INFLUENCE OF FLOUR PROPERTIES ON CERTAIN QUALITY FACTORS IN CHEMICALLY LEAVENED BISCUITS

by

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INTRODUCTION

Until the recent great commercial activity in the field of self-rising flour mixes, the use of chemical leavening was confined to a few materials such as self-rising biscuit flour and pancake flour. In the last few years a great number of new products of this type have appeared on the market, including quick biscuit mixes, cake and muffin mixes, doughnut mixes, pie crust mixes, etc., which contain not only the necessary leavening agents but in addition, shortening, flavorings, seasoning, etc.

In spite of these widespread commercial developments, little information exists in the scientific or technical literature on the basic chemistry or fundamental rules involved in the formulation of premixed flour products. It was the purpose of this research to investigate the relationship of a number of chemical and physical factors, which are inherent or variable in flour, to the characteristics of a chemically leavened product. Such information should prove useful in formulating a rational basis for the selection of ingredients and the planning of formulas and new products.

REVIEW OF THE LITERATURE

Very little information has appeared in the literature on the relationship of the biochemical properties of flour to the final quality of a chemically leavened cereal product. This deficiency in knowledge is in marked contrast to the volume of literature on bread production by yeast fermentation. There is no doubt that a great deal of useful empirical information on this subject exists among housewives, chefs and manufacturing control laboratories. Such information is, unfortunately, not available for the purpose of review.

The Action and Composition of Leavening Agents

Since self-rising flours depend for their leavening on "baking powders", it seems appropriate here to review briefly the nature and mode of action of these ingredients.

The term "baking powder" is applied to any compound that is incorporated into dough to produce gas for leavening by chemical reaction. It is a mixture of bicarbonate of soda and an acid-reacting material, incorporated into starch or flour as carriers or diluents. So long as the powder is kept dry, its acid and alkaline constituents do not react with each other but, when moistened, contact occurs and carbon dioxide gas is produced by the chemical reaction. Reduced to its simplest equation, the baking powder reaction may be expressed as follows (22):

Acid + baking soda + water + heat $\longrightarrow$ carbon dioxide gas + neutral salt residue + water.

Baking powders may be grouped according to the rate of their reaction. These groups are (4):

1. Quick-acting powders which evolve most of their gas in the cold and within 2 to 4 minutes.

2. Medium-acting powders which evolve most of their gas in the cold but do so rather slowly, requiring about 15 minutes to liberate 40 percent of their gas.

3. Slow-acting powders which evolve their gas very slowly in the cold, requiring about 15 minutes to liberate 40 percent of their gas.

4. Combination-acting powders which evolve only a part of the gas in the cold and the remainder when heat is applied. The chemical makeup of these various types of powders is as follows:

Types of Reaction Produced by Different Acids

Type of reaction	Acid-reacting component
Quick	Tartrates and ordinary type monocalcium phosphate
Medium	Special anhydrous monocalcium phosphate of delayed solubility
Slow	Sodium aluminum sulfate and pyrophosphate
Combination	Monocalcium phosphate and sodium aluminum sulfate

The acid-reacting ingredient of a baking powder controls the rate of reaction. Because of the close relationship between rate of reaction and the acid-reacting component, baking powders may be classified according to their acid-reacting ingredients as follows:

A. Tartrate powders are those in which potassium acid tartrate (cream of tartar), with or without the addition of tartaric acid, is the acid-reacting ingredient.

B. Phosphate powders are those in which monocalcium phosphate is the acid-reacting ingredient.

C. Sulfate powders are those in which sodium aluminum sulfate is the acid-reacting ingredient.

D. Sulfate-phosphate or combination powders are those in which the acid-reacting component is composed of sodium aluminum sulfate and monocalcium phosphate.

E. Pyrophosphate powders are those in which the acid-reacting ingredient is essentially sodium acid pyrophosphate.

Tartrate baking powders usually contain both cream of tartar and tartaric acid as acid-reacting components. They react rapidly and completely in the cold, and do not require heat to complete the evolution of gas. Their saline residues, Rochelle salt and sodium tartrate, do not affect the flavor or appearance of the finished product to any apparent degree. The use of tartaric acid raises the strength or acidity of the acid-reacting component and makes it possible to incorporate sufficient starch to insure satisfactory keeping qualities.

Cream of tartar ($KHC_4H_4O_6$) is potassium bitartrate, a white crystalline substance made by purifying argol and the lees of wine vats. Cream of tartar is the most costly of acid reagents used in baking powder (4).

Tartaric acid ($H_2C_4H_4O_6$) is the acid of grapes. It has a complex molecular structure, and like cream of tartar, is a by-product of wine making; it also may be recovered from the sediment removed from grape juice. It is a very active reagent, having 2½ times the neutralizing power of cream of tartar; 100 parts by weight will neutralize 116 parts of soda.

Sodium aluminum sulfate baking powders, commonly known to the trade as straight S.A.S. powders, are of no great commercial importance, because of the small amount now manufactured. Today, there are very few, if any, sodium aluminum sulfate powders on the domestic market. They are the lowest in cost of all baking powders, and their onetime popularity was due mainly to low price.

Phosphate baking powders are produced almost exclusively for commercial bakers, hotels, restaurants, and institutions, and are marketed in bulk. In some of these powders the acid component is sodium acid pyrophosphate only, while in others small percentages of monocalcium phosphate and calcium lactate are added to the pyrophosphate. Like aluminum sulfate, sodium pyrophosphate reacts very slowly on sodium bicarbonate until heat is applied, but it differs from the other compound in that a faster reaction is obtained when subjected to heat. Pyrophosphate baking powders are used almost exclusively in the manufacture of bakery-made doughnuts and cakes. By their use it is possible to make up large batches of dough, let them stand several hours before baking, and still obtain a good finished product. When first mixed, their leavening effect is sufficient only to make the dough light and workable, the greater portion of the gas being evolved after the dough is subjected to the heat of the oven. They have some disagreeable or stringent flavor characteristics, particularly if the soda-pyrophosphate ratio is too low, but they have excellent keeping quality, even under adverse storage conditions.

Phosphate baking powders generally are made with the regular hydrated type of monocalcium phosphate ($CaH_4(PO_4)_2H_2O$) as the acid-reacting component. They react relatively fast in the cold dough or batter, but not completely; approximately two-thirds of the reaction takes place during the first few minutes in the cold and one-third in the oven. The residue obtained from phosphate baking powder is disodium phosphate, tricalcium phosphate, and possibly dicalcium phosphate. The disodium phosphate residue is soluble but is probably the least objectionable saline residue of baking powders. Both dicalcium and tricalcium phosphates are nearly insoluble and may be considered inert from the point of view of flavor and baking quality. From the point of view of nutrition, however, they are of considerable importance as a source of both calcium and phosphorus. Monocalcium phosphate ($CaH_4(PO_4)_2H_2O$) is a salt formed by the reaction of phosphoric acid and chemically purified lime; 100 parts by weight will neutralize 80 parts of soda (4).

Leavening Ingredients for Self-Rising Flour Products

According to the Federal Register of May 27, 1941, the Food and Drug Administration, in paragraph 15.050, has defined self-rising flour as follows:

> Self-rising flour, self-rising white flour, self-rising wheat flour is an intimate mixture of flour, sodium bicarbonate, and the acid-reacting substance monocalcium phosphate or sodium acid pyrophosphate or both. It is seasoned with salt. When it is tested by the method prescribed in sub-section (c), not less than 0.5 percent of carbon dioxide is evolved. The acid-reacting substance is added in sufficient quantity to neutralize the sodium bicarbonate. The combined weight of such acid-reacting substance and sodium bicarbonate is not more than 4.5 parts to each 100 parts of flour used.

About 1938 a special anhydrous monocalcium phosphate ($CaH_4(PO_4)_2H_2O$) of slow solubility was made available to the baking powder industry. It has a more efficient leavening action because of its delayed solubility. The dough or batter can be mixed before the monocalcium phosphate has dissolved; thus more of the leavening action can be retained for the oven. This type of monocalcium phosphate has replaced most of the regular hydrated forms as the acid ingredient in self-rising flours. Less baking soda and monocalcium phosphate may be used to obtain the equivalent leavening action.

Influence of Leavening Action on Dough Characteristics

Smith and Bailey (26) investigated the effects of various inorganic residues from chemical leavening compounds upon the physical properties of bread. They noted that disodium phosphate alone, of all baking powder reaction products, exerted a pronounced effect upon gluten by inhibiting the formation of a firm, tough, compact mass. They concluded that hydration of gluten to a certain degree, due to disodium salt, might prove advantageous in promoting friability and shortness in baked goods. The gluten of the dough assumes greater elasticity and a higher degree of solubility, due to the formation of a disperse phase of dissolved protein induced by the salt. This condition is responsible for an increase in the volume of the baked product only up to a certain point, beyond which the acidity may render the gluten too soft to admit of further permanent distension by the carbon-dioxide evolved from the baking powder. Consequently, some of the glutenous film collapses with resultant disorganization of cellular structure of the finished baked product. Furthermore, the continuation of gluten dispersion through increasing acidity finally results in a dense crumb of very coarse texture. Gluten also becomes more elastic with alkalies. Any alkalinity beyond a critical point, however, results in a correspondingly excessive increase in soluble protein, which as a disperse phase, is supposed to increase more rapidly than when induced by acid.

Factors Which Influence Biscuit Quality

Other information in the literature which pertains to self-rising flour and biscuit quality deals mainly with the biscuit test and its lack of replicability among various laboratories. In attempting to standardize the procedure, subcommittees of the American Association of Cereal Chemists on Methods of Testing Self-Rising Flour have done considerable work for several years, most of which has led to inconclusive results.

Gookins and his committee (16) studied the effect of a 0.6 percent difference in protein content of two soft wheat family patent flours on biscuit quality, and found that no significant difference existed between the biscuits made from the two flours. They investigated the effect of excess phosphate in a self-rising flour formula using hard wheat flour, and found that the biscuit score was not materially improved, but that the pH was lowered.

They also determined how well several collaborators in various localities checked on the scoring and rating of four unknown self-rising flours. The resulting total scores did not check very well, the main source of variation being in the volume score. This committee concluded that since the biscuit baking test is not sensitive enough to determine ordinary variations in flour quality, it should be considered a test for determining only the following properties of a flour or self-rising mixture:

1. Flour soundness and flavor
2. Flour color
3. Proper chemical balance of self-rising ingredients
4. Leavening power of the self-rising ingredients

The following year Gookins (17) and his committee co-workers showed that baking to a uniform oven loss of 14 percent did not result in a more uniform biscuit volume. They concluded that this was not a satisfactory approach to standardizing variations among different laboratories.

An optimum amount of water was shown by Logue and Ranker (21) to be necessary for best biscuit quality. They also showed that the pH of the finished biscuit is a valuable help in indicating correct proportions of leavening agents; optimum results were obtained when the leavening was regulated to yield a pH of 7.0 to 7.3 in the baked product.

Gookins (15) found that the specific volume of biscuits did not vary significantly with different absorption. The color and texture were about the same, except that in the very dry doughs the inside of the biscuit was too compact. He stated that optimum absorption for the biscuit dough was considerably higher than the Farinograph absorption. These results confirmed data obtained by a previous committee.

The granulation of the flour was suggested by Dunn (12) to affect the shortening requirements of the flour for optimum results, since it seems probable that the shortening requirement depends upon the amount of surface to be covered.

The optimum shortening level for flours of the type generally supplied for biscuit-making purposes was determined by Schwain and Loving (25) to be approximately 19 percent. In employing this high shortening level, the absorption must be decreased to compensate for the stimulating effect of the extra fat on dough mobility; a decrease in water absorption of about 0.4 percent is required for every 1 percent increase in shortening.

Comparative biscuit tests with a liquid fat (cottonseed oil) and a solid shortening (hydrogenated vegetable oil) indicated that the optimum shortening level is independent of the type of shortening.

Biscuit flours of varying strength, as indicated by protein content and viscosity, did not differ materially either in their tolerance to varying percentages of shortening or in the quantity required to yield optimum biscuits. However, the softer flours gave superior biscuits, and maximum biscuit quality was obtained with slightly lower percentages of shortening than are needed with stronger flours.

McKim and Moss (23) confirmed that for each 2.5 percent increase in shortening, the absorption decreased 1 percent.

It was the purpose of the present research to determine the effect of variations in the quality of the basic constituents of the flour on the baked product. For this purpose the biscuit test was chosen because a fairly rigorous testing procedure was available which has been interpreted in the scientific literature and in addition it was thought that it would show results applicable to other chemically leavened products. The influence of factors such as protein content, shortening requirement, wheat variety of both hard and soft types, malt supplementation, flour granulation and absorption were investigated by technics employed in the cereal laboratory.

MATERIALS AND METHODS

Description of Flours Used

With the exception of standard hard and soft wheat flours which were obtained from commercial sources, all flours used in this study were milled on the Buhler experimental mill.

The hard wheat protein flours were obtained by blending together flours of similar protein content disregarding environmental and variety factors. Synthetic hard wheat flours were made by the addition of dried gluten and wheat starch to the standard hard wheat flour. Synthetic soft wheat flours were made by the same method. The flours from pure hard wheat varieties were obtained from the Federal Hard Wheat Quality Laboratory at Manhattan, Kansas. The soft wheat varieties were secured from the Federal Soft Wheat Quality Laboratory located at Wooster, Ohio. Both of these groups of samples were produced in the 1946 crop year. Two flours differing in granulation were obtained by varying the tempering time of a hard wheat sample and milling it on the Allis experimental mill. The malt-supplemented flours were made by adding various increments of malted wheat flour, or extracts thereof, to the standard hard and soft wheat flours.

To designate a particular flour used in this work, the key given in Table 1 was used. The characterization of these flours by chemical and physicochemical methods appears in Table 2.

Table 1. Flour samples and their key designation.

Flour sample	Key designation
Hard wheat standard flour	H.S.
Composite Hard Wheat Flour Samples with different protein content	H.P. #1
"	H.P. #2
"	H.P. #3
"	H.P. #4
"	H.P. #5
Hard wheat standard flour, 33.3% wheat starch added	H.R. #1
Hard wheat standard flour, 14.3% wheat starch added	H.R. #2
Hard wheat standard flour, 3.0% gum gluten added	H.R. #3
Hard wheat standard flour, 5.6% gum gluten added	H.R. #4
Soft wheat standard flour	S.S.

Table 1. (cont.).

Flour sample	Key designation
Soft wheat standard flour, 15.3% wheat added	S.R. #1
Soft wheat standard flour, 2.5% gum gluten added	S.R. #2
Soft wheat standard flour, 5.0% gum gluten added	S.R. #3
Soft wheat standard flour, 7.5% gum gluten added	S.R. #4
Early Blackhull	E.B.
Wichita	Wichita
Red Chief	R. Chief
Pawnee	Pawnee
American Banner	A.B.
Blackhawk	B.H.
Trumbull	T.B.
Thorne	Thorne
Clarkan	C.K.
Purkof	Purkof
Fine granulation flour	Gran. #1
Coarse granulation flour	Gran. #2
Hard wheat standard flour, 0.5% malted wheat flour added	H.M. #1
Hard wheat standard flour, 1.0% malted wheat flour added	H.M. #2
Hard wheat standard flour, 1.5% malted wheat flour added	H.M. #3

Table 1. (cont.).

Flour sample	Key designation
Hard wheat standard flour, 2.5% malted wheat flour added	H.M. #4
Hard wheat standard flour, 5.0% malted wheat flour added	H.M. #5
Hard wheat standard flour, 10.0% malted wheat flour added	H.M. #6
Soft wheat standard flour, 0.5% malted wheat flour added	S.M. #1
Soft wheat standard flour, 1.0% malted wheat flour added	S.M. #2
Soft wheat standard flour, 1.5% malted wheat flour added	S.M. #3
Soft wheat standard flour, 2.5% malted wheat flour added	S.M. #4
Soft wheat standard flour, 5.0% malted wheat flour added	S.M. #5
Soft wheat standard flour, 10.0% malted wheat flour added	S.M. #6
Soft wheat standard flour, 20 ml malted wheat flour extract acced	S.M.E. #1
Soft wheat standard flour, 30 ml malted wheat flour extract added	S.M.E. #2
Soft wheat standard flour, 40 ml malted wheat flour extract added	S.M.E. #3
Soft wheat standard flour, 100 ml malted wheat flour extract added	S.M.E. #4
Soft wheat standard flour, 20 ml protease inactivated malted wheat flour extract added	S.M.I.P. #1
Soft wheat standard flour, 30 ml protease inactivated malted wheat flour extract added	S.M.I.P. #2

Table 1. (concl.).

Flour sample	Key designation
Soft wheat standard flour, 40 ml protease inactivated malted wheat flour extract added	S.M.I.P. #3
Soft wheat standard flour, 100 ml protease inactivated malted wheat flour extract added	S.M.I.P. #4

Table 2. Characterization of flours.

Sample	Ash[1]	Protein[1]	Viscosity 20g flour[1]	Viscosity 2 g protein[2]	Farinograph absorption[1]	Valorimeter reading
		%	degrees MacMichael		%	
H.S.	0.40	9.2	137	172	59.0	42
H.P. #1	0.45	7.8	67	127	58.8	44
H.P. #2	0.45	9.3	101	125	54.9	50
H.P. #3	0.47	10.6	140	123	57.4	52
H.P. #4	0.48	12.2	183	118	59.8	55
H.P. #5	0.52	14.0	234	110	61.7	53
H.R. #1	0.35	7.2	49	171	58.0	24
H.R. #2	0.39	8.4	87	155	58.0	28
H.R. #3	0.39	11.4	169	123	60.0	57
H.R. #4	0.38	13.0	175	114	65.0	55
S.S. #1	0.38	7.4	60	107	54.0	32
S.R. #1	0.30	7.0	45	119	54.4	26
S.R. #2	0.32	8.0	77	90	56.0	40
S.R. #3	0.39	9.3	95	80	58.0	46
S.R. #4	0.40	11.0	114	67	60.0	68
E.B.	0.37	10.5	137	138	62.6	48
Wichita	0.43	10.0	142	143	64.2	53
R. Chief	0.45	10.3	137	138	71.5	46
Pawnee	0.43	11.6	170	108	65.0	56
Gran.#1	0.48	9.3	103	124	-	51
Gran.#2	0.52	9.5	96	106	-	51
A.B.	0.41	8.4	53	80	59.0	34
B.H.	0.38	10.2	84	75	62.5	31
T.B.	0.39	9.7	126	128	62.5	45
Thorne	0.33	8.0	84	137	62.5	34
C.K.	0.43	8.3	77	113	65.0	33
Purkof	0.43	9.0	133	164	67.5	57

[1] 14 percent moisture basis.
[2] Dry matter basis.

Baking Method

The baking procedure employed for biscuits was essentially that given in Cereal Laboratory Methods (5th edition) (2). A variation from this method involved rolling the dough to a thickness of ¼ inch instead of 3/8 inch. The ¼ inch dough sheet was found to give a biscuit of greater uniformity and the additional advantage was obtained of requiring small quantities of ingredients. It was found that the thickness to which the dough was rolled (¼ or 3/8 inch) did not influence the biscuit grade. A modified scoring method also was adopted.

<u>Equipment</u>. The following equipment was used in the baking test:

Beam balance

Torsion balance

Hobart C-10 electric mixer with three quart mixing bowl and flat beater. The mixing speeds were: low, 145 rpm; second, 257 rpm; high, 457 rpm

Duplex flour sifter

Bread board with canvas cloth

Rolling pin with stocking cover

Square wooden sticks, ¼ inch by ¼ inch (2)

Round cutter, diameter 2 inches

Spatula

Low sided aluminum baking sheets

Oven - Despatch electric with rotating hearth

Measuring device - Rape seed and a 3 inch x 6 inch x 6 inch pan, volume 1800 cc

MacBeth pH meter, glass electrode

Bloom Gelometer for compressibility determination on biscuit crumb (fuller description follows)

Crumbliness tester - to determine the percent of biscuit crumb which passes a mechanically shaken ¼ inch screen (fuller description follows)

Basic Baking Formula.

	Weight grams	Percent (flour basis)
Flour (15% moisture basis)	200.0	100.0
Anhydrous Monocalcium Phosphate	3.0	1.5
Sodium Bicanbonate-for Soft Wheat Flour	2.5	1.25
for Hard Wheat Flour	3.0	1.5
Salt	4.0	2.0
Water	varied	varied
Hydrogenated shortening (Crisco)	varied	varied

Baking Procedure. The flour is weighed on the beam balance and transferred to the mixing bowl. To the flour are added phosphate, soda, and salt, weighed out on the torsion balance. The flour and leavening ingredients are sifted together four times. The dry mixture is placed in the mixing bowl, shortening added, and the large lumps which may form are broken by hand using a flat beater. Using the Hobart C-10 mixer, the shortening is cut in for 3 minutes at low speed. Ice water is added and mixing is finished at second speed for 15 seconds. The dough is rolled out on a lightly floured cloth-covered board, and very lightly dusted with flour. The dough is slightly rounded up and partially flattened by hand. The soft, spongy, but not sticky dough, is rolled once lightly in each direction from the center, then the rolling pin is pushed down to the supporting strips and away from the operator in a second rolling. The dough is then folded double and turned through a 90° angle, rolled again as before, and the result is a smooth dough of the proper size to cut eight biscuits. These are cut with a lightly floured cutter two inches in diameter. Seven of these unbaked biscuits are weighed in a tared pan on a beam balance and this weight is recorded. The seven biscuits are arranged in a circle on a baking sheet with about one-half inch space between biscuits. The eighth biscuit is placed in the center. Baking is carried out at a temperature of 450° F. for 15 minutes. The dough clinging to the mixer and paddle are cleaned between batches, but this equipment is not washed.

Flours are baked in triplicate, rotating the order. For example, if flours #1, #2, #3, are being tested, they are baked in the order #1, #2, #3; #3, #2, #1 and #2, #1, #3.

The odor and flavor of the eighth biscuit are observed and recorded while it is hot. The combined weight of the remaining seven biscuits is recorded immediately after they are taken from the oven.

Evaluation of Biscuit Qualities. The volume of the biscuits is determined in a square aluminum pan whose dimensions are: 3 inches wide, 6 inches long, 6 inches high. The volume of the pan was determined using rape seed by filling the pan to overflowing and leveling the seed in a manner similar to the procedure used for determining the test weight of wheat. This volume of seed required to fill the pan is measured in a graduate cylinder. Four biscuits are placed on edge on a thin layer of seed in the bottom of the pan and covered with seed. The three remaining biscuits are placed on the seed in the same manner and covered with seed. The excess seed is leveled off and measured in a 500 cc graduated cylinder. Specific volume is calculated by dividing the volume of the seven biscuits by the dough weight for the seven biscuits, and multiplying this quotient by 20. Specific lightness is calculated by the same method using the baked weight of the seven biscuits instead of the dough weight.

The grain of the baked biscuit is evaluated by visual observation of horizontal or vertical sections of cold biscuits with reference to a control. The grain is an index of the physical structure of the biscuit crumb with reference to: (a) the size, shape and homogeneity of the cells, and (b) the thickness of the cell walls.

Tenderness is estimated by measuring the resistance to compression of the biscuit crumb. In this work the Bloom Gelometer was used to measure crumb compressibility and a specially built Crumbliness Tester gave an indication of the resistance of the crumb to abrasion.

Flavor is that quality of the flour which affects the smell, taste and aroma of a biscuit baked from it. It is evaluated by organoleptic comparison with reference to a control involving: (a) the smell of a flour at room temperature or when mixed with hot water, and (b) the smell and taste of hot and cold biscuits. Scoring is carried out with consideration of the following points given by R. A. Barackman in the 1933-34 Self Rising Flour Committee Report (27), the extent of the mark-down being made with reference to a sound, fresh, properly leavened standard flour, and a numerical score accompanying the descriptive terms as follows:

Scoring factor	Desirable	Undesirable
Flour condition	sweet	rancid, musty
Flour quality	sweet	wheaty, starchy
Leavening	neutral	acid or sour, alkaline or soapy
Salt	pleasing	salty, flat
Eating quality	good or chewy	doughy, dry, and crumbly

Crumb color is an expression of the color of the cut surface of the biscuit crumb, evaluated by visual comparison with reference to the crumb of a biscuit made from a control flour.

Crust color is a relative value obtained by visual comparison with reference to the crust of a biscuit made from a control flour.

The external appearance is judged by visual comparison of the general appearance of the biscuits. Favorable characteristics are: symmetrical, regular, straight and even sides. Unfavorable characteristics are: rough, cracked or uneven side walls, and flat product.

The numerical score given to each of these eight quality factors is shown on the accompanying score card in Table 3. The total score is obtained by adding the individual numerical scores.

It is to be noted that the score card comprises quality values obtained by subjective judgment; viz., external appearance, texture, flavor, color of crust and crumb, as well as others obtained by objective measurement technics; viz., tenderness (compressibility), lightness and volume. Compressibility values, for example, varied from 61 to 155 (g stress for 4 mm penetration). These experimentally determined measurements were transferred to the numerical scale of 1 to 15 necessary for inclusion in the score card, by appropriate statistical methods. By similar methods, lightness and volume measurements were transferred statistically to a numerical scale of 10. This operation was carried out by assuming that the experimental measurements fell within a normal distribution curve, which was virtually true. The steps followed in these calculations appear in Table 18 in the Appendix.

The pH is determined electrometrically using a glass electrode. The fresh crumb of two biscuits is macerated with 100 cc of distilled water in the monel unit of a Waring Blendor for seven seconds. The pH is obtained on the stirred suspension. For a properly leavened biscuit the pH should be between 7.2 and 7.5.

Table 3. Score card for biscuits.

Factor	Numerical score	Flour sample #1	#2	#3	#4	#5	#6
External appearance	(12)						
Texture	(13)						
Tenderness (compressibility)	(15)						
Flavor	(15)						
Crust color	(10)						
Crumb color	(15)						
Lightness	(10)						
Volume	(10)						
Total	(100)						

Use of Bloom Gelometer to Determine Compressibility

The Bloom Gelometer, shown in Fig. 1, is an instrument manufactured by the Precision Scientific Company for testing the gel strength of gelatine products. In this work it was used for determining the compressibility of the biscuit crumb, which is taken as an index of tenderness.

The instrument determines the weight required to force a plunger a given distance into a gel. In this work a one-half inch slice of the biscuit crumb was used instead of the gel. The instrument consists of a base with leveling screws on the bottom. Built into the base is a movable platform which is raised or lowered by means of a gear system with a coarse and a fine adjusting mechanism. Two parallel rods rise vertically from the back of the base and hold at the top a V-shaped metal hopper which contains metal shot. The hopper drains out into a tube which guides the shot into a movable hopper. This movable hopper controls the flow of shot down the tube. In the up position the flow of shot is stopped and in the down position the shot flows into a small cup. An arm connected to the hopper rides between two contact points of an electro-magnet.

The cup is removable from a metal platform which is suspended from the hopper by a spiral spring. The amount of shot delivered in a given time is controlled by an adjusting nut which changes the angle of the movable hopper in relation to the stream of shot.

Fig. 1. Bloom Gelometer used to determine compressibility of biscuit crumb.

A plunger extends down from the base of the suspended platform. This plunger is forced down into the crumb of the biscuit 4 mm by the weight of the shot. The amount of shot necessary to force the plunger down into the crumb 4 mm is controlled by an electromagnetic system. The lower end of the spiral spring is connected to a small rod which in turn is connected to the metal platform holding the shot receiver. This rod passes through the center of a small contact disc which is fastened securely to the rod. The contact disc moves between an upper and a lower contact point. These contact points are connected to an electro-magnet which automatically releases the hopper spout arm when the contact disc strikes the lower contact point.

Adjustment of Spiral Spring. To insure that the load producing a given depression is not composed in part of the weight of the pan system or used in part to overcome any tension in the spiral spring, it is necessary to counterbalance the weight of the pan system by such a tension in the spiral spring that equilibrium is produced when the contact disc is just barely resting on the lower contact. This condition is produced by first placing the circuit switch in the on position, then loosening the spring adjustment lock nut and adjusting it until the contact disc on lowering makes the first perceptible electrical contact with the lower contact. When properly set, a slight movement of the pan system will cause a succession of contacts in the circuit, producing a sound in the electromagnetic system very much like that of a telegraph sounder. After this adjustment is made the spring adjustment lock nut is tightened.

Setting of Upper Contact. To regulate the extent of the depression of the crumb surface by the plunger, the upper contact is made adjustable. To set the upper contact so that a definite plunge of four millimeters is produced, a biscuit slice one-half inch thick is placed on the elevating platform. The crumb and the platform are raised by turning the elevating platform knob and the micro-elevating knob until the crumb meets the plunger, and raises the contact disc slightly free from the lower contact thus preventing a swinging motion of the pan system which occurs when the latter is unsupported.

The upper contact locking screw is loosened and a machined gauge is introduced between the upper surface of the contact disc and the upper contact. The upper contact is adjusted until it makes a gentle contact with the gauge while the gauge rests on the contact disc. When the proper position for the upper contact has been found, the upper contact locking screw is tightened to hold the upper contact in position. If this operation has not changed the position of the upper contact, the gauge and the supporting crumb are removed.

Electromagnetic System Adjustment. By adjusting the electromagnetic system up or down, any desired rate of delivery of shot, within limits, may be obtained. In order to make this adjustment the locking nut at the rear of the electromagnetic system is first loosened. The electromagnetic system adjusting nut is now free to turn. Lowering the electromagnetic system will result in less flow of shot, while raising it will increase the flow. After the correct flow of shot has been determined, the set screw within the adjusting nut is tightened.

In order to deliver 200 (±5) grams of shot in five seconds, the instrument should be adjusted as follows:

The weight of shot delivered is determined for any given position of the electromagnetic system in this time interval, and then the electromagnetic system is raised or lowered depending on whether the net weight obtained was less or greater than 200 (±5) grams. A convenient method for making the determination is as follows: The hopper is filled with about 800 grams of polished lead shot which is furnished with the instrument, the circuit switch is set in the off position, a one-half inch slice of biscuit crumb is placed on the elevating platform and the latter is raised about one-sixteenth of an inch. The shot receiver is placed on the pan system and while starting a stopwatch, the hopper spout arm is raised to its upper position with a quick but uniform motion. At the end of five seconds the flow of shot is stopped by switching on the current at the toggle switch.

The net weight of shot is determined and five or more determinations are averaged together. The first weight obtained and any others that are not made precisely as outlined above are discarded. The rate of flow of shot is determined at frequent intervals since it changes slowly due to wearing of the shot.

Determination. To determine the compressibility of the biscuit crumb a one-half inch slice of the crumb is centered on the elevating platform. The circuit switch is placed in the on position. The elevating platform with the crumb is raised by means of the platform elevating knobs until the contact disc just makes contact with the upper contact. This is indicated by the telegraph sounder. The shot receiver is placed on the pan system and immediately the hopper spout arm is raised to its upper position with a quick but uniform motion. The raising of the hopper spout arm immediately starts the flow of the shot, depressing the surface of the crumb until the contact disc makes contact with the lower contact. This closed the circuit which acts on the electromagnetic system by moving the bar which holds the hopper spout arm in the upper position. When this bar moves, withdrawing the support of the hopper spout arm, it immediately falls, thus cutting off the flow of the shot.

The weight of shot delivered into the shot receiver, plus the weight of the shot receiver itself, is the weight required to move the plunger through the prescribed distance. This resistance to stress of the biscuit crumb gives an index of the compressibility or tenderness of the biscuit crumb.

For each batch of biscuits, the tenderness was determined on one of the biscuits. The biscuits were allowed to cool at room temperature for one hour. To insure a consistent one-half inch slice of the biscuit crumb, a cutting box was made which had a slot cut into the sides one-half inch above the base. The bottom crust was cut off the biscuit first. This was done by putting two one-fourth inch blocks into the box, putting the biscuit into the box with the bottom side down, and cutting the crust off with a knife riding through the slots in the side. The blocks are then removed, cut side of the biscuit is put down in the box and the top crust cut off with the knife riding in the slots. The tenderness was determined immediately after the crumb slice was secured.

Crumbliness Tester

In addition to the compressibility index obtained with the Bloom Gelometer, a crumbliness tester was designed and built to determine the resistance of the crumb to abrasion. A photograph of this machine appears in Fig. 2.

One part of the machine is a cylindrical container six inches long and two inches in diameter. This container is mechanically shaken through a ten-inch arc by a 1/25 horse power motor, 1750 rpm, driving a series of 2 three-speed pulleys which were belt connected to the motor and to each other. By placing a belt on different size pulleys the speed of shaking may be reduced to the desired value. An eccentric connects the second pulley to a lever arm at the end of which

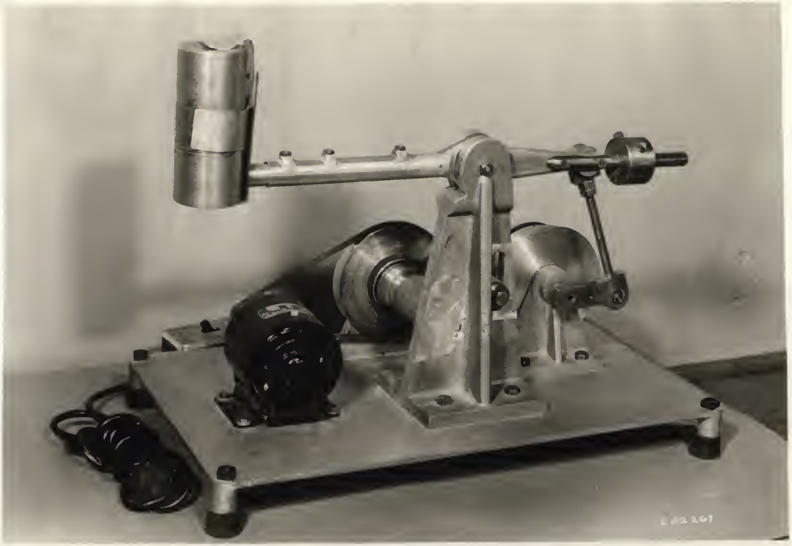

Fig. 2. Crumbliness Tester.

the container is attached. A speed of 207 complete shakes per minute was used. The can is divided into two sections, the top section being 6 inches high, and the bottom section 2 inches high. These two sections are threaded so that they may be screwed together to make one container. A $\frac{1}{4}$ inch mesh screen was cut into a two-inch circle and fitted into the bottom section on a small shoulder which is built into this section.

The operation of the instrument consisted of placing a weighed quantity of crumb from each bake, one hour after removal from the oven, into the upper section of the container. The screen was put into the lower section, and the two screwed together. The container was placed in position at the end of the lever arm, and the motor started. At the end of eight minutes the motor was stopped and the amount of crumb which had passed through the screen was weighed. This amount was calculated on a percentage basis. To obtain a uniform section of biscuit crumb, the same cutting box as was used for preparing the Gelometer sample was employed.

Viscosity Test

Viscosities were determined on all except the malt supplemented flours by the digestion method using both 20 grams of flour, 14 percent moisture basis, and 2 grams protein dry weight basis as described in Cereal Laboratory Methods, (5th edition).

Bayfield (5) suggested that both the 20 gram and the 2 gram protein viscosities should be used to evaluate flour strength, the choice depending upon the information desired. The 20 gram one-hour digestion should be used in measuring flour strength. The 2 gram protein viscosity should be used as a tentative measure of flour quality.

Garnatz (14) pointed out that viscosity is a useful means of determining strength of flours used in the biscuit and cracker trade. He presents data on the relationship between protein content and viscosity in degrees MacMichael for cracker flours, but not for biscuit flours.

Alexander (1) stated that viscosity is one of the physical tests that has been utilized to good advantage in characterizing flour strength. Many factors may influence viscosity readings, such as mineral content, and quantity and quality of the gluten, but in general the higher the viscosity reading, the greater the hydration capacity of the flour and the greater the gluten strength.

Absorption

The absorption of the various flours was determined in a series of baking tests by varying the amount of water by increments of 2.5 percent. The amount of shortening used in these bakes was 12.5 percent for the hard wheat flours and 10 percent for the soft. The dough handling characteristics, as well as the quality of the baked biscuits, were noted. A dough with proper absorption should be soft but not sticky. The specific volume was found to be the best grading factor for the baked biscuit since it would increase with successive increments of water to an optimum absorption value and then decrease.

Shortening

The optimum shortening content was determined by a series of bakes using the optimum absorption and varying the shortening content by increments of 2.5 percent. As in the absorption determination the dough handling characteristics and the quality of the biscuits were evaluated. Too little shortening causes the dough to be short, and too much causes it to be sticky and elastic. The correct shortening content along with the proper absorption gives a soft, spongy dough. The specific volume was again found to be the best grading factor for the baked biscuit, since it increased to an optimum and then decreased.

Farinograph Absorption

Farinograms were run on all of the flours used in this work with the exception of the malt supplemented samples, by titrating to the 500 unit consistency value, in order to check the baking absorption. It was also thought that a correlation might exist between the biscuit quality and the valorimeter reading as determined on the farinograms.

Amylase Enzyme Determination

Amylograms and maltose values were determined on the malt supplemented flours. The purpose of these two determinations was to characterize the flours as to their alpha and beta amylase content. In this work the amylograph was used which is a torsional viscosimeter which automatically records the resistance to shear offered by a flour suspension as the temperature of the suspension is increased at a constant rate of approximately 1.5 degrees C. per minute. This instrument, described by Brabender (6), enables a continuous record to be made, in graphical form, of the viscosity of a flour-water suspension as the temperature is uniformly increased. The increase in viscosity is due to the gelatinization of the starch, the viscosity being influenced by the action of amylase enzymes present. The usefulness of the instrument in the examination of flour and starches has been investigated by many workers, including Schmidt and Scholtz (24), Brabender, Mueller and Koster (8), Brabender, Mueller and Heide (7), Anker and Geddes (3), and Brown and Harrel (9). Johnson, Shellenberger, and Swanson (18) studied the utility of the amylograph for evaluating the diastatic activity of various flours. They found that the marked liquefying action of alpha amylase on the viscosity of a starch paste favors the use of the amylograph as a convenient means of determining alpha-amylase activity of wheat flours. They found a correlation coefficient between the diastatic activity and amylograph curve height of -0.693, and for the gassing power determination and amylograph curve, -0.833.

EXPERIMENTAL RESULTS

Protein Content

The effect of protein content on biscuit quality was studied with both hard and soft wheat flours. In the case of hard wheat flour protein two methods of investigation were used. A series of protein composites of hard wheat flours were made up from small crop samples, available in the Department of Milling Industry, without regard to variety and environmental factors. The second method involved the addition of gum gluten to a standard flour in order to raise the protein content and wheat starch to lower the protein content. The gum gluten and the wheat starch were obtained from commercial sources. The effect of protein content on the biscuits made from soft wheat flour was investigated by raising the protein content with the commercial gum gluten, and lowering the protein content by the addition of commercial wheat starch.

The results of the baking tests with these flours are summarized in Tables 4, 5, and 6. The results are averages obtained by using the optimum shortening and absorption for the flours. External appearance, texture, crumb and crust color were determined by three comparison bakes for each series.

The results obtained from the flours with varying protein content show in general that the best biscuit is obtained with flours with a low protein content, the composited experimentally milled hard winter wheat flours producing the best total score at a protein content of 7.8 percent. This flour yielded the most tender biscuits, whereas the flours with successively higher protein content produced biscuits which were progressively tougher. The biscuit with the best external appearance was produced with the commercially milled hard winter wheat flour used as a standard which had been bleached with Agene and Novadel. The side walls of the biscuits from the other flours were cracked and were therefor graded down. The texture of the grain was best in the biscuits from the flours of low protein content, and became steadily coarser with thicker cell walls as the protein content of the flour increased. No difference could be distinguished in the flavor, crust color or crumb of biscuits produced from this series of flours. No significant trend in lightness and volume of the biscuits from these flours appeared, but the best volume and lightness scores were secured with the flour having a 12.2

Table 4. Influence of flour protein content on biscuit properties obtained by compositing experimentally milled hard winter wheat flours of similar protein content.

	Sample designation and protein content expressed in percent[1]					
	H.S. 9.6 (11)	H.P.#1 7.8 (6)	H.P.#2 9.3 (4)	H.P.#3 10.6 (4)	H.P.#4 12.2 (4)	H.P.#5 14.0 (5)
Quality factors						
Optimum absorption %	65.0	60.0	65.0	65.0	70.0	70.0
Optimum shortening %	15.0	10.0	15.0	15.0	17.5	20.0
Specific volume	44.5	48.8	46.7	46.9	54.4	48.6
Gelometer compressibility	127.7	113.0	119.0	161.0	166.0	183.0
pH	7.4	7.4	7.3	7.4	7.3	7.4
Score values						
External appearance	12	10	11	11	10	10
Texture	13	13	12	12	11	11
Tenderness	7	12	10	1	1	1
Flavor	15	15	15	15	15	15
Crust color	10	10	10	10	10	10
Crumb color	15	15	15	15	15	15
Lightness	4	8	3	4	9	7
Volume	4	8	6	6	10	8
Total score	80	91	80	72	83	79

[1] Values given are means of the number of determinations indicated in parenthesis.

Table 5. Influence of flour protein content on biscuit properties obtained by the addition of commercial wheat starch and gum gluten to a commercial hard winter wheat flour.

	Sample designation and protein content expressed in percent[1]				
	H.S. 9.6 (11)	H.P.#1 7.2 (4)	H.P.#2 8.4 (4)	H.P.#3 11.4 (4)	H.P.#4 13.0 (4)
Quality factors					
Optimum absorption %	65.0	57.5	60.0	67.5	70.0
Optimum shortening %	15.0	10.0	12.5	17.5	17.5
Specific volume	44.5	39.7	43.9	42.1	45.6
Specific lightness	58.0	52.0	55.1	54.5	56.3
Gelometer compressibility	127.7	168.4	152.0	150.0	139.0
pH	7.4	7.4	7.4	7.4	7.4
Score values					
External appearance	12	11	11	12	12
Texture	13	13	13	12	12
Tenderness	7	1	2	2	4
Flavor	15	15	15	15	15
Crust color	10	10	10	10	10
Crumb color	15	15	15	15	15
Lightness	4	1	2	2	3
Volume	4	1	3	2	5
Total score	80	67	71	70	76

[1] Values given are means of the number of baking tests indicated in parenthesis.

Table 6. Influence of flour protein content on biscuit properties obtained by the addition of commercial wheat starch and gum gluten to a commercial soft wheat flour.

	Sample designation and protein content expressed in percent[1]				
	S.S.	S.R.#1	S.R.#2	S.R.#3	S.R.#4
	7.4	7.0	8.0	9.3	11.0
	(4)	(5)	(5)	(4)	(4)
Quality factors					
Optimum absorption %	60.0	57.5	60.0	62.5	65.0
Optimum shortening %	10.0	10.0	12.5	12.5	15.0
Specific volume	51.3	49.8	50.0	51.0	51.7
Specific lightness	64.1	60.1	58.7	60.6	63.0
Gelometer compressibility	81.7	86.0	81.0	94.0	72.0
pH	7.3	7.3	7.3	7.3	7.3
Score values					
External appearance	12	11	11	11	11
Texture	12	12	12	11	11
Tenderness	9	7	9	4	12
Flavor	15	15	15	15	15
Crust color	10	8	9	9	9
Crumb color	15	15	15	15	15
Lightness	6	3	2	3	5
Volume	7	5	5	6	7
Total score	86	76	77	84	85

[1] Values given are means of the number of baking tests indicated in parenthesis.

percent protein content. The pH of the biscuit crumb for these flours varied between 7.3 and 7.4. The general trend was for the total score to decrease as the protein content increased.

The series of flours prepared by adding gum gluten to the standard flour in order to raise the protein content, and wheat starch to lower the protein content show inconsistent results. The biscuit with the best external appearance was secured with the flours having protein contents of 11.4, 13.0 percent, and the hard standard flour itself. The texture of the grain was best for the two low protein flours and the standard flour, while biscuit grain obtained with the two higher protein flours was slightly coarse. A significant trend for tenderness was not secured. The best tenderness score was obtained with the hard standard flour and the toughest biscuit was secured with the lowest protein content flour. The flavor, crust and crumb color, and the pH of the crumb were unaffected by varying the protein content. The best total score was obtained with the biscuits baked from the standard flour but a trend did not appear for this grading factor with this series of flours.

Wheat Variety

The biscuit baking qualities of various hard and soft wheat varieties are summarized in Tables 7 and 8.

Table 7. Influence of hard winter wheat variety on biscuit properties.

	Sample designation[1]				
	H.S. (11)	Wichita (4)	E.B. (4)	R. Chief (4)	Pawnee (4)
Quality factors					
Optimum absorption %	65.0	67.5	62.5	77.5	70.0
Optimum shortening %	15.0	12.5	12.5	17.5	15.0
Specific volume	44.5	48.1	59.7	41.2	47.6
Specific lightness	58.0	61.8	64.5	54.3	60.1
Gelometer compressibility	127.7	111.0	128.5	152.6	132.0
pH	7.4	7.4	7.4	7.37	7.45
Score values					
External appearance	12	11	11	9	12
Texture	13	13	13	12	13
Tenderness	7	12	7	2	6
Flavor	15	15	15	15	15
Crust color	10	10	10	10	10
Crumb color	15	15	15	15	15
Lightness	4	8	9	2	7
Volume	4	8	9	1	7
Total score	80	92	89	66	85

[1] Values given are means of the number of baking tests indicated in parenthesis.

Table 8. Influence of soft wheat varieties on biscuit properties.

	Sample designation[1]						
	S.S. (34)	B.H. (5)	T.B. (5)	Purkof (4)	C.K. (5)	Thorne (4)	A.B. (5)
Quality factors							
Optimum absorption %	60.0	62.5	62.5	67.5	65.0	62.5	65.0
Optimum shortening %	10.0	10.0	10.0	12.5	10.0	12.5	10.0
Specific volume	51.3	49.7	48.1	48.3	49.2	47.6	45.6
Specific lightness	64.1	61.2	62.4	59.8	63.2	58.9	60.2
Celometer compressibility	81.7	83.0	80.0	103.0	80.0	74.0	79.0
pH	7.3	7.4	7.4	7.3	7.37	7.4	7.3
Score values							
External appearance	12	11	11	11	11	12	12
Texture	13	13	12	11	11	12	13
Tenderness	9	8	9	2	9	12	10
Flavor	15	15	15	15	15	15	15
Crust color	10	10	10	10	10	10	10
Crumb color	15	15	15	15	15	15	15
Lightness	6	3	5	2	5	2	3
Volume	7	5	3	3	4	2	1
Total score	87	80	80	69	80	78	79

1 Values given are means of the number of baking tests indicated in parenthesis.

The data obtained with the experimentally milled hard winter wheat varieties are of interest, since they show that the varieties which have good bread making qualities also produce good biscuits. Wichita, Early Blackhull and Pawnee all gave good biscuits. The flour from the Wichita sample yielded the best biscuit while Early Blackhull and Pawnee produced biscuits which graded lower. The Red Chief sample gave the poorest biscuit which was flat, with poor volume and lightness as well as coarse grain structure.

All the biscuits from the experimentally milled soft wheat varieties graded nearly the same with the exception of the variety Purkof. Tenderness score was highest for Thorne with Blackhawk, Trumbull, Clarkan, and American Banner having nearly the same score. Thorne and American Banner gave the most symmetrical biscuits with the smoothest and straightest side walls. The texture of the grain was best for the samples of Blackhawk and American Banner, the texture being poorest for the samples of Purkof and Clarkan. The volume of the biscuits resulting from these flours were all average or below average. Blackhawk produced the best volume, while American Banner gave the poorest volume. The lightness score was greatest for Trumbull and Clarkan, and the poorest for Purkof. The pH of the crumb of the biscuits resulting from these flours varied between 7.3 and 7.4. Flavor, crumb and crust color were all found to be satisfactory for these varieties.

Addition of Malted Wheat Flour

The influence on biscuit properties of the addition of malted wheat flour to the hard and soft commercially milled standard flours is shown in Tables 9 and 10, respectively. Malted wheat flour was added to these two flours in increments of 0.5 percent, flour basis, up to 2.5 percent, as well as in amounts of 5 percent and 10 percent.

The results with hard wheat flour show that biscuit quality is improved with the addition of malted wheat flour. The improvement is not always regular, however, since the total score reached 87 with 1.5 percent malted wheat flour then fell off to 81 with 2.5 percent, and increased again to 87 with the 10 percent addition.

The external appearance of the biscuits was not materially improved with increments of malted wheat flour. The texture of the grain showed improvement with 0.5 percent, 1.0 percent and 1.5 percent, but with higher increments the texture became progressively coarser. A definite trend in crumb tenderness was not secured, but the tenderest biscuit resulted from the 10 percent addition. The crust color of the biscuits improved steadily with successive additions of malted wheat flour from a faint brown for the flour with no malt added to a deep golden brown with the 10 percent addition.

The volume of the biscuits improved steadily up to 2.5 percent malt flour, but addition beyond this point caused the

Table 9. Influence on biscuit properties on the addition of malted wheat flour to a commercial hard wheat flour.

	Sample designation and percent malt flour added[1]						
	H.S. 0.0 (11)	H.M.#1 0.5 (6)	H.M.#2 1.0 (6)	H.M.#3 1.5 (6)	H.M.#4 2.5 (6)	H.M.#5 5.0 (6)	H.M.#6 10.0 (6)
Flour characteristics							
Maltose value	244	328	367	406	445	455	555
Max. amylograph visc.	280	140	130	110	90	70	50
Quality factors							
Optimum absorption %	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Optimum shortening %	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Specific volume	44.5	44.9	46.8	48.6	48.0	45.6	45.9
Specific lightness	60.0	59.5	59.2	59.7	61.2	61.8	59.5
Gelometer compress.	127.5	123.7	110.0	122.0	145.0	131.0	108.0
pH	7.25	7.3	7.3	7.3	7.35	7.35	7.35
Score values							
External appearance	12	12	12	12	12	12	12
Texture	12	13	13	13	12	12	11
Tenderness	7	9	12	9	3	6	13
Flavor	15	15	15	15	15	15	15
Crust color	5	6	7	8	9	10	10
Crumb color	15	15	15	15	15	15	15
Lightness	7	6	4	7	7	8	6
Volume	4	4	6	8	8	5	5
Total score	82	80	84	87	81	83	87

[1] Values given are means of the number of baking tests indicated in parenthesis.

Table 10. Influence on biscuit properties on the addition of malted wheat flour to a commercial soft wheat flour.

	Sample designation and percent malt flour added[1]						
	S.S. 0.0 (34)	S.M.#1 0.5 (5)	S.M.#2 1.0 (5)	S.M.#3 1.5 (5)	S.M.#4 2.5 (5)	S.M.#5 5.0 (5)	S.M.#6 10.0 (5)
Flour characteristics							
Maltose value	96	151	195	231	265	315	415
Max. amylograph visc.	740	150	100	80	80	40	30
Quality factors							
Optimum absorption %	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Optimum shortening %	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Specific volume	51.3	52.7	54.5	52.5	51.8	50.3	50.0
Specific lightness	64.1	65.3	66.3	64.1	66.7	63.4	63.3
Gelometer compress.	81.7	81.0	60.0	80.0	67.8	47.0	73.7
pH	7.3	7.25	7.25	7.25	7.3	7.3	7.3
Score values							
External appearance	12	12	12	12	12	12	12
Texture	13	13	13	13	12	11	11
Tenderness	9	9	15	9	13	15	12
Flavor	15	15	15	15	15	15	15
Crust color	8	8	8	9	10	10	10
Crumb color	15	15	15	15	15	15	15
Lightness	6	8	8	6	9	6	6
Volume	7	8	9	8	7	5	5
Total score	85	88	95	87	93	89	86

1 Values given are means of the number of baking tests indicated in parenthesis.

volume to decrease. The lightness of the biscuits was variable throughout this series of flours and flavor and crumb color were unaffected. The pH generally increased with successive additions of the malted wheat flour, from 7.25 with the flour with no malt to 7.4 with 10 percent addition.

The results obtained by adding malted wheat flour to the soft wheat standard flour were similar to those with the hard wheat flour. The total score was greatest with the addition of 1.0 percent malted wheat flour but fell off gradually with higher increments. The external appearance of the biscuits was similar in the whole series. The texture was best for the flour containing no malted wheat flour as well as for the samples containing up to 1.5 percent. Above this value the grain became significantly coarser. The tenderness was variable throughout this series but the crust color improved steadily with increasing increments of the malted wheat flour. Lightness increased, in general, up through the 2.5 percent addition and dropped with the 5 and 10 percent additions. The volume increased with addition up to 1 percent but decreased steadily with higher increments. The pH of the crumb remained relatively constant throughout the whole series and the flavor and crumb color were unaffected by the addition of malted wheat flour.

Addition of Malt Extract

The influence of adding a water extract of malted wheat flour to the commercially milled standard soft wheat flour is shown in the data of Table 11. The extract was prepared by adding 20 grams of malted wheat flour to 200 ml of distilled water. This was shaken 200 times per minute for one minute every 15 minutes for one hour. The suspension was then centrifuged at 1500 rpm for 5 minutes and filtered through a No. 2 Whatman paper using a Buchner funnel with vacuum.

The results obtained by the addition of the extract to the soft standard flour agreed closely with the results of the addition of malted wheat flour itself to the same flour. The external appearance of all the biscuits was satisfactory but the crumb texture became coarser with the additions of the extract. Tenderness score increased with increasing amounts of extract up to 30 ml beyond which the biscuits became tougher. The crust color of these biscuits was dark at the levels of 40 to 100 ml of extract and lightness and volume score increased up through 20 ml of extract but decreased at levels higher than 20 ml. The pH of the biscuit crumb was variable throughout this series. Total score suggested that the best biscuits were obtained by supplementing the standard flour with 20 ml of malted wheat flour extract. With higher amounts of extract the quality of the biscuit decreased,

Table 11. Influence on biscuit properties on the addition of malted wheat flour extract to a commercial soft wheat flour.

	Sample designation and ml extract added[1]				
	S.S.	S.M.E.#1	S.M.E.#2	S.M.E.#3	S.M.E.#4
	0	20	30	40	100
	(34)	(4)	(3)	(3)	(3)
Flour characteristics					
Maltose value	96	195	210	225	500
Max. amylograph viscosity	740	200	180	150	120
Quality factors					
Optimum absorption %	60.0	60.0	60.0	60.0	60.0
Optimum shortening %	10.0	10.0	10.0	10.0	10.0
Specific volume	51.3	52.0	49.5	48.5	48.8
Specific lightness	64.1	64.9	62.8	59.3	60.6
Gelometer compressibility	81.7	62.0	66.0	93.0	92.0
pH	7.35	7.4	7.45	7.3	7.25
Score values					
External appearance	12	12	12	12	12
Texture	13	12	11	11	11
Tenderness	9	14	14	4	5
Flavor	15	15	15	15	15
Crust color	9	9	9	10	10
Crumb color	15	15	15	15	15
Lightness	6	7	5	2	3
Volume	7	7	4	3	4
Total score	86	91	85	72	77

[1] Values given are means of the number of determinations indicated in parenthesis.

producing a biscuit which had coarse texture, poor tenderness score, and poor lightness and volume scores.

Effect of Inactivation of Protease in Malt Extract

The influence on biscuit properties on the addition of malted wheat flour extract in which the proteolytic enzymes had been inactivated to a commercial soft wheat flour is shown in Table 12. The proteolytic enzymes were inactivated by the method of Dirks and Miller (11). This method consisted of raising the pH to 10 with 0.1253 N.NaOH and lowering it to the original pH (6.15) with 0.1253 N.HCl. The amount of salt produced by the reaction between the NaOH and HCl was calculated and the amount of salt added to biscuit mix was correspondingly reduced.

The results obtained in this phase of the work were very similar to those with the untreated extract. The external appearance of the biscuits was uniform and symmetrical for all of this series. The crumb texture was best for the standard flour without the addition of the extract but it became coarser with additions of extract. The tenderness of the crumb was best with the 20 ml addition but it became tougher with the 30, 40, and 100 ml additions. The color of the crust was a golden brown at the 40 ml and 100 ml levels, and below these levels the color was a light brown. The lightness score increased up through the 400 ml levels but decreased at

Table 12. Influence on biscuit properties on the addition of protease inactivated malted wheat flour extract to a commercial soft wheat flour.

	Sample designation and ml extract added[1]				
	S.S.	S.M.I.P.#1	S.M.I.P.#2	S.M.I.P.#3	S.M.I.P.#4
	0	20	30	40	100
	(34)	(3)	(3)	(3)	(3)
Flour characteristics					
Maltose value	96	153	168	178	255
Max. amylograph viscosity	740	210	190	180	140
Quality factors					
Optimum absorption %	60.0	60.0	60.0	60.0	60.0
Optimum shortening %	10.0	10.0	10.0	10.0	10.0
Specific volume	51.3	54.6	52.0	51.3	50.1
Specific lightness	64.1	63.9	66.0	66.8	63.5
Gelometer compressibility	81.7	66.0	98.0	97.0	97.0
pH	7.3	7.37	7.37	7.3	7.2
Score values					
External appearance	12	12	12	12	12
Texture	13	12	11	11	11
Tenderness	9	14	3	3	3
Flavor	15	15	15	15	15
Crust color	9	9	9	10	10
Crumb color	15	15	15	15	15
Lightness	6	6	8	9	6
Volume	7	9	7	7	5
Total score	86	92	80	82	77

[1] Values given are means of the number of determinations indicated in parenthesis.

the 100 ml level and the volume score increased up through the 20 ml level and decreased at higher levels. The total score for this series of flour was best for the 20 ml malt extract supplement, with a score of 92, and decreased to 77 at the 100 ml level.

Flour Granulation

The influence of flour granulation on biscuit properties is shown in Table 13. In the case of the coarse flour the wheat was tempered for 3½ hours to a moisture level of 13.5 percent and for the fine granulation the same wheat, a hard red winter, was tempered for 3½ hours to a moisture level of 14 percent. Both samples were milled on the Allis Chalmers experimental mill. The granulation of the flours was determined by the method of Wichser et al. (29) using the Ro-Tap shaker and screen sieve technique. The short-temper wheat yielded coarser flour, 9.4 percent more being retained on the 400 mesh standard sieve than the long temper flour and 17.8 percent more on the 250 mesh standard sieve.

These flours were baked with 65 percent absorption and 15 percent shortening. The coarser flour graded only one point better for lightness and volume score and one point less in tenderness score. The total score for the two flours differed by one point only, the coarser flour having a total score of 96 and the finer flour having a total score of 95.

Table 13. Influence of granulation of a hard winter wheat flour on biscuit properties.[1]

	Coarse granulation[2] (3 bakes)	Fine granulation[2] (3 bakes)
Quality factors		
Optimum absorption %	65.0	65.0
Optimum shortening %	15.0	15.0
Specific volume	52.1	50.9
Specific lightness	65.4	64.1
Gelometer compressibility	98.0	81.0
pH	7.3	7.3
Score values		
External appearance	12	12
Texture	13	13
Tenderness	14	15
Flavor	15	15
Crust color	10	10
Crumb color	15	15
Lightness	10	9
Volume	7	6
Total score	96	95

[1] Values given are means of the number of determinations indicated.

[2] Granulation differences were indicated by the fact that 17.8 percent more of the coarse flour was retained on the 250 mesh screen than the fine flour and 94 percent more on the 400 mesh screen.

Correlation of Shortening Requirement with Viscosity and Protein

The maximum apparent acidic viscosity of the flours used in the protein and variety series were determined by both the 20 grams flour, 14 percent moisture basis and the 2 grams protein, dry basis. These values together with the optimum percentage of shortening, percent protein, baking absorption, and farinograph absorption are given in Table 14.

The correlation of the viscosity values, 20 gram flour method, with shortening content was +0.79, a coefficient of considerable significance. Since viscosity is dependent upon the hydration capacity of the flour protein, a similar correlation coefficient may be expected to exist between the protein content and the shortening content. This coefficient was found to be +0.76.

Correlation of Farinograph and Bake-Test Absorption Values

The absorption of the flours used in this work was determined by both the baking tests and by the farinograph, titrating in the latter case to the 500 unit line on the kymograph paper. The values obtained for these determinations are given in Table 14. Comparison of these two determinations gave a correlation coefficient of +0.74. Generally the absorption determined by the farinograph was about 5 percent lower

Table 14. Relationship of shortening requirement, viscosity, protein content, and absorption in hard and soft wheat flours.

Flour	Viscosity 20 g[1]	Viscosity 2 g protein[2]	Protein[1] %	Shortening %	Baking absorption %	Farinograph absorption %
H.S.	137	172	9.2	15.0	65.0	59.0
H.P. #1	67	127	7.8	10.0	60.0	58.8
H.P. #2	101	125	9.3	15.0	65.0	54.9
H.P. #3	140	123	10.6	15.0	65.0	57.4
H.P. #4	183	118	12.2	17.5	70.0	59.8
H.P. #5	234	110	14.0	20.0	70.0	61.7
H.R. #1	49	171	7.2	10.0	57.5	58.0
H.R. #2	87	155	8.4	12.5	60.0	58.0
H.R. #3	169	123	11.4	17.5	67.5	60.0
H.R. #4	175	114	13.0	17.5	70.0	65.0
S.S.	60	107	7.4	10.0	60.0	54.0
S.R. #1	45	119	7.0	10.0	57.5	54.4
S.R. #2	77	90	8.0	12.5	60.0	56.0
S.R. #3	95	80	9.3	12.5	62.5	58.0
S.R. #4	114	67	11.0	15.0	65.0	60.0
E.B.	137	138	10.5	12.5	62.5	62.6
Wichita	142	143	10.0	12.5	67.5	64.2
R. Chief	137	138	10.3	17.5	77.5	71.5
Pawnee	170	108	11.6	15.0	70.0	65.0
Gran. #1	103	124	9.3	15.0	65.0	-
Gran. #2	96	106	9.5	15.0	65.0	-
A.B.	53	80	8.4	10.0	65.0	59.0
B.H.	84	75	10.2	10.0	62.5	53.8
T.B.	126	128	9.7	10.0	62.5	56.4
Thorne	84	137	8.0	12.5	62.5	53.8
C.K.	77	113	8.3	10.0	65.0	60.8
Purkof	133	164	9.0	12.5	67.5	61.9

$r_{\text{visc. (20 g) x shortening \%}} = +0.79$

$r_{\text{protein (\%) x shortening \%}} = +0.76$

$r_{\text{farinograph absorption x bake absorption}} = +0.74$

[1] 14 percent moisture basis.
[2] Dry matter basis.

than the baking absorption value. This is in agreement with the results published by the 1934-35 Committee on Methods of Testing Self-Rising Flours (28).

Crumbliness and Compressibility

The crumbliness machine was designed to provide an objective method for determining the tenderness of the biscuit crumb. However, determinations on the crumb of biscuits made with a hard and a soft wheat flour showed that the machine does not yield values closely related to compressibility, so that the properties of compressibility and crumbliness must be considered independently.

Preliminary data on the effect of the cooling period were obtained with the machine by allowing biscuits to cool 30 minutes, 3 hours, 6 hours, 24 hours, and 48 hours after removal from the oven. At each of these periods sections of crumb were shaken for periods of 1, 5, and 8 minutes. These determinations were made on 10 samples for each of the cooling and shaking times with biscuit crumbs obtained by baking both the soft and hard wheat flour. A summary of these determinations is shown in Table 15. The standard deviation, mean, and variance analysis are shown in the Appendix, Table 19.

The results of the above study indicate that for the hard wheat flour there was a general increase in crumbliness with the

Table 15. Influence of cooling and shaking time on percent throughs on the crumbliness machine.[1]

Biscuit cooling time (hours)	Percent crumb through screen at various shaking times: 1 min.	5 min.	8 min.
		Hard wheat flour	
0.5	10.85	57.55	62.85
1	12.08	58.55	69.65
3	9.85	63.25	71.55
6	8.35	59.55	73.15
24	8.95	60.35	74.15
48	19.7	71.63	78.95
		Soft wheat flour	
0.5	6.15	21.85	37.35
1	4.75	22.45	37.05
3	4.55	28.15	45.28
6	1.99	21.25	38.85
24	5.05	51.55	67.05
48	8.05	46.05	61.25

[1] Values shown are means for 10 determinations.

length of the staling time. Using a 1 minute shaking time, the percent of crumb passing the screen increased from 10.85 at 30 minutes cooling time to 19.7 at 48 hours. For the 5 minute shaking time the percent through the screen increased from 57.55 at 30 minute cooling time to 71.63 at the 48 hour staling time. The 8 minute shaking time showed an increase from 62.85 at the 30 minute period to 78.95 at the 48 hour staling period.

Results obtained with the biscuit crumbs produced from soft wheat flour were similar to those with the hard wheat flour biscuit crumbs; i.e., an increase from 6.15 to 8.05 for the 1 minute shake; of 21.85 to 46.05 for the 5 minute shake; and of 37.35 to 61.25 for the 8 minute shake.

Crumbliness was determined on biscuits obtained from all the flours used in this work which were baked using optimum shortening and absorption values. The results of these determinations are shown in Table 16. Also shown in this table are the protein content and the compressibility value obtained with the gelometer.

Correlation of the gelometer and crumbliness values for the hard wheat flour yielded a coefficient of +0.44. Correlation of similar data for the soft wheat flour gave a highly significant coefficient of +0.84. When the data for both types of flour are considered together the correlation coefficient was found to be +0.46.

The protein content and the crumbliness value of both the

Table 16. Relationship of crumbliness, protein content and gelometer compressibility for hard and soft wheat flour biscuit crumbs.

Flour	Protein[1] %	Crumbliness %	Gelometer compressibility
H.S.	9.2	48.9	127.7
H.P. #1	7.8	67.4	113.0
H.P. #2	9.3	71.3	119.0
H.P. #3	10.6	66.3	161.0
H.P. #4	12.2	67.3	166.0
H.P. #5	14.0	62.2	183.0
H.R. #1	7.2	65.8	168.4
H.R. #2	8.4	65.7	152.0
H.R. #3	11.4	63.2	150.0
H.R. #4	13.0	71.2	139.0
Wichita	10.0	40.8	111.0
E.B.	10.5	44.0	128.5
R. Chief	10.3	41.7	152.6
Pawnee	11.6	31.9	132.0
Gran. #1	9.3	41.9	98.0
Gran. #2	9.5	44.3	81.7
S.S.	7.4	45.3	81.7
S.R. #1	7.0	65.7	152.0
S.R. #2	8.0	65.8	168.4
S.R. #3	9.3	71.2	139.0
S.R. #4	11.0	63.2	150.0
B.H.	10.2	34.3	83.0
T.B.	9.7	35.6	80.0
Purkof	9.0	54.3	103.0
C.K.	8.3	44.4	80.0
Thorne	8.0	53.0	74.0
A.B.	8.4	57.0	79.0

$r_{\text{compressibility x crumbliness (hard wheat flour)}} = +0.44$

$r_{\text{compressibility x crumbliness (soft wheat flour)}} = +0.84$

$r_{\text{compressibility x crumbliness (all flours)}} = +0.46$

$r_{\text{protein content x crumbliness (soft wheat flour)}} = -0.147$

$r_{\text{protein content x crumbliness (hard wheat flour)}} = -0.005$

[1] 14 percent moisture basis.

soft and hard wheat flour were found to be insignificantly correlated. Thus the correlation coefficient for the soft wheat flour was a -0.147, and for the hard wheat flour a -0.005.

Crumbliness was found to be not significantly altered by the addition of various increments of malted wheat flour, malted wheat flour extract, or malted wheat flour extract whose proteolytic enzymes had been inactivated. These results are shown in Table 17.

DISCUSSION

The baking results secured from two series of hard wheat flours with variable protein content show considerable variability. In the composite series, the best total score was obtained with the lowest protein flour (7.8 percent). In the gluten-and-starch-supplemented series using the hard standard flour, the lowest total score was secured with the flour having the lowest protein content of 7.2 percent and the best total score was obtained with the unsupplemented standard flour. In the series of flours composited for various protein levels there was a significant trend for the biscuit crumb to become tougher with increasing protein content. With the gluten-supplemented series of flours, however, the trend seemed to be in the opposite direction. In neither series of flours was there a trend in the volume

Table 17. Influence of amylase supplementation on crumbliness.

Flour	Treatment	Crumbliness %
H.S.	none	48.9
H.M.#1	0.5% malted wheat flour	46.6
H.M.#2	1.0% malted wheat flour	46.1
H.M.#3	1.5% malted wheat flour	49.2
H.M.#4	2.5% malted wheat flour	52.5
H.M.#5	5.0% malted wheat flour	52.6
H.M.#6	10.0% malted wheat flour	59.7
S.S.	none	45.3
S.M.#1	0.5% malted wheat flour	38.3
S.M.#2	1.0% malted wheat flour	48.3
S.M.#3	1.5% malted wheat flour	37.2
S.M.#4	2.5% malted wheat flour	45.8
S.M.#5	5.0% malted wheat flour	36.1
S.M.#6	10.0% malted wheat flour	32.0
S.M.E.#1	20 ml malted wheat flour extract	37.9
S.M.E.#2	30 ml malted wheat flour extract	43.8
S.M.E.#3	40 ml malted wheat flour extract	38.1
S.M.E.#4	100 ml malted wheat flour extract	38.8
S.M.I.P.#1	20 ml malted wheat flour extract (protease inactivated)	36.6
S.M.I.P.#2	30 ml malted wheat flour extract (protease inactivated)	38.2
S.M.I.P.#3	40 ml malted wheat flour extract (protease inactivated)	33.7
S.M.I.P.#4	100 ml malted wheat flour extract (protease inactivated)	33.0

and lightness score of the biscuits.

Alterations in the chemical properties of the gum gluten and commercial wheat starch used in these studies may be responsible for the difference in behavior of flours made with them in comparison with natural flours. Furthermore, Finney (13) has stressed the importance of the water soluble portions of flour in reconstituting fractionated flours. In the present case no water soluble fraction was added. It would be interesting to see what results would be obtained from flours whose protein content had been increased by the addition of gluten washed from the standard flour and whose protein content had been decreased by the addition of wheat starch washed from the same flour, and where the water-soluble fraction was reincorporated in each case.

The results obtained by adding gum gluten and wheat starch to the commercially milled soft wheat flour are similar to those obtained with the supplemented hard wheat flour series. Nevertheless, the total score did not have a definite trend with the protein content and the same criticism of the results obtained with the supplemented hard wheat flours would also apply to these results. The addition of commercial gum gluten and commercial wheat starch altered the behavior of the flour in such a manner that it did not behave as a natural flour.

The baking results obtained with pure hard wheat varieties are of interest since they show that the varieties which have good bread baking qualities also produce good biscuits. Wichita, Early Blackhull, and Pawnee all gave good quality biscuits whereas inferior results were obtained with Red Chief. All of the soft wheat varieties with the exception of Purkof gave satisfactory biscuits.

According to Kneen and Sandstedt (20), malted wheat flour has five beneficial effects on a bread dough. These may be listed as increased sugar production, increased gas retention, improved grain and texture, and improved crust color. That malt confers similar improvement to a biscuit dough is borne out by the results obtained in the present study. The results further indicate that the beneficial action is secured by the action of the amylases, and that the proteolytic enzymes do not act either beneficially or detrimentally on the biscuit quality.

The increase in crust color of biscuits with the addition of malted wheat flour or extracts thereof is very significant since it indicates that the beta amylase enzyme of the supplement apparently has sufficient time to act on the starch to produce appreciable amounts of free sugar in the short interval between mixing of the biscuit dough and the time when the enzyme would become inactivated due to oven temperature. This beneficial effect could not be anticipated since the use of malt supplements which has been confined to bread doughs involves activity of the sugar producing enzyme for several hours during the fermentation period.

It is also notable that the significant improvement in volume and external appearance of biscuits due to the use of malt was accompanied by an improvement in the interior of the biscuit, but only up to a certain level, usually 1 percent addition in the case of malted wheat flour, and 20 ml for the extracts. The appearance of coarse and open crumb grain beyond these levels indicated that starch as well as amylase enzymes may play a significant role in the gas retention of a biscuit dough. Attention also may be drawn to the fact that compressibility score seemed to improve with the addition of malt up to the optimum, and then decrease with further increments, indicating that a certain amount of starch modification due to amylase activity may be beneficial, whereas an excessive amount is detrimental to biscuit quality.

The results from the granulation study indicate the possibility that the coarser flour yields better biscuits. However, the differences in granulation between the two flours studied were not very great, and the difference in the total score was only one point. The coarser granulation was one point higher in lightness and volume score, and one point lower in tenderness score. It is believed that the difference in the baking quality of these two particular flours is significant, but that the variation in granulation of the two flours is too small to attribute the difference in results to this factor alone. As has been pointed out by Dunn (12), flour granulation may affect the shortening requirements for optimum results. A study of the relation between granulation and shortening requirements of the flour would be interesting, but with the present methods of milling in which granulation is an uncontrolled factor, such a study is nearly impossible.

Correlation of protein content to shortening requirement for all flours baked, with the exception of the malt-supplement series, yielded a coefficient of +0.76. The correlation coefficient of viscosity (20 g) to shortening was +0.79. These results show that the requirement of shortening to produce the optimum biscuit is dependent to the strength of the flour as determined by the protein content and the viscosity value.

The baking test and farinograph method to determine absorption showed a correlation value of +0.74. However, the farinograph absorption, when the 500 Brabender unit line was used, was generally about 5 percent lower than the baking absorption value. Since individual opinion plays a large part in the determination of absorption by baking methods, it would be very difficult to duplicate by baking, the absorption values on the same flour in different laboratories. The farinograph absorption seems to offer a convenient means for checking absorption values in different laboratories.

The crumbliness machine was designed to provide an objective method for determining differences in biscuit crumb characteristics. Preliminary data were obtained on the machine by following the rate of staling of the biscuit crumb at different shaking speeds. There were two reasons for carrying out this study; namely, to find the proper cooling time prior to determination as well as the shaking speed at which the machine was the most accurate. It was also desired to follow the staling rate of the biscuit crumb. It was found that the accuracy of the machine was not dependent on the cooling time and the shaking speed. For convenience, therefore, the three hour cooling period and eight minute shaking time was chosen.

The staling rate of bread has been studied by Katz (19), Cathcart (10), and others. Their work indicates that the crumbliness increases with the cooling time, the greatest increase being within the first 24 hours after the bread is taken from the oven. In this work with biscuit crumb, the greatest increase in crumbliness occurred between the 6 and the 24 hour periods. After the 24 hour period the crumbliness did not vary significantly. Katz (19) explains the delay in the development of crumbliness by assuming that it takes time for water to diffuse from the starch to the protein. Increased crumbliness is probably not noticeable until this diffusion has taken place.

The staling study in which the crumbliness test was used showed that the biscuit crumb produced from hard wheat flour is more brittle and breaks up more readily than the crumb from the soft wheat flour. These results with the hard wheat flour did not parallel the gelometer compressibility values ($r=+0.44$)

so that in the case of hard wheat flours it is apparent that different crumb properties are being measured. On the other hand a rather high correlation coefficient (+0.84) was secured for the soft wheat biscuits relating gelometer compressibility to crumbliness. These results would suggest that hard wheat flours contain some factor which affects crumbliness and which is not present in soft wheats. That protein content alone is not an important factor in this case was indicated by nonsignificant correlation values between protein content and crumbliness for biscuit crumb from both hard and soft wheats. Katz (19) has suggested that staling involves alteration of the chemical properties of starch without chemical change in the gluten.

Crumbliness was not found to be altered by the addition of various increments of malted wheat flour, malted wheat flour extract, or malted wheat flour extract whose proteolytic enzymes had been inactivated. One of the functions of the addition of malted wheat flour is to improve the texture of the crumb, but these results indicate that it does not affect the strength of the crumb meshwork.

CONCLUSIONS

A number of variables inherent in wheat flour were shown to influence the quality characteristics of phosphate-soda leavened biscuits baked from various flours.

In a series of hard wheat flour samples, obtained by compositing for protein content without regard to environmental and varietal factors, the best biscuits were obtained from the composite with the lowest protein content; namely, 7.8 percent.

The addition of commercial gum gluten to increase the protein content, and of commercial starch to decrease the protein of a hard standard flour yielded inferior baking results in every case to those obtained from the unaltered standard flour itself containing 9.2 percent protein. The poorest biscuits were given by a sample of the flour diluted with starch to a protein content of 7.2 percent. Similarly a standard soft wheat flour of 7.4 percent protein yielded better biscuits than any mixture of this flour with gum gluten or starch.

Hard wheat varieties which are considered good for bread production generally yielded good quality biscuits. Thus, the hard wheat varieties Wichita, Pawnee and Early Blackhull gave satisfactory biscuits, while Red Chief produced biscuits of inferior quality. The soft wheat varieties Blackhawk, Trumbull, Clarkan, Thorne and American Banner all produced a satisfactory biscuit, whereas the variety Purkof gave unsatisfactory results.

Supplementation of hard and soft wheat flour with malted wheat flour showed that the biscuit quality was improved with increments up to 2.5 percent. By the use of malt extracts in which protease enzymes had been inactivated, this improvement was shown to be due to the amylase component of the malted wheat flour. The results indicate that saccharification due to beta amylase is an important factor in biscuit doughs and that malt enzymes affect gas retaining properties due to action on the starch component.

Differences in granulation of a hard wheat flour were found to have only a slight effect on the quality of the biscuit, the coarser flour grading only one point better than the fine granulation flour.

The optimum shortening content required for biscuit baking was found to be highly correlated with the viscosity value and the protein content of both the hard and soft wheat flour.

The baking absorption and farinograph absorption were highly correlated, except that the farinograph value was about 5 percent lower.

Staling studies on the biscuit crumb using a specially designed crumbliness tester showed that the crumbliness increased as the staling period increased, the greatest increase occurring between the 6 and 24 hour interval after baking.

Comparison of the data from the crumbliness machine and the compressibility index as given by the Bloom Gelometer showed that these values were unrelated for hard wheat flours but that a high correlation existed when comparing the two sets of data for soft wheat flours alone. Protein content and crumbliness were found to be insignificantly correlated in the soft and hard wheat flours and it was not significantly altered by the addition of malt supplements.

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APPENDIX

Table 18. Calculations for converting experimental value to score value.

$P(\lambda > \bar{X})$ 1/	$.5 - P(\lambda > \bar{X})$ 2/	λ 3/	$\bar{X}$ Hard 4/	$\bar{X}$ Soft 4/	Decile Interval Hard	Decile Interval Soft	Score
				1. Volume			
				(m(hard) = 46.21, σ = 3.30. m(soft) = 50.38, σ = 3.03)			
.1	.4	1.28	50.44	54.61	>50.44	>54.61	10
.2	.3	.84	48.98	53.15	48.99-50.44	53.16-54.61	9
.3	.2	.525	47.94	52.11	47.95-48.98	52.12-53.15	8
.4	.1	.025	47.04	51.21	47.05-47.94	51.22-52.11	7
.5	.0	0.000	46.21	50.38	46.22-47.04	50.39-51.21	6
.6	-.1	- .025	45.38	49.55	45.39-46.21	49.56-50.38	5
.7	-.2	- .525	44.48	48.65	44.49-45.38	48.66-49.55	4
.8	-.3	- .84	43.44	47.61	43.45-44.48	47.62-48.65	3
.9	-.4	-1.28	41.98	46.15	41.99-43.44	46.16-47.61	2
1.0	-.5	-	-	-	≤41.98	≤46.15	1
				2. Lightness			
				(m(hard) = 59.49, σ = 4.14. m(soft) = 63.2, σ = 3.60)			
.1	.4	1.28	64.8	67.81	>64.8	>67.81	10
.2	.3	.84	62.97	66.41	62.98-64.8	66.42-67.81	9
.3	.2	.525	61.66	65.09	61.67-62.97	65.1 -66.41	8
.4	.1	.025	59.59	64.1	59.6 -61.66	64.11-65.09	7
.5	.0	0.000	59.49	63.2	59.5 -59.59	63.21-64.1	6
.6	-.1	- .025	59.39	62.3	59.4 -59.49	62.31-63.2	5
.7	-.2	- .525	57.32	61.31	57.33-59.39	61.32-62.3	4
.8	-.3	- .84	56.01	59.99	56.02-57.32	60.0 -61.31	3
.9	-.4	-1.28	54.18	58.59	54.19-56.01	58.6 -59.99	2
1.0	-.5	-	-	-	≤54.18	≤58.59	1

Table 18. (concl.).

$P(\lambda > \bar{X})$ 1/	$.5-P(\lambda > \bar{X})$ 2/	λ 3/	$\bar{X}$ Hard 4/	$\bar{X}$ Soft 4/	Decile Interval Hard	Decile Interval Soft	Score
				3. Tenderness 1/15 = .0667			
.0667	.4333	+1.5	155.2	106.0	>155.2	>106	1
.1333	.3667	+1.11	147.5	100.1	147.6-155.2	100.2-106.0	2
.2000	.3000	+0.84	142.1	96.1	142.2-147.5	96.2-100.1	3
.2667	.2333	+0.62	137.7	92.8	137.8-142.1	92.9- 96.1	4
.3333	.1667	+0.43	134.0	89.9	134.1-137.7	90.0- 92.8	5
.4000	.1000	+0.25	130.4	87.2	130.5-134.0	87.3- 89.9	6
.4667	.0333	+0.083	127.1	84.7	127.2-130.4	84.8- 87.2	7
.5333	-.0333	-0.083	123.7	82.2	123.8-127.1	82.3- 84.7	8
.6000	-.1000	-0.25	120.4	79.7	120.5-123.7	79.8- 82.2	9
.6667	-.1667	-0.43	116.8	77.0	116.9-120.4	77.1- 79.7	10
.7333	-.2333	-0.62	113.1	74.2	113.2-116.8	74.3- 77.0	11
.8000	-.3000	-0.84	108.7	70.9	108.8-113.1	71.0- 74.2	12
.8667	-.3667	-1.11	103.3	66.8	103.4-108.7	66.9- 70.9	13
.9333	-.4333	-1.50	95.6	61.0	95.7-103.3	61.1- 66.8	14
					95.6	61.0	15

1/ $P(\lambda > X)$ - Probability that λ will be greater than X (the raw score). Assuming normal distribution, then this value is the decimal equivalent of 1 divided by the total numerical or score card value.

2/ $.5 - P(\lambda > X)$ - Substituting in the above value and subtracting from 0.5.

3/ $\lambda = \frac{X-m}{\sigma}$ - λ is secured by looking up the above value of $.5-P(\lambda > X)$ and reading the value of λ under the λ column in normal curve tables.

4/ $\bar{X}$ is secured by calculating for the value of X in (3) knowing λ, m (mean), and σ (standard deviation). Intervals are then secured by writing in the lower values, the upper values for each score value having been calculated.

Table 19. Mean, standard deviation, and coefficient of variability of data relating the effect of cooling time and shaking time on crumbliness.[1]

Biscuit cooling time hrs.	Shaking time								
	1 minute			5 minutes			8 minutes		
	X	S	C.V.	X	S	C.V.	X	S	C.V.
				Hard wheat flour					
0.5	10.85	2.6	24.0	57.55	5.5	9.6	62.85	6.1	9.7
1	12.08	4.4	36.5	58.55	4.7	8.0	69.65	5.5	7.9
3	9.85	3.9	39.6	63.25	2.8	4.4	71.55	5.8	8.1
6	8.35	4.9	58.7	59.55	8.5	14.3	73.15	3.9	5.4
24	8.95	4.6	51.0	60.35	6.1	10.1	74.15	7.6	10.3
48	19.7	6.6	33.5	71.63	6.4	8.9	78.95	4.7	5.9
				Soft wheat flour					
0.5	6.15	1.7	27.6	21.85	9.2	42.0	37.35	11.4	30.6
1	4.75	1.1	23.2	22.45	4.7	20.9	37.05	6.2	16.9
3	4.55	1.4	29.9	28.15	8.0	28.5	45.28	8.4	18.5
6	1.99	0.9	45.2	21.25	5.1	24.0	28.85	3.6	9.3
24	5.05	2.0	40.0	51.55	8.1	15.6	67.05	3.7	5.5
48	8.05	2.1	26.1	46.05	3.2	7.1	61.25	7.6	12.4

[1] Values shown are for 10 determinations.

X = mean
S = standard deviation
C.V. = coefficient of variability = $\frac{S}{X} \times 100$