EFFECT OF OVERGRINDING UPON THE FLOUR MILL STREAMS

by

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INTRODUCTION AND REVIEW OF LITERATURE

For the utilization of cereals in most cases grinding is a necessary step. Sifting is often also necessary. Unfortunately, it is practically impossible to separate by grinding and sifting all the different grain components. Thus, after grinding and sifting, the endosperm will still contain some bran and germ and the bran will contain some endosperm. The degree of separation of the different grain components depends upon the wheat properties and the method of processing the grain.

New equipment and processes are constantly invented to accomplish the two main purposes in cereal technology: to obtain the maximum yield and at the same time to obtain a high quality product. In many cases, as yield is increased baking quality decreases.

Grinding involves shearing, pressing, crushing, or a combination of these operations, accompanied by heat generation. The above physical factors alter the different chemical components of the cereal grains (9) (61). Proteins, carbohydrates and lipids are the most important chemical components of cereal grains.

The degree of alteration of wheat flour properties during milling depends on the type of mill and the way the mill is operated. In the case of a pair of rolls particle size reduction will be mainly a function of the distance between the two rolls, pressure, differential, speed, and surface. In many cases the alteration produced by the different physical factors involved in milling is desirable. The process is, indeed, necessary for the production of flour. However, a severe grinding may lead to an undesirable final product.

In the case of flour for bread production, certain important characteristics of the final product are closely related to the way milling is performed. Average particle size and diastatic activity are two of the most important of those characteristics related to the milling process.

Since a good bread volume and certain other properties are important to the miller and baker, it is worthwhile to consider the two major factors related to those parameters, namely, gas production and gas retention in the dough. Gas production is closely related to diastatic activity and diastatic activity depends in turn on the amount of amylases and starch damage. A certain minimum amount of gas must be produced in order to yield a bread of satisfactory volume. Even in dough formulas containing ample amounts of sugar, modifications of starch by amylases are known to improve bread quality. Gas retention is closely related to protein quantity and quality. During wetting and dough mixing, flour proteins react with other dough components, and gluten is formed. The complex of proteins, lipids, water and other constituents forms the matrix that will retain the gas.

There has always been considerable discussion as to the relative importance of the size of the flour particle. Many flour millers are of the opinion that granulation is very important in producing high quality flour. Some believe that the success of their particular brand is due to a definite degree of fineness, which they have adopted as standard (33).

The investigations dealing with the effects of granulation of flour on chemical composition and baking quality may be divided into two main groups. One includes those which were conducted in order to observe the behavior of the different sized particles of which flour is normally composed; the other, those in which the whole flour, ground to a definite fineness was the subject of investigation.

As early as 1914, Richardson (57) showed that flour containing a large proportion of granulates which passed through a No. 21 silk bolting cloth tended to lump and the baking quality of the flour was impaired.

The next observation on the subject by LeClerc et al. (39) was that the quality of the coarse and very fine portions of flour was inferior to that of the intermediate-sized particles. In every case, the quality of the bread made from the intermediate granulates was superior to that of the original flour. The very fine granulate resulted to be the poorest part of the flour with respect both to the quantity and quality of the gluten. The quality of the bread produced was inferior as was also the water absorption capacity.

Some six years later Alsberg and Griffing (2) reduced the flour in two ways. In the first case, the flour was ground to four different degrees of fineness. Each sample contained the whole flour reduced to a given degree of fineness. In the second case, the flour was ground for 36 and 53 hours in a porcelain ball mill with flints. As a consequence of these treatements, flours were much more finely disintegrated than by roller milling alone. Those workers concluded that "overgrinding flour injures the starch granules so that part of the starch swells and disperses when the flour is doughed." One result is an increase in the amount of cold water extract from dispersed starch. Another result is increased diastatic starch conversion in the flour, followed by increased initial rate of fermentation. Severe overgrinding injured the flour for baking purposes despite increased absorption due to the swelling of starch granules. Evidence was presented that overgrinding injured the gluten, but moderate overgrinding may injure the starch granules without influencing the gluten.

The Rumsey method (58) measures the amounts of reducing sugars formed by autolytic activity of flour. Mangels (43) reached the conclusion that "the diastatic activity of flour as measured by Rumsey's method is the result of the combined effect of diastase concentration and the relative susceptibility of the starch of the flour to diastase attack. The variation in diastatic activity of flour appears to be due, in large part, to the suceptibility of the starch granules to diastase attack, rather than to the concentration of diastase present."

Shollenberger and Coleman (64) found that when flours were ground a number of times or to a certain degree of fineness, "the doughs of the finest materials were, in some instances, inclined to be sticky and weak. The excessive grinding showed some tendency to slow up the rate at which the flour absorbed water, but the total quantity absorbed increased very markedly and consistently with the number of times." As to the color and grain of the bread crumb, the best bread scores were from materials treated the least. The texture was affected little. No very pronounced alteration in the color and condition of the crust was noticeable. Those workers found that the cold water extract and the diastatic power increased progressively with excessive grinding.

Malloch's (42) investigation further emphasized the necessity for distinguishing between the resistance of the starch to diastatic action and the actual activity of the diastatic enzymes in studying the saccharogenic power of flour-water mixtures.

The saccharogenic activity of the flours was also found by Pascoe _et_ _al_. (48) to be largely influenced by the degree of granulation. The autolytic saccharogenic activity of an aqueous suspension of a flour sample that had been milled in the commercial mill and reground in a ball mill for twenty hours was increased approximately 35%. Pascoe et al., stated that without extended fermentation periods the basic baking procedure does not permit detection of flours low in saccharogenic activity by means of loaf volumes values. This was attributed to the presence of ample amounts of sugar during the relatively short fermentation.

Investigations of Karacsonyi (33) showed that overgrinding wheat flours resulted in substantial increases in diastatic activity as measured by the Rumsey autolytic method. The magnitude of the increase was in inverse ratio to the initial diastatic activity of the untreated flour.

In studies on the effects of overgrinding upon flour quality, Pulkki (55) reduced the flour to various degrees of fineness to pass through the following sieves: 60 g.g., 6xx, 10xx, 14xx and 25xx. He found similar results to those obtained by former workers in this field. The medium-fine flour (through 10xx) showed better baking properties than the coarser and finer products. The coarsest (original) and the finest (through 25xx) materials gave smaller loaves, and the qualities of crust and crumb were inferior; e.g., the color of the crumb was grayish. The reduction in the size of particles increased water absorption substantially; the period required for Farinograph dough development was simultaneously lengthened. With increasing degree of fineness, great increases in amylolytic activity were noted.

Jones (31) studied the effect of grinding on diastatic activity. He used different wheat varieties and different grades of semolina and found that primary stocks (primary means coming from the breaks, i.e., unreduced) had a low maltose figure while those coming from the last reduction had a high maltose figure. He also found that the differences in diastatic activity between flours from different types of wheat are not necessarily due to differences in amylase content or in starch susceptibility but they are at least partly to be attributed to differences in the physical hardness of the endosperm as affecting the extent of the damage to the starch during milling. The harder wheats showed more starch damage than less hard wheats when ground to the same degree.

Wichser and Shellenberger (69) made a subsequent study of ash in relation to flour quality. In this study, a straight flour was separated into several well defined particle size groups and a study was made of ash and protein contents and the baking characteristics of each fraction. Quantitative removal of bran fragments from the flour fractions was accomplished by using an accurate and efficient air ellutration apparatus. It was found that straight grade flour contained a relatively small number of bran fragments.

No correlation between the ash content and the baking quality of the flour was found. In fact, if the ash content was the only factor considered in relation to baking quality, it might be concluded that flour containing the greatest amount of ash produced a more desirable bread. As would be expected, the content of protein in the flour was shown to be closely related to loaf volume. It appeared therefore that the ash content of flour is not related to flour quality. When bran fragments were removed, flour fractions differing in the natural mineral matter in the endosperm yielded equally satisfactory bread.

Harris (22) studied variations in particle size in flours milled from wheat varieties grown in several locations and varying in qualities. He reported the following results: "fractions separated from experimentally milled hard red spring wheat flour according to particle size were influenced by the location of growth, and to a lesser extent by variety, for wheats found satisfactory in milling quality. All interactions involving the three sources of variation, varieties, locations, and sieve sizes were very significant. Six fractions from one hard red spring wheat flour differed in loaf volume, the best loaves occuring with the intermediate particle sizes, and the smallest loaf with the smallest size of particle. The fraction yielding the smallest loaf had abnormal mixing properties. Flour ash content varied inversely with particle size."

The relation of particle size to certain flour characteristics was also studied by Sullivan et al., (66). A 90% patent flour from hard wheat was air-classified into six particle size ranges and the fractions obtained were analyzed for particle size distribution, ash, protein, maltose value, gassing power, and Amylograph viscosity. At about 15 micron particle size, ash content was well below the original flour. From 15 to 30 microns, the ash content was still lower than in the original flour but greater than at the 15 micron size. From 15 to 70 micorns the ash content was still lower than in the original but greater than at the 30 micron size. At about 70 micron size, the ash content was higher than in the original flour. Protein content followed the same general pattern as the ash content. Maltose values and gassing power decreased with increasing particle size. Specific surface correlated well with maltose values and gassing power. Amylograph hot paste viscosity showed an increase from the very small particle size range to a peak at around 20 to 30 microns. There was then a drop in the viscosity as the particle size increased, followed by an increase in the coarsest size range.

In later studies, Sullivan et al., (67) developed a quantitative method for the determination of starch damage index. This method was based on the fact that damaged starch granules are much more suceptible to the action ofbeta-amylase than undamaged granules. By use of this method it was shown that starch damage index of flour was dependent mainly on the type of wheat milled and the kind and severity of grinding. Despite finer granulation of the sample ground by impact, the starch damage index was considerably less than that of the roller ground flour. The type of stock used for grinding was found to be important in the relationship between any of those variables. Starch damage index was not affected by tempering time, except when this was very short. Absorption increased as starch damage increased. Both, absorption and starch damage positively correlated with particle size and specific surface only when the same type of grinding action (pin or ball milling) was employed.

Ponte et al., (54) studied the starch damage in white bread flours made from wheats from different varieties and from wheats of the same variety but grown in different regions. The Sandstedt and Mattern method (59) was used to estimate and compare the starch damage. Starch damage ranged from 6.7 to 10.5% in the flours, the arithmetic mean being 8.2%. Less starch damage was found in flours milled in the Southwest than in flours milled in other regions of the United States. There was a close relationship between starch damage and diastatic activity, absorption, and baking performance of flour. In a group of Southwest flours having a rather narrow range of starch damage, the relation of baking quality to starch damage was not clear. From these investigations it was speculated that an optimum degree of starch damage exists for a particular flour, at least so far as conventional sponge and dough baking was concerned.

Schulze and MacMasters (62) studied the manner of breakage of endosperm cell walls in flour milling. They found that the cell walls are broken transversely. In some, the cell wall remained intact, or the complete cell wall may also remain together with the adjacent cell walls of neighboring cells connected by the middle lamella. No cleavage between cell walls, along the middle lamella was observed. Adhesiveness between cell walls and middle lamella is apparently too strong to be broken during milling.

Ball-mill action on Buhler experimentally milled flour has been studied recently by Schlesinger (61). He found that ball-milling of flour caused smaller average particle size, higher maltose value, increased Farinograph absorption, longer Farinograph mixing time, lower loaf volume, and poorer baking score. Moisture, sedimentation, and protein values were essentially unchanged. Ash increased slightly because of jar abrasion. Starch damage and the increased water thus required, rather than gluten damage, was shown to be the cause of poor baking results. Although, improvement in bread quality was obtained by lowering absorption and by increasing the mixing time of the ball-milled flour, as indicated by the longer Farinograph mixing time, the strenuous ball-mill action, which damaged starch granules, impaired the breadmaking ability of normal flour.

Gracza (16) compared the average particle size and specific surface of flours and air-classified flour fractions. The 5 most commonly used methods of measuring average particle size included: the average particle size by the Fisher apparatus, the mass median size, the critical cut median, the 80% size median and the Rosin-Rammler mean. Since the individual measurements differentiate among the samples to a similar degree, any of the five methods could be used for practical purposes. If better accuracy was desired, those methods which carried the least sources of error were best. For instance, it was pointed out that the surface by weighted mean size would be an ideal choice if:

"a) Particle size is defined by settling rate of the sphere with identical density and with diameter assigned as size of particle.

b) errors of arbitrary statistical assumptions are to be eliminated.

c) the particles have practically no surface owing to internal fissures.

If requirements are different, the ideal choice may fall on a measurement by another method."

The protein alteration in flour damaged by ball-milling and roller milling was studied by D'Appolania and Gilles (9). Protein alterations in flour milled with various degrees of severity by ball and roller mills were measured by determinations of nonprotein nitrogen, specific color reactions, Sephadex column chromatography, gel electrophoresis, and changes in the sulphydryl groups. The undamaged and damaged flours were fractionated into four fractions including starch, sludge, gluten, and water soluble proteins. The proteins of the water-soluble fraction were studied most extensively. The possibility of protein denaturation was indicated by a decrease in the nitrogen content of the water-solubles which was not due entirely to the increase of soluble, damaged starch fractions. The percentage of nonprotein nitrogen in the water-solubles, determined by three independent protein precipitating agents, increased as the extent of flour damage increased. Two color reactions one specific for amines, amino acids, and peptides, and the other specific for alpha-amino acid groups, were used to test the water-solubles extracted from the undamaged and damaged flours. The results supported the nonprotein nitrogen values previously mentioned. Average values obtained from determinations of Sephadex-G-50 columns showed that there was a slight increase in the content of protein of lower molecular-weight in the damaged flour. These data indicate an alteration of some kind in the over all make-up of the proteins structure.

The investigations dealing with the effects of grinding on the chemical components of cereals showed that grinding produces changes in the carbohydrates and proteins. Little investigation has been made on the effect of grinding on lipids of cereals. Mitchell and Henick (45) pointed out that oxidative rancidity does not take place in viable seeds but upon crushing or milling, the biological equilibrium characterizing viable seeds is altered. Hydrolytic, enzymic, and oxidative rancidities may develop at a rate that is governed by the temperature and moisture content of the product (53). During grinding the temperature is increased and moisture content is decreased. The degree of increase in temperature and decrease in moisture depends on the type of grinder and the way the grinder is operated.

The Milling Process

In designing a milling process due consideration should be given to kernel structure.

The kernel of wheat has three major components (37): the protective outer layers (composed of the pericarp, the seed coat, and some nucellar tissue), the endosperm, and the germ. The pericarp generally is divided into outer and inner pericarp. The outer pericarp is composed of the epidermis, hypodermis, and remnants of thin-walled cells. The inner pericarp is composed of the intermediate cells, cross and tube cells. The seed is composed of the seed coat, some nucellar tissue, the endosperm, and the germ. The endosperm includes the aleurone cell layer and the starchy endosperm. The germ is made up of the scutellum, the embryonic axis, and the epiblast. The main parts of the scutellum are the epithelium, parenchyma, and provascular tissues. The most prominent parts of the embryonic axis are the plumule, the primary root, and the secondary lateral rootlets (37).

The chemical composition of the three main components (bran, germ and endosperm) of the kernel of wheat is different (1) (24) (29). Compounds present in the bran and germ are deleterious to the baking properties of flour (38). This is why it is so important to obtain the endosperm in the purest possible form.

The milling of wheat involves many manufacturing processing steps of which cleaning, conditioning, grinding, and sifting are the most important (40) (63).

Most of the impurities contained in the bulk of wheat have physical properties which are different from the properties of the wheat kernel. Mechanical implements have been designed, based on the differences, to separate the undesirable matter from the wheat. Physical differences occur in size, shape, specific gravity, behavior in air currents, surface friction, magnetic properties, and friability under impact.

Conditioning consists of the application of warm or cold water or steam and hot or cold air to wheat. The purpose of conditioning is to accentuate the differences inherent in different parts of the kernel and thus to make easier the separation of endosperm, bran, and germ. Certain types of conditioning can also improve the quality of some flour. The amount of heat and water applied to the wheat and the duration of the application have to be carefully regulated. Considerable research has been done on this aspect of the milling process and it is still not completely understood (63) (68).

During the milling of wheat numerous streams are produced. As mentioned above the main purpose is to separate as completely as possible the grain constituents, namely, bran, germ, and endosperm. Each stream is ground and then sifted; the sifter separates different fractions according to particle size. The finest portion is usually considered to be a flour stream. The total number of flour streams in a flour mill depends on the flow of the mill. Normally, the larger the mill the more flour streams are necessary.

The properties of straight flour depend on the properties of the flour mill streams and the properties of each of the flour mill streams depend on the stock from which the flour has been separated (67).

On this basis, the flour mill streams were selected to study the different sections of the grain from which they come. The purpose of this study was to study the effects on composition and bread-making properties of overgrinding various flour mill streams.

MATERIALS AND METHODS

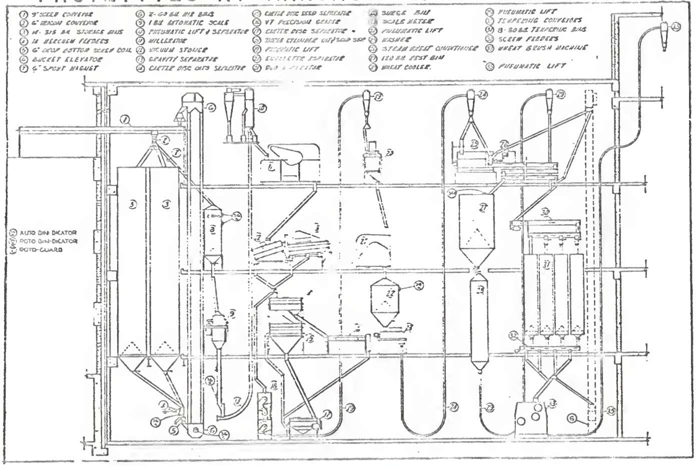
Wheat Preparation.--The mixed grist of hard winter wheat used in this experiment was cleaned in the cleaning house of The Grain Science and Industry Department, Kansas State University, by use of equipment commonly found in commercial mills. The flow sheet of the cleaning house is shown in Fig. 1. The clean, dry wheat was tempered to 16% moisture and allowed to stand in bins for 20 hours before milling.

The pilot mill in the same department was used for the milling. After the flour mill was started and operated for two hours, the break rolls were adjusted to release the following percentages of the stock of each break roll through No. 20 light wire on the test sifter: 1 Bk-39%, 2Bk-40%, 3BkC35%, 3BkF-55%, 4BkC-15%, 4BkF-35% and 5Bk-25%. Reduction rolls were also adjusted. The flow sheet of the flour mill is shown in Fig. 2.

Sampling.--Samples were taken from the flour streams in sufficient amount (approx. 5 lbs each) to provide enough material for the regrinding. The samples taken are listed in Table 1; the moisture, ash and protein content of the streams are also given in this Table.

The abbreviations used to designate the flour streams are:

FIG.1. SCHEMATIC FLOW OF GRAIN CLEANING FACILITIES AT KANSAS STATE UNIVERSITY.



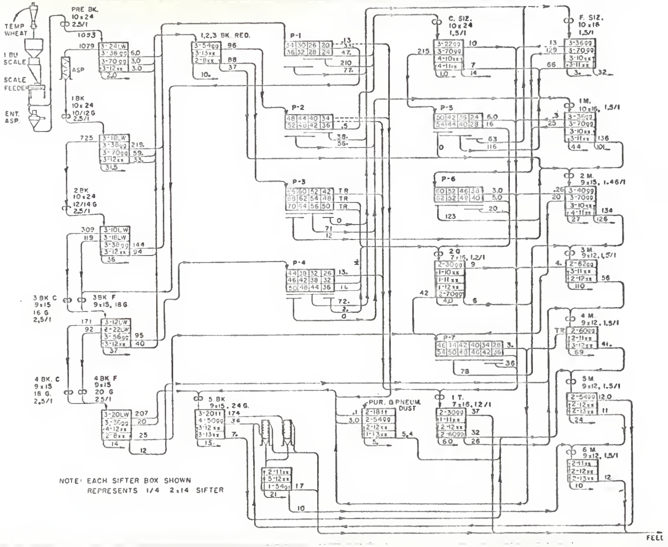


FIG.2. 200 C.W.T. FLOUR MILL, KANSAS STATE UNIVERSITY.

NOTE: EACH SIFTER BOX SHOWN REPRESENTS 1/4 2x14 SIFTER

1B = first break
2B = second break
3B = third break
4B = fourth break
5B = fifth break

1M = first middlings
2M = second middlings
3M = third middlings
4M = fourth middlings
5M = fifth middlings
6M = sixth middlings

CS = coarse sizings
FS = fine sizings
1T = first tail
2Q = second quality
B&SD = bran & short dusting
ST = straight grade

The same symbols are used on the graphs presented. After each sample was taken and weighed, it was placed in a metal can which then stood at 40°F until ready for use for the grinding, physical and chemical tests.

For the sake of simplicity the streams that contained less than 0.5% ash are called low ash streams and those whose ash content is above this value are called high ash streams. Low ash streams are also called head streams or head end streams, because they are obtained in the first part of the milling process. High ash streams are called tail streams or tail end streams because they are obtained in the last part of the milling process.

Regrinding.--The samples were reground by ball milling. Three jars were used for the additional grinding. The capacity of each jar was 1700 cc, and 200 gms. of flour was used in each. The grinding time was 5 hours or 20 hours. Three sets of samples were obtained in this way: the original samples (0 hours grinding), and samples ground for 5 hours and 20 hours, respectively.

After grinding the three series of flours were tested for moisture, ash, protein, average particle size, color, diastatic activity, falling number, and hydrogen ion concentration. Farinograms and the baking test were also performed.

Moisture.--An air-induction oven was used for the moisture determination. The temperature inside the oven was adjusted to 130°C and the weighed samples were put into the oven for 1 hour (5). The samples were then brought to room temperature in a desiccator and again weighed. A Mettler electric balance was used for the weighings.

The loss in weight represented the moisture loss.

Color.--The Agtron colorimeter (12) was used for measuring the color of the samples. This apparatus is based on the principle that the reflectance is higher from whiter samples. The two standard Agtron discs were used to calibrate the apparatus at 0 (Disc 6935) and 100 (Disc 5095) micro amperes. Those calibrations were done every 15 minutes according to the instructions. Additionally, color determinations were made on a slurry with the Kent-Jones and Martin color grader.

Nitrogen Determination.--The Kjeldhal method (5) was used for the nitrogen determination. A one-gram sample was used in each case. Normality of acid and base for the titrations was of 0.1253. A factor of 5.7 was used for converting the nitrogen to protein.

Ash.--The temperature inside the oven was adjusted to 550°C. The weighed samples were ashed overnight (5). A Mettler electric balance was used for the weighings before and after the burning of the samples.

Average Particle Size.--The Fisher (Sub Sieve Sizer) (7) (13) (14) was used. This apparatus is based on the principle that the amount of air let through a constant weight of flour depends on the size of the particles of the flour. The porosity was adjusted to 0.465. Double reading or direct reading was used according to the average particle size of the sample. The results were expressed in microns; 1.44 grams were used for each test.

Diastatic Activity.--The Sandsted and Mattern method was used (59).

Falling number.--The falling number apparatus was used to determine the alpha amylase activity (15) (17) (18) (19).

Seven grams of flour were suspended in twenty-five cubic centimeters of water.

Hydrogen Ion Concentration.--A Beckman pH meter was used for this determination (5).

Two buffers of 4 and 9 pH were used to calibrate the apparatus. Readings were taken at 21°C.

Farinograph.--The Brabender Farinograph was used to obtain the farinograms of the samples. The 50-gram bowl was used for these experiments. The temperature inside the bowl was maintained to 30°C and the fast speed was used. A calculated amount of flour was used to adjust the sample to the 14% moisture basis (4) (44).

Baking test.--A National small size mixer was used and the mixing time was based on the farinogram results, but was modified if required, to obtain optimum consistency of the dough. A fermentation cabinet was used to maintain the dough at 86°F and a relative humidity of 98%. Punching was done by hand. The automatic puncher could not be used for the overground samples due to their excessive stickiness. The proofing temperature was 98°F and the relative humidity was 98% in a proofing cabinet that was used for this purpose. A National revolving reel oven was used for baking; the temperature was maintained at 425°F and the doughs were baked for 25 minutes (5).

Crumb and Crust Color Determination.--A Photovolt-Reflectometer, model 610 equipped with a green filter was used for measurement of crumb and crust color. The lower the reading the darker the color (51).

RESULTS AND DISCUSSION

The lowest ash streams, coarse sizings and third middlings, of the original flour had a higher moisture content than the high ash streams as can be seen in Table 1. Generally, ash increased as protein content increased.

Analyses of flour mill streams have been made by many investigators who found similar results (11) (32) (47). The head end streams had a lower ash content than the tail end streams. This is because the head end streams come from the inner endosperm, while the tail end streams come from the part of the endosperm closer to the bran (46) (52). The outer endosperm has a higher ash content than the inner endosperm. Protein and ash seem to show similar gradients of distribution in the wheat kernel.

Hinton (23) found the following percentages of protein in the kernel: pericarp, 4.4%; aleurone layer, 19.7%; and endosperm, 13.7%, 8.8% and 6.2% respectively (from outer to inner endosperm).

The effects of increasing the amount of flour in the ball-mill, while maintaining the time of grinding at 5 hours, are summarized in Table 2, and shown graphically in Fig. 3. In this figure, particle size in microns, color in agtron units and moisture per cent are plotted against weight in grams. The average particle size of the original flour was 28.0 microns. Efficiency of regrinding decreased as ball

Table 1 ANALYSES OF THE ORIGINAL STREAMS

	Moisture %	Ash* %	Protein* %
1B	15.2	0.39	9.9
2B	15.2	0.36	10.6
3B	15.0	0.42	12.9
CS	14.6	0.31	9.5
FS	14.5	0.32	9.7
1M	14.6	0.29	9.7
2M	14.8	0.30	9.8
4M	14.8	0.55	15.1
3M	14.3	0.31	10.0
1T	14.0	0.40	9.6
4M	14.2	0.34	10.2
5B	14.3	0.77	16.4
5M	13.9	0.40	10.1
B&SD	13.3	1.40	13.4
6M	13.5	0.66	10.4

*Reported on 14% MB

Table 2 WEIGHT vs. PARTICLE SIZE, COLOR, AND MOISTURE (STRAIGHT FLOUR)

Flour Weight	Fisher S.S.S. Ave. Particle Size	Color	Moisture
Grams	Microns	Agtron Units	%
100	9.8	78.5	12.6
150	11.3	79.7	12.7
200	12.1	80.7	12.7
250	13.0	81.0	12.8
300	14.5	79.7	12.7
250	18.0	79.0	12.9

Table 3 GRINDING TIME vs. SIZE & COLOR (STRAIGHT FLOUR)

Grinding Time	Fisher S.S.S. Ave. Particle Size	Color
Hours	Microns	Agtron Units
0	28.1	67
5	15.2	78
10	13.1	76
15	11.7	74
20	11.3	73
25	10.8	73
30	9.9	74

FIG. 3. INFLUENCE OF BALL MILL LOAD ON THE DEGREE OF FLOUR PARTICLE SIZE REDUCTION, AND MOISTURE, AND COLOR CHANGE.

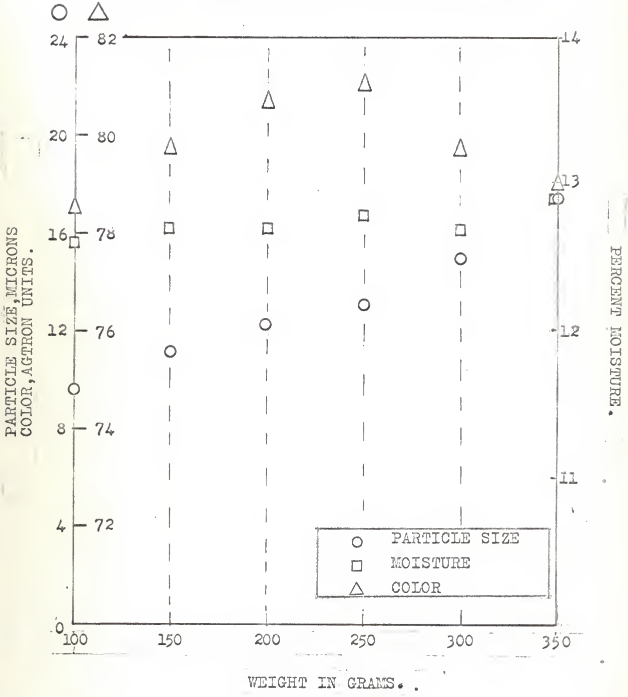
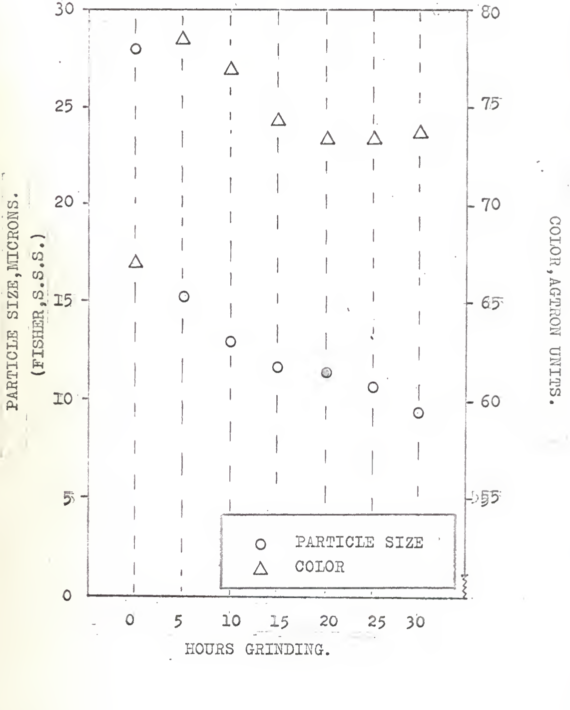


FIG. 4. EFFECT OF GRINDING TIME UPON FLOUR AVERAGE PARTICLE SIZE AND COLOR.

(200 gm.used.)



mill load increased. The moisture content was affected little. The color of the flour improved when 100, 150, 200 or 250 grams were placed in the jar, but the improvement was not as high when 300 and 350 grams were placed in the jar.

An experiment was made to study the effects on particle size reduction and color in straight flour when 200 grams of it were ground in the ball mill for increasing periods of time. Results are shown numerically in Table 3 and are shown graphically in Fig. 4. From this study it can be deducted that most of the reduction in size took place during the first 5 hours of grinding from 28.1 to 15.2 microns. The original flour had an average particle size of 28.1 microns. This represents approximately 45.5% reduction in size. After 5 hours of additional grinding, the average particle size was 13.1 microns; this is only a 7.8% additional reduction. The percentage reduction in particle size in the next 20 hours of additional grinding was still less.

The color of the flour improved with 5 hours of grinding but with 10, 15, 20, 25 or 30 hours grinding the flour became darker. This might be due to dispersion of the flour pigments.

The moisture, average particle size, color, diastatic activity and pH for all the flour streams and for the original, 5 and 20 hours grinding are shown in Table 4.

Table 4

Effects of Grinding upon Moisture, Average Particle Size, Color, Diastatic Activity, and pH of the Flour Mill Streams

Flour Stream	Grinding Time	Moisture	Size	Color	Diast. Activity	pH
	hours	%	microns	Agtron units	mg/10g flour	
1B	0	15.0	24.0	68.0	76	
1B	5	14.5	16.9	72.0	220	
1B	20	14.6	12.8	70.0	598	
2B	0	14.4	21.5	68.0		
2B	5	13.9	11.4	74.5		
2B	20	14.0	8.7	73.0		
3B	0	14.6	25.6	68.0	85	
3B	5	14.0	18.5	74.0	221	
3B	20	14.0	11.7	73.0	550	
CS	0	14.4	27.6	76.0	111	
CS	5	14.0	15.4	81.5	295	
CS	20	14.0	13.0	73.5	454	
FS	0	14.1	26.0	76.0	176	
FS	5	14.0	15.1	82.5	379	
FS	20	14.0	12.0	80.0	512	
1M	0	14.2	26.0	80.0	166	
1M	5	13.9	14.5	83.0	344	5.78
1M	20	14.0	12.1	75.0	803	5.82
2M	0	13.6	26.2	76.0		
2M	5	13.4	10.4	80.0		
2M	20	13.4	8.2	77.0		
4B	0	13.1	18.4	63.5		
4B	5	13.1	13.0	67.5		
4B	20	13.3	11.2	67.0		

Table 4 (Cont.)

Effects of Grinding upon Moisture, Average Particle Size, Color, Diastatic Activity, and pH of the Flour Mill Streams

Flour Stream	Grinding Time	Moisture	Size	Color	Diast. Activity	pH
	hours	%	microns	Agtron units	mg/10g flour	
3M	0	13.8	32.0	73.0	166	5.90
3M	5	13.2	14.8	82.0	298	5.90
3M	20	13.6	10.4	78.0	768	5.90
4M	0	13.2	25.5	72.0		
4M	5	12.9	11.4	77.5		
4M	20	12.7	7.8	73.5		
5B	0	13.3	23.7	51.0	126	6.31
5B	5	13.3	20.0	63.0	251	6.30
5B	20	12.0	18.0	62.0	325	6.27
5M	0	13.1	24.2	69.0		6.10
5M	5	12.9	11.5	73.5		6.15
5M	20	12.8	8.4	73.5		6.18
B&SD	0	12.9	19.4	27.0	231	6.35
B&SD	5	12.7	18.6	32.0	301	6.33
B&SD	20		16.5	36.0	519	6.38
6M	0	13.2	21.4	61.0	264	6.24
6M	5	12.9	17.6	70.0	341	6.25
6M	20	12.9	14.6	66.5	418	6.27
ST	0	15.2	28.0	67.0	121	
ST	5	13.6	16.0	76.0	276	
ST	20	13.5	11.0	72.0	715	
1T	0	13.8	22.0	67.5	198	
1T	5	12.9	20.0	71.5	308	
1T	20	12.9	18.0	71.5	445	

The results shown in this Table are illustrated in Figs. 5 to 15. The flour streams are arranged on the graphs in order of increasing ash content. The range in ash content from the lowest to the highest was so wide that it was necessary to break the abcissa in order to plot all the different streams on the same graph.

The explanation of symbols used for the different flour streams has been given previously.

Average Particle Size.--The effect of grinding on particle size reduction is shown in Fig. 5. In this graph average particle size is plotted against the ash content of the mill streams in the order of increasing ash content.

As can be seen in figure 5, grinding decreased particle size of all streams. The tail streams had a smaller original average particle size than the head streams. The 20 hours grinding produced a larger decrease in average particle size than the 5 hours grinding, but most of the reduction in size took place during the first 5 hours of grinding. The degree of reduction in average particle size was not the same for all the different streams; the low ash streams suffered a more severe change than the high ash streams. This is probably because the poor or tail streams contained more particles from the outer endosperm than did the head streams, consequently, the former contained more ash and also more fiber than the latter as shown by

FIG.5. EFFECT OF GRINDING UPON AVERAGE PARTICLE SIZE OF THE FLOUR MILL STREAMS.

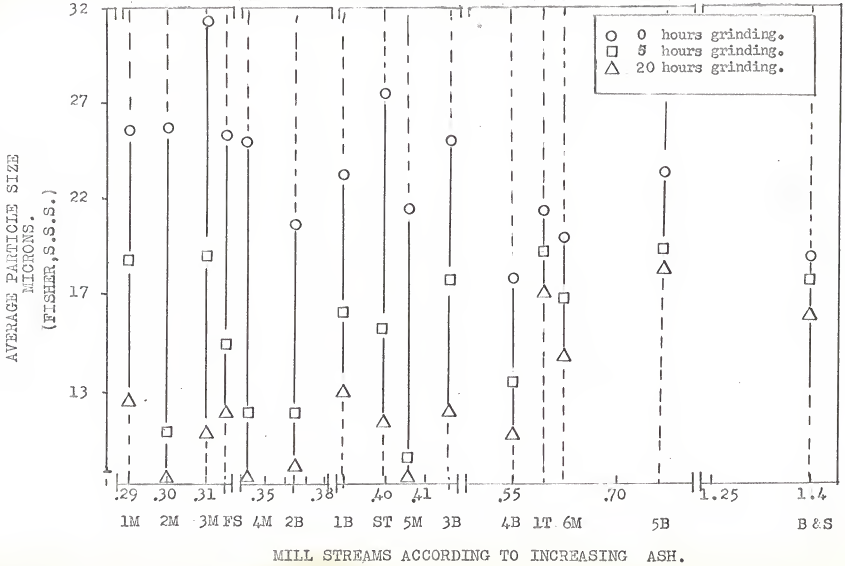


FIG. 5. EFFECT OF GRINDING UPON AVERAGE PARTICLE SIZE OF THE FLOUR MILL STREAMS.

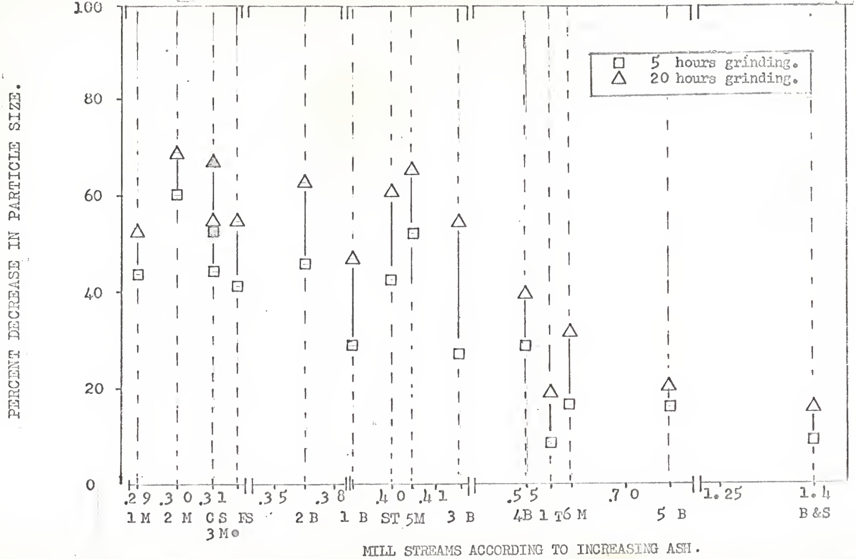
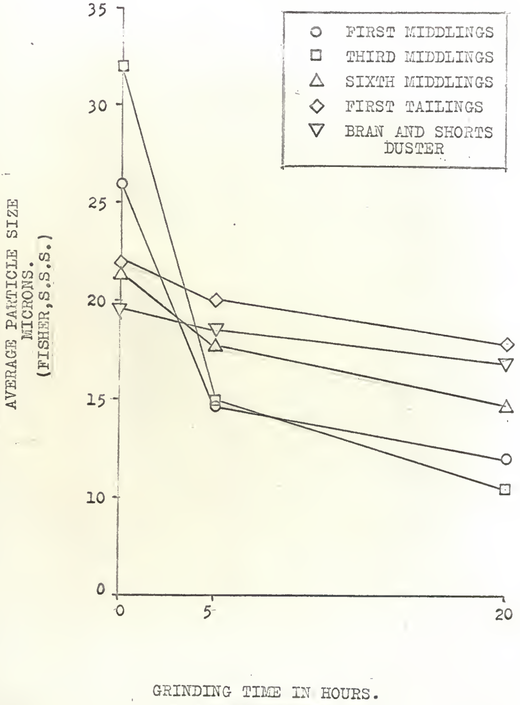


FIG.7. EFFECT OF GRINDING UPON AVERAGE PARTICLE SIZE REDUCTION.



Schlesinger (60). The head end streams contained more starch which is more easily ground than fiber because of differences in chemical composition.

Similar results were found by Kent et al., (36) who worked with the different products obtained from different zones of the kernel of wheat and reached the conclusion that the reducibility of subaleurone endosperm by pin milling was lower than that of inner endosperm; the finer fractions of pin-mill reground flours contained relatively more inner endosperm; the coarser fractions contained more subaleurone endosperm than the original flour. Kent et al., (36) reported further that percentage reduction of inner endosperm of hard red spring during pin-mill regrinding of roller-milled flour varied between 29% and 81% according to moisture content of the wheat and of the flour. Reducibility was greater when the wheat was ground at higher moisture and when the flour was reground at lower moisture. Percentage reduction of subaleurone endosperm of the same hard red spring wheat varied between 1% and 50% but reaction to moisture variation in wheat and flour was similar to that of inner endosperm.

The percentage of reduction in particle size is shown in Fig. 6. It can be seen that the head streams had a much higher average percentage reduction in particle size than the tail streams did. The bran and short dusting stream had the lowest and the second middlings stream had the highest percentage decrease of particle size reduction.

The effect of grinding upon average particle size is shown also in Fig. 7. Third middlings had the largest average particle size and the one with the smallest particle size after twenty hours of regrinding. It can be seen that most of the reduction in particle size was effected during the first five hours of regrinding. The bran and short duster fraction showed the smallest change in average particle size. This was the stream with the highest ash content; the fiber content in this stream is usually also high (60). Kent (35) found that there is a higher proportion of peripheral (small) cells in break flour than in reduction flour. All these facts explain why that stream had the lowest percent reduction in average particle size.

Color.--Color is plotted against the different flour mill streams in Fig. 8, which shows the effects on color when flour streams are ground for 0, 5 and 20 hours. Color is expressed in agtron units. The original head streams had a better color than the original tail streams; this was because the tail streams were contaminated with bran particles. Hlynka (24) stated "the change in flour color is slow up to 65% extraction, rather faster progressively, in the range 65 to 75%, and progressively very much faster above 75%. The mineral content of the wheat kernel is concentrated in the areas adjacent to the bran coat and in the

FIG.8. EFFECT OF GRINDING UPON COLOR OF THE FLOUR MILL STREAMS.

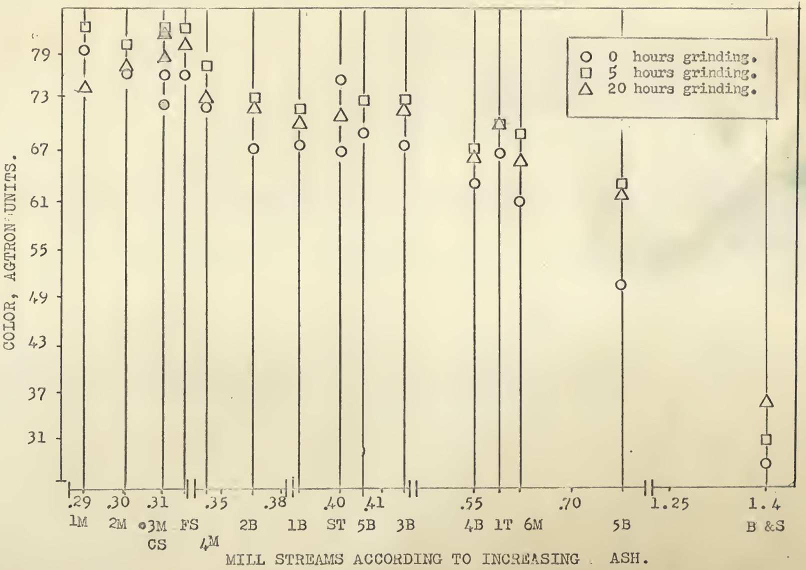
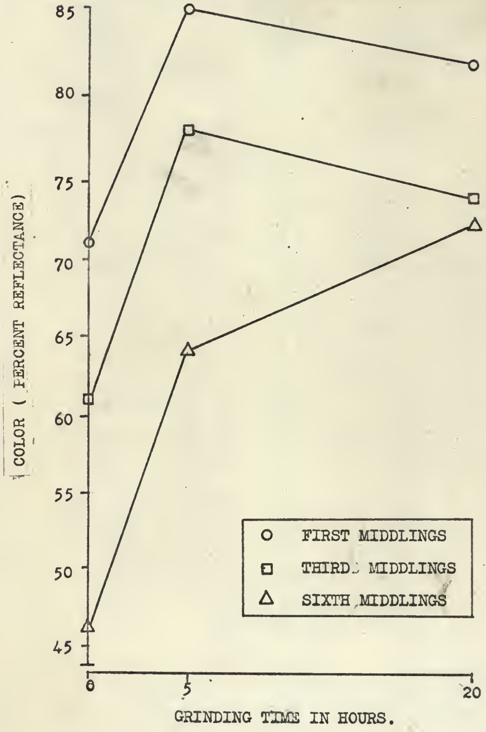


FIG.9
EFFECT OF GRINDING UPON COLOR OF THE FLOUR MILL STREAMS.



bran itself. Flour products which contain high levels of ash will contain great quantities of fine bran particles. Such flour products will be dark in color." This explains why first middlings gave a reading of 75 agtron units and the bran and short dusting stream gave one of only 29. It can be seen from the graph how the color became darker in progressing from the head stream to the tail streams. After 5 hours regrinding all the streams improved in color, but the tail streams improved more than the head streams.

After 20 hours regrinding many of the head streams became darker but the tail streams still improved in color. The reason for the head streams becoming darker when reground for 20 hours is not readily evident. The maximum temperature reached inside the jar was 33°C and the nonenzymatic browning reaction is not likely to be a significant factor (21). Some dispersion of the flour pigments may have occurred. The results of the color determination of three of the flour streams (first, third and sixth middlings) are shown in Table 5 and illustrated graphically in Fig. 9. In this case, the color was determined using a slurry of the mentioned samples, and a photoreflectometer was used for the determinations. The results are similar to those obtained using the Agtron color meter. The color of the first and third middlings improved with 5 hours grinding but became darker with 20 hours grinding. The color of sixth middlings improved with 5 or 20 hours grinding.

Diastatic Activity.--The changes in diastatic activity are shown in Fig. 10. The original streams showed a trend toward slight increase in diastatic activity, with a value of 166 for first middlings and of 264 for 6 middlings. The reason for the higher diastatic activity in 6 middling is due to the fact that this stream (as most tail streams) came from stock that has been ground several times in previous steps of the milling process, the combined effect of pressure and heat during roll grinding contributed to the increase in diastatic activity. The values are expressed as milligram maltose per 10 grams of flour.

The diastatic activity after 20 hours regrinding was higher than after 5 hours regrinding. The percentage increase was higher from 5 to 20 hours than from 0 to 5 hours regrinding. This was true only for diastatic activity. In the other tests most of the change took place during the first 5 hours regrinding. Similar results were found by Jones (31) who concluded: "If ground particles constitute a feed passing through smooth rolls a second time, any that escape disintegration will be very much flattened and will carry very severe internal damage. In this way the effect is cumulative. The maltose figure of such particles increasing markedly after each milling."

The percentage increase was not the same in all the flour mill streams as can be seen in Fig. 11; head streams showed a higher increase than tail streams; the value for first middlings increased from 166 to 820 milligrams per 10 grams of flour in the 20 hours regrinding, while the value for 6 middlings increased from 275 to 410. This was probably because the head streams contained more of the starchy endosperm than the tail streams. The action of alpha and B-amylases was more intense for the same reason; more particle size reduction was obtained and consequently more surface was exposed to the action of the enzymes. Another fact that would account for the greater starch damage of the streams coming from the central part of the kernel (head streams) is that this part contains a greater amount of large granules than the outer part. Bradbury et al., (6) pointed out that "the cells in the endosperm are of three types: 1) peripheral, next to the aleurone layer; 2) central, in the centers of the cheeks; and 3) prismatic, located between the other two. Prismatic and central cells contain large lenticular starch granules and small spherical or many sided granules; peripheral cell contain granules of an intermediate size." Under equal conditons of grinding large granules are more suceptible to damage than smaller granules for obvious reasons. Results of this study are in agreement with data reported in literature (2) (5) (9) (33) (42) (43) (48) (54) (55) (61).

The diastatic activity value (8) is the result of the combined action of both alpha- and beta-amylases and susceptible starch. "Gross diastatic activity figure" is the term

FIG.10. EFFECT OF GRINDING UPON DIASTATIC ACTIVITY OF THE FLOUR MILL STREAMS.

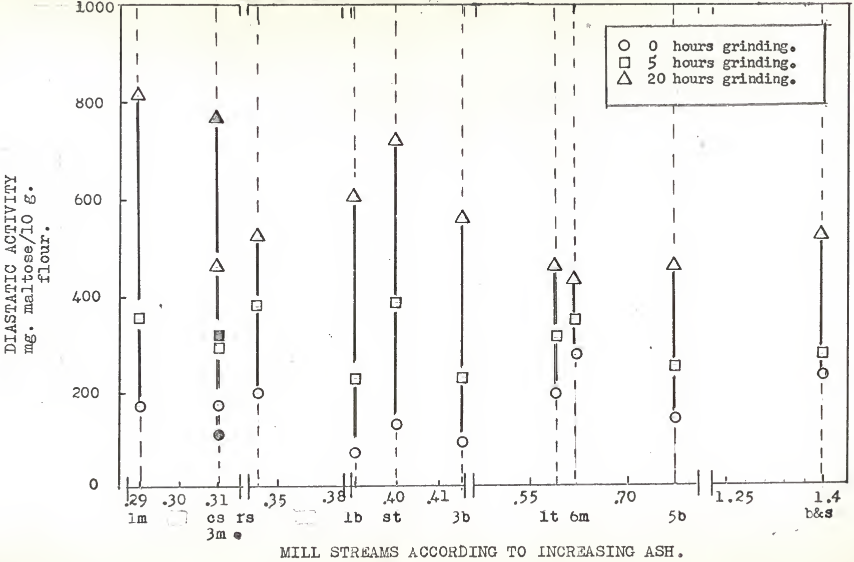


FIG.11. EFFECT OF GRINDING UPON DIASTATIC ACTIVITY OF THE FLOUR MILL STREAMS.

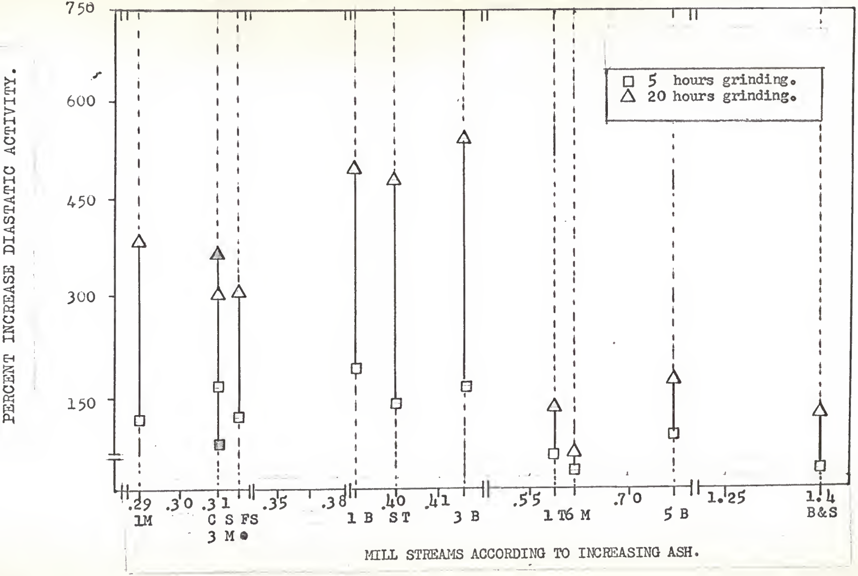
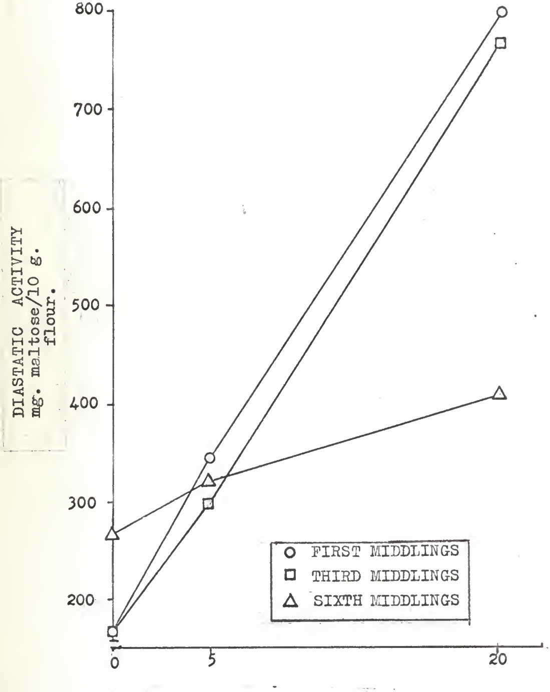


FIG.12.

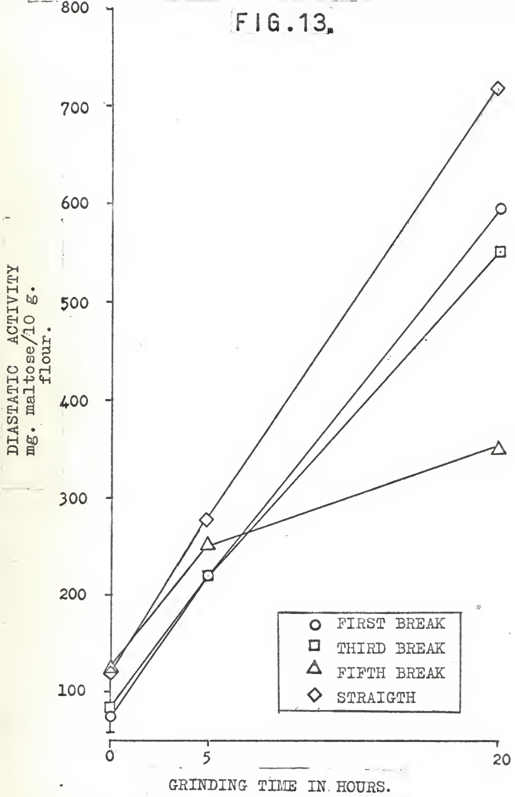
EFFECT OF GRINDING UPON DIASTATIC ACTIVITY OF THE FLOUR MILL STREAMS.



GRINDING TIME IN HOURS.

EFFECT OF GRINDING UPON DIASTATIC ACTIVITY OF THE FLOUR MILL STREAMS.

FIG.13.



used to include all of the maltose formed during an autolytic digestion of flour and is considered to be derived from interaction of at least the three sources mentioned above. The main source is that supplied by the action of beta-amylase on the damaged or susceptible starch and is influenced mainly by the amount of susceptible starch. The second source is that supplied by the action of alpha-amylase on susceptible starch, its magnitude depending on the amount of alpha-amylase and susceptible starch. A third and minor source of maltose derives from the action of beta-amylase on any material rendered susceptible to it by previous alpha-amylase action. If there are other amylases present they would contribute a fourth source of maltose.

A step-wise amylolytic digestion would provide a better understanding of the relationship existing between alpha- and beta-amylase and between each amylase and the substrate. Dadswell (8) digested amylase-free raw wheat starch with an excess of beta-amylase at 30°C and washed free of soluble sugars. This material was subjected to a series of amylolytic digestions by allowing successive small equal amount of either beta-or alpha-amylase to act at 30°C in buffered solutions. The amylase was then destroyed and all soluble sugars were removed after each digestion. When the alpha-amylase digestions were interspersed with beta-amylase treatments, it was found that the amount of maltose formed due to alpha-amylase action was not significantly different from that obtained when no beta-amylase was used, but the amount of maltose formed due to beta-amylase action was increased as a result of a previous digestion with alpha-amylase, although successive treatments with beta-amylase alone gave practically no maltose. On the basis of this starch degradation, the second source of maltose in the gross diastatic activity figure is dependent on the presence of beta-amylase and the third source, although due to beta-amylase, is dependent on some alpha-amylase activity having previously taken place.

From these considerations concerning the diastatic activity figure one may deduct that the increase in gross diastatic activity as a result of regrinding was due primarily to increase in starch susceptibility since the alpha and beta amylase concentration were maintained the same. Percent increase in diastatic activity is shown in Fig. 11. It can be seen from this figure that the head streams increased in diastatic activity much more than the tail streams. First middlings increased 3.5 times in diastatic activity, 6 middlings was the streams with the least increase in diastatic activity (from 264 to 418 milligrams maltose per 10 grams of flour). Third break was the stream with the greatest increase in diastatic activity (from 85 to 550 milligrams maltose per 10 grams of flour).

The increase in diastatic activity in first, third and sixth middlings is shown in Fig. 12. In the original streams, sixth middlings had the highest diastatic activity. After

20 hours regrinding, the increase in diastatic activity was the lowest in sixth middlings and highest in first middlings. Middlings had a greatest diastatic activity than break streams probably because the streams that feed the middling rolls have been ground several times before reaching the middling rolls.

Diastatic activity is plotted against grinding time in hours in Fig. 14. First, third, and fifth break are shown. First and third break original streams had the same diastatic activity but when ground the increased diastatic activity was higher in first break than in second break. The original fifth break stream had the highest diastatic activity of the 3 but had the lowest increase when reground. The break streams had, as a whole, a low diastatic activity value. The stocks that feed these rolls have not been overground.

Falling Number.--This is a recently developed test that measures the time in seconds required to stir and to allow the viscosimeter stirrer to fall a certain distance through a hot aqueous flour suspension liquefied by alpha amylase. The time in seconds is recorded by means of an automatic timer.

This test was developed by Hagberg (18) (19) and by Perten (50) as a quick index for the alpha amylase activity of the grain. The estimation and control of experimental

Table 5 Effect of grinding upon the color of the flour mill streams

Photovolt Reflectometer Readings

Stream	0 hours grinding	5 hours grinding	20 hours grinding
1M	71	85	82
3M	61	78	74
6M	46	64	72

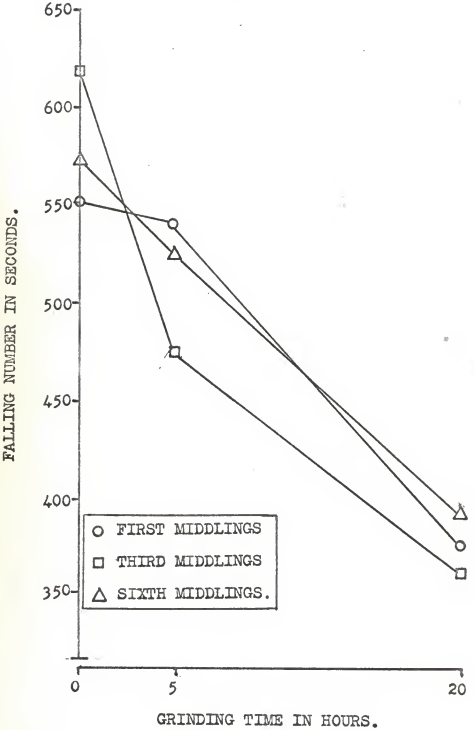
Table 6 Effect of grinding upon the falling number of the flour mill streams

Falling Number (seconds)

Stream	0 hours grinding	5 hours grinding	20 hours grinding
1M	502	490	375
3M	619	475	369
6M	572	525	390

EFFECT OF GRINDING UPON THE FALLING NUMBER OF THE MILL STREAMS.

FIG.14.



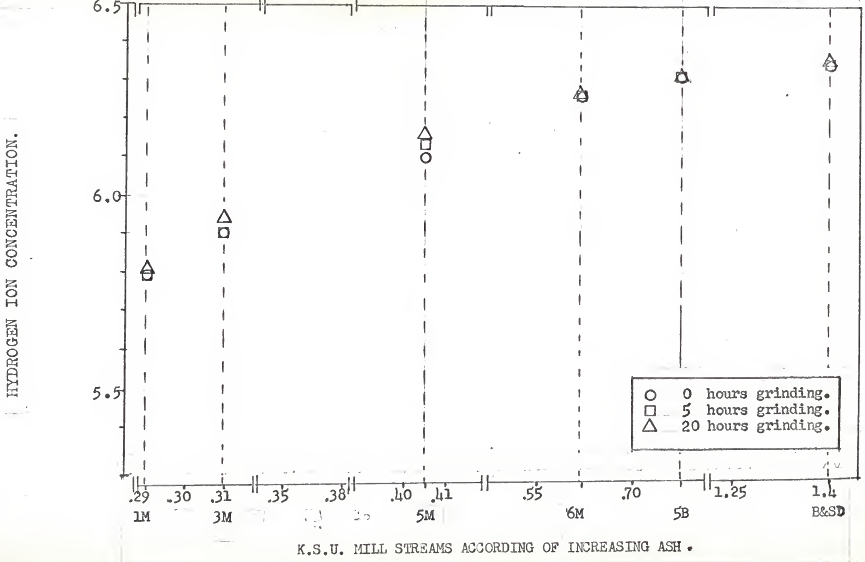
error in the falling number test has recently been studied by Greenway et al. (17). In this study he changed the different specifications to operate the apparatus. He found that the major sources of error in the test occur when the following factors are not carefully controlled: temperature of the water used in the test, position of tube during mixing, volume of water used in the test, and number of viscosimeter-timer strokes.

The results of the falling number determination on 1st, 3rd and 6th middlings are given in Table 6 and shown graphically in Fig. 14. These determinations were made for two purposes: first, to find out how grinding affected the falling number and second how the falling number results compared to the diastatic activity values. From Fig. 14 it can be seen that the falling number was affected by grinding in the three samples analyzed. The time in seconds became shorter as a result of grinding; twenty hours grinding produced a greater change than 5 hours grinding. The results obtained from the falling number are in agreement with the results obtained from the diastatic activity determination.

Hydrogen Ion Concentration.--The pH of the flour mill streams did not change appreciably with regrinding.

The low ash streams suffered more change in pH than the high ash streams, as can be seen in Fig. 15. There was a

FIG.15, EFFECT OF GRINDING UPON pH OF THE FLOUR MILL STREAMS.



tendency for the pH to increase in going from the low to the high ash streams.

Kent-Jones (34) has pointed out that for patent flours, without any maturing or bleaching agent, pH influences alpha- and beta-amylase activity as well as the rheological properties of the dough. Since there was no appreciable change in pH as a result of regrinding, the results on diastatic activity and farinogram were not affected, and the reason for the changes in diastatic activity and farinogram characteristics are to be found in some of the other flour components affected by regrinding.

Kent-Jones (34) found that the pH value is lower for patent flours than for low grade flours. Of the different products obtained from the same wheat, the best flour, which comes from the central portions of the grain, has the lowest pH, while the pH of bran is very high. This may explain the higher pH in the high ash streams. Halton and Fisher (20) suggested that this phenomenon is not due directly to the mineral content of flour, although it is correlated with ash content, but that some hydrolysable constituent is present in low grade flours which is absent from short patents.

Farinogram Characteristics.--Two important physical properties are indicated by the farinograph curve: 1) the optimum absorption or the amount of water required for a dough to reach a definite consistency, and 2) a general

Table 7

Farinogram Parameters

	Grinding Time	Absorption	Peak-time	Stability	Tolerance Index	Valorimeter	Arrival Time	Departure Time	Time to Breakdown
	Hours	%	Min.	Min.	Units		Min.	Min.	Min.
1BK	0	52.4	6.0	12.0	40.0	58.0	1.0	13.0	11.5
1BK	5	67.8	20.5	16.0	10.0	95.0	8.5	24.5	24.0
1BK	20	92.2	24.0	15.0	30.0	97.0	17.0	32.0	25.0
3BK	0	60.4	8.0	11.0	40.0	66.0	4.5	15.5	20.5
3BK	5	72.6	10.0	24.0	10.0	80.0	5.5	15.5	29.0
3BK	20	90.6	24.5	12.5	20.0	98.0	18.0	30.5	29.5
CS	0	55.7	7.5	12.0	30.0	64.0	20.0	14.0	13.0
CS	5	73.0	17.0	20.0	10.0	92.5	5.0	25.0	28.0
CS	20	93.0	27.0	15.5	40.0	98.0	14.5	30.0	27.0
FS	0	58.8	8.0	12.5	50.0	66.0	2.5	15.0	13.5
FS	5	73.0	18.0	21.0	15.0	94.0	6.3	27.0	31.0
FS	20	93.0	25.0	17.0	40.0	96.0	17.0	31.0	35.0
1M	0	58.6	8.0	17.5	25.0	67.0	1.5	19.0	20.0
1M	5	75.4	23.0	10.5	0	97.5	9.5	20.0	27.0
1M	20	97.3	37.0	12.0	20.0	over 100	29.5	41.5	42.0
3M	0	58.4	7.25	12.0	50.0	67.0	2.75	14.7	14.7
3M	5	75.0	16.0	13.0	10.0	90.5	12.0	25.0	26.0
3M	20	95.6	39.0	15.0	25.0	over 100	29.0	43.0	45.0
1T	0	60.4	5.0	10.5	50.0	53.0	11.7	11.0	10.0
1T	5	67.0	10.0	12.0	20.0	74.0	13.0	13.0	15.0
1T	20	83.4	13.0	19.0	30.0	81.0	20.0	20.5	20.5

Table 7

Farinogram Parameters

	Grinding Time	Absorption	Peak-time	Stability	Tolerance Index	Valorimeter	Arrival Time	Departure Time	Time to Breakdown
	Hours	%	Min.	Min.	Units		Min.	Min.	Min.
5BK	0	69.4	9.0	17.0	10.0	69.0	21.0	21.0	21.0
5B	5	82.6	20.0	20.0	15.0	96.0	32.0	32.0	33.0
5B	20	87.4	19.0	18.0	30.0	92.0	29.5	29.5	25.5
B&SD	0	67.6	7.5	7.0	60.0	61.0	3.5	10.5	12.0
B&SD	5	71.0	18.0	24.0	20.0	03.0	6.0	30.0	30.5
B&SD	20	81.1	11.5	18.5	40.0	79.5	7.0	25.5	24.0
6M	0	71.8	4.5	11.0	60.0	61.0	1.5	12.5	9.5
6M	5	78.0	7.5	10.5	20.0	68.0	2.5	12.5	12.5
6M	20	90.4	14.5	21.0	30.0	85.5	1.5	22.0	20.5
ST		58.9	6.5	13.0	30.0	60.0	2.0	15.0	16.0
ST		72.5	12.0	14.0	10.0	84.0	7.0	21.0	22.0
ST		95.0	25.0	16.0	30.0	98.5	19.0	35.0	35.0

profile of the mixing behavior of the dough. The reolhogical properties of the dough have been considered of importance (4) (44).

The major factors that may affect the farinogram are temperature, the technique of the operator, the baking ingredients, amylolytic enzymes, and proteolytic enzymes.

The effect of grinding on farinogram characteristics is shown in Table 7.

There was a slight tendency in the original streams for the absorption to be higher in streams with the higher ash content. Third middlings had the lowest absorption and fifth break and bran and short dusting had the highest absorption, as can be seen in Fig. 16.

Pence and Swanson (49) studied the rate of water penetration into wheat during tempering. They found that 1) "the wheat kernel is not enclosed in a non-permeable membrane, but absorbs water freely through the entire bran surface. 2) Temperature influences the rate at which water may enter the wheat. 3) The bran coat has a greater affinity for water than the endosperm of the wheat."

This last conclusion may explain the higher absorption in the high ash streams. High ash streams contained a higher percentage of bran fragments than the head streams, and consequently they absorbed more water.

When reground, the low ash streams increased in absorption in higher amount than the tail streams. Twenty hours regrinding gave a higher absorption than 5 hours regrinding.

FIG.16. EFFECT OF GRINDING UPON FARINOGRAPH ABSORPTION OF THE FLOUR MILL STREAMS.

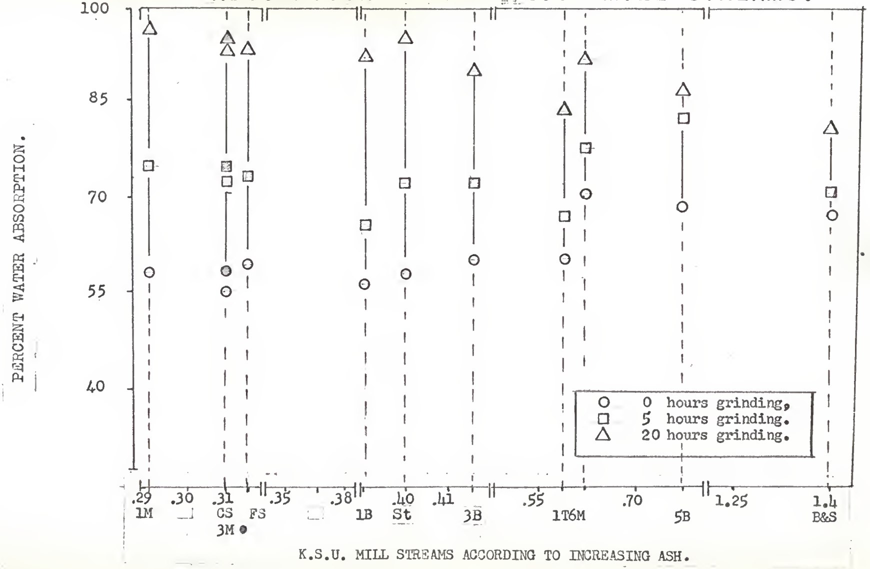


FIG.17. EFFECT OF GRINDING UPON FARINOGRAPH ABSORPTION OF THE FLOUR MILL STREAMS.

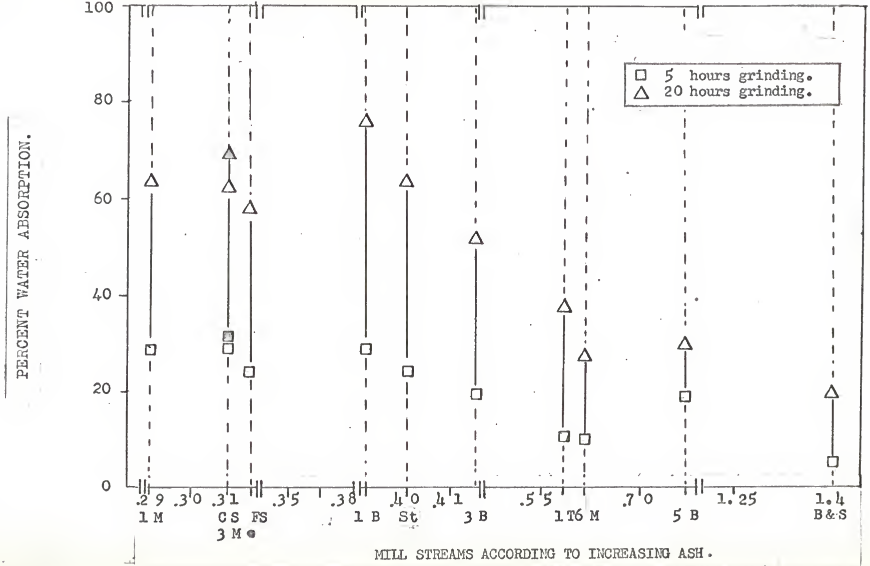


FIG.18. EFFECT OF GRINDING UPON FARINOGRAPH PEAK TIME OF THE FLOUR MILL STREAMS.

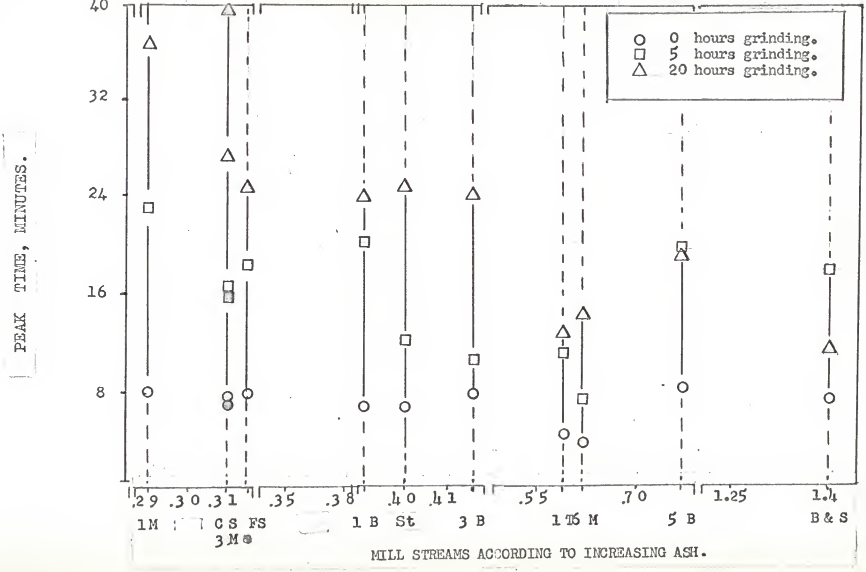


FIG.19. EFFECT OF GRINDING UPON FARINOGRAPH DEPARTURE TIME OF THE FLOUR MILL STREAMS.

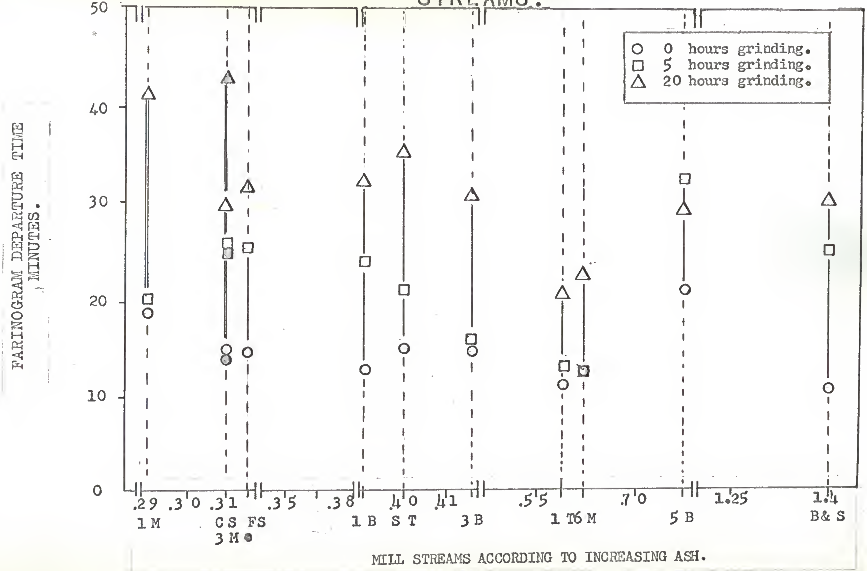
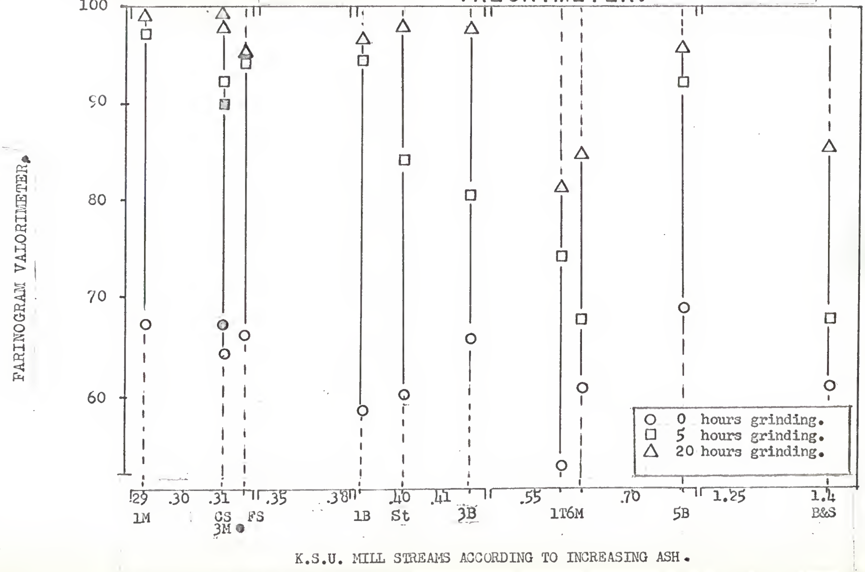


FIG.20. EFFECT OF GRINDING UPON FARINOGRAM VALORIMETER.



It can be seen in graph 16 how the low ash streams increased more in absorption than the high ash streams. Schlesinger (61) found similar results; he found that farinograph peaks and tolerances increased markedly, suggesting that starch condition may be a factor in determining rheological values. Why the farinogram curve lengthens under the influence of ball milling is not understood. The longer curve would point to a stronger flour, yet, the modifications in the farinograph curve is not confirmed by the baking test.

It has been shown (4) that the result of the addition of salt to flour during dough formation is the same as that obtained by regrinding the flour. By the addition of 2% salt the arrival time was increased from 3.5 to 4.5 minutes, the peak time was increased from 7 to 20 minutes, and the stability from 14.0 to 48.5 minutes. It is known (56) that salt has a strengthening and tightening effect on the gluten of the dough, which may be due in part to its inhibiting action on proteolytic enzymes.

Schlesinger (61) suggested that the "longer farinogram curve in reground flours may have resulted from the freeing of protein particles from the conglomerate flour particles by the mechanical action, so they may form a stronger gluten in the farinogram bowl." It may be that in spite of the stronger gluten the amount of gas produced due to starch damage is too great to be retained by the tridimensional network formed by the gluten, resulting all this in a poor loaf of bread.

The percentage increase in farinogram absorption as a result of overgrinding is shown in Fig. 19. This graph shows clearly that the head streams had a much higher increase in absorption when reground than the tail streams.

Upon regrinding peak time increased in all the flour streams, this was the farinogram parameter most affected. The change in the head streams was greater than in the tail streams. Twenty hours regrinding produced a greater change than 5 hours regrinding. Third middlings was the most affected stream (from 7.25 to 39 minutes) and bran and short dustings was the least affected (from 7.5 to 11.5 minutes), as seen in Fig. 20; the change was again greatest in the head end streams. Farinograph valorimeter values suffered the least change of all the farinograph parameters, but still head streams showed the greatest change. All other farinogram parameters were greater in the reground flours.

Baking.--The term "baking quality" is a rather broad concept that encompasses many factors. For most bakers the final production objectives are a well risen loaf of bread with a silky texture and a fine, uniform grain. Results of the baking test are shown in Table 8; bread volume, in cubic centimeters, overall quality and crust and crumb color are reported. These data are presented graphically in Figs. 21 to 25.

Table 8

Effects of Grinding upon Bread Volume, Bread Score and Crust and Crumb Color

	Volume	Quality (Bread Score)	Crust Color	Crumb Color
	c.c	%	%	%
1B	0 518	70	29.0	51.0
1B	5 516	45	27.0	49.0
1B	20 375		24.0	43.5
3BK	0 584	80	26.6	53.0
3B	5 553	31	22.5	50.0
3B	20 486		17.1	46.0
CS	0 735	80		
CS	5 492	50		
CS	20 158			
FS	0 722	85		
FS	5 520	50		
FS	20 159			
1M	0 615	75	31.0	59.0
1M	5 437	50	22.5	51.5
1M	20 375		21.0	46.0
3M	0 645	85	28.0	55.8
3M	5 507	50	27.0	42.5
3M	20 398		20.0	42.0

Table 8 (Cont.)

Effects of Grinding upon Bread Volume, Bread Score and Crust and Crumb Color

	Volume	Quality (Bread Score)	Crust Color	Crumb Color
	c.c	%	%	%
1T	0 700	70		
1T	5 583	45		
1T	20 156			
5B	0 621	45	17.5	43.0
5B	5 580	30	14.0	41.0
5B	20 567		11.0	40.0
B&SD	0 455	50		
B&SD	5 287	30		
B&SD	20 153			
6M	0 603	60	18.5	43.0
6M	5 519	45	15.0	41.0
6M	20 257			
ST	0 522	85	40.0	51.0
ST	5 470	50	22.7	50.0
ST	20 422		22.0	41.0

Bread volume decreased upon regrinding of the flour; in all the flour streams the volume of the bread baked from the original streams was better than the volume of bread from ground streams.

There was more gas production, and consequently more gas bubbles, inside the loaves in the samples made from overground flour. The dough was stickier, probably due to more dextrins present in the overground flour.

The decrease in bread volume might be due to damage of both starch and protein. Since there is less gluten protein in the high ash streams, the decrease in volume due to gluten damage was relatively small. The relationship between gluten quality and quantity and bread volume has been studied by many authors and many theories have been advanced as to the influence of the amount of the different gluten constituents present in each type of flour.

The effect of regrinding on the percentage decrease in bread volume is shown in Fig. 22. There was no particular trend toward decrease in bread volume. The break streams showed the smallest percentage of decrease. First tailings had the greatest decrease. The reason for this may be that first tailings contains a high percentage of the germ fraction. The germ contains a reducing agent, glutathione, which greatly weakens the gluten making it incapable of retaining the gas produced during fermentation, which in turn results in a poor loaf of bread (38). Regrinding probably dispersed

FIG.21. EFFECT OF GRINDING UPON BREAD VOLUME OF THE FLOUR MILL STREAMS.

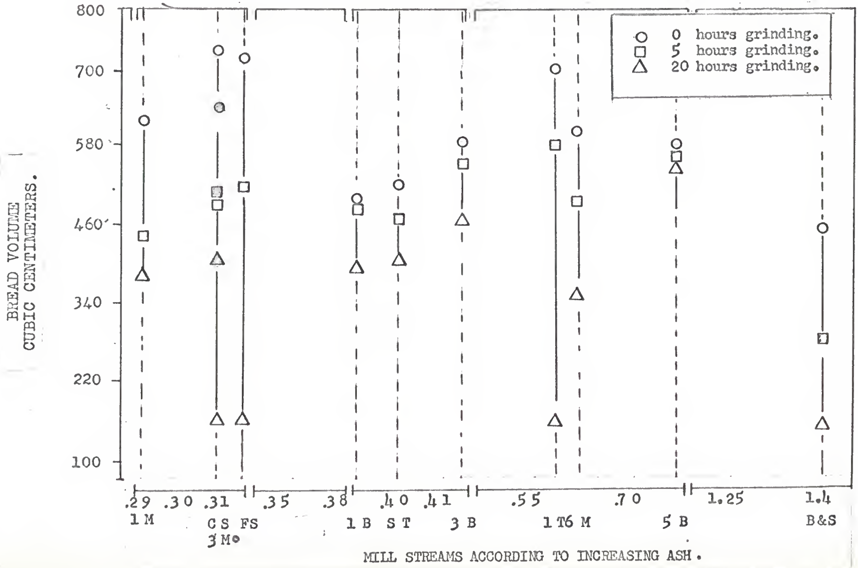


FIG.22. EFFECT OF GRINDING UPON BREAD VOLUME OF THE FLOUR MILL STREAMS.

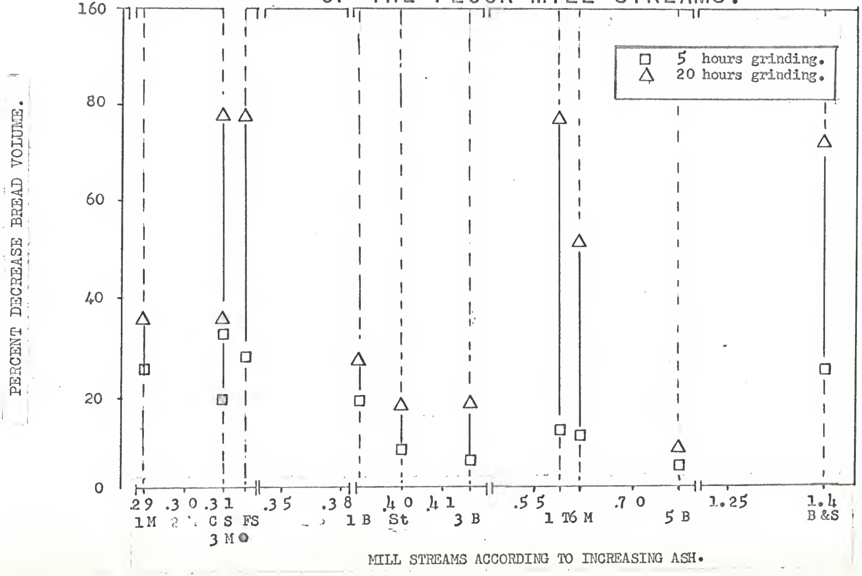


FIG.23. EFFECT OF GRINDING UPON BREAD SCORE OF THE FLOUR MILL STREAMS.

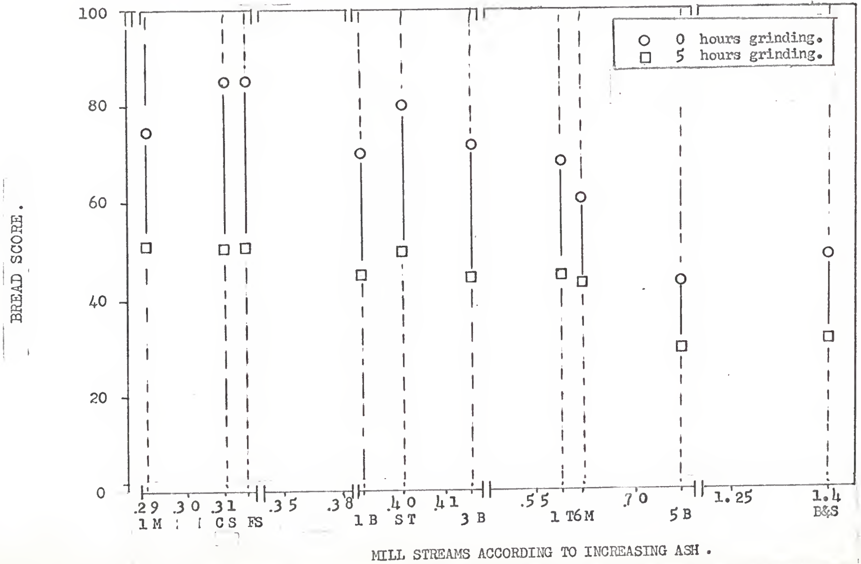


FIG.24. EFFECT OF GRINDING UPON CRUST COLOR OF BREAD.

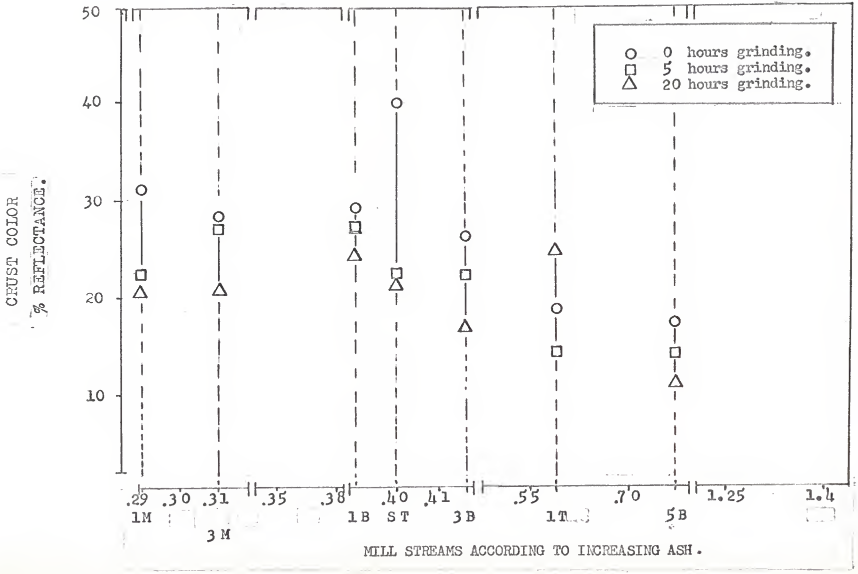
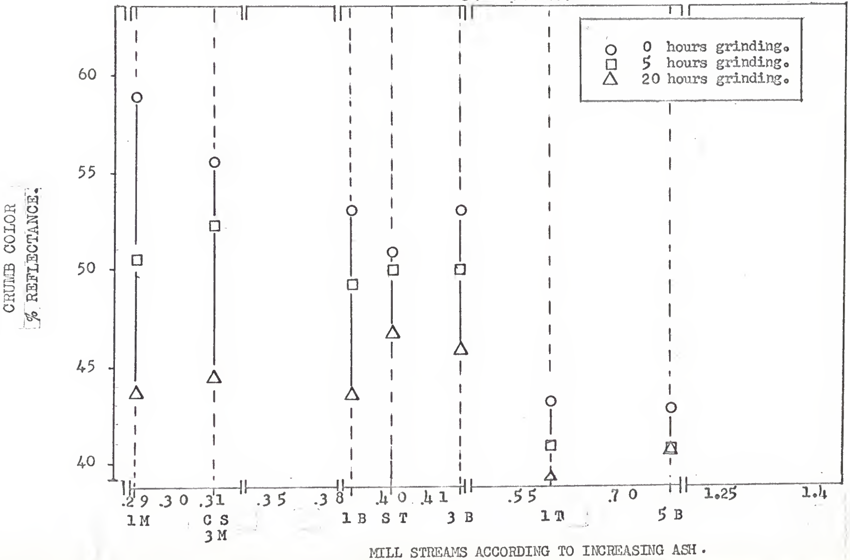


FIG.25. EFFECT OF GRINDING UPON CRUMB COLOR OF BREAD.



the germ fraction making glutathione more active in the dough.

Bread Score.--The overall quality of the bread was lower for the reground flours.

The score of bread made from the original streams was higher for the low ash streams. Third middlings gave bread with a score of 85 and bread made from bran and shorts dustings scored 50. The difference in color between original and overground flours was higher for the low ash streams. In third middlings the difference in color was about 38, while in fifth break it was only 14, or the difference between 43 and 29.

The injured starch granules present in flour have a marked water absorbing capacity (61) (66). A higher percent of damaged starch in a flour results in a greater degree of absorption. On the other hand, it has been noted in previous studies that the damaged starch is particularly susceptible to amylase action, being readily converted first into dextrins and then into maltose, substances which have a greatly reduced water-absorption capacity. The removal of this starch fraction by amylase action, especially if the flour initially had a relatively large proportion of this fraction and if rather high levels of amylase supplement are employed, will result in a marked reduction in the absorption levels of the dough. Consequently if dough handling difficulties are to be avoided, the use of amylase supplements should be accompanied by an appropriate downward adjustment of the absorption. The presence of a high level of dextrins in the overground flours could have been the cause of crumb sogginess in bread made from those sterams.

The dough from overground streams could not be punched with the punching rolls because of excessive stickiness. This stickiness was probably caused also by the dextrins present in the streams with a high level of damaged starch. Gas production is the result of the combined effects of alpha- and beta-amylases as well as starch damage. There was apparently excessive gas production and as a result the loaves had soggy crumb and reduced volume.

Bread Crust Color.--Originally head end streams gave a lighter crust color than the tail streams. Upon additional grinding the crust color of bread was always darker than that of bread from the corresponding original streams.

There was little difference in degree of change in crust color from stream to stream and from head end to tail end, as can be seen in Fig. 24.

The characteristic color of the bread crust is due to the non-enzymatic browning or Maillard reaction (41). The compounds formed during this reaction contribute to the characteristic flavor of bread (10) (28) (30). Browning usually takes place, when organic products containing free amino group and free reducing sugars interact at elevated temperatures.

Maillard (41) demonstrated that the first reaction involved a condensation of the free aldelydic group of the sugar molecule and the free amino-group of the aminoacid. Those two groups react at a one-to-one ratio as was recently established (21) (65). The reaction occurs faster at high temperatures but can still occur at a lower rate at lower temperatures. Several investigators postulated the Amadori rearrangement (15) (21) and Hodge and Rist (26) definitely proved its existence. The Amadori rearrangement involves isomerization of the N-substituted glycosylamine to form 1-amino-1-deoxy-2-ketose (25) (26) (27). This rearrangement occurs spontaneously in the dry state at room temperature. The 1-amino-1-deoxy-2-ketose upon heating undergoes dehydration and forms fission products which fluoresce and are strong reductants. Temperature, moisture, pH, and forms of the amino present influence the kind of compounds produced. Control of the browning reaction can be achieved, according to Johnson, (28) in several ways:

1) "Reactants--Since most browning involves reaction of the free aldehydic group of sugars, carbonyls or acids with compounds containing an amino group, the presence of both in a system are prerequisite to reaction. Control may be achieved by substitution of one reactive sugar for one not active.

2) "Acidity--Since raising the pH in the alkaline range tends to make the aldehyde group of sugar more available, this increases the rate of browning. Thus, control of the browning reaction can be achieved in part by lowering the pH to the acid side of neutrality.

3) "Concentration of reactants--Since the rate of reaction of the condensation of sugar with the amino group is sensitive to concentration of the reactants, browning may be controlled by regulating the amount of one or both of the reactants.

4) "Temperature of reaction--Since browning is accelerated by elevated temperatures, control of temperature is the most important factor relating to rate of browning. Thus, in baking of bread and cakes, crust color can be controlled to some degree by use of carefully regulated oven temperatures.

5) "Moisture--Relative humidity is related to the rate of browning in the dry state. When the relative humidity approaches 30 percent, browning proceeds rapidly. If evaporation is excessive from a surface, as in the baking of bread, browning may not occur until the moisture level is reduced and the surface temperature of the crust increases."

From these considerations concerning the browning reaction one may deduce that the darker color of the crust of bread made from reground flour was due to the presence of higher amounts of the two reactants: free aldehydic groups of sugar molecules and free amino groups of the amino acids.

It has been shown (9) (61) that over grinding affects both protein and starch. This would mean that more of the two reactants required for the browning reaction occur in reground than in normal flour.

Bread Crumb Color.--Originally, the low ash streams gave a bread of better crumb color than the high ash streams. Upon regrinding, the crumb color of the bread baked from the reground flour streams was darker. The crumb color of the bread made from the head streams was the most affected; it almost reached the same color as that of the bread from the tail streams. First middlings decreased from 59 to 44 upon regrinding of the streams and the fifth break decreased from 43 to 41. This was a difference of 15 in the first case and 2 in the second. Differences in crumb color of bread made from the other streams were intermediate. The excessive water absorption of the reground head streams may have been the cause for the darkening of the crumb color.

CONCLUSIONS

The following changes were observed on the flour mill streams as a result of regrinding: A slight tendency toward loss of H_2O was observed. There was also a decrease in particle size; the longer the regrinding the greater the decrease in size. The low ash streams showed more reduction than the high ash streams in average particle size. Upon 5 hours regrinding the color improved in all the flour mill streams; after 20 hours regrinding the low ash streams became darker, the high ash streams still improved in color. The diastatic activity increased, that of the low ash streams showed a greater increase than that of the high ash streams. The increase in diastatic activity from 0 to 5 hours grinding was smaller than the increase during 5 to 20 hours. The pH of the flour mill streams changed very little. There was a slight tendency for the original and over ground high-ash streams to be highest in pH. Farinograph water absorption increased with overgrinding. All other farinogram parameters: peak time, stability, tolerance index, valorimeter, arrival time, departure time, and time to breakdown had a tendency to increase. Volume of the bread made from the overground streams was less than that of the bread baked from the original streams. The break streams suffered less damage as far as decrease in bread volume was concerned. Bread score was also lower for the bread from the overground streams; low-ash streams decreased in overall quality more than the high ash streams.

The stocks from which the low ash streams were obtained seem to be more susceptible to the effect of shearing, pressing, crushing, and heat generation during grinding. It may be conjectured that those streams should be handled carefully in order to avoid excessive damage and the consequences that this would bring. On the other hand, the stocks giving high ash flour streams could be handled more severely. The yield could be improved this way, but care should be taken to avoid producing a flour of too high ash content.

In regular flour there is usually enough beta-amylase; unfortunately beta-amylase can act only upon damaged starch. Alpha-amylase is necessary to make the starch available to beta-amylase attack. Malt is added to flour in order to increase alpha-amylase activity. This study suggested that in order to increase the gross diastatic activity of flour, one high ash stream could be reground in order to provide enough damaged starch so the beta-amylase can work properly. A high ash stream would be selected because it showed the least starch and protein damage. The proteins in the tail streams are not able to form a good quality gluten, so not much damage can be done to these proteins. The flour color (as measured by the agtron colorimeter and the photovolt-reflectometer) of the high ash streams was improved when they were ground for 20 hours. The benefits that the regrinding of one of the tail streams would bring would be:

1. Increase in water absorption.
2. Decrease in the amount of malt needed.
3. Improvement in color.
4. Increase in speed of fermentation.
5. The ability to control the diastatic activity with grinding equipment can be of value to help make a uniform flour.

The cost of regrinding would have to be compared with the cost of malt to be substituted and the other benefits that this method would bring to the overall quality of the flour.

SUGGESTIONS FOR FUTURE WORK

More refined techniques are necessary to study the effect of overgrinding upon flour. A deeper knowledge of the starch and protein structure is also necessary. The investigation of the effect of regrinding flour as to obtain a minimum decrease in particle size would be of interest since many investigators have postulated the theory of an optimum granulation for each type of flour. The knowledge of the relationship of the different types of grinders and their effect upon the physical and chemical properties of the grain components would be of value in determining what type of grinder to use to accomplish the desired results. An investigation of the reason for the darkening of the head end streams when they were reground would be of interest.

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EFFECT OF OVERGRINDING UPON THE FLOUR MILL STREAMS

by

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AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

An investigation was undertaken to study the effect of regrinding upon flour coming from different sections of the kernel of wheat. The flour mill streams of the pilot mill in the Department of Grain Science and Industry at Kansas State University were selected for this purpose.

The different sections of the kernel of wheat have different properties. During milling, the endosperm is gradually separated from the bran and then reduced in particle size until flour is obtained. Many chemical and physical properties of the ground material are changed during milling. The purpose of this work was to study the degree of change effected in each flour stream during regrinding.

Regrinding was chosen to accentuate changes caused by milling and so to make them more easily measurable.

Samples of the mill streams were taken in sufficient amount to furnish material for both regrinding and testing. The regrinding was done in a ball mill. Three sets of samples were used; the original samples (no regrinding), those after 5 hours regrinding and those after 20 hours regrinding.

The original samples were analyzed for moisture, protein and ash. The three series of samples were analyzed for moisture, average particle size, color, diastatic activity, falling number test, pH, farinogram, and baking test.

A decrease in moisture was observed in most of the reground samples. There was a decrease in particle size as a result of regrinding. The degree of change being greater in the head streams than it was in the tail streams. The color of the head streams improved with 5 hours regrinding but became darker with 20 hours regrinding. The color of the tail streams improved with both 5 hours and 20 hours regrinding. An increase in diastatic activity was observed; the longer the regrinding the greater the change. Head streams change in diastatic activity was greater than tail streams. Falling number results were similar to those obtained for diastatic activity. The pH was not affected by regrinding but high ash samples gave a higher pH than low ash samples. Farinogram parameters were enlarged as a result of regrinding. Bread volume decreased as a result of regrinding the samples. The overall quality of the bread was poorer in the reground samples and the curst and crumb color were darker than in original samples. All the results seem to indicate that head streams are more susceptible to the effect of regrinding than tail streams.

It seems probable from the results obtained that the tail streams could be ground more severely than head streams, but care should be taken to avoid too high increase in the ash content of the flour. Some flour mills are using impact mills to a limited extent for reducing the endosperm. In this way a minimum starch damage is accomplished.

There is also the possibility of increasing the diastatic activity of the flour by regrinding a small portion of the tail end flour streams. Less supplementation with alpha-amylase (malt) would be required and some other properties of the flour would be improved by this method.