CORRELATION OF BAKING RESULTS WITH SOME PHYSICAL PROPERTIES OF DOUGHS

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INTRODUCTION

Physical properties of flour doughs have been of concern to the bakers of bread ever since the art of bread baking was developed. Bakers of bread associate certain characteristics of doughs as determined by "feel" with quality or the ability of a dough to produce a large loaf of bread with good texture. These quality factors which are "felt" are probably the physical properties being recognized. It has been only recently, however, that the science of measuring physical properties has taken a prominent place among cereal investigations. This may be partly due to an attempt to place the baking of bread upon a scientific basis rather than relying upon the skill of the individual baker. Since the experience of the bakers has indicated the association of certain physical conditions of flour dough with quality factors, an increasing interest has been shown and much investigational work done. With the development of chemistry, physics, mathematics and engineering, progress in studying the physical properties of doughs and their association to baking quality has been made possible.

Recent advances in the determination of the physical properties of flour dough have centered attention upon mechanisms which measure composite effects of elasticity, plasticity and viscous properties as a function of continuous mixing. With the development of new devices for testing physical properties of dough, new problems arise regarding the interpretation of the measurements in the light of practical application. The development of the Swanson-Working (1933) type of recording dough mixer has brought such problems. Several workers have demonstrated the usefulness of the Swanson-Working recording dough mixer as a practical means of measuring physical properties of doughs and have attempted to associate these properties with baking characteristics. While research work with the Swanson-Working recording dough mixer has advanced the knowledge regarding the usefulness of recording dough mixers, no systematic and statistical treatment relating the curve characteristics directly to baking characteristics has been made. To investigate such a possible relationship is the purpose of this study.

REVIEW OF LITERATURE

A flour dough is a unique substance having physical properties similar to liquids and solids. It is a colloidal material having three intermingled properties; elasticity, viscosity, and plasticity. Elasticity is manifested when a dough is stretched and upon removal of the stress it tends to recover its original shape. The elasticity is imperfect as recovery of a dough after removal of the stress may be only partial, depending on whether the elastic limits are exceeded and merge into plastic flow. Plasticity is manifested in a dough when a certain pressure is necessary before flow can begin. Plastic properties merge into viscous properties as soon as the stress is great enough to overcome the yield value. All three properties tend to merge into one another or are affected by each other. Their individual measurement is therefore difficult.

Halton and Scott Blair (1937) after studying the physical properties of dough made the following summary:

> Dough is neither a true solid nor a true liquid but possesses properties associated with both states of matter. The reason why dough combines elastic properties of a solid with viscous properties of a liquid is due to its particular internal structure. Flour dough contains protein chains which behave like coiled springs and are responsible for its elastic behaviour. Those proteins are not, however, linked to each other at all points with equal strength. When the dough is extended some of the linkages break almost at once causing deformation which cannot be recovered (flow), while others maintain the rigid structure of dough. All these adjustments in the protein network have to take place in the presence of a starch-water mixture which, although primarily a fluid also possesses some rigid properties, thus complicating the situation and making impossible the complete relaxation of even those protein units which are capable of truly elastic recovery.

Since the three physical properties of doughs tend to merge into one another a measurement of their composite effects presents an alternative. The measurement of these physical properties has probably been one of the most fruitful lines of investigation. Several mechanical devices for measuring the physical properties of doughs as a function of continuous mixing have been described in the literature.

History of the Recording Dough Mixers

Hogarth (1892) obtained a United States patent for an invention which had provisions for testing different flour characteristics. The machine patent claimed to test the power of the flour to absorb water, the actual consistency, the power required to drive the kneading machine, and the quality of the gluten entering into the composition of the sample being tested. No further literature dealing with the usefulness of this invention could be found. This invention seemed to have been forgotten until Brabender and Hankoczy (Bailey 1940) placed a similar machine on the market.

The Brabender Farinograph was developed in Europe and introduced to America about 1930. The Farinograph consists essentially of a mixing bowl in which two horizontal, helical or spiral-like blades revolve toward each other at a differential speed. The blades are turned by a synchronous motor. The force applied to the mixing blades is exerted on a lever and dynomometer system which indicates pressure in grams. From the lever a recording device is attached which records the magnitude of the force required to turn the blades against each other in a dough. The system is equipped with a thermostat to maintain a constant temperature while mixing. A dampening system is provided to minimize the to and fro swing of the pan while mixing.

Concerning the Brabender Farinograph, Munz and Brabender (1940) stated:

> The Farinograph is adapted to the measurement of dough plasticity as a function of continuous mixing. This instrument has proved successful in estimating the capacity of a strong flour to yield doughs of acceptable properties when blended with weak flours. From the characteristics of Farinograms other dough properties, such as rate of hydration, sensitivity to mixing, and buckiness can be estimated. The Farinograms are of limited value in certain other particulars, however. Thus they fail to reveal the direction and magnitude of the effect of chemical treatments, or the recovery or tendency of the dough to regain certain of its original properties after excessive mixing.

Swanson and Working (1933) discussed the development of a new type of recording dough mixer. During the course of their investigations it was observed that as the dough was mixed an increasing force was required to move the mixing pins through the dough until an optimum was reached at which time a decrease in the force followed. This change in force was registered by a spring steel rod to which was attached the stationary mixing bowl.

These observations led to the suggestion of measuring of the energy input by a recording wattmeter attached in the circuit of the dough mixer. The wattmeter curve indicated the correctness of the observation made while mixing a dough with the pull-fold type mixer. The wattmeter curves also indicated differences which existed between flours in respect to time required to mix the doughs to optimum,amount of energy input at optimum development, and decrease in energy input as the doughs were overmixed. The wattmeter, while having certain advantages, was not particularly suitable as the variable energy losses such as friction could not be estimated.

The next attempt to record the physical properties of a dough resulted in the development of a recording dough mixer in which friction was reduced to the minimum. It was necessary to limit the circular movement of the mixing bowl to one eighth of an inch to avoid collisions between the fixed and revolving pins. The twist given a bowl by four pins revolving in a planetary system against the four fixed pins was magnified by a lever system. On the opposite end of the lever was attached a pen which indicated in a graph the force exerted on the mixing bowl by the revolving pins. The chart on which the graph was made moved slowly. Thus a graph was drawn depicting the consistency of the dough, and hence the physical properties, as a function of continuous mixing. The original recording dough mixer was equipped for adjustments for four mixing speeds, and shock dampening. For each curve, 400 g of flour were required.

As only small quantities of flour are usually available in in variety work at experiment stations, it was desirable to develop a method requiring only small amounts of flour. A micro model of the recording dough mixer, adapted to small samples, was constructed by Dr. E.B. Working and used in studies reported by Larmour, Working and Ofelt (1939). Models of this machine with certain mechanical modifications but still retaining the basic principles are now available commercially. It was with such a commercial model that the work reported in this investigation was done.

A micro recording dough mixer which required only 7 g of flour was described by Malloch (1938). This machine, while designed to test physical properties of flour doughs, essentially like other recording dough mixers, differed in type of mixing, speed of revolving pins and type of curve produced. He considered the following curve characteristics significant: (1) height, (2) time required to develop a dough to maximum consistency, (3) position and sharpness of the break following the maximum height, and (4) the width of the curve following the break. The break in the curve following maximum resistance to revolving pins, which is not found in curves made with other recording dough mixers, was found to be an inherent factor. The break in the curve was neither influenced by protein content, absorption nor size of sample. A partial correlation coefficient (r = +0.44), independent of protein content, was obtained between the break and loaf volume in using 28 samples. This indicated that this break in the curve was associated with some protein quality factor. Malloch stated that any interpretation placed on the recording dough mixer curve must be closely associated with baking characteristics to be of utmost value.

Absorption Studies

The determination of the absorption or the amount of water to add to give a dough the proper consistency for best baking results is difficult. Near and Sullivan (1935) used the Brabender Farinograph to measure the amount of water necessary to bring all doughs to a given consistency. Flours which had been previously baked and the absorptions determined were used first to establish the consistency level. Absorption was found to increase with increasing protein content and improving gluten quality.

Halton (1938) studied the relationship of absorption to physical properties and baking quality. He concluded that proper absorption for a flour was a compromise between a desirable high viscosity and a low modulus of elasticity. High viscosity was desirable as it imparted rigid properties to the dough and aided in limiting the flow. A low modulus of elasticity was desirable as it increased the ease with which gas produced by fermentation could expand the dough. The ratio of viscosity to elasticity was lowered by increasing absorption.

Merritt and Bailey (1939) investigated the relationship of absorption to mobility with the use of the Farinograph. These authors concluded that optimum absorption as determined by the baked loaf of bread often differed from the absorption necessary to bring all dough to a common consistency when taken out of the mixer. However, the amount of water required to bring all doughs to a common consistency increased with the strength of the flour which was in agreement with commercial practice.

Aitken and Geddes (1939) enriched flours with dry gluten and found absorption requirements to increase with increasing protein.

Swanson (1941) indicated the influence which absorption has upon the micro recording dough mixer curve. While increasing the absorption caused the height of the curve to be materially reduced; the main varietal pattern was retained. Too high an absorption may cause a curve to have a development slope which is concave.

Ofelt and Sandstedt (1941) attempted to bring the Swanson-Working recording dough mixer curves to a common height as is customary with the Farinogram by adjustment of the absorption. That such a procedure did not bring all doughs to a common consistency was evident because the high protein sample gave a very narrow, regular curve indicative of a "slack" dough, whereas the low protein sample gave a very wide irregular curve indicative of a stiff dough.

Absorption, or the amount of water in a dough that is necessary to give optimum handling properties, varies with the formula and the amount of water present in the flour. In order that the absorption for a series of flours be comparable it is necessary that absorption be adjusted to a common moisture basis. Merritt and Stamberg (1941) and Stamberg and Merritt (1941) gave a method for calculating absorption on a corrected moisture basis and pointed out the necessity of using a constant dry matter weight when making dough mixer curves or baking. These authors found good agreement between the minimum mobility by the Farinograph and plasticity of flour doughs measured by a plastometer, when using an optimum absorption established by baking.

Markley (1939) suggested that flour absorption for baking could be made a function of the protein content when samples are mixed to the "clean up".

The effect of varying the flour-water ratio in doughs was studied by Markley and Bailey (1938) by means of the Brabender Farinograph. These workers showed that the viscosity of doughs increased in curvilinear fashion as the flour concentration increased. A straight line was obtained when the logarithm of minimum mobility was plotted against the logarithm of flour concentration. Time required to mix a dough to minimum mobility increased in curvilinear fashion with increase in absorption.

A high significant correlation, r = +0.77 (1 percent point =+0.27), was found between absorption and protein content by Markley, Bailey, and Harrington (1939). Absorptions were adjusted so that all doughs when mixed to optimum development had a consistency of 550 Brabender units. That the correlation between protein content and absorption might have been higher if a less diverse series of flour had been used was indicated with a series of Canadian flours which gave a correlation coefficient of r = +0.99. These authors suggested that the absorption determination be made a function of the protein content rather than relying upon the skill of the individual baker.

Johnson and Swanson (1942) determined the absorption for making micro mixer curves from a previously determined absorption protein content regression line. The regression line was established by adding enough water to a flour to yield a dough with optimum handling properties for several protein levels and varieties.

Mixing Studies

The physical properties of the doughs are dependent to some extent upon the mixing treatment. Recording dough mixers have done much to encourage investigations of mixing and its effect on the physical properties of doughs. Swanson and Working (1933) have shown that as a dough is mixed, the consistency becomes greater until a maximum is reached, after which the resistance to mixing decreases. Likewise, they showed that energy input increased until an optimum was reached, after which a decrease in energy input followed. These investigators indicated the differences existing between flours in the amount of energy required to mix to optimum consistency. Swanson (1939) concluded that the recording dough mixer was designed to test the rate of dough development, resistance to mechanical action and rate and extent of increase in mobility of dough as a result of mechanical treatment.

Markley (1938) investigated the mixing requirements of flour samples diluted with starch to give several protein levels. The time required to mix a dough to minimum mobility was essentially constant until an eight percent protein content was reached. Above eight percent protein the mixing time increased in linear form with increasing protein content. Markley postulated that at least seven percent protein was required to form a continuous protein phase or a protein envelope around the starch granules. His work was done with the Brabender Farinograph.

Ofelt and Sandstedt (1941) diluted high protein samples with starch and found that the time required to mix to maximum consistency with the Swanson-Working recording dough mixer increased with decreasing protein. Similar evidence was presented by Bayfield, Working and Harris (1941). This does not agree with the evidence obtained with the Brabender Farinograph.

Aitken and Geddes (1939) concluded that development time as measured by the Farinograph increases with increasing protein content. This work was in agreement with other results obtained on the Brabender Farinograph.

Markley, Bailey and Harrington (1939) obtained a significant correlation coefficient, r = +0.88 (1 percent point= 0.27), between the amount of mixing time required to bring all doughs to a minimum mobility and protein content. They suggested that mixing time for flours be determined from a sliding scale based on protein content rather than from a constant mixing time. This work was done with the Brabender Farinograph.

The effect of mixing on the physical properties of doughs was studied by Bohn and Bailey (1936). The amount of mixing which gives maximum dryness of "feel" was found to give an optimum loaf of bread. Optimum bread was obtained at the mixing time which corresponded to the point of minimum mobility as shown by the Farinograph curve. These authors concluded that minimum mobility and dryness of feel were closely related. Stress readings with a "stress meter" designed to measure mobile flow or plasticity, were highly correlated with consistency as determined by the Brabender Farinograph.

Swanson (1941) considered that when a flour was mixed until it had a smooth appearance and had reached a maximum consistency, that the protein molecules were oriented in a parallel pattern. Larger quantities of protein increased the density and hence an increase in resistance to the mixing pins and an increase in curve height could be expected.

Barmore, Finney and McCluggage (1941) studied the relative value of optimum mixing time as compared to fixed mixing time when evaluating quality of wheat varieties to produce desirable bread. They demonstrated that any mixing time other than optimum resulted in a decrease in loaf volume and quality of the finished loaf of bread. The optimum mixing time as indicated by the baker's judgment as to when the dough was fully developed paralleled the time of development as indicated by the micro recording mixer curve. The work reported by these authors (1942) supported their previous conclusions.

Bayfield, Working and Harris (1941) compared optimum and fixed mixing time for a series of varieties. No definite conclusions regarding the merit of the two procedures were made. Those varieties whose mixing time deviated most from the fixed mixing time were found, in some instances, to give inferior bread.

Markley and Bailey (1939) studied the increase in mobility of doughs upon either prolonged mixing or fermentation with the effects of varied mixing times upon loaf characteristics. It was found that mobility of a dough increased as fermentation increased. This increased mobility due to fermentation was similar to increase in mobility obtained by prolonged mixing. Increase in mobility due to overmixing as measured with a Farinograph was not found to be correlated neither with five minute mix loaf volume nor mixing stability score nor protein content. Their mixing stability score, as expressed by $\frac{\text{5 min. mix loaf vol.}}{\text{2 min. mix loaf vol.}}$, was negatively correlated with the two minute mix loaf volume. It was suggested that relative damage to the quality of bread by overmixing was greatest in high protein flours. They postulated that failure to obtain a significant correlation between increased mobility and mixing stability was due to the fact that neither the two minute nor the five minute mixing treatment had a true relation to the individual samples.

Halton and Scott Blair (1937) investigated the relationship of viscosity and modulus of elasticity to bread making qualities. Excessive mixing lowered both the viscosity and elasticity and resulted in inferior bread. Viscosity and elasticity tended to increase upon resting the dough, following excessive mixing.

The work of Baker and Mize (1937) indicated that the type of gas surrounding the mixed dough had a pronounced effect upon the physical properties. Thus doughs after a prolonged mixing in vacuum did not become soft, sticky and of low viscosity as did doughs mixed in air or oxygen. Doughs mixed in hydrogen tended to yield doughs having characteristics similar to freshly milled flours. These authors assumed that hydrogen gas reduced some substance within the flour which had been previously oxidized through the process of ageing. They suggested that mixing orients the protein molecules in the dough and hence sensitizes them to action of oxidizing and reducing agents.

Munz and Brabender (1940) demonstrated that overmixed doughs lose extensibility and increase in resistance to extension on resting. Flours which showed greatest sensitivity to overmixing generally had the greatest tendency to recover the properties of a normally mixed dough. Optimal mixing time was considered a relative term and must be qualified by type of mixer, formula and chemical treatment accorded the flour.

Factors Affecting Physical Properties of Doughs as Indicated by Recording Dough Mixer Curves

Bohn and Bailey (1937) studied several factors which affect the physical conditions of flour doughs. Stress readings or plasticity decreased as fermentation progressed. Mobility increased as elasticity decreased. Sodium chloride increased the band width of the Farinogram and also increased the stress reading. Shortenings such as lard, compound shortening or hydrogenated oils increased the time required to reach a point of minimum mobility. Dry milk solids caused a more pliable dough and increased the mixing time. Papain decreased the stress reading, the effect becoming more noticeable as fermentation time progressed.

In a series of papers Swanson (1940a, 1940b and 1941; Swanson and Andrews, 1942) discussed several factors which influence the physical properties of dough. He (1940a) stated, "The characteristics of a dough mixer curve are the resultant of changing plastic, elastic, and viscous properties of dough while being mixed." A study of the effect of autolysis on the pattern of mixer curves indicated that resistance to the mixing pins was lowered progressively as the autolysis time was increased up to certain limits. Autolysed doughs reacted much like doughs treated with papain. Potassium bromate had little effect on retarding the effect of autolysis.

The effect of enzymes, enzyme activators, and enzyme inhibitors on curve characteristics was studied by Swanson (1940b). Pepsin, trypsin, and papain, when given a ten minute incubation period, decreased the height and width, but increased the weakening angle of the curve. Extracts of wheat germ and cysteine mono-hydrochloride had similar effects. Potassium bromate had little inhibiting effect upon autolysis or enzymatic activity. Diastatic enzymes had little effect on the curve characteristics.

The effect of protein on curve characteristics was studied by Swanson (1941). An increase in protein content increased the height of the curve while quality of the protein determined the varietal pattern to a large extent. Flours diluted with wheat starch until they contained 3.6 percent protein retained varietal characteristics. Samples diluted with corn starch to a protein content below five percent gave very wide curves. He concluded that width of curve was not necessarily a measure of elasticity in a dough as it was difficult to visualize a starch-water system having a modulus of elasticity under a continuous shearing.

The effect of surface active agents on the characteristics of recording dough mixer curves was investigated by Swanson and Andrews (1942). Surface active agents had pronounced effects on curve patterns. The amount of mixing required to develop doughs to maximum consistency was noticeably longer when surface active agents were added to the dough. They advanced the theory that the surface active agents effected a reduction in the interfacial tensions and allowed greater intramolecular penetration of the water; also, that various bonds may be broken, changing the polyhedral molecular form of the protein through laminar to fibrillar form. It was suggested by these authors that the action of surface active agents was essentially one of denaturation of the gluten proteins.

That starch affects the physical properties of a dough was shown by Markley (1937). The Farinograph was used as a plastometer to measure changes in mobility, as a function of continuous shearing, of starch-water mixtures. Viscosity of the starch-water systems decreased while being mixed but increased upon resting. This author pointed out that starch and water form a thixotropic system in which a gel at rest becomes a sol upon the application of a shearing force.

Baking Procedures

American cereal chemists and bakers have long relied upon baking results as the final criterion of flour quality. This criterion has received support because bread is the major product for which flour is used. If a flour can be made to produce satisfactory bread for the public then the other quality measurements may appear to be of lesser importance. However, some doubt may be cast on this philosophy in the light of commercial production of bread. The ease with which a flour can be made into satisfactory bread must be considered. Thus physical properties whether they are related or not to the final product, bread, must be given due emphasis in judging the quality of flour.

Two general terms, often employed indiscriminately, are used to describe baking results. Baking strength and baking quality, while not having the same significance, have often been used to mean the same thing. Larmour, Working and Ofelt (1939) maintained that with adequate methods of evaluation, baking strength is analogous to the ability of a flour to produce a loaf of bread of large volume, and good texture and grain. Baking quality was expressed in terms of loaf volume to be expected from the protein content. Provided adequate methods are used the quality of flour as judged by the baking of bread is a function of two factors, protein content and protein quality.

Much literature deals with different baking procedures. No attempt will be made to review all methods but rather, to indicate recent trends. Prior to 1930 literature dealing with protein content and loaf volume indicated a non-linear relationship. The data of Thomas (1917) showed that above 14 to 15 percent of protein the loaf volume tended to decrease. The baking results reported were obtained with a lean formula and probably devoid of any bread improvers.

The American Association of Cereal Chemists (Blish, 1928) in an attempt to standardize experimental baking have specified a procedure familiarly known as the A.A.C.C. basic method. The original A.A.C.C. basic formula contained 3 percent yeast, 2.5 percent sugar, 1 percent salt as basic ingredients with constant mix, fermentation and proof time. These specifications originally called for a fixed formula, absorption, mixing time, fermentation, and proof time. It appears now that few people adhere to the procedure originally outlined with this formula. Geddes (1934) pointed out that the A.A.C.C. baking procedure served as a reference point and that supplementary tests or additions may be considered appropriate. Supplements such as variable absorption, mixing time, fermentation time, oxidizing agents, and diastatic supplements were considered valuable.

Larmour and Macleod (1929) studied the application of the potassium bromate differential test in the estimation of the quality of Canadian hard red spring wheats. These authors concluded that the addition of small quantities of potassium bromate to the A.A.C.C. basic test formula was desirable. The addition of small quantities of potassium bromate resulted in greater positive response in terms of loaf volume for the higher protein samples. Harris (1930) and Larmour (1931) demonstrated a higher correlation between loaf volume and protein content when the test formula included potassium bromate.

The balance between gas production and gas retention during dough development by fermentation has been recognized as important in the production of desirable bread. It has been generally accepted that in testing flours by baking that insufficient gas should not be tolerated as it forms a limiting factor. Larmour and Brockington (1934) concluded that only estimates of baking strength were obtainable unless adequate sugar was present throughout fermentation. Punching and potassium bromate were found to influence gas retention and the volume of the resultant loaf.

Bayfield and Shiple (1933) showed the inadequacy of the lean A.A.C.C. basic baking formula for evaluation of soft red winter wheats. Their results indicated that the addition of potassium bromate and the increase of the fermentable sugar level aided materially in testing the potential qualities of wheat gluten.

Geddes and McCalla (1934) concluded that small amounts of potassium bromate were necessary for baking experimentally milled flours. It was also found necessary to eliminate yeast starvation throughout fermentation by adequate amounts of sugar in order to make loaf volume independent of the sugar level. The incorporation of 0.1 percent ammonium di-hydrogen phosphate, 0.5 percent diastatic malt (200° Lintner) and 2.5 percent additional sugar to the basic formula was found to eliminate yeast starvation from being a limiting factor in producing desirable bread.

Twenty four baking procedures were studied by Aitken and Geddes (1934). Variations from the A.A.C.C. basic formula included variable absorption, mixing time, fermentation time, and various supplements such as additional sugar, oxidizing agents and diastatic malt. These authors concluded that the procedure giving the best differentiation between flours included in addition to the basic A.A.C.C. method the following ingredients: 0.3 g high diastatic malt (200° Lintner), 0.1 g ammonium di-hydrogen phosphate, and 0.001 g of potassium bromate and 2.5 g of additional sugar per 100 g of flour. This is now familiarly known as the malt-phosphate-bromate formula. These authors asserted that loaf volume must be considered the criterion of baking strength provided that adequate methods are employed to obtain the data.

Harris and Sanderson (1938) compared the A.A.C.C. basic formula and the malt-phosphate-bromate formula (Aitken and Geddes, 1934) on a series of hard red spring wheats. A correlation coefficient, $r = +0.8361$ $(P < 0.0001)$ was obtained between loaf volume and protein content with the malt-phosphate-bromate formula as compared with $r = +0.5892$ $(P < 0.0001)$ for the A.A.C.C. baking formula. These authors concluded that for North Dakota hard red spring wheats the malt-phosphate-bromate formula gave better differentiation than the A.A.C.C. basic formula.

The use of milk in commercial baking is a common practice. Its wide use in experimental baking is relatively recent. Barmore, Finney and McCluggage (1939) studied 20 different baking formulas and concluded that a rich, highly bromated, commercial type formula was best suited for testing potential bread making qualities of varieties grown in the hard red winter wheat area. These authors found the linear relation between loaf volume and protein content to be valuable as a means of adjusting loaf volumes to a given protein basis for comparison of their baking quality.

Larmour, Working and Ofelt (1939) demonstrated the usefulness of a commercial type formula containing six percent dry milk solids. Milk was found to impart a "buffering effect" against excessive amounts of potassium bromate which was deemed necessary to bring out the potentiality of a flour to produce desirable bread.

Bayfield, Working and Harris (1941) used a rich, commercial type formula for variety evaluation. Linearity between protein content and loaf volume was obtained. The regression of loaf volume on protein content varied among the varieties which suggested that change in loaf volume with protein content was to some degree dependent on inherent quality factors. It was concluded that further testing would be necessary to establish whether or not the regression lines of loaf volume on protein content for the varieties were dependent upon inherent factors.

Interpretation of Physical Properties as Related to Baking Characteristics

American cereal chemists have long relied upon baking tests as the final criterion of flour quality. Geddes, Larmour and Mangels (1934) while making comments about the adaptation of American methods of testing flour to European conditions, maintained that any physical means of testing flour quality must of necessity be highly correlated with baking results. However, it must be recognized that the ability of the flour to produce a desirable loaf of bread may be altered by changes in formula and method of baking and that other factors aside from those exhibited in a baked product may be important. If any physical method of testing quality is to be used instead of baking, it must then be highly correlated with baking results.

Kunz and Brabender (1940) stated that the Farinograph was adapted to the measurement of dough plasticity as a function of continuous mixing. Some of the important characteristics of the Farinogram observed by Stamberg and Merritt (1941) were: height of curve (this is usually adjusted by the absorption), time to reach maximum plasticity, slope of curve from peak to some arbitrary point and width of curve at various points. These authors did not correlate these curve characteristics directly with baking properties.

The relationship of the normal Farinogram to the baking strength of western Canadian wheat samples was studied by Geddes, Aitken and Fisher (1940). The following curve characteristics were considered of major importance: dough development angle or the angle made by the first portion of the curve and a horizontal line drawn from the peak and the down slope of the curve to an arbitrary point, and mean band width or the average width at point of minimum mobility or peak of the curve.

Higher simple correlation coefficients between protein content and loaf volume were obtained than between loaf volume and the principal Farinogram characteristics. Mean band width was not significantly correlated with loaf volume. Dough development angles and increases in mobility upon over mixing were negatively correlated. Dough development time was positively correlated with protein content and loaf volume. Partial correlation coefficients, independent of protein content, between curve characteristics and loaf volume were either of low order or nonsignificant. These authors concluded that no increased precision in estimating loaf volume from protein content was obtained by the inclusion of any Farinogram measurement. The greatest utility of the Farinogram was considered largely as a source of accessary information such as an aid in determining correct absorption, optimum mixing time and mixing tolerance.

Swanson and Working (1933) demonstrated differences existing in recording dough mixer curves made with the Swanson-Working recording dough mixer using diverse type flours. Concerning these differences these authors stated, "It will be necessary to obtain curves of a considerable number of flours from different wheat classes in order to establish correlation between curve characteristics and baking quality". Swanson (1939) showed further the different curves produced by diverse types of flour. Some flours showed a more rapid rate of hydration or development time, and some of the flours broke down rapidly following the peak.

An interpretation of the recording dough mixer curve characteristics in the light of physical properties and baking characteristics was given by Swanson and Clark (1936). They divided the mixer curve into seven curve characteristics.

The first, dough development time, or the time necessary to reach a peak on the curve, was considered the mixing time required to mix a dough to optimum development. They stated that mixing time of a flour could be predicted from the curve after correlation between the curve development time and the particular bread mixer had been established.

Second, the absorption-protein factor which was indicated by the height of the curve. The curve height was found to increase directly with protein content and to decrease inversely with absorption.

Third, the peak elasticity as indicated by the width of the curve at the point of optimum development. This was of importance inasmuch as modern baking processes using machinery requires doughs with good elastic properties. Later, Swanson (1940) placed a reservation on this meaning of curve width because he found that starch and water mixtures gave a wide curve band. It was difficult to conceive that a starch-water mixture under a shearing force would possess much elasticity.

Fourth, final elasticity was indicated by the width of the curve when a dough was overmixed until little resistance was offered to the revolving pins. This curve characteristic varied with different flours.

Fifth, rate of dough weakening was expressed by the angle formed between the horizontal line drawn from the peak and the general slope of the curve beyond the peak. Curves exhibiting a small angle were considered to possess the greatest tolerance to overmixing.

Sixth, the range of adaptability was determined by drawing a line through the center of the peak and measuring the length of time this line remained on the curve. Flours which produced curves with a longer time had a better range of adaptability.

Seventh, the area of dough weakening was obtained by dividing the sum of peak elasticity and final elasticity by two and multiplying by the absorption-protein factor. By this factor the tolerance of the flour to overmixing was indicated.

Swanson (1936) studied further the relationship of the recording dough mixer curve to quality in wheat varieties. Flours which gave a small area under the curves and a rapid breakdown following the peak were considered to have a low mixing tolerance. Curves with a broad top and an amplitude beyond the peak which persists was indicative of a good bread flour. Because mixer curves have characteristics which are a function of varietal differences he suggested that preliminary testing of new varieties may be made by means of the recording dough mixer. He cautioned, however, that mixer curve information should be supplemented with baking data when testing new wheats.

Larmour, Working and Ofelt (1939) studied a series of wheat varieties at several protein levels by means of baking and recording mixer curves. No attempt was made to correlate statistically the curve characteristics with baking but the following summary was given:

> The greatest usefulness of the mixing curves, provided the protein content is known, is to characterize the type to which the flour belongs. They serve to establish quality differences between wheats that may or may not be equal in strength, and thus give an indication of the manner in which they may be expected to perform.

Bayfield, Working and Harris (1941) indicated the difference in mixer curves existing between protein levels of several hard red winter varieties. Micro mixer curves were extremely different among varieties. Mixing time became shorter with increasing protein while the height of the curve increased. However, no attempt was made by these authors to segregate the curve characteristics and correlate them directly to baking results.

MATERIALS AND METHODS

Sixty-three flours representing 12 pure wheat varieties each having four to six protein levels were used. These samples were composites, made according to protein content and variety, from wheats grown in cooperative testing plots in the state of Kansas.[1] Each composite sample consisted of several smaller samples of approximately the same protein content. These samples were chosen because they represented a cross section of wheat quality. Ten varieties, Turkey, Tenmarq, Comanche, Pawnee, Blackhull, Early Blackhull, Chiefkan, Nebred, Kanred and Cheyenne were representative of the hard red winter class of wheat. Kawvale was a semi-hard wheat, while

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[1] Cooperative plots under the direction of A. L. Clapp of the Agronomy department.

Clarkan was true soft wheat, both classed in grain grading as soft red winter wheat.

All wheats were milled on a Buhler experimental mill located in an air conditioned room held at approximately 78°F. and 65 percent relative humidity. Analysis for all the wheats and flours were made in the laboratories of the Milling Department of the Kansas State College, according to approved procedures.

All flours were held in a warm room for six weeks to age before removing to a cold storage room held at about 45°F. prior to baking or making of micro recording dough mixer curves.

The absorption was obtained through the use of an absorption-protein content regression equation. (Absorption 15 percent moisture basis) = 0.92 flour protein + 49.03). This regression equation was established as follows: The absorption, corrected to a 15 percent moisture basis, was determined manually by the "feel" of a high and low protein dough of each variety. The regression of absorption on protein content was then computed by the method of least squares (Snedecor, 1940).

Micro mixer curves (Plate I) were made before baking. The procedure for making these curves was as follows: The flours were weighed to give 35 grams of dry matter and adjustments in calculated absorption were made for the moisture of the flour according to recommendation of Merritt and Stamberg (1941). The flours were placed in the mixing bowl and the predetermined amount of water added. The flour-water mixture was mixed in a Swanson-Working-National recording dough mixer using a number nine spring setting. The mixing was continued through a peak and until little resistance to the revolving pins was evident. Most curves required about seven minutes. To obviate any effect which temperature might have on the curves, all ingredients and apparatus were held at about 77°F. in an air-conditioned room.

The flours were baked by three procedures; the malt-phosphate-bromate formula of Aitken and Geddes (1934), the rich formula of Ofelt and Larmour (1940), and the latter formula with overmixing for two minutes beyond the peak indicated by the micro mixer curve. The formulas used the following ingredients:

Ingredient	M-P-B 1/ grams	Rich 2/ grams
Flour (15% moisture basis.)	100	100
Sugar	5.0	6.0
Salt	1.0	1.5
Yeast	3.0	2.0
Shortening	0.0	3.0
Dry milk solids	0.0	6.0
$KBrO_3$	0.001	0.004
Malt syrup	0.3 (200°L.)	0.25 (120°L.)
$NH_4H_2PO_4$	0.1	0.0
Water	As calculated from regression equation.	Plus 2 percent over that calculated by regression equation.

1/Malt-phosphate-bromate formula. (Aitken and Geddes, 1934)
2/Rich formula. (Ofelt and Larmour, 1940)

The doughs for baking were mixed at 96 revolutions per minute in a Swanson-Working type mixer using a bowl with two opposite pins. All doughs were mixed to optimum development as determined from the micro mixer curves. A preliminary study showed that the mixing time shown by the curve was about one-fourth minute too long for the malt-phosphate-bromate formula, while for the rich formula an increase of about one-half minute in mixing time was required. The increase of mixing time required by the rich formula confirms the work of Ofelt (1939), Harris (1940) and West (1941).

Yeast, sugar, salt, malt, and potassium bromate were added by burettes from stock solutions of proper concentration. Any additional water required was added from another burette. Ammonium di-hydrogen phosphate, when used, was added with the sugar, salt and malt solution. Dry milk solids were weighed and blended with the flour. Hydrogenated shortening was added to the flour with a pipette calibrated to deliver three grams of fat heated to 55°C.

The doughs were fermented at 30°C. and at approximately 85 percent relative humidity, for intervals of 105 minutes (to first punch), 50 minutes (to second punch), and 25 minutes (to pan), or a total of three hours. The National pup sheeter was used for punching and the Thompson laboratory molder for molding. Proofing was at 30°C. and about 85 percent relative humidity for 55 minutes. Tall form, approved baking pans were used. All doughs were baked in an electric Despatch oven at 425°F. for

25 minutes. The oven was equipped with a rotating hearth (Finney and Barmore 1939). Loaf volumes and weights were recorded immediately after the baked loaves were removed from the oven. Approximately 16 hours after baking, all loaves were cut and scored for texture, grain, and crumb color. One loaf was baked from each flour on successive days until satisfactory loaf volumes checking within 25 cc were obtained. The baking laboratory in which all the baking was done was maintained at a temperature of 77 ±1°F.

EXPERIMENTAL RESULTS

The analytical data for wheats and flours are presented in Table 1 and baking data are given in Table 2. All tabular data are arranged similarly in order of increasing loaf volume within a given variety. The data obtained from the curves shown in Plate I are presented in Table 3. The data from the curves were obtained according to the diagram presented in Plate II.

The means for loaf volumes, protein content and curve characteristics for each variety are summarized in Table 4. As the different composites used in this study were made from wheat samples grown under different environments it is realized that the data in Table 4 are not intended for ranking the varieties. Also, because the varieties did not have identical mean protein contents, the means in Table 4 for each variety are not directly comparable.

Table 1. Analytical data for wheats and flours used in this investigation.

Serial number	Curve number Plate I	Test weight lb.	Flour yield %	Wheat 1/ prot. %	Wheat moist. %	Wheat 1/ ash %	Flour 1/ prot. %	Flour 1/ moist. %	Flour 1/ ash %	Flour 1,2/ absorp. %
				Turkey (C. I. 1558)						
1688	1	59.6	68.9	9.4	12.4	1.91	8.1	14.6	0.428	56.8
1689	2	59.2	70.4	10.2	12.4	1.85	9.0	14.0	0.435	57.4
1690	3	58.7	69.7	11.4	12.4	1.81	10.4	14.3	0.436	58.7
1691	4	56.7	70.7	13.2	12.1	1.79	11.6	14.2	0.456	59.7
1692	5	58.1	70.5	14.5	12.1	1.77	13.2	14.0	0.455	61.2
1693	6	56.6	70.0	15.7	12.3	2.00	14.5	13.7	0.453	62.4
				Tenmarq						
1694	7	58.0	69.7	9.2	12.3	1.66	8.6	14.0	0.385	57.0
1695	8	59.6	68.2	10.2	12.0	1.70	9.3	14.3	0.417	57.8
1696	9	58.4	69.4	11.7	12.1	1.68	10.5	13.8	0.424	58.8
1697	10	57.1	68.7	12.8	11.9	1.77	11.8	13.9	0.434	60.0
1698	11	57.2	70.4	14.1	12.1	1.74	13.2	13.7	0.443	61.2
1699	12	54.4	69.3	16.1	12.3	2.17	15.2	13.7	0.502	62.9
				Comanche						
1737	13	58.3	71.6	10.3	12.0	1.72	9.2	13.5	0.393	57.6
1738	14	58.7	69.5	11.3	12.0	1.72	10.4	13.7	0.402	58.7
1739	15	58.8	70.3	12.9	12.1	1.65	11.9	13.6	0.409	60.0
1740	16	58.7	70.4	14.3	11.9	1.86	13.3	13.5	0.401	61.3
1741	17	57.9	70.0	14.5	11.9	1.81	14.5	13.5	0.413	62.3
1742	18	54.6	68.4	16.7	12.0	2.12	16.1	13.0	0.459	63.8

Table 1. (cont.)

					Pawnee					
1731	19	60.5	71.4	9.3	12.4	1.47	8.6	13.9	0.387	57.0
1732	20	60.6	69.9	10.5	11.9	1.72	9.5	13.8	0.428	57.8
1733	21	60.3	69.3	11.3	11.9	1.80	10.3	13.7	0.424	58.6
1734	22	58.8	70.2	12.8	11.9	1.61	11.8	13.5	0.405	60.0
1735	23	59.0	70.8	14.1	11.8	1.50	13.2	13.4	0.414	61.1
1736	24	57.0	69.4	16.0	12.1	1.76	14.9	13.4	0.444	62.7
					Blackhull					
1700	25	61.7	66.8	9.0	12.4	1.69	8.7	14.0	0.395	57.1
1701	26	60.6	68.8	10.1	11.9	1.77	9.4	14.0	0.435	57.8
1702	27	59.4	68.8	11.5	12.4	1.85	10.7	13.4	0.422	58.9
1703	28	58.1	68.0	13.0	12.2	1.87	12.3	13.3	0.431	60.3
1704	29	59.2	67.5	14.1	12.2	1.79	13.6	13.8	0.404	61.5
1705	30	57.9	68.7	15.0	12.4	2.05	14.5	13.6	0.413	62.1
					Early Blackhull					
1725	31	60.4	66.4	10.4	12.1	1.88	9.4	13.3	0.422	57.7
1726	32	58.9	68.1	11.6	12.2	1.93	10.7	13.5	0.403	58.9
1727	33	59.0	68.5	13.0	12.2	1.85	12.0	13.0	0.410	60.1
1728	34	57.2	68.9	14.0	10.9	1.84	13.3	13.2	0.401	61.3
1729	35	56.5	66.4	15.9	12.2	1.93	15.2	13.3	0.406	62.9
1730	36	54.6	69.0	17.2	12.3	2.17	16.5	12.7	0.452	63.9

Table 1.(cont.)

					Chiofkan					
1710	37	62.1	67.3	10.4	12.1	1.74	9.9	14.0	0.445	58.2
1711	38	62.2	69.7	11.4	12.3	1.69	10.9	13.5	0.432	59.1
1712	39	60.5	70.8	12.9	12.0	1.75	12.1	13.4	0.422	60.1
1713	40	60.9	68.3	14.2	12.1	1.60	12.9	13.8	0.404	60.9
1714	41	59.6	67.0	16.0	12.4	1.35	15.0	14.3	0.506	62.1
					Nebred					
1706	42	60.6	73.4	11.6	12.2	1.61	10.9	13.9	0.444	59.1
1707	43	58.7	71.7	12.9	12.4	1.84	12.0	13.7	0.473	60.1
1708	44	59.6	69.9	14.2	11.9	1.72	13.2	13.7	0.404	61.2
1709	45	57.9	69.5	16.2	12.0	1.96	15.0	13.9	0.424	62.8
					Kanred					
1743	46	58.7	68.2	11.7	12.2	1.67	10.8	13.4	0.438	59.0
1744	47	57.7	67.6	12.8	11.9	1.66	11.8	13.7	0.416	59.9
1745	48	55.2	68.8	14.5	12.3	2.01	13.0	13.4	0.479	61.0
1746	49	56.6	71.6	15.7	12.3	1.92	14.7	13.2	0.439	62.6
					Cheyenne					
1747	50	59.8	72.4	10.2	12.5	1.63	9.3	13.3	0.435	57.7
1748	51	57.2	71.2	10.9	12.1	1.78	9.9	13.0	0.475	58.2
1749	52	60.2	72.7	12.7	12.0	1.60	11.2	13.0	0.434	59.2
1750	53	60.1	72.1	14.3	12.3	1.74	12.8	13.3	0.406	60.3

Table 1. (concl.)

					Kawvale					
1715	54	58.7	69.4	9.3	12.3	1.57	7.8	12.9	0.435	56.5
1716	55	60.3	68.7	10.4	12.0	1.76	9.3	12.9	0.486	57.7
1717	56	58.8	73.3	11.3	12.2	1.91	10.3	12.9	0.498	58.6
1718	57	55.9	69.0	13.4	12.1	1.98	12.3	13.4	0.471	60.3
1719	58	57.2	69.7	14.2	12.2	1.70	13.0	12.7	0.477	61.0
1720	59	57.0	69.3	15.8	12.4	1.74	14.3	13.0	0.448	62.1
					Clarkan					
1721	60	61.0	69.0	10.3	12.2	1.87	9.3	12.4	0.408	57.7
1722	61	61.4	65.2	11.4	12.4	1.86	10.3	12.6	0.397	58.6
1723	62	57.8	68.2	12.9	12.2	1.83	11.5	12.2	0.384	59.6
1724	63	61.2	68.0	14.1	12.7	1.60	12.9	13.0	0.319	61.0

1/ 15 percent moisture basis.

2/ Interpolated from flour protein-absorption graph, equation of which is: Flour absorption (15% moisture basis) = 0.92 flour protein + 49.03.

Table 2. Baking data for flours used in this investigation.

Serial number	Curve number	Malt-phosphate-bromate: Loaf vol. cc	Malt-phosphate-bromate: Texture 1/ grain %	Malt-phosphate-bromate: Crumb 2/ color %	Rich: Loaf vol. cc	Rich: Texture 1/ grain %	Rich: Crumb 2/ color %	Rich overmixed: Loaf vol. cc	Rich overmixed: Texture 1/ grain %	Rich overmixed: Crumb 2/ color %
				Turkey (C.I. 1558)						
1688	1	600	70 c	73 cy	700	78 c	76 cy	663	75 c	79 cy
1689	2	618	75 c	72 y	745	80 c	71 cy	708	77 c	80 cy
1690	3	770	78 c	73 y	843	81 c	75 cy	768	79 c	81 cy
1691	4	828	73 c	74 cy	905	84 c	78 cy	820	81 c	81 cy
1692	5	938	80 c	80 cr	1025	85 c	80 cy	878	83 c	83 cy
1693	6	1055	72 c	77 cy	1085	77 c	82 cy	953	82 c	84 cy
				Tenmarq						
1694	7	603	73 c	83 cy	655	77 c	84 cy	625	79 c	80 cr
1695	8	665	75 c	80 cy	700	77 c	83 cr	668	79 c	82 cr
1696	9	773	79 c	80 cr	780	84 c	87 cw	733	81 c	84 cr
1697	10	855	79 c	80 cr	865	87 c	88 cy	785	83 c	85 cr
1698	11	911	80 c	72 cy	970	84 c	85 cr	843	86 c	88 cr
1699	12	1050	78 c	82 cy	1066	82 c	88 cy	940	84 c	88 cr
				Comanche						
1737	13	640	72 c	75 cy	712	78 c	81 cr	665	73 c	80 cy
1738	14	725	77 c	75 cy	752	82 c	83 cr	723	77 c	80 cy
1739	15	829	81 c	79 cy	873	85 c	84 cr	775	77 c	82 cy
1740	16	909	80 c	81 cy	950	86 c	88 cr	818	81 c	83 cy
1741	17	1007	79 c	82 cy	993	88 c	86 cr	865	85 c	83 cr
1742	18	1233	72 c	78 cy	1188	81 c	87 cr	1045	84 c	83 cr

Table 2. (cont.)

					Pawnee					
1731	19	585	70 c	77 cy	697	75 c	83 cw	660	77 c	78 cw
1732	20	655	73 c	76 cy	708	78 c	83 cw	650	75 c	80 cw
1733	21	677	75 c	76 cy	740	80 c	83 cw	695	78 c	81 cw
1734	22	850	79 c	82 cy	868	82 c	86 cr	768	77 c	81 cy
1735	23	903	81 o	84 cy	900	84 o	86 cr	783	80 c	81 cy
1736	24	1080	80 o	83 cy	1028	85 o	85 cr	883	79 o	83 cy
					Blackhull					
1700	25	625	75 c	76 cy	725	81 c	84 cy	700	74 c	80 cy
1701	26	678	76 c	73 cy	735	79 c	83 cr	698	74 c	82 cr
1702	27	740	82 c	79 cy	852	80 c	83 cr	705	78 c	82 cr
1703	28	853	79 o	79 cy	920	80 o	83 cr	788	79 c	86 cr
1704	29	909	78 o	78 cy	966	84 o	84 cr	--	--	--
1705	30	980	74 o	79 cy	1045	84 c	85 cy	903	81 c	83 cr
					Early Blackhull					
1725	31	615	69 c	68 cy	748	75 c	82 cr	675	73 c	79 cy
1726	32	709	71 c	71 cy	783	79 c	82 cr	750	77 c	80 cy
1727	33	783	74 o	75 cy	840	82 c	85 cr	815	77 c	82 cy
1728	34	904	78 c	77 cy	940	84 o	81 cr	845	78 c	82 cy
1729	35	982	80 o	80 cy	1038	84 o	85 cr	890	81 c	84 cy
1730	36	1070	81 o	80 cy	1155	80 o	83 cr	950	78 o	84 cy

Table 2. (cont.)

					Chiefkan					
1710	37	645	70 c	75 cy	695	75 c	77 cy	598	65 c	75 cy
1711	38	707	75 c	74 cy	705	78 c	75 cg	605	65 c	75 cg
1712	39	745	70 c	75 cy	740	78 c	79 cy	538	64 c	75 cg
1713	40	808	76 c	75 cy	813	80 c	82 cy	707	73 c	79 cg
1714	41	853	69 c	76 cy	880	80 c	82 cy	738	76 c	80 cg
					Nebred					
1706	42	790	80 c	75 cy	895	84 c	80 cy	788	81 c	80 cy
1707	43	825	82 c	75 cy	899	83 c	82 cy	820	82 c	80 cy
1708	44	875	78 c	75 cy	965	83 c	80 cy	843	83 c	81 cy
1709	45	1035	78 c	79 cy	1078	79 c	80 cy	980	85 c	84 cr
					Kanred					
1743	46	692	72 c	71 cy	733	76 c	79 cy	705	73 c	78 cy
1744	47	783	74 c	74 cy	793	78 c	80 cy	723	74 c	79 cy
1745	48	907	77 c	73 cy	875	80 c	81 cy	793	78 c	81 cy
1746	49	1010	74 c	77 cy	965	85 c	81 cy	850	82 c	82 cy
					Cheyenne					
1747	50	627	73 c	78 cy	700	78 c	80 cr	633	81 c	81 cr
1748	51	675	74 c	73 cy	725	76 c	79 cy	638	73 c	81 cr
1749	52	698	74 c	78 cy	740	79 c	81 cr	653	74 c	83 cr
1750	53	825	75 c	78 cy	855	83 c	84 cr	698	76 c	84 cr

Table 2. (concl.)

					Kawvale					
1715	54	593	72 c	77 cd	638	77 c	73 dy	605	65 c	74 cg
1716	55	650	65 c	72 cd	705	79 c	78 cy	638	73 c	80 cy
1717	56	709	75 c	74 cd	748	81 o	84 cy	675	75 c	81 cy
1718	57	845	80 o	78 cd	889	85 c	84 cy	853	78 c	84 cy
1719	58	933	80 o	79 cd	935	85 o	83 cd	863	83 c	87 cy
1720	59	1008	73 o	80 cy	1023	80 o	85 cr	948	86 c	85 cr
					Clarkan					
1721	60	668	78 c	79 cy	758	80 c	85 cw	655	74 c	83 cw
1722	61	703	78 c	78 cy	765	80 c	86 cw	707	75 c	87 cw
1723	62	730	80 c	80 cy	840	82 c	85 cw	720	77 c	87 cw
1724	63	770	77 c	81 cy	853	83 c	85 cw	805	85 c	88 cw

1/ Texture-grain, c = close, o = open.

2/ Crumb color, cr = creamy, cy = creamy yellow, cg = creamy gray, cd = creamy dull.

EXPLANATION OF PLATE I

Swanson-Working-National micro recording dough mixer curves of flours used in this investigation. The curve numbers are given in connection with the data presented in several tables.

PLATE I

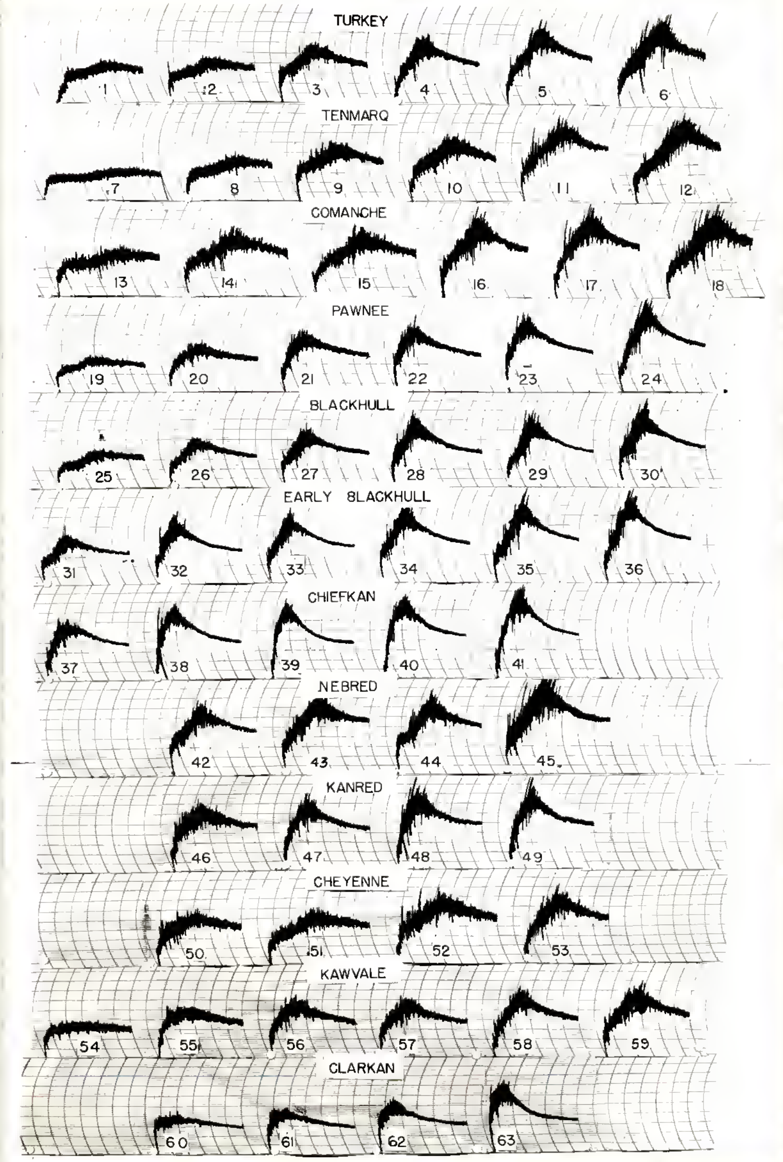
TURKEY
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Table 3. Numerical measurements taken from mixer curves of flours used in this investigation.

Serial number	Curve number	Mixing time min.	Angle DOT degrees	Angle DOW degrees	Height H units	Width RM units	Angle WOM degrees	Area cm^2	Decrease in loaf vol. cc [1]
				Turkey					
1688	1	3.7	15	164	36	0.9	4	18.6	37
1689	2	3.4	18	156	40	1.2	7	21.2	37
1690	3	2.8	59	125	52	1.3	18	19.9	75
1691	4	2.5	58	102	58	1.6	20	15.4	83
1692	5	2.7	54	100	68	2.0	26	19.3	147
1693	6	3.0	50	93	76	2.5	35	26.3	127
				Tenmarq					
1694	7	6.0	6	167	30	0.9	6	27.6	30
1695	8	3.7	18	157	40	1.3	6	25.1	32
1696	9	3.1	31	135	52	1.7	14	25.1	47
1697	10	3.3	35	123	58	1.8	20	27.6	80
1698	11	3.0	50	109	66	2.0	20	27.0	127
1699	12	3.5	45	105	76	2.4	32	30.2	126
				Comanche					
1737	13	4.9	14	158	43	1.1	8	32.8	47
1738	14	3.6	31	134	58	1.6	15	29.6	29
1739	15	3.8	35	130	58	1.6	15	30.8	98
1740	16	2.8	49	108	70	2.3	25	25.1	132
1741	17	2.6	54	96	76	2.0	29	24.4	128
1742	18	3.6	45	108	76	2.7	29	24.7	143

Table 3. (cont.)

				Pawnee					
1731	19	2.5	20	161	33	0.9	4	12.9	37
1732	20	2.3	40	127	45	1.2	10	13.5	58
1733	21	2.0	58	104	54	1.5	18	12.2	45
1734	22	1.8	55	104	60	1.6	22	15.4	100
1735	23	1.6	62	89	68	2.0	29	14.1	117
1736	24	2.1	66	74	80	2.2	38	17.4	145
				Blackhull					
1700	25	3.5	20	153	36	0.8	7	13.6	25
1701	26	2.3	42	120	46	1.0	18	13.5	37
1702	27	2.3	49	110	53	1.1	21	14.1	47
1703	28	2.0	59	90	63	1.2	30	16.1	132
1704	29	2.0	61	90	64	1.7	29	15.4	---
1705	30	2.0	60	89	70	1.9	32	16.1	142
				Early Blackhull					
1725	31	2.5	44	119	46	1.3	16	13.5	23
1726	32	1.8	64	86	60	1.8	30	11.6	33
1727	33	2.0	58	95	60	1.6	27	14.8	25
1728	34	2.0	60	92	65	1.8	28	15.5	105
1729	35	2.3	58	83	71	1.8	34	18.6	153
1730	36	1.9	66	68	81	2.3	46	16.7	205

Table 3. (cont.)

					Chiefkan				
1710	37	2.0	65	95	56	1.4	19	10.3	97
1711	38	1.6	70	82	65	1.4	28	14.8	100
1712	39	1.8	75	70	67	1.6	35	10.3	102
1713	40	1.8	72	70	76	1.8	38	14.1	106
1714	41	2.0	70	71	78	2.5	40	14.1	142
					Nebred				
1706	42	2.5	45	116	62	1.7	17	20.6	107
1707	43	2.6	49	113	70	1.8	21	25.1	79
1708	44	2.8	45	115	67	2.1	20	24.4	122
1709	45	2.8	51	95	84	3.2	34	28.9	98
					Kanred				
1743	46	2.4	45	121	58	1.6	13	19.3	28
1744	47	2.0	60	97	63	1.7	21	14.6	70
1745	48	1.8	70	88	70	2.0	26	12.2	82
1746	49	1.8	67	83	73	2.0	30	10.9	155
					Cheyenne				
1747	50	3.0	35	134	50	1.1	11	19.9	67
1748	51	3.5	30	140	50	1.5	11	23.8	87
1749	52	3.5	39	124	64	1.5	16	28.9	87
1750	53	2.9	50	110	66	1.7	20	21.2	157

Table 3. (concl.)

					Kawvale				
1715	54	3.0	11	160	34	0.3	8	16.7	23
1716	55	2.5	37	130	43	1.2	12	15.4	65
1717	56	2.3	50	112	53	1.4	13	14.8	63
1718	57	2.2	50	111	54	1.4	19	16.1	72
1719	58	2.5	50	100	62	1.4	20	18.6	75
1720	59	2.8	47	105	64	1.6	25	23.1	103
					Clarkan				
1721	60	2.0	11	160	36	0.8	7	11.6	103
1722	61	1.8	32	135	41	1.0	13	10.3	58
1723	62	1.4	47	114	48	1.1	18	10.3	120
1724	63	1.5	80	82	64	1.6	39	11.6	48

1/ Rich formula optimum mix loaf volume minus rich formula two minute overmix loaf volume.

Table 4. Means of loaf volumes, protein content and curve characteristics for each variety.

Variety	Sample number	Flour prot. %	M.P.B.[1] loaf vol. cc	Rich[2] loaf vol. cc	Mixing time min.	Angle DOT deg.	Angle DOW deg.	Height H units	Width RM units	Angle WOH deg.	Area cm^2	Decrease[3] loaf vol. cc
Turkey	6	11.13	801.5	883.5	3.0	42.3	123	55.0	1.6	18.3	20.1	84.3
Tenmarq	6	11.42	809.5	839.3	3.8	30.8	132	54.0	1.7	16.3	26.4	73.7
Comanche	6	11.49	797.5	873.8	3.6	38.0	122	65.2	1.9	19.8	27.9	96.2
Pawnee	6	12.77	881.3	959.3	2.0	49.8	110	56.7	1.8	20.2	14.3	83.7
Blackhull	6	12.15	751.6	766.6	2.4	48.5	109	55.3	1.3	22.8	15.6	76.6
Early Blackhull	6	11.15	739.7	821.0	2.1	58.3	91	65.8	1.8	30.2	14.8	90.7
Chiefkan	5	11.02	717.8	804.0	1.9	70.4	78	68.4	1.7	32.0	12.7	109.4
Nebred	4	12.82	843.8	917.3	2.7	47.5	110	70.8	2.2	23.0	24.8	101.5
Kanred	4	11.38	791.7	823.5	2.0	60.5	97	66.0	1.8	22.5	14.3	83.8
Cheyenne	4	12.59	891.3	911.3	3.2	38.0	127	57.5	1.5	14.5	23.5	99.5
Kawvale	6	12.57	848.0	841.5	2.5	40.8	120	52.5	1.3	18.5	17.5	66.8
Clarkan	4	10.82	706.3	755.0	1.7	37.5	123	47.3	1.1	19.3	11.0	82.3

1/ Malt-phosphate-bromate loaf volume.

2/ Rich formula loaf volume.

3/ Rich formula optimum mixed loaf volume minus rich formula overmixed loaf volume.

EXPLANATION OF PLATE II

Schematic diagram of mixer curve. The curve characteristics are segregated as follows: Lines are drawn through the center of the development slope, DO and the weakening slope, WO. Lines are drawn at intersection of DO and WO, TON, and where the black inking predominants over the white chart paper at the peak, MM' and RR'. A line is dropped from point O perpendicular to the base line.

1. Mixing time: The number of arcs or fraction thereof, from the time the curve starts and point O is reached. Distance between arcs is equal to approximately one minute.

2. Development angle, DOT: The angle between development slope DO and the horizontal line OT.

3. Area, cm^2: Area under curve to point of maximum consistency, O. The boundary of the area is formed by following points ABO, the arc OF or fraction thereof and the base line FA. Area is measured with a planimeter.

4. Range of tolerance to mixing, DOW: The angle formed between the development slope DO and the weakening slope WO.

5. Height, H: The distance expressed in horizontal chart units (each major unit = ten, and each minor unit = two) from point O to the base line.

6. Width, R-M: The distance between MM' and RR' at maximum consistency expressed in horizontal chart units.

7. Weakening angle, WON: The angle between the weakening slope WO of the curve and line ON extended horizontally from the peak O.

PLATE II.

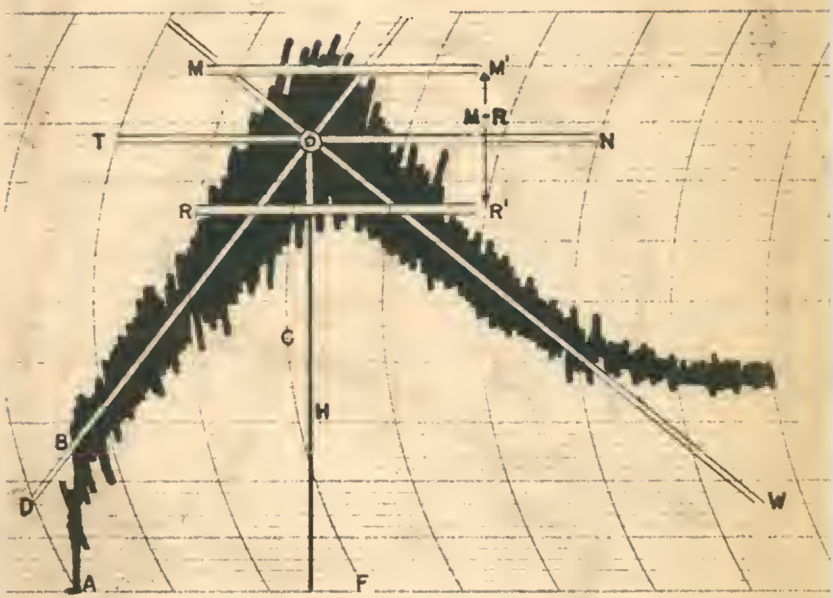

Table 5. Summary of simple, partial and multiple correlation coefficients for loaf volume, protein and curve characteristics.

Variables Correlated X		Y		Correlation coefficients 1/ Simple rxy	Partial 2/ r.	Multiple 3/ r.
Protein content,	%	M.P.B. 4/ loaf volume,	cc	+ 0.9479		
Protein content,	%	Rich loaf volume,	cc	+ 0.9214		
Mixing time,	min.	Angle DCT,	degrees	- 0.6815		
Mixing time,	min.	Area,	cm^2	+ 0.6958		
Area,	cm^2	M.P.B. loaf volume,	cc	+ 0.2228		
Area,	cm^2	Rich loaf volume,	cc	+ 0.2204		
Protein content,	%	Curve height,	units	+ 0.9189		
Curve height,	units	M.P.B. loaf volume,	cc	+ 0.8455	-0.2029	
Curve height,	units	Rich loaf volume,	cc	+ 0.7906	-0.3553	+ 0.9323
Protein content,	%	Curve width,	units	+ 0.8533		
Curve width,	units	M.P.B. loaf volume,	cc	+ 0.8295	+0.1244	
Curve width,	units	Rich loaf volume,	cc	+ 0.7853	-0.0046	
Protein content,	%	Angle WOM,	degrees	+ 0.8362		
Angle WOM,	degrees	M.P.B. loaf volume,	cc	+ 0.7202	-0.4146	+ 0.9595
Angle WOM,	degrees	Rich loaf volume,	cc	+ 0.6971	-0.3443	+ 0.9311
Protein content,	%	Decrease in loaf vol.,	cc	+ 0.6901		
Angle WOM,	degrees	Decrease in loaf vol.,	cc	+ 0.6365	+0.4736	+ 0.6986

1/ 1 percent level of significance, r = 0.250 (Snedecor, 1940).
2/ Independent of protein content.
3/ Includes protein content and variables indicated.
4/ M.P.B. refers to malt-phosphate-bromate.

Simple correlations between the different curve characteristics as well as between loaf volume, protein content and curve characteristics are summarized in Table 5. Also included in Table 5 are partial correlation coefficients between loaf volume and certain curve characteristics, with protein content held constant. Multiple correlation coefficients, where protein content and curve characteristics were correlated with loaf volume, are shown for certain curve characteristics. The multiple correlation coefficients are shown only where the partial correlation coefficients proved significant.

DISCUSSION OF EXPERIMENTAL RESULTS

Analytical data

Table 6. Statistical treatment of analytical data for wheats and flours used in this investigation.

Variables correlated X	Y	Correlation coefficient rxy 1/
Test weight lb. Mean, 58.09 lb.	Flour yield % 69.44 %	-0.0667
Test weight lb. Mean, 58.09 lb.	Flour ash % 0.420 %	-0.0434
Wheat ash % Mean, 1.786 %	Flour ash % 0.420 %	+0.1385
Wheat protein %	Flour protein % 2/	+0.9880

1/ 1 percent level of significance, r = 0.250 (Snedecor, 1940)
2/ Regression equation for estimation of flour protein from wheat protein: flour protein = 0.98 wheat protein - 0.75, standard error of estimate = 0.11 percent.

It is generally considered that test weight of wheat indicates to some degree the flour yield which might be expected. Test weight of wheat, in this study, was not significantly correlated with neither flour yield nor flour ash. The failure to obtain a significant correlation can be explained on the basis of the narrow range exhibited between test weight of the various samples, moisture history of the wheat and varietal response to milling. The same explanation can be given for the insignificant correlation between flour ash and flour yield. The test weights averaged 58.60 pounds per bushel.

The percent of ash in the wheat was not significantly correlated with the percent of ash in the flour. It is likely that these variables might have been found significant if the wheats had been milled to obtain the maximum amount of flour.

The percent of wheat protein was highly correlated with the percent of flour protein. The standard error of estimate of the flour protein from the wheat protein was 0.11 percent, which was well within the limits of error usually set for the determination of the protein in the laboratory by Kjeldahl procedure. Percent of flour protein could thus be estimated with a fair degree of accuracy from knowledge of the percent of wheat protein.

Baking Result

The figure for volume of the baked loaf of bread was the only one obtained by actual measurement. Sufficient evidence was found in the literature to support the opinion that loaf volume was a measure of baking strength and flour quality, provided adequate methods were used to obtain the data.

The mean loaf volume for each variety presented in Table 4 indicated that the two formulas did not give the same relative loaf volumes. To test the significance of this apparent disagreement between the two formulas, the loaf volume and protein content data of Tables 1 and 2 were submitted to covariance analysis.

Table 7. Analysis of covariance of loaf volume and protein content data for the malt-phosphate-bromate formula and rich formula combined.

Source of variation	Degrees freedom	Mean square	F. ratio	F 1/ ratio
Difference for testing adjusted variety means.	11	14,989.39**	24.43	2.43
Difference for testing between formulas.	1	69,900.00**	67.31	6.90
Difference for testing variety-formula interaction.	11	4,478.73**	4.31	2.43
Residual error.	101	1,038.43		

1/ 1 percent level of significance. (Snedecor, 1940).
** Highly significant.

It is evident that differences between varieties and formulas were highly significant. The variety-formula interaction was also significant indicating that varieties react differentially to treatment accorded them by baking formulas. For this reason comparison of varieties must be made within a given formula and curve characteristics must be compared separately with each baking formula.

Covariance analysis of loaf volume data and protein content within a given formula indicated significant differences between variety mean loaf volumes regardless of formula concerned. The ratio of error variance to mean loaf volume variance was approximately three times greater for the rich formula than for the malt-phosphate-bromate formula. This suggested that the rich formula was providing the greatest differentiation between samples.

The regression coefficients of loaf volume on protein content for each variety shown in Table 9 did not prove significantly different as a group (Table 8). It was likely that the samples as a group could be considered representative of a random distributed population insofar as the regressions of loaf volume on protein content were concerned. These data do not appear to support the view that the regression of loaf volume on protein content is a varietal characteristic. It is probable that if many more samples for each variety had been available that significance of regression coefficient differences might have been found.

Table 8. Analysis of covariance of the loaf volume and protein content data, treating each formula separately.

Source of variation.	Degrees of freedom	Mean squares	F. ratio	F. 1/ ratio
Difference for testing adjusted mean loaf volume for malt-phosphate-bromate formula.	10	7,392.00**	5.47	2.70
Residual error.	50	1,352.06		
Test of significance for individual variety regression of loaf volume on protein content.	39	742.66	1.82	2.00
Difference for testing adjusted mean loaf volume for the rich formula.	10	12,573.07**	15.81	2.70
Residual error.	50	795.37		
Test of significance for individual variety regression of loaf volume on protein content.	39	567.11	1.40	2.00

1/ 1 percent level of significance. (Snedecor, 1940)
** Highly significant.

Table 9. Regression and correlation coefficients computed between loaf volume and protein content for the individual varieties and baking formulas.

Variety	No. of samples	Regression coefficients 4/ M.P.B. b. 1/	Regression coefficients 4/ Rich b 2/	Correlation coefficients 4/ M.P.B. rxy 1/	Correlation coefficients 4/ Rich rxy 2/	Correlation coefficient 3/, 4/ rxy
Turkey	6	71.8	61.4	0.993	0.999	0.811
Tenmarq	6	65.9	64.0	0.992	0.998	0.811
Comanche	6	81.8	66.5	0.984	0.983	0.811
Pawnee	6	77.6	54.3	0.992	0.985	0.811
Blackhull	6	59.6	55.8	0.972	0.988	0.811
Early Blackhull	6	65.3	59.2	0.996	0.985	0.811
Chiefkan	5	41.1	39.1	0.980	0.974	0.878
Nebred	4	59.3	46.4	0.971	0.963	0.950
Kanred	4	82.9	60.3	0.991	0.998	0.950
Cheyenne	4	51.9	41.3	0.967	0.947	0.950
Kawvale	6	67.2	62.2	0.990	0.997	0.811
Clarkan	4	27.6	29.8	0.995	0.940	0.950
Total	63	65.7	56.6	0.9417	0.9214	0.250

1/ Malt-phosphate-bromate formula.
2/ Rich formula.
3/ 5 percent level of significance, (Snedecor, 1940).
4/ All coefficients are positive.

The simple correlation coefficients between loaf volume and protein content for both formulas, with the exception of Cheyenne and Clarkan in the instance of the rich formula, were exceedingly high and significant (Table 9). The lack of significance of the correlation coefficients between loaf volume and protein content for Cheyenne and Clarkan with the rich formula was disconcerting and no adequate explanation could be given. One may postulate that significance might have been attained had sufficient samples of the two varieties been available. The correlation coefficients within a variety indicated that loaf volume by any one formula, could be predicted from protein content if the quality of the gluten were held constant.

Twelve percent of the total variation in the loaf volume with the malt-phosphate-bromate formula was not accounted for by protein content, while with the rich formula 16 percent of the total variation in loaf volume data was not accounted for by protein content. The 12 and 16 percent variation not accounted for by protein content can be partly attributed to the different qualities of protein in the varieties and partly by random error in the baking procedure. That the varieties accouhted for a significant amount of variation in the loaf volume data has been shown in Table 8.

The relationship between protein content and loaf volume is shown in Plate III, Figs. 1 and 2. It was evident that with either formula the relationship between loaf volume and protein

EXPLANATION OF PLATE III

Fig. 1. Relationship between loaf volume and protein content with malt-phosphate-bromate formula.

Fig. 2. Relationship between loaf volume and protein content with rich formula.

The legend for the symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Pawnee,	P	Cheyenne,	X
Blackhull,	B	Kawvale,	K
Early Blackhull,	E	Clarkan,	I

PLATE III

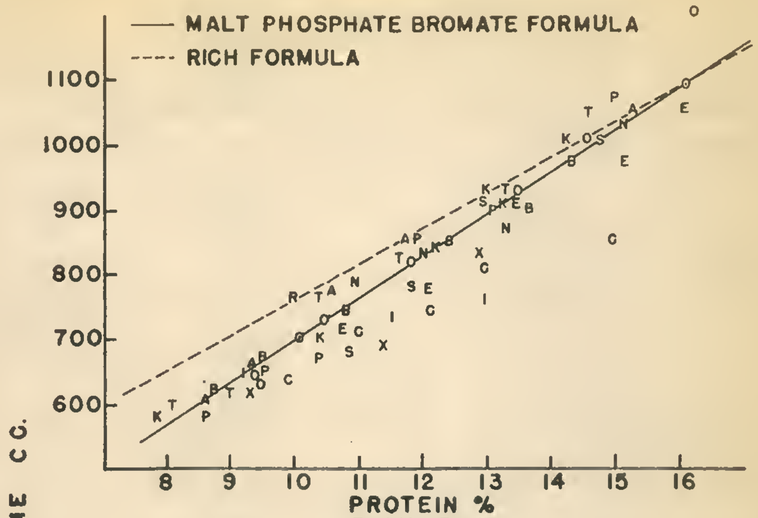

FIGURE 1

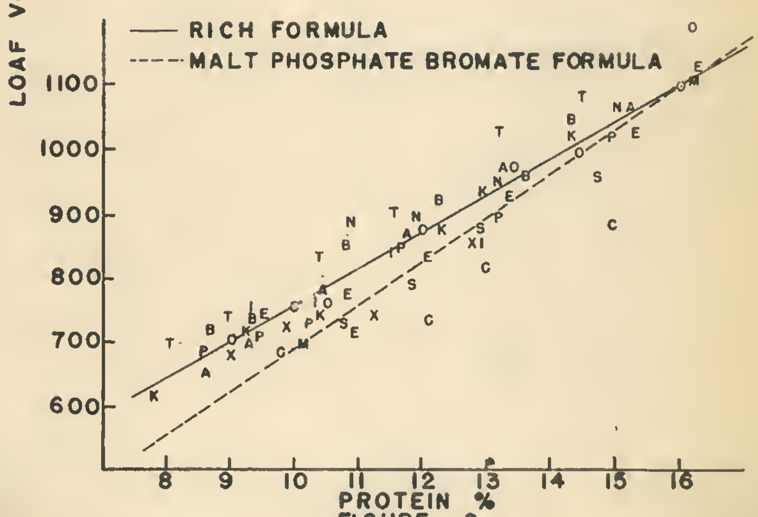

FIGURE 2

content was linear. The total simple correlation coefficient between loaf volume and protein content for the malt-phosphate-bromate formula (Fig. 1) was r = +0.9417 while that for the rich formula (Fig. 2) was r = +0.9214. A comparison of the solid and dashed lines of either figure showed that the malt-phosphate-bromate formula gave a smaller loaf for a given protein content than did the rich formula. With the former formula loaf volume increased more with each increment in protein than did the latter. The individual regression lines for each variety were not shown as they would merely confuse the picture. The various symbols represent the varieties which enter into the regression.

Texture, grain and crumb color scores were subjective quality notations made according to the opinion of the baker. Texture of the baked bread was found to improve in general with increasing protein content, while the grain became more open and reached an optimum at about the 12 to 13 percent protein levels. The bread produced with the rich formula, in general, had better texture and grain than that produced by the malt-phosphate-bromate formula. The texture and grain varied to some extent among the varieties. Tenmarq, Turkey, Comanche, Kawvale, Pawnee, Nebred, and Blackhull had a slightly better texture and grain than the other varieties. Chiefkan, Cheyenne and Early Blackhull were either open or had heavy cell walls.

The crumb color scores indicated that Turkey, Kawvale, and Nebred samples were decidedly yellow indicating high pigmentation. Turkey and Nebred samples had a high luster compared to Kawvale. Tenmarq exceeded all other varieties in a creamy whiteness of crumb color with a highly desirable sheen. Clarkan samples had a clean, white, but dull crumb color, while Chiefkan exhibited a creamy-gray crumb color. All other samples were satisfactory.

Mixing Time Studies

The mixing time of flours is an important physical property of dough. Numerous workers have studied mixing time of flours and there appears to be some disagreement on several points. Mixing time data from the Farinogram do not agree with those obtained from the Swanson-Working recording dough mixer curve. Since Swanson and Clark (1936) presented evidence which showed that the mixer curve indicated the mixing requirement of a flour, studies of mixing time have received considerable attention.

Bayfield, Working and Harris (1941) concluded that the mixing time decreased with increments of protein. Ofelt and Sandstedt (1941) presented similar evidence. The present results with the Swanson-Working-National curves appeared to indicate that the mixing time tended to decrease with increased protein up to a certain protein content and then mixing time increased as the protein content increased further. The

EXPLANATION OF PLATE IV

Fig. 1. Relationship between the mixing time and protein content for several varieties.

The legend for the symbols is as follows:

Turkey, T

Tenmarq, A

Comanche, O

Pawnee, P

Blackhull, B

Fig. 2. Relationship between the mixing time and protein content from several varieties.

The legend for the symbols is as follows:

Early Blackhull, E

Chiefkan, C

Nebred, N

Kanred, S

Cheyenne, X

Kawvale, K

Clarkan, I

PLATE IV

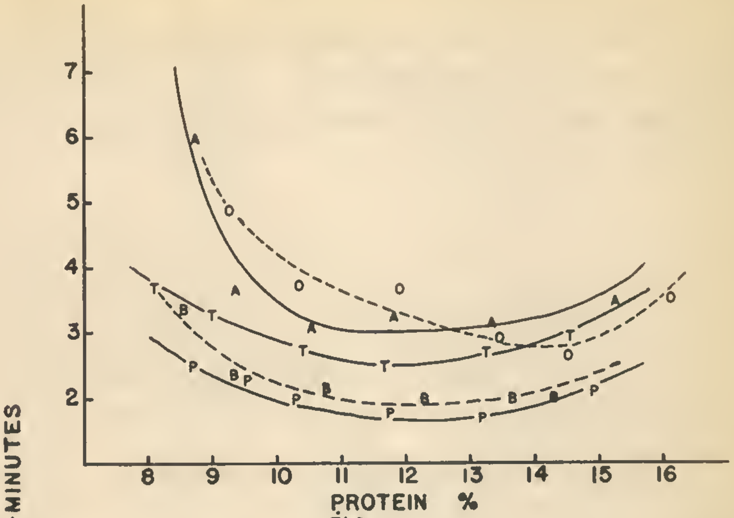

FIGURE I.

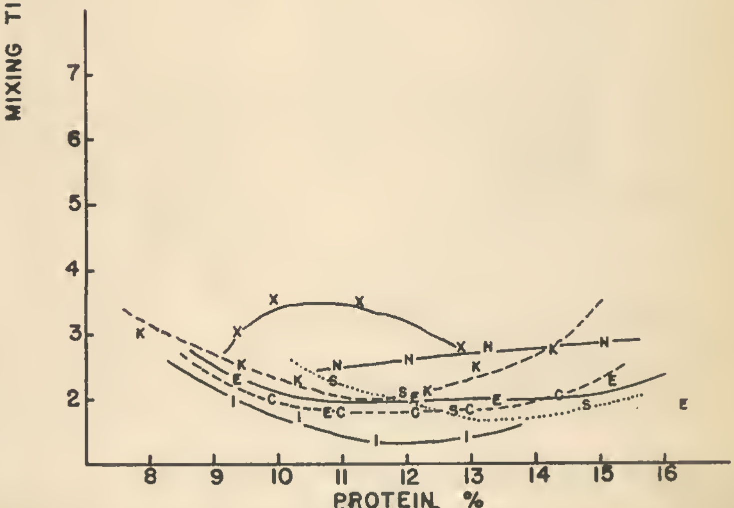

FIGURE 2

EXPLANATION OF PLATE V

Fig. 1. Relationship between development angle DOT and protein content for several varieties.

The legend for the symbols is as follows:

Turkey, T

Tenmarq, A

Commanche, O

Pawnee, P

Blackhull, B

Fig. 2. Relationship between development angle DOT and protein content for several varieties.

The legend for the symbols is as follows:

Early Blackhull, E

Chiefkan, C

Nebred, N

Kanred, S

Cheyenne, X

Kawvale, K

Clarkan, I

PLATE V

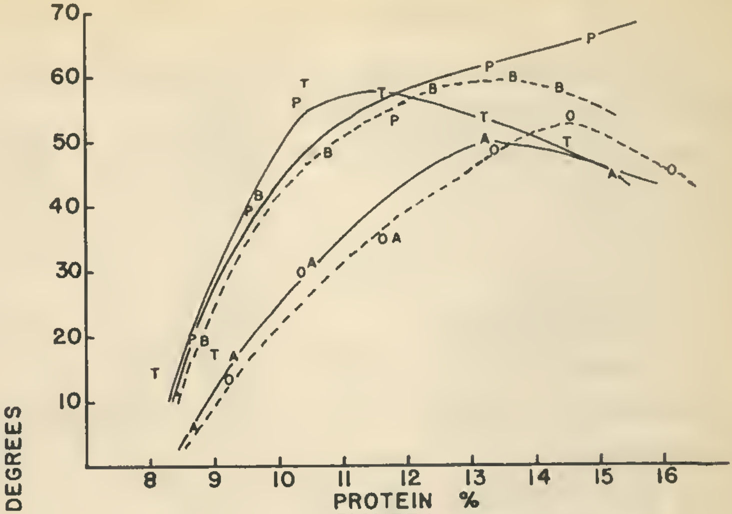

FIGURE 1.

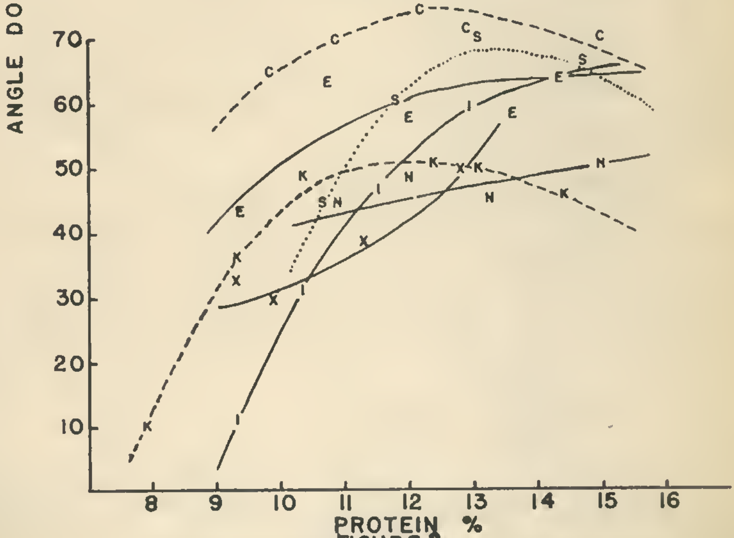

FIGURE 2.

EXPLANATION OF PLATE VI

Fig. 1. Relationship between mixing time and development angle DOT for several varieties.

Fig. 2. Relationship between mixing time and area under the curve to maximum consistency.

The legend for the symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Blackhull,	B	Cheyenne,	X
Early Blackhull,	B	Kawvale,	K
Pawnee,	P	Clarkan,	I

PLATE VI

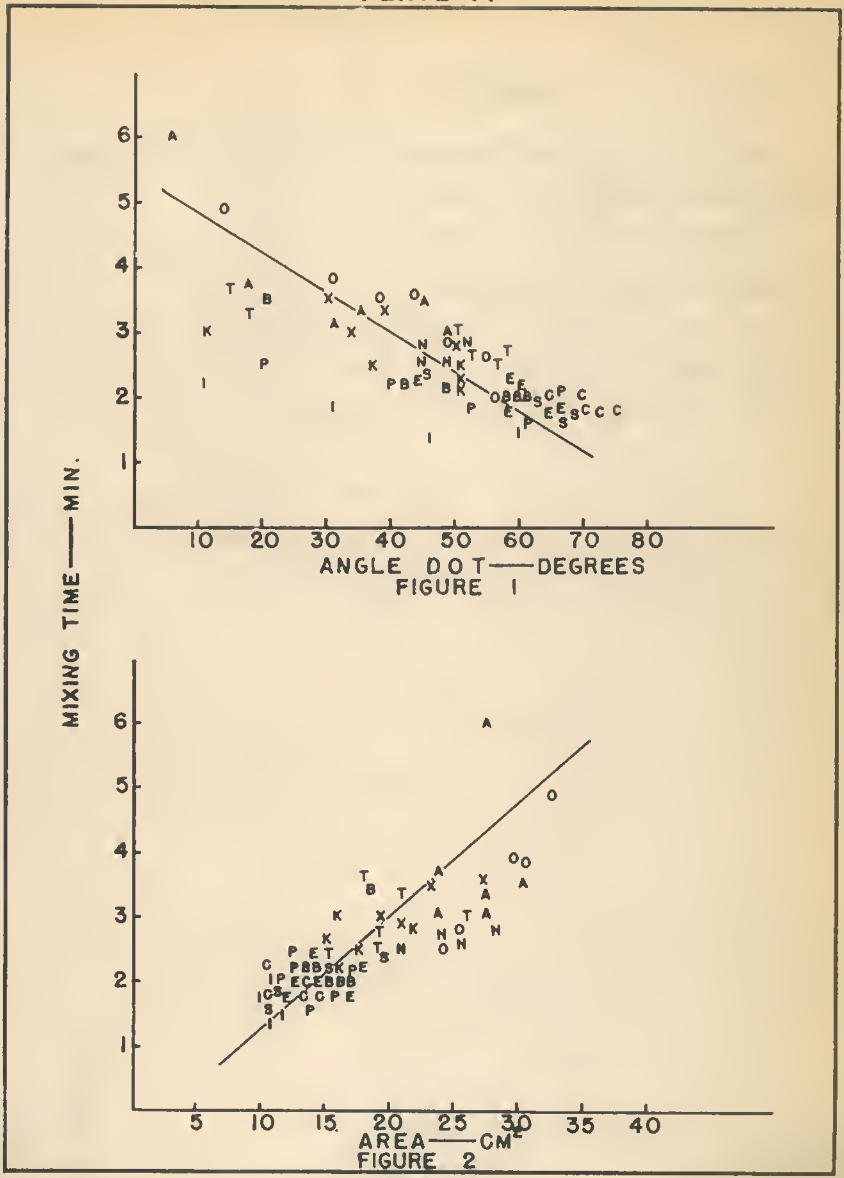

FIGURE 1

FIGURE 2

relation between mixing time and protein content as shown in Plate IV, Figs. 1 and 2, seems to support the present observation. The minimum for most varieties was approximately 11 to 13 percent protein. This minimum tended to shift somewhat with different varieties. The varieties differed considerably in mixing requirements. The mean mixing times given in Table 4 showed the mixing requirements of the different varieties.

The lack of agreement between data from Farinograms and Swanson-Working-National curves in regard to the relationship between mixing time and protein content, may be due to the nature of the mixing action of the two machines. The Brabender Farinograph has a gentle kneading action, while the Swanson-Working type mixer has an action like American commercial mixers, which are of the pull-fold type and vigorous in treatment.

The mixing time established by the micro mixer, with adjustment for formula, was found to parallel the mixing time required to mix a dough to optimum development for baking. This corroborated the findings of Swanson and Clark (1936) and of Barmore, Finney and McCluggage (1939). Optimum development was associated with dryness of the "feel" and smoothness of the dough. This was in agreement with the conclusions of Bohn and Bailey (1936).

The relationship between the development angle DOT and protein content is shown in Plate V, Figs. 1 and 2, and that between development angle DOT and mixing time is shown in Plate VI, Fig. 1. The simple correlation coefficient between the development angle DOT and mixing time was r=-0.6615. This negative correlation would become positive if the complimentary angle DOH had been used. The variety Clarkan, a soft winter wheat, deviated most from the average regression of mixing time on development angle. However, the significance of this deviation was not tested.

Dough mixing time together with height of curve has been considered indicative of the amount of energy input required to mix a dough to optimum. That mixing time was associated to some extent to energy input is shown in Plate VI, Fig. 2. The area under the curve to maximum consistency may not be an exact measure of energy input. It was presented, however, as being a curve characteristic which best described energy input. The area may be considered as a measurement of work, because the height of the curve indicates force required to move the mixing pins through the dough while the mixing time indicates the time during which the force operates. The area under the curve, as a dough develops to optimum, coincides with energy input measurements obtained from the wattmeter curve presented by Swanson and Working (1933). The simple correlation coefficient between mixing time and area under curve to maximum consistency was r = +0.6958. It was apparent that mixing time does not necessarily indicate energy requirements for mixing a flour to maximum consistency.

EXPLANATION OF PLATE VII

Fig. 1. Relationship between angle DOW (range of tolerance) and protein content for several varieties.

Fig. 2. Relationship between curve height H and protein content for several varieties.

The legend for the symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Pawnee,	P	Cheyenne,	X
Blackhull,	B	Kawvale,	K
Early Blackhull,	E	Clarkan,	I

PLATE VII

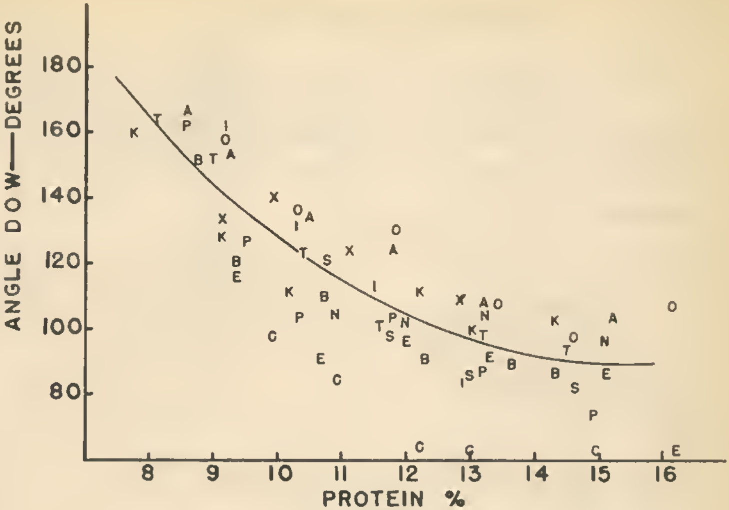

FIGURE 1

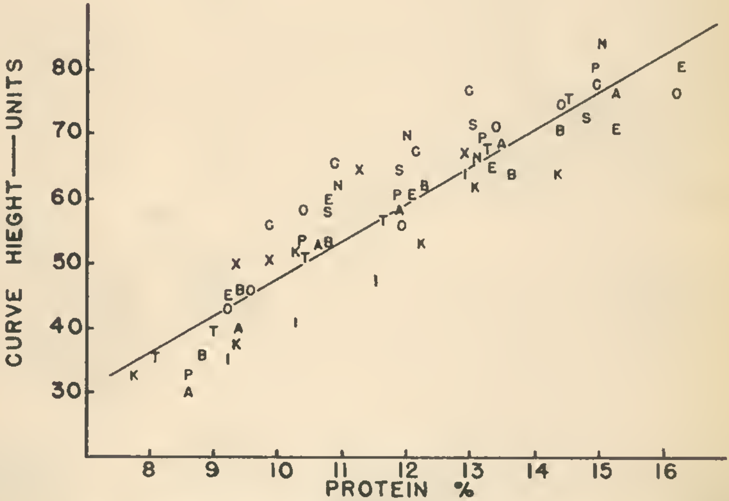

FIGURE 2

The area under the cruve to maximum consistency was not found significantly correlated with loaf volume using either formula. The graphs, plotting area against loaf volumes are not shown inasmuch as the oorrelation coefficients (Table 5.) were nonsignificant. The simple correlation between malt-phosphato-bromate loaf volumes and area was r = +0.2228 while that for the rich formula was r= +0.2204

Range of Mixing Tolerance (Angle DOW)

The relationship between angle DOW (believed to indicate range of mixing tolerance) and protein content is shown in Plate VII, Fig. 1. It appeared that the relationship between angle DOW and protein content was curvilinear and negatively correlated. The protein content had a pronounced influence on the sharpness of the peak of the curve (angle DOW). Thus in studying curves and comparing curve patterns it is necessary that the protein content of samples be known. No attempt was made to correlate statistically angle DOW with protein content inasmuch as the relationship appeared to be curvilinear.

Height of Curve (H)

Plate I shows that as the doughs were mixed the curves reached a maximum peak. Swanson (1941) suggested that at the peak, the protein molecules are oriented in parallel fashion. The larger amounts of protein meant greater density of the protein network and thus a greater force was required to move the mixing pins through the dough at the peak. He also showed that increasing the absorption decreased the height of the curve.

In this investigation the influence of absorption upon curve height was secondary because absorption was made a function of protein content. The relationship between curve height and protein content shown in Plate VII, Fig. 2, was linear and high (r = +0.9189, Table 5). That the varieties do not vary much among themselves was shown in Table 4. The range in curve height among the varieties was 18 units while protein content caused a change of approximately 50 units.

The linear relationship between curve height and loaf volume is shown in Plate VIII, Figs. 1 and 2. The simple correlation coefficient (r = +0.8455), between curve height and malt-phosphate-bromate loaf volume, was considerably lower than the coefficient (r = +0.9479), between protein content and malt-phosphate-bromate loaf volumes. The partial correlation, independent of protein content, between curve height and malt-phosphate-bromate loaf volumes was insignificant (r = -0.2029). This indicated that the height of the curve was not related to quality of the gluten as reflected in baking by the malt-phosphate-bromate formula. Curve heights and malt-phosphate-bromate loaf volumes were correlated because of the protein content and not because of the protein quality. The simple correlation coefficient r = +0.7906), between curve height and rich loaf volumes, probably was not significantly different from the simple

EXPLANATION OF PLATE VIII

Fig. 1. Relationship between loaf volume, malt-phosphate-bromate formula, and protein content for several varieties.

Fig. 2. Relationship between loaf volume, rich formula, and protein content for several varieties.

The legend for the symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Pawnee,	P	Cheyenne,	X
Blackhull,	B	Kawvale,	K
Early Blackhull,	E	Clarkan,	I

PLATE VIII

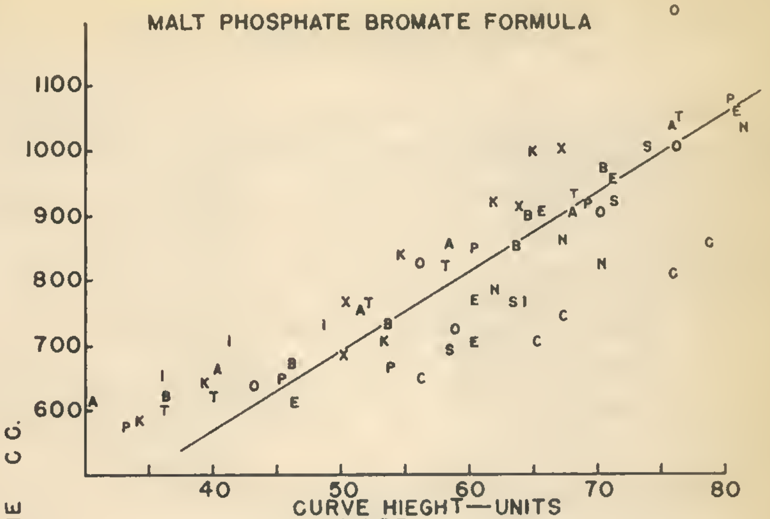

FIGURE I

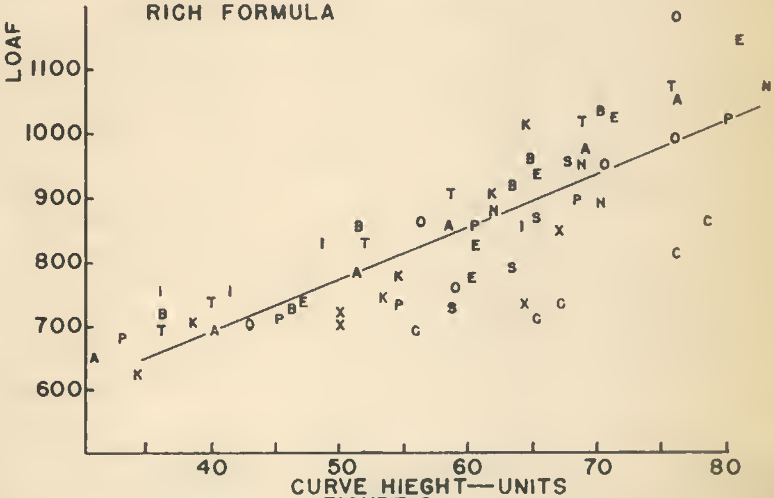

FIGURE 2

EXPLANATION OF PLATE IX

Fig. 1. Relationship between curve width R-M and protein content for several varieties.

Fig. 2. Relationship between the weakening angle WCN and protein content for several varieties.

The legend for the symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Pawnee,	P	Cheyenne,	X
Blackhull,	B	Kawvale,	K
Early Blackhull,	E	Clarkan,	I

PLATE IX

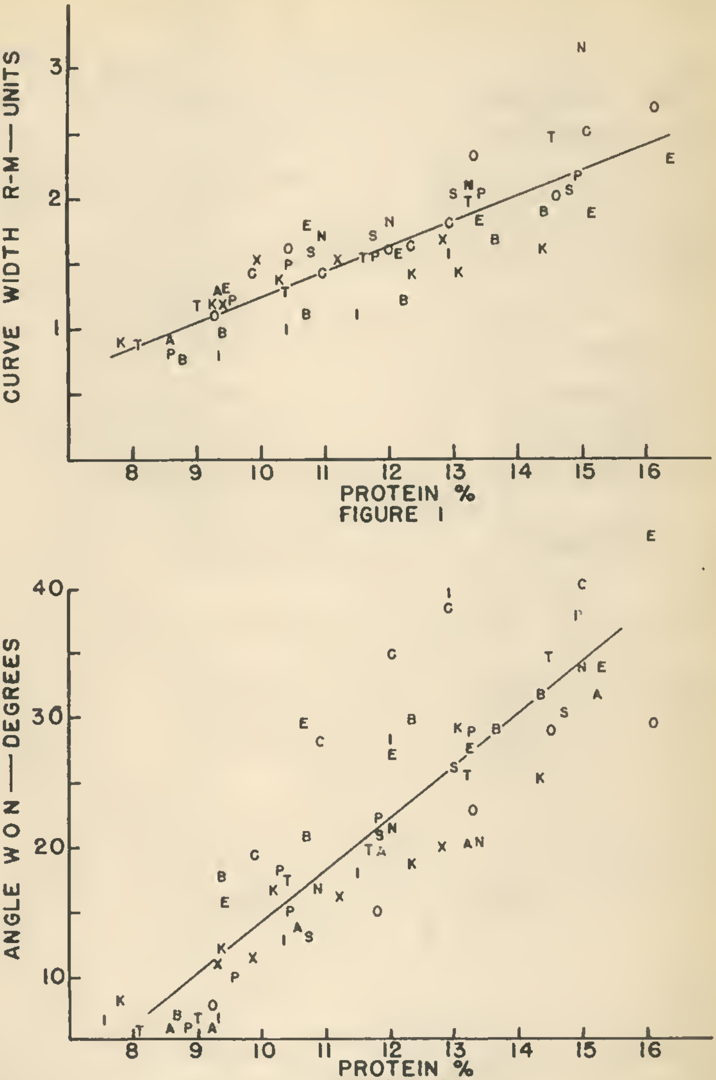

FIGURE 1

FIGURE 2

correlation coefficient (r = +0.8455) obtained between the malt-phosphate-bromate volumes and curve height.

The partial correlation, independent of protein content, between curve height and loaf volumes, rich formula, proved to be significant (r = -0.3658) but of low order. The multiple correlation (r = +0.9323) including protein content and curve height being correlated with loaf volumes, indicated that no increased precision in estimating loaf volume from the protein content (r = +0.9214) could be obtained by including curve height. The negative significant partial correlation, in the instance of the rich formula, may probably be caused by one variety, Chiefkan, having a high curve and very poor baking quality.

Width of Curve (R-M)

The relationship of the width of the curve at point O to baking characteristics has received comparatively little attention. The width of the curve was once associated with peak elasticity (Swanson and Clark, 1936). Later, Swanson (1941) showed that systems which could not have much elasticity produced a wide curve. Examination of Plate I showed that the width of the curve increased with protein content. This observation of the curves suggested that the width of the curve at maximum consistency might be related to baking results.

The relationship between width of curve and protein content shown in Plate IX, Fig. 1, indicated that the width

EXPLANATION OF PLATE X

Fig. 1. Relationship between loaf volume, by the malt-phosphate-bromate formula, and curve width (R-M) for several varieties.

Fig. 2. Relationship between loaf volume, by the rich formula, and curve width (R-M) for several varieties.

The legend of the symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Pawnee,	P	Cheyenne,	X
Blackhull,	B	Kawvale,	K
Early Blackhull,	E	Clarkan,	I

PLATE X

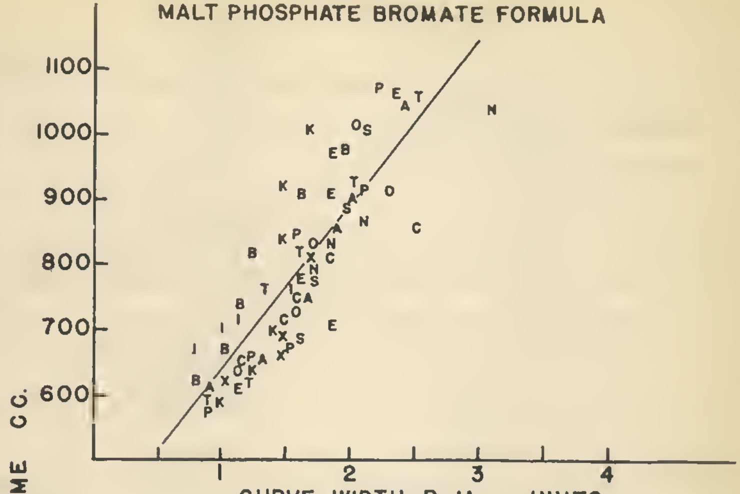

FIGURE 1

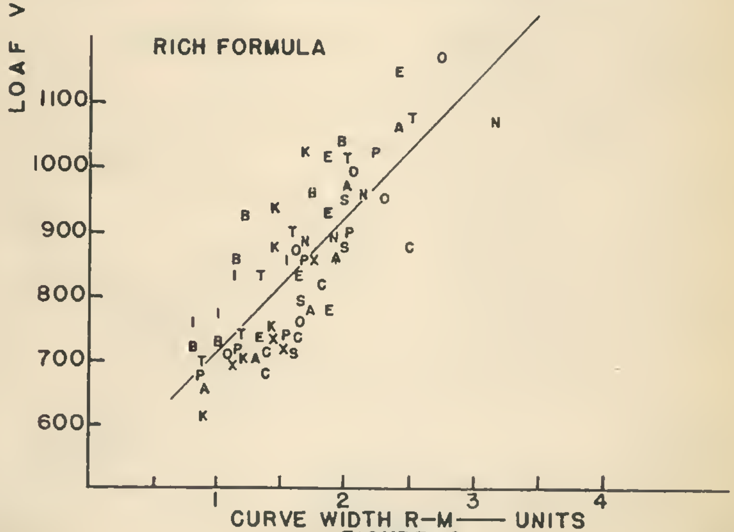

FIGURE 2

increased with increasing protein content. The relationship was linear. The simple correlation coefficient, r = +0.8533 (Table 5), between protein content and width of curve suggested a high degree of association.

The relationship between width of curve and loaf volume by either formula is shown graphically in Plate X, Figs. 1 and 2. A linear relationship was obtained with either formula. The simple correlation coefficient (r = +0.8295), between loaf volumes, malt-phosphate-bromate, and curve widths was about as high as the simple correlation coefficient (r = +0.8533) between protein content and curve widths. The simple correlation coefficient (r = +0.9479) between protein content and loaf volume was considerably higher, indicating that loaf volume, malt-phosphate-bromate formula, was more closely associated with protein content than it was with width of curve. The partial correlation coefficient, independent of protein content, between loaf volumes, malt-phosphate-bromate, and curve widths, was insignificant. That curve width was not associated with loaf volume, by the malt-phosphate-bromate formula, when compared on a common protein level, was further indicated by the means of loaf volume, protein content and curve width. (Table 4).

The simple correlation coefficient (r = +0.7853) between the loaf volumes, rich formula, and curve widths was about equal in magnitude to the simple correlation coefficient (r = +0.8295) obtained between the malt-phosphate-bromate loaf volumes and curve widths. The relationship existing between

EXPLANATION OF PLATE XI

Fig. 1. Relationship between loaf volume, malt-phosphate-bromate formula, and weakening angle WON for several varieties.

Fig. 2. Relationship between loaf volume, rich formula, and weakening angle WON for several varieties.

The legend for the symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Pawnee,	P	Cheyenne,	X
Blackhull,	B	Kawvale,	K
Early Blackhull,	E	Clarkan,	I

PLATE XI

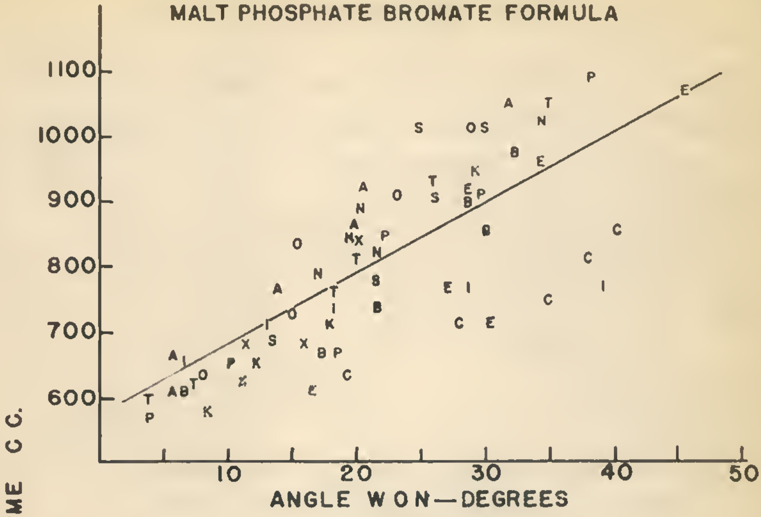

FIGURE I

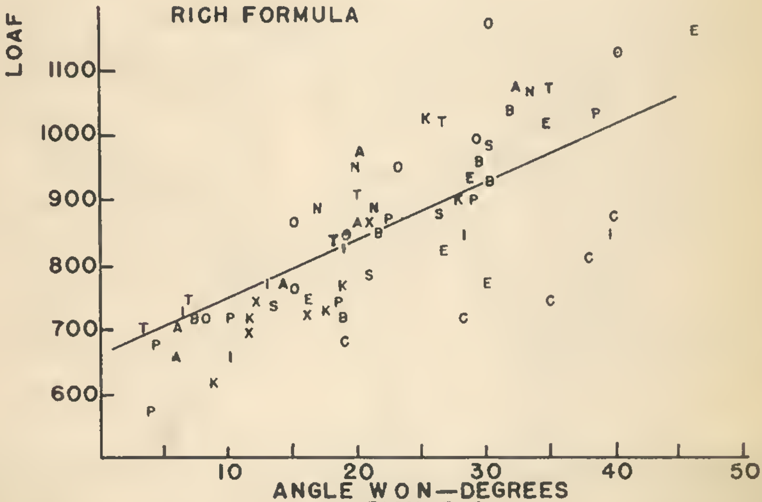

FIGURE 2

loaf volumes, rich formula, and curve widths was not as closely associated as was the relationship between the same formula loaf volumes and protein content (r = +0.9214 as compared to r = +0.7853). The partial correlation coefficient (r=-0.0046), independent of protein content, between loaf volumes, rich formula, and the curve widths was insignificant. Curve width thus appeared to be associated with loaf volume only because of the high correlation between protein content and loaf volume, on the one hand, and between protein content and curve width on the other. Curve width did not appear to be associated with quality of the gluten as measured by baking.

Weakening Angle (WON)

The weakening angle WON or the slope of the curve after maximum consistency has received considerable attention by numerous workers. Swanson (1939) concluded that varieties which exhibited a large amplitude which persisted after passing the peak were of better baking quality. Weakening angle of a curve has often been associated with sensitivity of a flour to overmixing.

Examination of Plate I showed that the various varieties differ considerably in respect to the weakening angle. Also, it showed that the high protein samples tend to have larger weakening angles.

The relationship between protein content and weakening angles WON was linear as shown by Plate IX, Fig. 2. The simple correlation coefficient (r = +0.8362, Table 5) indicated a close association between protein content and weakening angles.

The weakening angles were not as closely associated with the malt-phosphate-bromate loaf volumes as were protein content, curve heights, or curve widths. The simple correlation coefficient (r = +0.7202, Table 5) between the malt-phosphate-bromate loaf volumes and weakening angles indicated only a fair degree of association. The simple correlation coefficient (r = +0.9479) between protein content and malt-phosphate-bromate loaf volumes indicated a closer association than the simple correlation coefficient (r = +0.7202) between weakening angles and the same formula loaf volumes. Hence, weakening angle alone could not be used to any advantage to predict loaf volume.

The same relationships, as discussed for the malt-phospate-bromate formula, also hold true for the rich formula loaf volumes. The simple correlation coefficient (r = +0.6871) between the weakening angles and loaf volumes, rich formula, indicated that the degree of association for these two variables was less than that between protein content and the same loaf volumes (r = +0.9214).

The partial correlation coefficients, independent of protein content, between the loaf volumes of either formula and the weakening angles were computed separately and found to be significant. The partial correlation coefficient for the malt-phosphate-bromate loaf volumes was found to be (r = -0.4146), while the same coefficient for the rich formula volumes was found to be (r = -0.3443). These negative partial coefficients indicated that when the protein content is held constant, the loaf volume tended to decrease with increasing weakening angle. The opposite of this was shown when the simple correlation coefficient for loaf volume and weakening angles was positive. An explanation for this apparent disagreement may be made by examining Plates I and XI, Figs. 1 and 2. It was true that loaf volume increased as the weakening angle increased within any one variety if the protein level also increased. However, an examination of the weakening angle for the various varieties indicates that varieties such as Chiefkan, Early Blackhull, tended to have large weakening angles. These varieties are known to have relatively poor baking qualities. The weakening angle was probably associated with some gluten quality factor as well as with quantity of protein, as reflected in the baking results.

The multiple correlation coefficients, including the protein content and weakening angles being correlated with loaf volume, were computed for both baking formulas. Comparing the multiple correlation coefficient (r= +0.9595) with the simple correlation coefficient (r = +0.9479) between protein content and loaf volume for the malt-phosphate-bromate formula, it appeared that the inclusion of the weakening angle would not introduce additional precision in predicting loaf volumes from the protein content. The same conclusion may be made for the rich formula loaf volumes by comparing the multiple correlation coefficient (r = +0.9311) with the simple correlation coefficient (r = +0.9214).

Relation between Weakening Angle (WON) and Sensitivity to Overmixing

The weakening angle WON has been considered as a measurement of sensitivity to overmixing. Numerous workers have considered that wheat varieties with a mixer curve indicating a rapid breakdown following the peak were undesirable because they were sensitive to overmixing and hence, more difficult to handle in the bake shop.

Markley and Bailey (1939) did not find any significant relation between the weakening angle and mixing stability of a flour. They concluded, however, that overmixing a dough produced a smaller volume and inferior internal structure.

Several investigators have shown that doughs which have been overmixed tend to recover original properties upon resting. Munz and Brabender (1940) cautioned that dough recording mixers could not be expected to show the tendency of a dough to recover after excessive mixing. The work of Baker and Mize (1937) showed that mixing in air had an effect on the dough similar to oxidizing agents. It is evident that many factors complicate the relationship of the weakening angle to the baked loaf of bread.

EXPLANATION OF PLATE XII

Fig. 1. Relationship between the amount of decrease in loaf volume caused by overmixing the dough and the weakening angle WON for several varieties.

Fig. 2. Relationship between the amount of decrease in loaf volume caused by overmixing the dough and protein content.

The legend for symbols is as follows:

Turkey,	T	Chiefkan,	C
Tenmarq,	A	Nebred,	N
Comanche,	O	Kanred,	S
Pawnee,	P	Cheyenne,	X
Blackhull,	B	Kawvale,	K
Early Blackhull,	E	Clarkan,	I

PLATE XII

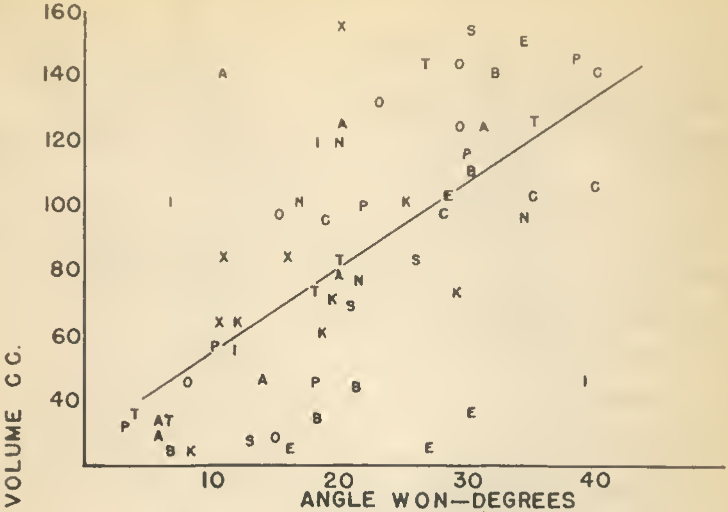

FIGURE I

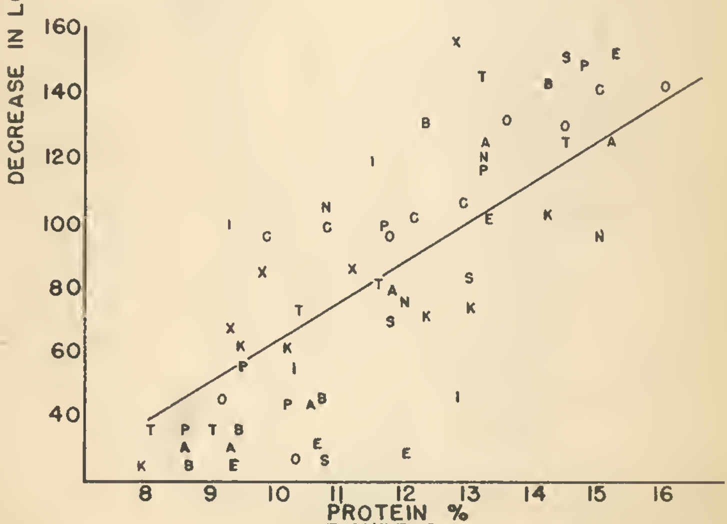

FIGURE 2

The results of baking when the doughs were overmixed are shown in Table 2. The differences in loaf volume obtained when the doughs were mixed to optimum and when overmixed two minutes are shown in the last column of Table 3. In every case the loaf volume of the overmixed dough was lowered. The amount of decrease in loaf volume, for most varieties, was more pronounced in the high protein samples.

The relationship between the decrease in loaf volume upon overmixing and protein content is shown in Plate XII, Fig. 2. The amount of decrease in loaf volume due to overmixing increased in a linear relation as the protein increased. The simple correlation coefficient (r = +0.6901) between protein content and decrease in loaf volume indicated that high protein samples are subject to greater damage by overmixing. This supported the conclusion of Markley and Bailey (1939).

The relationship between the weakening angle and the decrease in loaf volume caused by overmixing, as shown by Plate XII, Fig. 1, was linear. The smaller correlation coefficient (r = +0.6365) between the weakening angles and the decrease in loaf volumes caused by overmixing suggested a somewhat lesser degree of association than the larger coefficient (r = +0.6901) between protein content and the decrease in loaf volumes caused by overmixing. The partial correlation coefficient (r = +0.4736), independent of protein content, between the weakening angles and the decrease in loaf volumes by overmixing suggested that the decrease in loaf volumes was greater in varieties which exhibited larger weakening angles. Thus varieties like Early Blackhull and Chiefkan, which have exceedingly large weakening angles, may be expected to show marked decrease in bread quality when overmixed, depending, of course, on the protein content of the sample. The multiple correlation coefficient ($r = +0.6986$), including protein content and weakening angle being correlated with decrease in loaf volume, supported the view that the weakening angle gave a fair estimate of the sensitivity of flour to overmixing. The difference, however, between the simple correlation coefficient ($r = +0.6901$), between decrease in loaf volume and protein content, and the multiple correlation coefficient ($r = +0.6986$), between loaf volume and protein content including the weakening angle, was probably not significant. It is likely that no increased precision in estimating the damage to bread from overmixing may be obtained from the protein content with inclusion of the weakening angle.

From observation of the weakening angles and by assuming that the angle expressed sensitivity to overmixing, it was anticipated that a higher correlation between weakening angles and decrease in loaf volumes caused by overmixing would be obtained than actually resulted. Overmixing of a dough appears to be complicated by several factors. That overmixing does change the physical properties of doughs was indicated by the weakening angle of the curve. It may be that the protein network was broken down more or less by mechanical treatment. This however, was not necessarily reflected in the final bread, at least, not to the extent indicated by the mixer curve. Factors, such as oxidation or tendency to recover the normal physical state after overmixing, have been offered by several authors as an explanation for not having obtained a closer association between the weakening angles and damage to bread caused by overmixing. Munz and Brabender (1940) showed that doughs which have the greatest weakening angle often have the greatest tendency to recover from overmixing treatment upon resting.

With most varieties the texture and grain of loaves from overmixed doughs did not change much. Blackhull, Early Blackhull, Chiefkan and Clarkan samples had internal characteristics of somewhat lower quality than when their doughs were mixed to the optimum. The texture seemed of a lower quality, particularly because the cell walls tended to be thicker. Little change in crumb color was noticeable in loaves of bread resulting from overmixing.

SUMMARY AND CONCLUSIONS

1. Twelve pure wheat varieties each having four to six protein levels were milled, analyzed, and baked by three procedures. Micro recording dough mixer curves were made and the curves segregated into important characteristics which were measured. Curve characteristics were correlated statistically with baking results.

2. Test weight was not significantly correlated with flour yield or ash, nor was flour yield or wheat ash significantly correlated with flour ash. Flour protein was highly correlated with wheat protein. An estimate of percent of flour protein may be made from knowledge of percent of the wheat protein.

3. Statistical treatment of combined loaf volume data of the malt-phosphate-bromate formula and rich formula showed significant differences between varieties and formulas and a significant variety-formula interaction. Covariance analysis of the loaf volume data within a formula showed that mean loaf volumes of varieties were significantly different. When all varieties were considered as a group, then individual variety regressions of loaf volume on protein content were not significantly different. The rich formula gave greater differentiation between samples than the malt-phosphate-bromate formula.

4. Texture of the baked bread tended to improve as the protein content increased. The grain of the baked bread was increasingly open with increasing protein content, the best grain occurring at 12 to 13 percent protein. Large differences in texture and grain among varieties were not found. The crumb color of Turkey, Nebred, and Kawvale were yellow, while all other varieties, excepting Chiefkan which had a creamy gray hue, had satisfactory crumb color. Tenmarq exceeded all other varieties with a high sheen and creamy white crumb color.

5. The relationship of mixing time and of development angle with protein content were curvilinear. The development

angle was closely associated with mixing time and the relationship was inversely linear. Mixing time was significantly but not highly correlated with area under the curve to maximum consistency. Area under the curve to maximum consistency was presented as a measurement of energy input required to mix a dough to optimum development.

6. Area under the curve to maximum consistency was not significantly correlated with loaf volumes obtained by either formula.

7. The angle expressing range of mixing tolerance tended to decrease with increasing protein content but not in a linear relationship.

8. Height of curve was highly correlated with protein content and with loaf volumes of either formula and the relationship was linear. The height of the curve, independent of protein content, was not significantly correlated with loaf volume by the malt-phosphate-bromate formula while a negative significant correlation was obtained by the rich formula. Little improvement in the accuracy of predicting rich formula loaf volumes from protein content would be obtained by including the curve height in a multiple regression equation.

9. The width of the curve at maximum consistency increased in linear relation with the protein content and loaf volume with both formulas. The curve width, independent of protein content, was not found significantly correlated with loaf volumes of either formula.

10. The weakening angle of the curve increased in linear relation with increased protein content and with increased loaf volumes of either formula. The degree of association between loaf volumes by either formula and the weakening angles was not as high as the degree of association between loaf volumes of either formula and curve heights or widths. The loaf volumes of either formula were negatively correlated with the weakening angles, independent of protein content. Little would be added to the correlation between loaf volume and protein content by including the weakening angle.

11. Overmixing the doughs resulted in a decrease in loaf volume but little change in texture, grain and crumb color was observed. Damage to the bread was greatest in the high protein samples. A fair degree of association between decrease in loaf volume and the weakening angles was found. The weakening angles, independent of protein content, were positively correlated with decrease in loaf volume caused by overmixing the dough.

12. As a result of this investigation the following conclusions regarding the value of the micro mixer curve may be made: No curve characteristic was found to be as closely associated to loaf volume as protein content. Little would be added by the inclusion of any of the curve characteristics in an equation for estimation of loaf volume from protein content. It is not likely that the micro recording dough mixer curve can replace baking for the evaluation of baking strength and quality.

The greatest usefulness of the mixer curve appears to be that of furnishing accessory information supplementing baking data. Thus the mixer curve gives information regarding mixing time, sensitivity to overmixing, and a varietal pattern. Flours giving a curve similar to flours of known inferior qualities may readily be distinguished and discarded as unsuitable.

ACKNOWLEDGMENTS

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