was gradually increased the color deepened to an even golden brown, and the crust became smooth, tender, and at the same time crisp and pliable. The crumb of the bread became much whiter, finer and more even, and the spring better. This was true for every grade of flour used, although the lower grades of flour developed a much deeper golden color in the crust, and the crumb of the bread was increasingly darker as the bran content of the flour increased. In the flours F and G, and possibly E, the color and flavor were probably too pronounced for long continued use in making bread. However, for one who likes a flavor somewhat milder than that of graham flour, the low grade flours might be very acceptable.

The rate of fermentation in the lower grade flours
seemed to be considerably faster than in the patent flours. This is probably due to the fact that the low grade flours contain a higher percentage of salts. Bailey (44,45) states that the ash content of wheat flour is at the present almost universally used as an index of the grade. Patent flours may contain as low as 0.35 per cent ash while the lower grades occasionally exceed 2 per cent. These variations in ash content are of course due to the presence of more of the bran and embryo, both of which contain larger percentages of ash than does the floury part of the wheat kernel.

The beneficial effect of these salts must be due, either to increasing the acidity of the dough, thereby stimulating the yeast organisms to greater activity; or to the reaction between the salts and the gluten of the flour whereby the elasticity and tenacity of dough is increased.

LOSS IN WEIGHT DURING MIXING AND RISING.

This loss for all loaves in the entire series averaged 4.5%. As the doughs became stiffer the loss was less, due to the fact that the dough could then be handled with greater ease; there was less tendency for it to stick; and possibly the losses during fermentation were less. The total loss in weight decreased from 5.5 percent in bread made with the ratio of 1 part of liquid to 1.2 parts of flour by weight to 3.9 per cent when the ratio of 1 : 1.8 was used.
In addition to the loss during mixing and rising, there was doubtless a small percentage due to evaporation since the dough was allowed to rise in a rather dry atmosphere.

The loss during fermentation varied considerably, depending upon the quantity of yeast used, the kind and character of the flour, the length of the fermentation period and the extent to which the yeast organism was stimulated or inhibited by the presence of various substances in the dough.

Snyder and Vorhees (40) report that in experiments made at the Minnesota and New Jersey Agricultural Experiment Stations, it was estimated that from 1.5 to 8 per cent of the nutrients of the flour may be used up in this manner. The greatest loss they found to occur in the carbohydrates, 1.68 per cent of which was lost during fermentation. This corresponds roughly to a loss of from 0.9 to 4.5 per cent of the dough when using the ratios of liquid to flour of 1:1.3 to 1:1.8.

Jago and Jago (4) give the estimate of Danglish as one of the highest. He reported a loss of from 3 to 6 per cent. Jago, however, found that although they used 6 times the usual amount of yeast, and allowed the fermentation to continue for 10 days, only 2.5 per cent of the fermented dough was lost. In this case they also used a soft flour, distilled water and no salt. The total loss in the weight of the dough they report to be
only 0.59 per cent for a strong flour and 0.70 per cent for a weak flour, when the usual breadmaking process was followed.

LOSS IN WEIGHT DURING LAST RISING AND BAKING.

In all the loaves of the entire series 15.4 per cent of the weight of the molded loaf was lost, a small part of which may be accounted for by the evaporation during the last rising period but most of which was lost during the baking period.

This loss in weight gradually decreased as the proportion of the flour was increased. Loaves containing 1.2 parts of flour to 1 of liquid lost an average of 18.0 per cent, while those containing 1.9 parts of flour lost only 12.9 per cent of their original weight.

This loss then, is not proportional to the surface exposed to the heat since the slack loaves had much smaller volume than the stiffer doughs, yet the percentage loss was considerably greater in every case, though the time and temperature of baking were constant.

In this connection it may be noted that Vandevalde and Revijin (47) found that the water-content of bread diminishes regularly during the baking process, but that the form of the loaf exercised, apparently, no effect upon the amount of water lost.

YIELD.

In every case the yield of bread, as expressed by the ratio of the weight of flour to that of the baked
loaf, decreased with the increase in flour. This ratio for bread containing 1 part of liquid to 1.3 parts of flour averaged 1:1.50 and decreased to 1:1.39 for bread containing 1.8 parts of flour.

The yield, as expressed by the ratio of the weight of the flour to the volume of the loaf was quite constant throughout and for all loaves of 14 experiments it was 1:5.5. The averages for the loaves of each degree of stiffness varied from this general average by only .1 excepting in the case of the loaf containing 1.2 parts of flour to 1 part of water, which averaged 5.7.

The figures representing the average loss in weight during mixing and rising, during baking the average yield etc., are shown in table 1.

Effect of Kneading on Doughs Containing Varying Amounts of Flour.

In an attempt to improve the texture of the bread made from these various doughs the effect of increasing amounts of kneading was tested. Different batches containing exactly the same ingredients were mixed and kneaded in the electric mixer for 1, 2, 5, 7, 10 and occasionally for 15 minutes consecutively. They were then allowed to rise for 1 hour, were molded into loaves and after rising for 70 minutes, were baked at a temperature of 210°0 for 15 minutes and 195°0 for the remainder of the 50 minute period.
TABLE I.
Percentage loss in weight during mixing, rising and baking, together with ratios of yield.

<table>
<thead>
<tr>
<th>Ratio of liquid to flour</th>
<th>1:1.2</th>
<th>1:1.3</th>
<th>1:1.4</th>
<th>1:1.5</th>
<th>1:1.6</th>
<th>1:1.7</th>
<th>1:1.8</th>
<th>1:1.9</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss during rising &amp; mixing</td>
<td>5.5</td>
<td>4.8</td>
<td>4.5</td>
<td>4.8</td>
<td>4.4</td>
<td>4.3</td>
<td>3.9</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Loss during last rising &amp; baking</td>
<td>13.3</td>
<td>17.9</td>
<td>16.9</td>
<td>16.0</td>
<td>14.7</td>
<td>14.2</td>
<td>13.2</td>
<td>12.9</td>
<td>15.4</td>
</tr>
<tr>
<td>Yield: Ratio of wt. of flour to wt. of baked loaf</td>
<td>1:1.51</td>
<td>1:1.5</td>
<td>1:1.48</td>
<td>1:1.44</td>
<td>1:1.42</td>
<td>1:1.49</td>
<td>1:1.39</td>
<td>1:1.4</td>
<td>1:1.42</td>
</tr>
<tr>
<td>Yield: Ratio of wt. of flour to vol. of baked loaf</td>
<td>1:5.7</td>
<td>1:5.5</td>
<td>1:5.6</td>
<td>1:5.5</td>
<td>1:5.4</td>
<td>1:5.5</td>
<td>1:5.5</td>
<td>1:5.6</td>
<td>1:5.5</td>
</tr>
<tr>
<td>Vol. of baked loaf (in c.c.)</td>
<td>1310*</td>
<td>1334</td>
<td>1507</td>
<td>1536</td>
<td>1652</td>
<td>1796</td>
<td>1932</td>
<td>2080**</td>
<td></td>
</tr>
</tbody>
</table>

* average of 4 experiments.
** average of 3 experiments.
Results:

The greatest differences, due to the length of kneading, were noticed in the dough itself. That mixed for 1 minute only was very rough and uneven. It also seemed to be stiffer than the other doughs. As the kneading period was lengthened the dough became smoother, more velvety, and softer to the touch; the seeming stiffness disappeared and the doughs which were kneaded for 10 and 15 minutes were much stickier than those kneaded for a shorter period of time. This was true even in doughs containing 1.7 parts of high patent flour to 1 part of liquid.

During the fermentation period, however, the doughs which had been rough and uneven seemed to grow smoother until by the time they were ready for the oven, these differences were much less apparent.

The resulting bread showed very little if any difference due to the amount of kneading. In every case, whether a very slack dough or a stiffer dough was used, the texture of the resulting loaves was practically identical. In some cases the volume of the loaves increased by about 5 per cent when the kneading was continued for 10 minutes, but ordinarily there was very little or no difference in the volume. The loaves which were kneaded for 10 and 15 minutes seemed to show less tendency to crack during the baking process. The dough which was kneaded for 15
Plate VII.

Yeast Bread Made from High Patent Flour Showing the Effect of Various Amounts of Kneading on Dough of the Same Consistency.

Flour - A
Grade - High Patent
Ratio - 1 part of liquid to 1.7 parts of flour by weight.

1 minute 2 minutes 5 minutes 7 minutes 10 minutes 15 minutes
Time of mixing and kneading.
minutes seemed softer, and tended to bulge out over the edge of the pan more than did the other loaves. This tendency was frequently noticeable even in the baked loaf and may have been due to a slight weakening of the gluten brought about by the long continued kneading.

Plate VII illustrates a series of loaves which were kneaded 1, 2, 5, 7, 10 and 15 minutes respectively. The irregularity in the shape of some of the loaves was caused by a slightly uneven temperature in the oven, the outer and hotter side of the loaf being baked sooner than the inside or the side nearest the center of the oven.

These results hardly agree with those of Williams, who found that kneading by hand made the crumb whiter and more silky, and the distribution of the gas more even, making a better shaped loaf. This investigator found that kneading for 15 or 20 minutes added considerably to the whiteness and somewhat to the fineness of the bread but this improvement was, she thought, scarcely in proportion to the increase in labor that it involved.

CONCLUSIONS.

1. The optimum ratio of liquid to flour is 1 : 1.7 for patent flours. The proportion of flour decreases slightly when using lower grade flours, when the ratio of 1 : 1.6 seems best. For very low grade flour the ratio of 1 : 1.5 may give the most desirable results.

2. The volume of the bread increases decidedly with the
increase in the flour content of the dough, loaves containing 1.9 parts of flour to 1 part of liquid being 58 per cent larger than those containing 1.2 parts of flour.

3. The shape of the loaf improves with the increase in the flour content up to a certain point, which varies slightly with the grade of flour used. For patent flour the optimum ratio is 1 : 1.7, and stiffer doughs exhibit a decided tendency to crack during the baking process. This tendency seemed to be less noticeable in the lower grade flours.

4. As the flour content increases, the texture of the bread grows gradually finer and more even, the crumb whiter and more springy, and the quality of the loaf in general is improved. The ratio which produces the most desirable texture is 1 : 1.7 for patent flours, and the proportion of liquid to flour increases slightly for lower grade flours.

5. The color and character of the crust improve with the increase in the proportion of the flour. The bloom is better, and it becomes smoother and more pliable as the dough becomes stiffer.

6. The bread made from low grade flours is quite like that made from patent flours in practically all points excepting color and flavor. The color becomes more yellow and the flavor stronger and more characteristic of the wheat flavor, as the flour decreases in quality.
7. Results indicated that bread from low grade flours rise more quickly than that made from patent flours.
8. The yield of bread as expressed by the ratio of the weight of the flour to the weight of the baked loaf decreases gradually with the increase in the flour content. Results showed a decrease in yield from 1:1.51 in the slack doughs to 1:1.39 in the stiff doughs.
9. The loss in weight during mixing and rising decreased from 5.5 to approximately 4.0 per cent of the total weight of the ingredients as the flour was increased from 1.2 to 1.9 parts to 1 part of liquid.

   The loss in weight during the last rising and mixing also decreased with the increase in the flour content. For the same range in the flour content, this loss decreased from 13.8 to 12.9 per cent.
10. The effect of kneading doughs of different degrees of stiffness for varying lengths of time seemed to be negligible, at least as far as texture and general appearance were concerned. In a few cases the volume was slightly increased by long continued kneading.
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