

THE INFLUENCE OF KERNEL SIZE
ON THE MILLABILITY OF WHEAT

by

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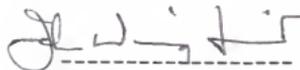
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INTRODUCTION

The term "wheat quality" indicates different meanings to people involving in wheat production and consumption chain. Farmers, as wheat producers; grain dealers, millers and bakers, as wheat consumers; desire some of the same wheat characteristics, but each emphasizes different ones. Needless to say, they look at quality of wheat from their own points of view.

Since the requirements for quality wheat of people in different business areas are, more or less, different, the criteria used to evaluate the quality of wheat are not the same.

The criteria used by millers to evaluate the milling quality, or millability of wheat involve the following considerations (44):

- (1) The cleanliness of wheat (freedom from foreign materials).
- (2) Class of wheat (hard or soft).
- (3) Flour yield.
- (4) Uniformity of kernel size and shape.
- (5) Kernel size (thousand kernel weight).
- (6) Response to conditioning.
- (7) Thickness of bran and aleurone layer.
- (8) Behavior during milling (break roll

release, middling reduction, sifting and over-all power requirements).

In addition, the ash content and the color of the wheat endosperm are getting more and more emphases.

To predict the milling quality of wheat, several physical tests have been used by millers. Among these tests, test weight, one thousand kernel weight, density, one thousand kernel volume, pearling value, and wheat kernel size distribution have been considered important.

The values of most physical tests indicate the general properties of the wheat mass. Research results have shown a general relationship between the results of these tests and the potential flour yielding capacity even though the relationship is rough and not always reliable.

It has been proved by research work that size distribution of wheat kernels plays an important role in influencing the results of the physical tests mentioned above. However, little study on the potential effects of wheat kernel size on milling process has been carried out.

Milling consists of processes treating many individual kernels, therefore, it is not sufficient to consider wheat only in mass form. Knowledge of how individual kernels affect the milling process may help millers to make necessary adjustment of their milling equipment when a change in the kernel size distribution of new incoming wheat occurs. This knowledge may also add a new specification for

wheat before it is purchased.

In addition, knowing millers' desire on wheat size, wheat breeders will be able to set up their more detailed breeding programs.

The objective of the present study is to investigate the behavior of different size wheat groups in the milling process; specially, the influences of kernel size on water absorption during the tempering, break release in break system, stock distribution in the milling system. Three different milling systems were designed for this purpose. The rheological properties of flours from different size wheat groups were also studied.

LITERATURE REVIEW

Physical and chemical differences are found not only among different wheat varieties, but also among different size kernels of the same wheat variety. In the latter case, the differences are due to the environmental influences, particularly, those which affect the rate of photosynthesis just preceding the ripening of the plant. Soil, moisture, humidity, sunshine, temperature, fertilization, and winds are considered the most potent (2).

Difference in physical and chemical properties of different size wheat kernels have great potential influences on the milling performance of the wheat, final flour yield, and the corresponding flour quality. In addition, most of physical tests of wheat can, to different degrees, be affected by kernel size distribution of wheat. The results of these physical tests are thought to be the indications of milling quality of wheat and some of them are widely used as wheat quality criteria in marketing.

The most widely used and simplest criterion to evaluate wheat is the weight of the wheat per unit volume. In the United States and Canada this is expressed in terms of pounds per bushel and normally called " Test weight per bushel ". In most countries using metric system test weight is expressed in kilograms per hectoliter.

The importance of test weight rests largely upon the

position it has been given in grain grading. One reason for the importance given to test weight in wheat grading is the very general correlation between test weight and the flour yield. Mangles and Sanderson (27) found a correlation coefficient of + 0.762 between test weight of wheat and flour yield for the years 1916 to 1924. In a study of 287 lots of wheat for years 1949 through 1954 Shuey (45) found a very similar correlation coefficient of + 0.744. However, the experience indicates that the test weight is only a rough, and many times an unreliable index of flour milling yield. The experimental data provided by Shuey (45) showed that wheats may have as much as nine lb. per bushel difference in test weight with the same milling yield (total flour extraction). There seems to be considerable evidence that above approximately 57 pounds per bushel the test weight of wheat has relatively little influence on flour milling yield. At lower weights the milling yield usually falls off rather rapidly with decreasing test weight(23).

The basic factors that affect the weight per unit volume of grain have been discussed by Hlyuka and Bushuk (22). They showed that, contrary to popular opinion, kernel size has little, if any, influence on test weight. Kernel shape and uniformity of kernel size and shape are important factors influencing test weight as much as they affect the manner in which the kernels orient themselves in the test kettle.

Potential flour yield is determined by: 1) the proportion

of endosperm in the mature kernel, which is a function of grain size and shape, embryo size, depth and shape of grain crease, and the thickness and density of the seed coat; and 2) the ease with which the endosperm can be separated from the non-endosperm components during milling, which is a complex function of many factors including grain hardness, density and fiber content. Moreover, the milling technique and the degree of sophistication of milling equipment are important factors in determining flour yields in practice (28).

When a milling system is employed, the relative flour yields will depend, other things being equal, upon the percentage of endosperm in the kernel. Therefore, from millers' point of view, the wheat possessing a high proportion of endosperm is desirable.

That the plumper kernels, or those which weigh more per kernel, have the larger percentages of endosperm was shown by figures obtained by Bailey (2). The data presented showed that in the last 15 days of growth the weight of the kernels increased 2 1/2 times. The percentages of endosperm steadily increased and the percentages of the seed coat plus the germ decreased. The data also indicated that in wheat which has been prematurely ripened by lack of moisture or other unfavorable growing conditions the percentage of endosperm is much less than in fully matured wheat.

Data presented by Hinton (21) showed that the ranges of

percentage of three major constituents of wheat grain in different varieties are; endosperm 81.4 - 84.5 %, germ (embryo and scutellum) 2.5 - 2.8 %, outlayers (pericarp, testa and aleurone layer) 14.1 - 15.9, respectively. The wheat used in his experiment involved different classes. Large variations could be seen between classes.

When a comparison of wheat kernel constituent is made within the same variety, the difference can also be found between large kernels and small kernels. By studying the density of wheat kernels, Bailey (2) concluded that small kernels, as a general rule, have larger proportion of bran and germ. Lockwood (26) also stated that the amounts of endosperm, germ and bran in wheat grain varied, especially the germ, not only in different wheat varieties, but also in individual grains of the same variety. The germ content of wheat varied from two percent to three percent and was usually higher in small kernels than in large kernels. Obviously, the higher the germ content, the lower the endosperm content.

The study on wheat bran thickness conducted by Crewe and Jones (9) showed that the size of non-shriveled grain was only slightly connected with thickness of outer bran layer and not at all with that of the aleurone layer, but immature, shriveled grains of wheat had thicker bran than mature grains.

Although no significant difference in bran thickness can

be seen between large kernels and small kernels, a striking difference in the ratio of total volume of kernel to the volume of bran exists between them. The calculation done by Shellenberger (44), based on the data of typical wheat kernels, showed that if the kernel was considered to be an oblate ellipsoid, it was found that there was nearly five percent increase in the ratio of the total volume of a wheat kernel to the total volume of the bran in favor of the large kernels. In their theoretical analysis of effects of grain shape and size on flour yields, Marshall et al.(28) pointed out that if the weight of the germ remained constant, the potential increase in milling yield became 2.9 - 3.0 % and 4.5 - 4.7 %, respectively, with an increases of 50 % and 100 % in grain volume. The greater proportion of endosperm in large kernels was partly because of the increased volume per unit surface area and partly because of the germ representing a smaller proportion of the total grain volume.

The representative values of the percentage of endosperm, germ (embryo and scutellum) and out layers (pericarp, testa and aleurone) presented by Kent (25) were; for smaller and larger wheat kernels 81.0, 3.5, and 15.5 %, and for larger kernels 83.5, 2.5 and 14.0 % respectively.

Milling experiments have proved that the flour yield of wheat is markedly affected by variation in size of wheat kernels. From the data presented by Pence (33) a fairly regular decrease in flour yield was observed as the kernels

decreased in size. Milling experiments conducted by Bailey (2) and Dattaraj et al (10) respectively also reached the same conclusion that a higher flour yield can be obtained from milling large wheat kernels.

Shuey (45) reported a procedure for sizing wheat according to average cross-sectional area. Using three sizes of wire-mesh sieves and determining the percentage of wheat kernels that will not pass endwise through each sieve, the predicted milling yield is determined by multiplying the percentage of the overs of each sieve (Tyler No.7, 9, and 12) by the value 78, 73, and 68%, respectively. The accumulated percentage is the predicted milling yield, or " potential flour yield ". A correlation of + 0.982 between predicted yield and the mill yield for 139 samples was reported.

Chuey and Grilles (47) studied the effects of increase of small kernel proportion on the flour yield. By changing the percentage of small kernels in wheat lots prior to milling they concluded that there was a decrease in the amount of patent and total flour as the percentage of small kernel was increased. Their data showed that removal of the small kernels usually increased the percent extraction of low ash flour, that is, it was possible to remove the small kernels and still obtain as much or more flour of comparable ash content than by grinding the whole lot of wheat.

However, by analyzing the data provided by Pence (33), it can be seen that this case is only true when the discussion

is restricted within the same variety. No definite relationship between size distribution and flour yield can be found by comparing the kernel size distribution of different wheat varieties and their corresponding flour yields. In an other word, a higher flour yield can not certainly be obtained from milling the wheat with a higher proportion of large kernels if several wheat varieties are compared or blended.

Baker et al.(4) concluded that kernel size was significant to flour yield in hard red winter and hard spring wheat, but was not significant to flour yield in soft red winter wheat. A low correlation was obtained between percent large kernels and flour yield in white wheat. This fact implies that larger proportion of endosperm dose not ensure a high flour yield. the easy with which flour is produced varies among different wheat varieties and classes.

Although bakers and other food producers do not think that the variation of ash content in flour has any influence on the quality of their products if it is only due to the different ash content of wheat endosperm, the ash content of final flour is considered as an important indicator in evaluating milling performance and one of the limiting factors on flour extraction for a given flour grade by millers. The ash in flour includes the minerals of wheat endosperm and minerals of non-endosperm materials in flour.

Total wheat ash is different among wheat varieties. The

amount of ash in the whole wheat is mainly influenced by variety and also by fertilizer treatments. Variety is not the only factor influencing ash composition. Soil and fertilizer exert a definite effect. The ash distribution in different flour fractions is also related to variety (12).

Several investigations have shown the nonuniform distribution of ash in the anatomical parts of wheat kernel. To examine the ash distribution in wheat kernel, Morris et al. (30) dissected individual wheat kernels and divided the cross-section of endosperm into four fractions. The results from his experiment considerably supported the conclusion stated by Cobb (8) that an increasing gradient in the concentration of ash from the center of the endosperm to the bran coat. Another similar experiment done by Morris et al (31) demonstrated the same gradient. By using microradiographic techniques, Katz and Querry (24) observed the distribution of calcium content in individual wheat kernels and found that the calcium content increased from inside to bran of the kernel.

The range in proportion of the total ash found in wheat component parts hand-dissected was presented by Hinton (20); aleurone layer 56.4 - 60.2 %, pericarp, testa, and hyaline layer 7.3 - 9.8 %, scutellum 5.5 - 8.3 %, embryo 2.8 - 4.0 %, endosperm 20.3 - 25.9 %. Hinton (21) in another study also found the similar ash distribution in various parts of wheat kernels.

The early milling experiment carried by Pence (33) showed that the ash content of the flour from small kernels was significantly greater than that of the large kernels. Shuey and Gilles (47) obtained the same relationship between ash content of wheat and the corresponding flour and wheat kernel size.

Since the ash content of flour is influenced by both the ash content of endosperm and the milling process that greatly affects the amount of non-endosperm materials with high ash content in flour, the level of ash in flour can not reflect the real ash content in wheat endosperm. According to available literature, no investigation has been done on the possible difference of ash content of wheat endosperm between wheat kernels with different sizes by dissection method other than milling.

The gradient of mineral distribution in the kernels may in part provide the explanation for the increase in lower ash content flour when the proportion of large kernels is increased. For small kernels, the proportional amount of inner endosperm sections with low mineral content would be less and possibly non-existing. Therefore, the ash content of the endosperm of small kernels would be higher than that of large kernels (43).

On the other hand, the endosperm of a small kernel is exhausted sooner than a large kernel during grinding. Therefore, the possibility that the bran of small kernels is

powderized is greater than in the case of large kernels. The presence of bran in flour is another part of the reason for a higher ash content of flour milled from small kernels.

It has been proved by research results and practical production experiences that protein content and quality of wheat and flour are important to the quality of food products in which they are used. Much attention on the content and quality of flour protein has been paid because the level of these two criteria directly affects the acceptability of flour by flour consumers.

The results of the experiment conducted by Pence (33) shown that within the same variety the large wheat kernels possess lower protein content than the small wheat kernels. A same tendency in protein content of flour was also found by milling sized wheat. Miller, et al (29) in studying the systemic differences in physical properties and composition of wheat groups separated by projection, also found a strong inverse relationship between kernel plumpness and protein content.

The pattern of protein distribution on the cross-sections of endosperm of wheat kernels reported by Morris et al. (30,31) was quite similar with the pattern of ash distribution. A sharp decrease in protein content from outer endosperm layers to inner layers was observed. Farrand and Hinton (13) concluded that a protein gradient found between the inner and outer endosperm could be expressed

logarithmically, and the slope of the gradient was correlated with the protein content of the wheat.

According to available literature, it seems that little research has been done on the quality difference of protein from different size kernels in terms of baking quality.

To achieve optimum milling performance and uniform final product quality, tempering wheat with great care has long been emphasized. The tempering process can be influenced by many factors. Swanson and Pence (51) presented much experimental data and from them they drew the following conclusions; 1) At 64.F or above, water penetrates the wheat kernels in two hours and is evenly divided through the endosperm, 2) The wheat kernel is not enclosed in a non-permeable membranes but absorbs water through the entire bran surface exposed to tempering action. 3) The bran coat has greater affinity for water than endosperm. 4) Temperature influences the rate at which water may enter the wheat.

Fraser and Bailey (16) thoroughly studied the factors affecting the rate of water absorption by wheat by immersing wheat sample into water and centrifuging the sample. Their conclusions were; 1) Variety is of great importance, but it is not the determining factor. 2) Absorption increases with length of time immersed and temperature of immersion water. 3) A great increase in the amount of absorption can be caused by scouring. This increase is proportional to the

scouring effect on the kernels. 4) Small sized kernels absorb moisture most rapidly. 5) Percentage of protein has very little effect on water absorption.

The mode of entry of water into the wheat grain during tempering has created considerable interest because of its importance in efficiently controlling the tempering process.

Hinton (19) found that testa was the layer offering greatest resistance to water enter. This was established by measuring the rate at which water was absorbed from a capillary tube in contact with wheat kernels from which testa, hyaline layer, and aleurone layer were successively removed.

Using iodine staining method, Seckinger (39) studied moisture distribution in wheat kernels and stated that little or no moisture penetrated the seed coat in 2 hours. Photos presented in his paper showed that with intact kernels the first sign of moisture in the endosperm was detected at the tip next to the germ and the preferential pass-way was through or around the germ rather than through the seed coat. Many other studies reviewed by Bradbury et al (7) also indicated that water entered the kernel first and most abundantly through the germ end and later through the bran and beard end of the grain.

Since the density and microscopic structure of wheat bran coat and endosperm are different, the rate at which water moves through the bran differs from the rate at which water

moves through the endosperm.

In his paper Becker (6) reported that there was a very rapid initial absorption of water when wheat grains were immersed into water. The average moisture gain due to this absorption was 0.045 g./g., dry basis, at 22. C. The nature of this phenomenon was thought to be due to the structure of the wheat kernel, for the outermost layer, the pericarp, was highly porous and should quickly become saturated by capillary imbibition. Since the initial absorption is mainly picked up by the outer layer, the amount of the initial absorption of each kernel should be proportional to the surface area of the kernel.

The water diffusion into endosperm from bran layer saturated with water actually is a slow process. The time for even water distribution in wheat endosperm is of great importance in practice. Seckinger et al. (39) reported that 24 hours were required for moisture to reach an even distribution throughout the endosperm. Factors affecting the time was studied by Stenvert et al. (48). Results showed that the time needed after damping to reach an even distribution of moisture in grain ranged from 6 to 24 or well over 24 hours, depending on variety and specific type of kernel (vitreous vis mealy, high protein vis low protein) chosen within a variety.

The structure of endosperm was thought to be very significant in affecting the rate of moisture movement (49).

The more ordered the endosperm structure became, the slower the rate of moisture movement. An ordered endosperm usually stayed with a high protein content. The permeability of the endosperm was affect not by the class of wheat (hard or soft), but only by whether the kernels were vitreous or mealy in character (49). Mealy endosperm were more permeable. The degree of permeability depended upon the degree of mealiness.

The existence of natural capillaries and of structure flaws and cracks was considered to be a important favorable factor in accelerating the process of diffusion (39). These channels could facilitate the conduction of water into the interior of the wheat kernels. From them water diffused into the substance of the kernel, and its flow in them was maintained by the draining action of this diffusion.

Of all physical tests developed and performed on wheat to predict its milling quality, none has been found as much as favor as experimental milling. For many years many strides have been made to develop techniques of evaluating the milling characteristics of wheat on laboratory scale by experimental milling processes.

Herman (18) reported in 1927 that the experimental milling test gave information on wheat which could not be obtained in any other way. The test was valuable for separating a definite amount of flour from a mill mixture which closely resembled the flour milled commercially in analytical data

and baking quality. Results from his Allis-Chalmers mill did not entirely duplicate the results of commercial milling, but they were strictly comparable. Herman (18) was able to foretell from experimental results the utility of the wheat in terms of flour yield, flour color, analytical data, and baking quality.

Pascoe (32) shown there was a significant correlation coefficient ($r = + 0.797 + 0.041$) between experimentally and commercially milled flour, with respect to its protein content. Bailey and Markely (3) found a correlation coefficient between the flour yields of commercial and laboratory milling tests of $+ 0.59 + 0.07$ with the laboratory relative humidity being controlled. The relative humidity of the commercial mill was not controlled.

Anderson (1), in making a comparison of experimental and commercial milling results, stated that commercial units used a greater number of grinding operations for reducing the endosperm to flour, with the experimental laboratory mills, i.e., Buhler, Allis-Chalmers, etc., with a small number of grinding operations, the grain was subjected to more severe grinding than was practiced in the commercial mills.

Several different mills and milling techniques have been developed to assist in determining milling quality. These units range from 5 gram mills to those modified laboratory scale commercial mills for up to hundreds of pounds of wheat

samples.

To meet the need for wheat breeders to evaluate the milling qualities of early-generation of new wheat varieties, Seeborg and Barmore (40) developed a milling-quality test procedure employing 5 grams of wheat. The test involved hydrating the samples to about 17.5% moisture, grinding them through two sets of break rolls, scalping the meal over a No.38 wire to separate bran from endosperm, and weighing the bran. The test has shown evidence of usefulness in breeding programs in which an improvement in milling quality was one of the objectives.

Finney and Yamazaki (14) described a micro-milling procedure involving two or three breaks in the rolls of a Tag-Heppenstall moisture, one break and two reductions in a Hobert grinder, a Ro-Tap sifter, and 100 g. wheat. Straight grade flour obtained by this method had ash and protein contents approaching those expected in Buhler and Alis-Chalmers milling. Finney et al. (15) also reported that the Hobert grinder in conjunction with the roll electrodes of a Tag-Teppenstall moisture meter can be used as a micro-mill to give flours having physical, chemical, and baking properties that are comparable to those of Buhler and commercially milled flours.

Ziegler (56) described the Buhler Automatic Experimental Mill. This mill was designed to be similar in principle and operation to the larger commercial mills. It employed a

continuous flow of three breaks and three reductions. The mill was much faster to use as there were no intermediate stocks to handle. Harris, et al.(17) concluded from their studies that the Buhler laboratory mill can differentiate wheat varieties ordinarily encountered in commerce and can provide reliable and valuable data. Seeborg and Barmore (41) recommended a number of mechanical changes to parts of the Buhler mill which might improve uniformity of results.

The great speed and easy of operation were achieved by the introduction of the Buhler mill. However, few measurable experimental data and less flexible adjustment limit its use in a milling technology research experiment.

Posner and Deyoe (36) discussed the suitability of the batch type Ross Walking Mill in experimental milling. They believed that this versatile mill unit gave more information on the milling quality of wheat than a fully automatic experimental mill. With the Ross Walking Flow the miller can get information on distribution of intermediate stocks, their quality and quantity.

Maintaining constant environmental conditions for milling experiment is an important factor in obtaining reproducible results. Bayfield et al. (5) found that yield and flour properties were influenced by both mill room temperature and humidity. They suggested that it would be desirable to select atmospheric conditions as nearly identical as possible with those obtained by large scale milling. Such

conditions would minimize the need for interpretation of results.

Several criteria have been created to evaluate the performance of milling and the milling properties of wheats. Wissmer (53) suggested the use of cumulative ash tables and curves of the mill streams as a means of measuring the efficiency of the mill under consideration. The curves can be used to determine the percentages of any ash flour or the ash content of a certain percentage of the flour in the mill.

Schlesinger (38) brought up two numbers calculated from the percentages of flour extraction and flour ash.

Milling Rating = Flour yield (%) - (Flour ash (%) X 100).

Milling Value = $\frac{\text{Flour yield (\%)}}{\text{Flour ash (\%) x 200}}$.

The higher the Milling Rating or the Milling Value, the better the wheat is for milling.

Dattaraj et al.(10) concluded in their study that Milling Rating and Milling Value indicated overall milling property better than flour yield alone because they were based on percentages of extracted flour and flour ash, the two main criteria of milling performance.

Great convenience and time saving have been obtained since different kinds of electrical divides were employed in grain moisture determination. Certain electrical properties of

grain depend largely on its moisture content and have been used as the basis for a considerable number of devices for determining moisture content. However, since the moisture content is indirectly measured by determining the electrical properties of grain, the accuracy of electrical instrument can be influenced by quite a few factors of grain itself in addition to the errors made by electrical devices.

Studies on factors affecting the accurate results of these electrical instrument have been reviewed by Zeheny (55). These studies indicated that the distribution of moisture within the kernels of grain or among kernels, the moisture state of outer coat (freshly dried or tempered), moisture level (too low or too high), uniformity of packing and orientation of grain kernels in sense elements, and mustiness or soreness of grain were contributing in incorrect results.

Aiming to determining the rate of water penetration into wheat by detecting the changes in apparent moisture content as measured with the conductance method and the capacitance method, Pomeranz and Bolte (35) studied the changes of moisture readings of freshly tempered wheat with the tempering time. The conclusion was reached that as water was distributed more evenly throughout the kernel, differences between the moisture contents determined by any of the electrical methods and actual moisture of conditioned wheat decreased as time after tempering increased.

MATERIALS AND METHODS

Preparation of Wheat

Two commercial hard red winter wheats were used in this study. Each commercial wheat was a blend of at least two different varieties of hard red winter wheats. Wheats used were free from rodent and diseased kernels. Description of the wheats is given in Table 1 and 2.

Wheats were separated into three groups by size. The separation was done by using the procedure shown in Figure 1. Wheat was first sifted in a vibratory sifter. The slope sieve was 46 inch long and 15 inch wide with openings of 0.025' x 0.025' inch (8 mesh). Fraction A over the sieve and fraction B through the sieve were sifted separately on Ro-Tap sifter with 7,8, and 8,9 mesh wires.

Wheat kernels over 7 mesh wire were taken as the large size group. Overs of 8 mesh wire and 9 mesh wire were considered as medium size group and small size group, respectively. The materials through 9 mesh wire consisting of broken kernels and impurities were abandoned. The size distributions of the original wheats are shown in the following. Each wheat variety uniformly distributed in each separated size group.

	7W(%) (large)	8w(%) (Medium)	9w(%) (Small)	pan(%)
Sample I	61.2	31.8	6.8	0.2
Sample II	56.2	30.1	12.5	1.2

Each kernel size group was cleaned on a Dockage Tester separately. The cleaning flow is shown in Figure 2. The feed rate and aspiration valve of the Dockage Tester were adjusted to obtain an optimum separation of impurities from wheat without breaking wheat kernels.

Cleaned Wheat samples were kept in sealed plastic bags and stored in a control environment room to avoid any loss of moisture and to maintain the three size groups at the same moisture level during the study.

Physical Testing

The test weight per Winchester bushel was determined on approved apparatus by the method prescribed by U.S.D.A. About 1 1/8 to 1 1/4 quarts was used to cause an overflow on the brim of the kettle. The filling and stoking of the kettle was accomplished without jarring the apparatus. The stroking was done cleanly with three full length zig-zag motions with the standard striker held tightly on the kettle with the flat sides of the striker in a vertical position. The test weight per bushel exposed to the nearest tenth of a pound was recorded.

One thousand kernel weight was determined with an

electronic seed counter using 40 grams of wheat and finding it from the weight of 1000 kernels.

Twenty grams of the sample, weighted to the nearest centigram, were pearled in a strong-scott barley pearler for 60 seconds to determined the pearling value. The remaining grain was sifted by hand on a 20 mesh wire Tyler standard sieve to remove all the dust and brokens. Pearling value of the sample was calculated by use of the following formula.

$$\text{P.V. \%} = \frac{\text{Remaining grain (free from dust and brokens)}}{20} \times 100.$$

Determination of Moisture Migration During Tempering

One thousand grams of wheat consisting of 20% of small size kernels, 30% of medium size kernels, and 50% of large size kernels were put into a thick plastic bag. The bag was then set into the rotatory drum shown in figure III. The calculated amount of water to bring up the moisture of the wheat sample to 15.5% was added. The damped wheat was then allowed to be mixed 15 minutes. While wheat being mixed, the plastic bag was sealed to avoid the moisture to be lost. During the time after tempering, about 30 grams of the tempered wheat sample were withdrawn from the bag at predetermined time intervals.. These samples were sifted on a Ro-Tap sifter with 7, 8, and 9 mesh wire sieves to separate different size kernels. The wheat kernels were ground in a coffee grinder (Woalindex Type 228, 1.00) for 1

minute and the moisture contents of the meals were determined in triplicate in an air oven according to AACC method 44-15A (AACC 1983).

Determination of the Effect of Wheat Kernel Size on Moisture Tester.

The effect of wheat kernel size on Motomco moisture tester (Model No. 919) was investigated. Three thousand grams of cleaned wheat from each of three size groups were blended and kept in a sealed plastic bag for 24 hours. By doing this, the possible nonuniformity in distribution of moisture content within the size group and among size groups could be minimized. After 24 hours kernel separation was accomplished on Ro-Tap sifter. Wheat samples with predetermined ratios (small:medium:large) by weight were prepared and well mixed. Triplicate moisture determinations were done on the testers and recorded. The average of the triplicate experimental results was reported.

Milling Experiment

Three different milling systems were designed to evaluate the effect of kernel size on milling performance. A diagram of these three procedures used in this experiment is shown in Figure 4.

To enable the wheat tempering to be properly performed and to simplify the comparison of the results from different systems, a reconstituted "Original wheat" was prepared. The

"Original wheat" consisted of 15% of small size kernels, 30% of medium size kernels, and 55% of large size kernels by weight. This ratio is close to the ratio in the original wheat samples.

In system A the "Original wheat" was directly tempered and milled as being done in nowday's commercial mills. Three thousand and one hundred grams of wheat (16% moisture) was milled in triplicate.

In system B 450 grams of small size kernels, 900 grams of medium size kernels, and 1650 grams of large size kernels (ratio; 15%:30%:55%) were tempered separately to 16% moisture content. Before milling tempered wheats were blended and well mixed. Three thousand and one hundred grams of the mixed wheat was milled in triplicate.

In system C 3000 grams of wheat of each size group was tempered separately to 16% moisture and 3100 grams of the tempered wheat was milled separately in triplicate.

For all samples 24 hour tempering time was used. To carry out precise water addition, wheat samples were kept in sealed plastic bag during mixing. The mixing of the tempered wheat was done with 5000 gram capacity tempering machine shown in Fig.3.

The amount of water used to bring up the moisture content of the wheat to 16 percent was calculated by the following formula.

$$W1 (100 - ml) = W2 (100-16) .$$

$$W2 = \frac{W1 \times (100 - ml)}{84} .$$

$$A = W2 - W1 = \frac{W1 \times (100-ml)}{84} - W1 .$$

ml -- Moisture content of untempered wheat.

W1 -- The weight of the untempered wheat.

W2 -- The weight of tempered wheat (16%
Moisture)

A -- Water needs to add (ml)

The Experimental Milling Flow shown in Fig.5 was used to perform the milling experiments. It is a batch type process consisting of Ross roll stands with 8 inch diameter and 6 inch long rolls. The Fig. 5 shows the milling flow used in this experiment consisting of 4 breaks, 1 sizing, 5 middlings, and 2 tailings. This versatile mill unit gives more information on the milling quality of wheat than a fully automatic experimental mill. With the batch-type Experimental Milling Flow the miller can get information on distribution of intermediate stocks, their quality and quantity.

Roll corrugations and gaps of break rolls are following;

Roll	Corrugations per inch	Gap
First break	12 Fast/10 Slow D-D	0.025"
Second break	12 Fast/ 14 Slow D-D	0.012"
Third break	16 Fast/ 16 Slow D-D	0.004"
Fourth break	20 Fast/ 22 Slow D-D	Adjustable

The gap of fourth break was adjusted to make wheat bran as clean as possible and to keep the bran intact at the same time.

The feed rate of the first break roll was carefully controlled by hand to restrict it within 23-25 gram per second. The feed rates of other rolls were controlled by the fixed feeding gates. Smooth rolls were employed in middling, sizing systems. The gaps of middling rolls were adjusted so that maximum flour could be extracted on each stage without the formation of flakes.

To enable each sample to be milled under similar conditions, the gaps of break rolls except fourth break and the feeding gates of all roles were fixed throughout the milling experiment.

The sieving was done on a Smico laboratory sifter with a speed of 160 rpm and 4 inch throw diameter. Sifting time for different stocks is indicated in Figure 5.

Samples from each flour stream were taken for moisture and ash analysis. Four hundred grams of straight flour were

prepared for farinograph test by blending flours from each flour stream with the same relative percentage as is in actual straight flour on "as is" moisture base.

Farinograph tests were performed according to AACC method 54-21 (AACC 1983). The amount of wet and dry gluten was obtained with GLUTOMATIC gluten washing machine. The quantity was determined by drying wet gluten for 4 minutes in GLUTORK 2020 drying pan .

Protein and ash content of flour or wheat were determined according to AACC method 46-13 and 08-01 (AACC 1983), respectively. Moisture content of flour was determined according to AACC method 44-15A (AACC 1983).

The calculation method for break release;

$$\begin{aligned} & W1-W2 \\ \text{First Break (\%)} &= \frac{\text{-----}}{W1} \times 100 \% . \\ & W2-W3 \\ \text{Second Break (\%)} &= \frac{\text{-----}}{W2} \times 100 \% . \\ & W3-W4 \\ \text{Third Break (\%)} &= \frac{\text{-----}}{W3} \times 100 \% . \\ & W5-W4 \\ \text{Fourth Break (\%)} &= \frac{\text{-----}}{W4} \times 100 \% . \end{aligned}$$

The calculation method for cumulative break releases;

$$\text{First Break (\%)} = \frac{W1-W2}{W1} \times 100 \%$$

$$\text{Second Break (\%)} = \frac{W1-W3}{W1} \times 100 \%$$

$$\text{Third Break (\%)} = \frac{W1-W4}{W1} \times 100\%$$

$$\text{Fourth Break (\%)} = \frac{W1-W5}{W1} \times 100\%$$

The meanings of the notations are expressed on Figure 5.

Figure:1 WHEAT SEPARATION SCHEME

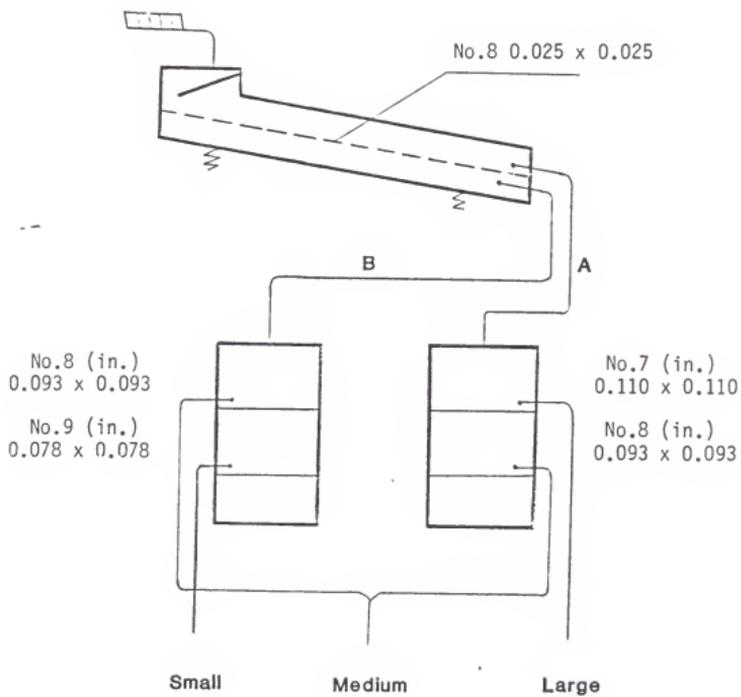


Figure:1 Wheat Separation Scheme

Figure: 2 DOCKAGE TESTER

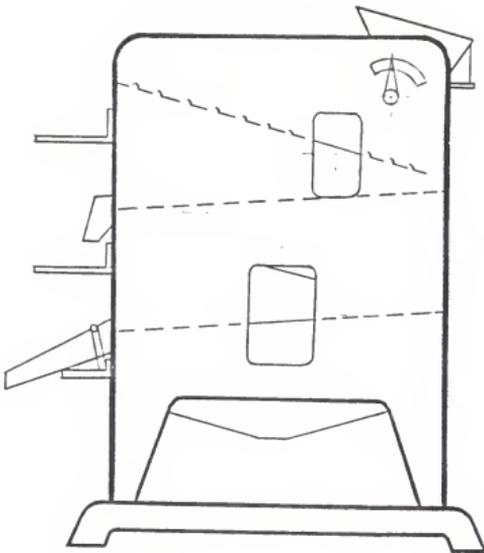


Figure: 2 Dockage Tester

Figure: 3 WHEAT TEMPERING MACHINE

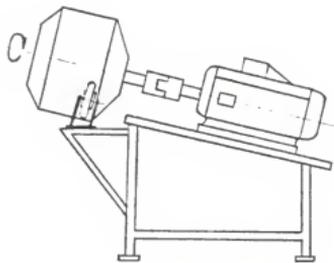
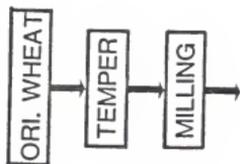


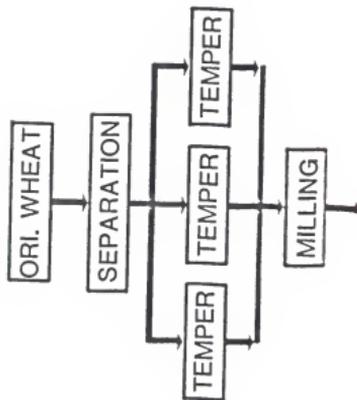
Figure:3 Wheat Tempering Machine

Figure: 4 MILLING PROCEDURES

SYSTEM A



SYSTEM B



SYSTEM C

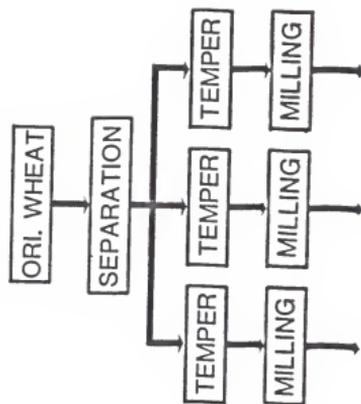


Figure: 4 Milling Procedures

Figure: 5 EXPERIMENTAL MILLING FLOW SHEET

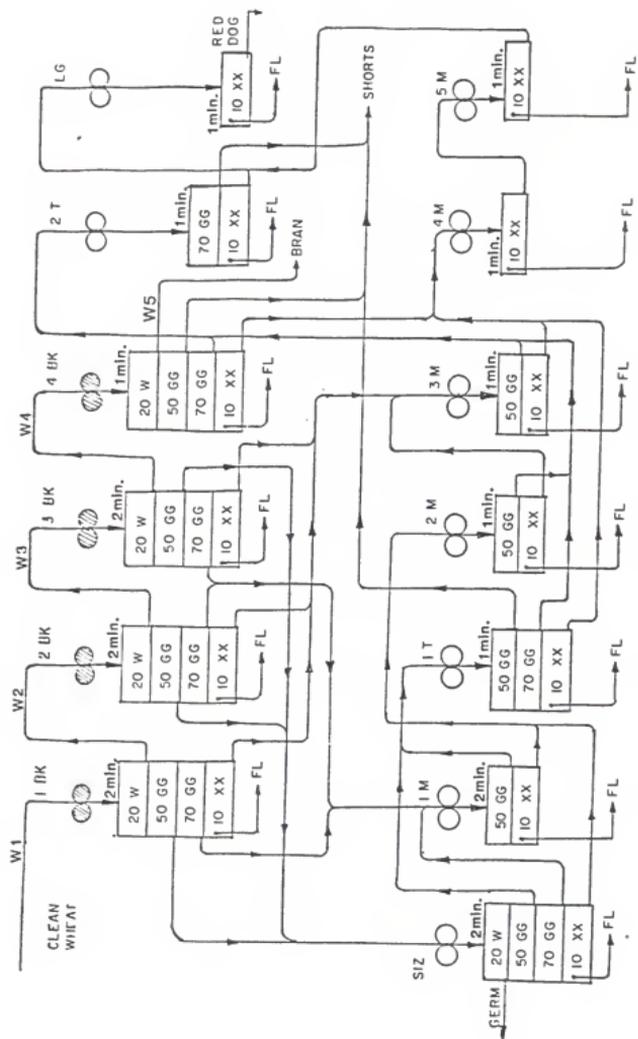


Figure 5 Experimental Milling Flow Sheet

RESULTS AND DISCUSSION

Wheat physical characteristics of each wheat size group are presented in Table 1 and 2. It can be seen that test weight and one thousand kernel weight decrease as the wheat size decreases. This result is in agreement with the finding of Dattaraj(10). In his study only shriveled wheat blends of one wheat variety were considered. In the present study, however, the physical test results show the differences of different size wheat kernels from the same batch of commercial wheat.

The pearling value has been considered to be an index of wheat hardness. The increasing tendency of pearling value with the decrease of wheat kernel size indicates that pearling values of wheats are comparable only when their kernel size distributions are similar.

In both sample I and sample II the straight grade flour yield has a positive relationship with the wheat kernel size. The ash content of the wheat and the flour, however, increases with the decrease of wheat kernel size.

In sample I the wheat protein content and the flour protein content of small and medium size wheat kernels are higher than that of large wheat kernels. Similarly, a higher protein content can be found in small and medium size wheat groups in sample II. One interesting point in sample II is that the flour milled from medium size wheat kernels gives

Table:2 WHEAT PHYSICAL TEST DATA
(Sample II)

	Large	Medium	Small
Test Weight (lb./bu)	60.0 ^a	54.7 ^b	53.4 ^c
T.K.W. (gms)	31.7 ^a	18.7 ^b	12.1 ^c
Pearling Value (%)	51.7 ^a	60.3 ^b	78.8 ^c
Wheat Ash (%) ‡	1.702 ^a	1.798 ^b	1.914 ^c
Wheat Protein (%) ‡	11.3 ^a	12.2 ^b	12.1 ^b
Str. Flour Yield (%) ‡	71.1 ^a	64.5 ^b	62.8 ^c
Str. Flour Ash (%) ‡	0.390 ^a	0.421 ^b	0.490 ^c
Str. Flour Protein (%) ‡	9.5 ^a	10.2 ^b	9.8 ^c

- * Values designated by different letters with "a" are significantly different from the corresponding values at 1% level.
- * Values designated by different letters are significantly different from the corresponding values at 5% level.
- * ‡ --- expressed on 14 % moisture base.

the highest protein content.

The change of the moisture content of each size group during the time after tempering was determined and the data were plotted in Fig.6 and 7. Such a fact can be seen that small wheat kernels absorbed much more water than large and medium kernels during tempering. As time after tempering proceeded, a migration of moisture occurred from the small kernels containing a higher moisture content to the large kernels containing relatively lower moisture content to reach the equalization of moisture. To the wheat sample I and II tested it took about 10 hours and 4 hours respectively for the migration to complete and the moisture equalization to be reached.

The whole process from picking up water by the out-layers of a wheat kernel to the final even water distribution throughout the whole kernel can be divided into two steps according to the rate of water diffusion. At the initial stage the water added is absorbed very quickly by the highly porous out-layers of wheat kernels. Because of the highly porous property of the out-layers this process can be finished quickly and out-layers are saturated with water. Secondly, the water picked up by the out-layers diffuses into the endosperm. This diffusion actually is a very slow process because of the dense endosperm and the testa layer that offers the greatest resistance to water entry (19).

Since the initial absorption is mainly picked up by the

Figure: 6 MOISTURE EQUILIBRATION OF
WHEAT SIZE GROUPS DURING TEMPERING
(SAMPLE I)

- ----- LARGE WHEAT KERNELS
- ⊙ ----- MEDIUM WHEAT KERNELS
- ----- SMALL WHEAT KERNELS

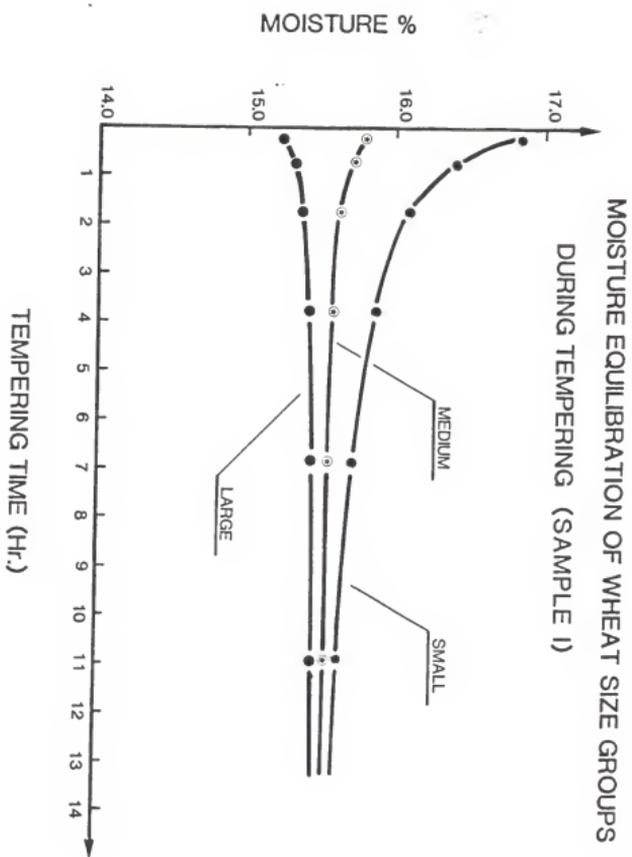
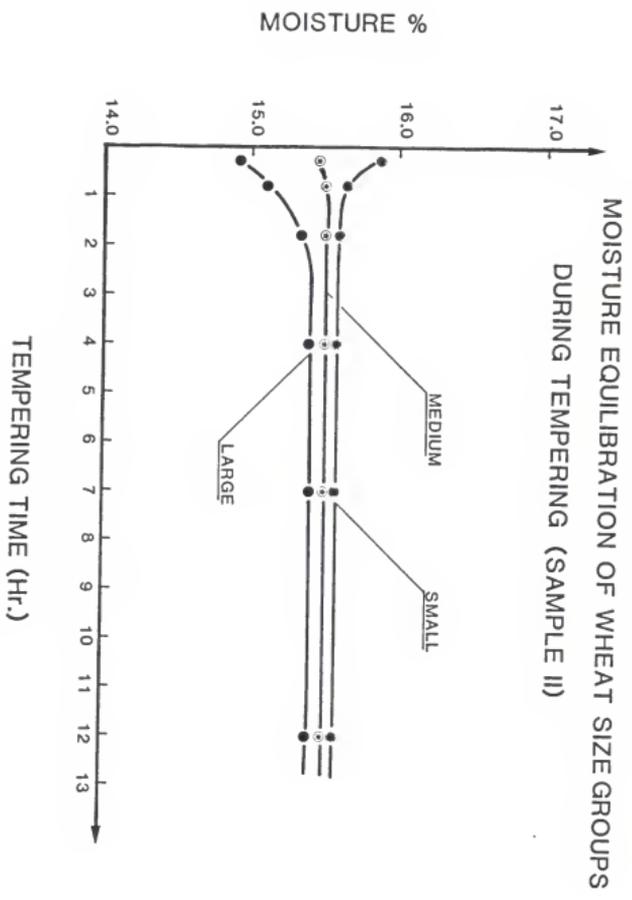


Figure: 7 MOISTURE EQUILIBRATION OF
WHEAT SIZE GROUPS DURING TEMPERING
(SAMPLE II)

- ----- LARGE WHEAT KERNELS
- ⊙ ----- MEDIUM WHEAT KERNELS
- ----- SMALL WHEAT KERNELS



out-layers, the amount of the initial absorption should be proportional to the surface area of the kernels. That small kernels have a higher surface to volume ratio than large kernels contributes to the phenomenon that the moisture content of small kernels is much higher than that of large kernels at the initial stage.

The curves shown in Fig.6 and 7 indicated that the moisture migration started immediately after the complement of tempering. Based on this fact it is reasonable to speculate that the resistance to the further water diffusion into the endosperm of large kernels is smaller than that of small kernels, that is, water diffuses into the endosperm of large kernels faster than into that of small kernels. The faster water diffusion into the endosperm in large kernels causes a rapid decrease in water content of out-layers of the wheat kernels and, on the other hand, because of the low surface to volume ratio, the water picked up by large kernels was less than that picked by small kernels. As a result, large kernels became the portions with a lower moisture content in the wheat mass. The relatively slow diffusion of water into the endosperm of small kernels kept a relative high moisture content in the out-layers of small kernels. The uneven moisture distribution in wheat mass naturally resulted in a migration of moisture from the high moisture content portions (small kernels) to the low moisture content portions (large kernels).

This moisture migration may be carried out by means of the evaporation of moisture from small kernel surfaces into intergranular spaces and the absorption by large kernel surfaces. On the other hand, the contact between wheat kernels may provide a direct way of water movement. The improvement of wheat milling quality brought about by tempering largely depends on two important factors, moisture and tempering time. The moisture equilibration shown in Fig. 7 and 8 indicates that wheat kernels with different size can differ in moisture content for quite a long time after the tempering. Therefore, any factors that can cause the separation and stratification of wheat kernels by size during the tempering process and the late conveying to tempering bins should be eliminated. A special attention should be put to the proper manner to convey the tempered wheat and to fill tempering bins. The moisture equilibration can be retarded by the formation of stratification. The parts consisting of small kernels will always contain a higher moisture content than those parts consisting of large kernels. This will result in a nonuniformity of the moisture content of the wheat reaching to mill and the consequent unstable flour production.

The data of break release in the break system are presented in Table 3. In the case of both HRW wheat I and HRW wheat II, a same tendency can be seen that the larger the wheat kernels, the higher the break releases in the

Table:3 COMPARISON OF THE BREAK RELEASE (%)

	LARGE	MEDIUM	SMALL	SYS.A	SYS.B
(SAMPLE I)					
IBK	38.63 ^a	28.51 ^b	22.25 ^c	33.55 ^d	33.41 ^d
IIBK	46.66 ^a	44.32 ^b	41.98 ^c	44.87 ^d	44.95 ^d
IIIBK	46.45 ^a	48.19 ^a	50.82 ^a	54.83 ^a	49.17 ^a
IVBK	50.26 ^a	54.92 ^a	58.83 ^a	60.73 ^a	58.88 ^a
(SAMPLE II)					
IBK	37.14 ^a	24.80 ^b	20.57 ^c	30.76 ^d	30.92 ^d
IIBK	49.25 ^a	44.38 ^b	42.11 ^c	46.02 ^d	45.95 ^d
IIIBK	60.90 ^a	61.64 ^a	62.26 ^a	62.35 ^a	60.80 ^a
IVBK	52.73 ^a	55.46 ^a	53.27 ^a	51.33 ^a	51.21 ^a

- * Values are expressed on "as is" moisture base.
- * Values designated by different letters are significantly different from the corresponding values at 1% level.

first break and second break, that is, the more endosperm chunks can be released or detached from the wheat bran.

The grinding action is the general result of shearing and compressing. When the same mill stand is employed, the grinding action is adjusted through the change of milling gap between the two rolls.

Throughout this experiment the gap of each mill stand of the break system was fixed. So, the kernel size of the wheat reaching to mill became the only factor influencing the break release. In another word, the ratio of the altitude of the minimum dimension of wheat kernels to the width of milling gap determined how severe the grinding action would be. In the first and second break this ratio of large wheat kernels was greater than that of small wheat kernels. Therefore, a more severe grinding action, especially the squeezing action, was forced on the large wheat kernels. This resulted in a more complete detachment of endosperm from out-layers of the wheat kernels. The lower surface to volume ratio that large wheat kernels have provided less available out-layer areas which the endosperm may stick on. As a result of these two factors, high break releases were obtained from large wheat kernels in the first and second break.

Compared to the case of large wheat kernels, the grinding action forced on small wheat kernels was relatively weak in the first and second break. Consequently, less endosperm was

released in the first two breaks and relatively more endosperm was relayed to the third and fourth break.

The yields of different intermediate sizing stocks (coarse, medium, and fine) in break system were calculated and presented in Table 4. It can be seen that more coarse size stocks, also called "sizings", and less fine stocks were produced from large wheat kernels than from small and medium wheat kernels. A positive relationship is present between the wheat kernel size and the sizings yield.

The sizings produced were sent to sizing system where they were purified. The purified sizings with the germ and small bran flakes removed were almost pure endosperm particles and became the main portion of low ash flour. The maximum sizing production is favorable for high yield of low ash flour (36). When small wheat kernels are milled, to increase the sizings yield it can be helpful to increase the break release of the first and second break system. This, however, may increase the amount of bran contaminated sizings and the chance of bran being powdered. It is reasonable to consider that the high sizing yield of large wheat kernels is one of the reasons for their high yield of low ash flour.

The data of cumulative break release presented in Table 5, from another aspect, show the different behaviors in the break system that different size kernels assume. From large kernels more stock is released in the early break systems. When a comparison is made between medium and small wheat

Table:4 YIELDS OF DIFFERENT
SIZING STOCKS IN BREAK SYSTEM (%)

	LARGE	MEDIUM	SMALL	SYS.A	SYS.B
(SAMPLE I)					
COARSE	50.29 ^{a'}	44.55 ^{b'}	40.99 ^{c'}	47.18 ^{d'}	48.50 ^{d'}
MEDIUM	14.81 ^a	14.96 ^a	16.03 ^a	16.62 ^a	15.65 ^a
FINE	11.11 ^a	12.04 ^b	13.31 ^c	12.15 ^b	12.43 ^b
FLOUR	5.30 ^a	5.83 ^a	6.42 ^a	5.99 ^a	5.20 ^a
(SAMPLE II)					
COARSE	53.26 ^{a'}	47.22 ^{b'}	44.07 ^{c'}	49.95 ^{d'}	50.11 ^{d'}
MEDIUM	14.53 ^{a'}	15.82 ^{b'}	16.54 ^{c'}	15.72 ^{d'}	15.77 ^{d'}
FINE	10.82 ^a	13.17 ^b	13.60 ^b	11.43 ^a	13.25 ^b
FLOUR	8.02 ^a	6.71 ^b	7.37 ^b	5.78 ^c	7.58 ^b

* COARSE --- Overs on 50 GG.

MEDIUM --- Overs on 70 GG.

FINE --- Overs on 10 XX.

* Values are expressed on "as is" moisture base.

* Values designated by different letters with " ' " are significantly different from the corresponding values at 1% level.
Values designated by different letters are significantly different from the corresponding at 5% level.

Table:5 CUMULATIVE BREAK RELEASE

	LARGE	MEDIUM	SMALL	SYS. A	SYS. B
(SAMPLE I)					
IBK	38.23 ^a	28.51 ^b	22.25 ^c	33.41 ^d	33.55 ^d
IIBK	67.23 ^a	60.19 ^b	54.89 ^c	63.34 ^d	63.36 ^d
IIIBK	82.50 ^a	79.37 ^b	77.82 ^b	81.38 ^c	83.45 ^d
IVBK	94.09 ^a	90.69 ^a	90.88 ^a	92.34 ^a	93.49 ^a
(SAMPLE II)					
IBK	37.14 ^a	24.80 ^b	20.57 ^c	30.92 ^d	30.76 ^d
IIBK	68.10 ^a	58.17 ^b	54.02 ^c	62.66 ^d	62.62 ^d
IIIBK	87.53 ^a	83.96 ^b	82.65 ^c	85.37 ^d	85.95 ^d
IVBK	94.10 ^a	92.86 ^b	91.89 ^c	92.85 ^d	93.15 ^d

- * Values designated by different letters with "a" are significantly different from the corresponding values at 1% level.
- * Values designated by different letters are significantly different from the corresponding values at 5% level.
- * Values are expressed on 14% moisture base.
- * Values are the averages of triplicate experiments.

kernels, a same tendency can be seen. The fact that the larger the wheat kernels, the more milling stock is released in the early break system can be one of the reasons for the high yield of low ash flour of large kernels. Since the working gaps of the late break rolls are much narrower than those of early break rolls, the grinding action of the late break rolls is much more severe than that of the early break rolls. Therefore, the chance for the bran to be powdered is greater in late break rolls than in early rolls. The milling stock of large wheat kernels reaching to the late break rolls is much less than that of medium and small wheat kernels. Therefore, with large kernels there is less fine bran particles resulted from the severe grinding action of the late break rolls.

The knowledge of the different tendency of break releases that wheats differing in size assume and the general relationship between wheat kernel size and the sizing production could be helpful to the controls of the milling process. By knowing these millers would be able to make necessary adjustment on their milling units to adjust the process to the new wheat with changing kernel size distribution.

The figure 8, 9, 10, and 11 show the cumulative ash curves of the HRW wheat samples milled in the different milling procedures (Fig. 4). The highest ash curve was obtained from the separated small wheat kernels. It is easily seen

Figure: 8 CUMULATIVE ASH CURVES
(SAMPLE I)

• ----- SMALL WHEAT KERNELS
•• ----- MEDIUM WHEAT KERNELS
- - - - - LARGE WHEAT KERNELS

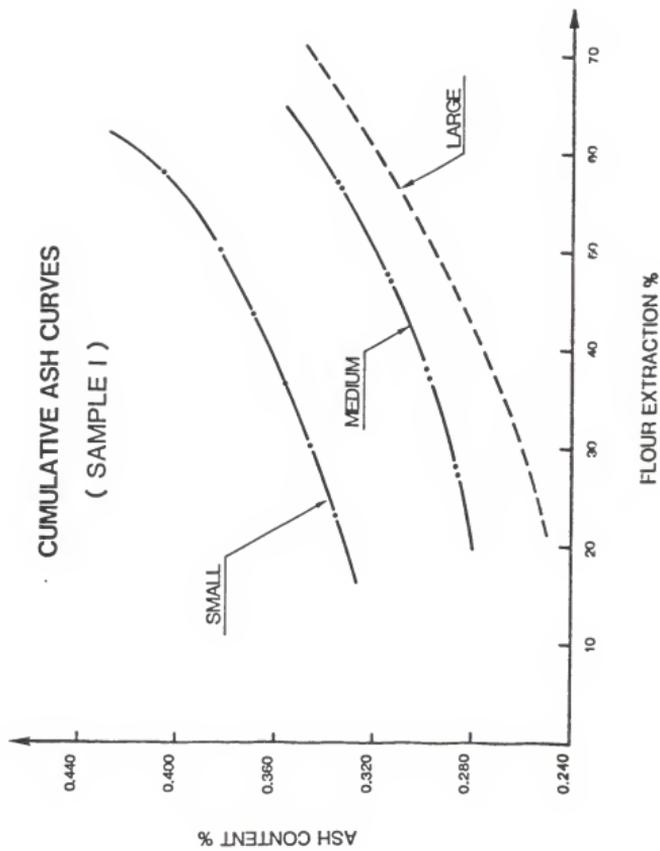


Figure: 9 CUMULATIVE ASH CURVES
(SAMPLE I)

⊕ ----- SYSTEM A
● ----- SYSTEM B
●● ----- SYSTEM C

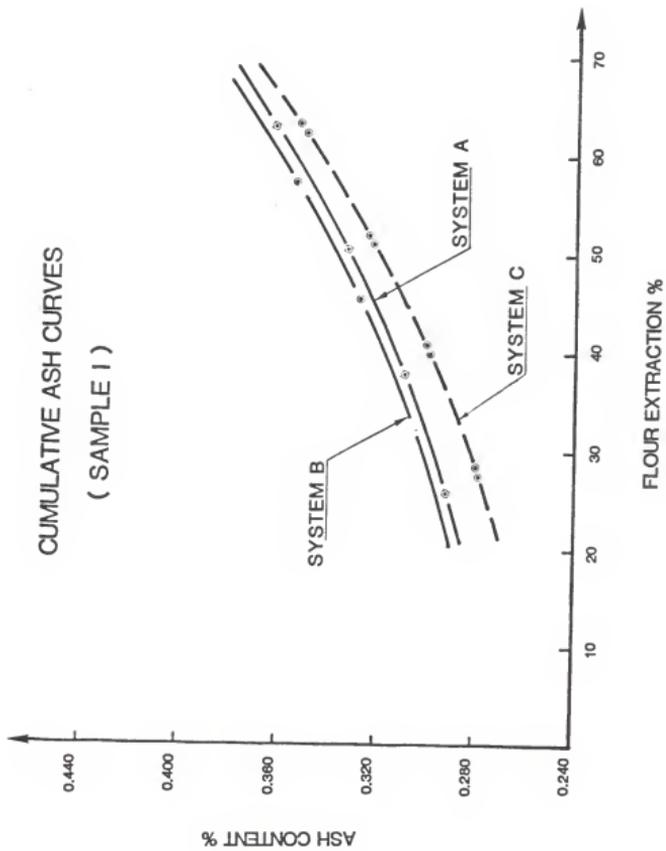


Figure: 10 CUMULATIVE ASH CURVES
(SAMPLE II)

• ----- LARGE WHEAT KERNELS
•• ----- MEDIUM WHEAT KERNELS
- - - ----- SMALL WHEAT KERNELS

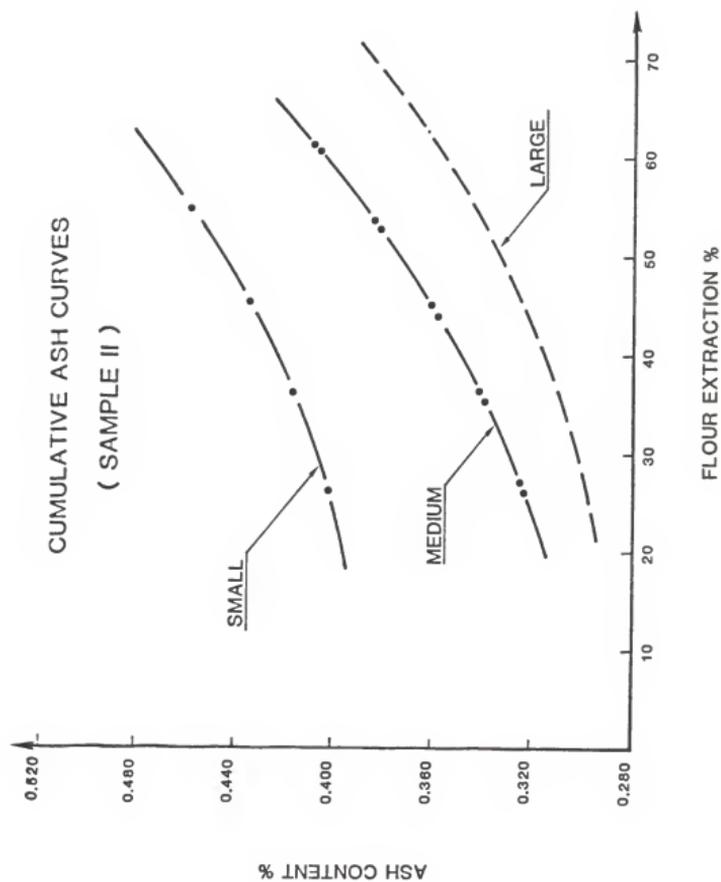
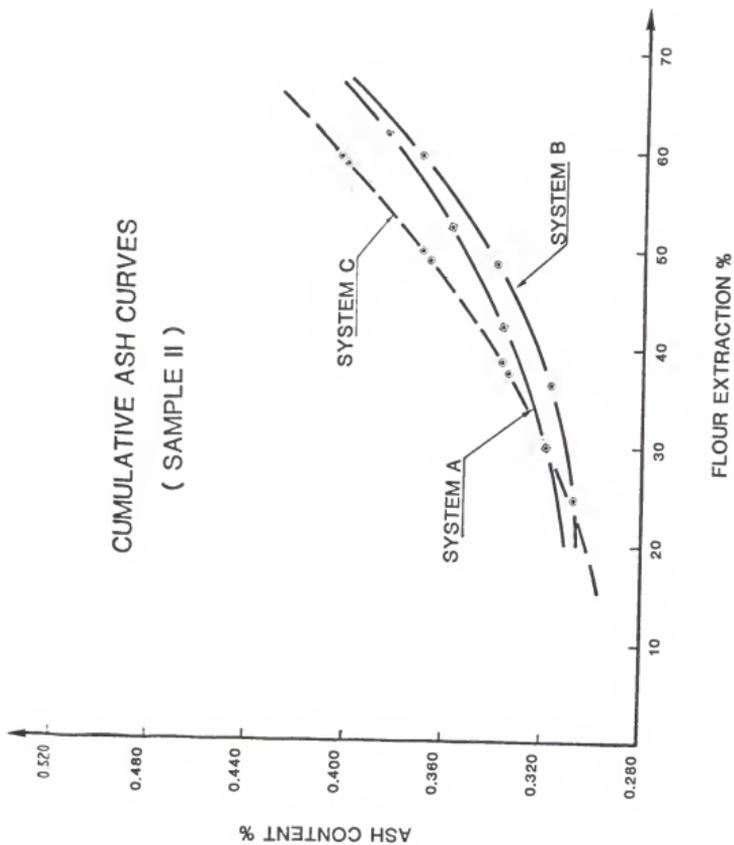


Figure: 11 CUMULATIVE ASH CURVES
(SAMPLE II)

⊕ ----- SYSTEM A
● ----- SYSTEM B
● ● ----- SYSTEM C

CUMULATIVE ASH CURVES
(SAMPLE II)



that for a given ash content the smaller the wheat kernel, the lower the flour extraction, that is, the yield of the flour with a given ash content is negatively related to the wheat kernel size. Since the cumulative ash curves of system A and system B are so close, they may not be significantly different.

If the cut-off point on the ash curves for patent flour was 0.35% ash, A comparison of patent flour yield can be made between the milling procedure A and the milling procedure C. (Fig.4). When the wheat consisting of 15% of small kernels (overs on 9W), 30% of medium kernels (overs on 8W), and 50% of large kernels (overs on 7W) , the same proportion used in the composed original wheat in this experiment, was milled by using milling procedure A, 57.5% and 48.5% of patent flour (0.35% ash) were obtained from wheat sample I and sample II, respectively. However, when the wheat with the same kernel size distribution was milled by using milling procedure C, that is, the wheat was separated by size and each size group was tempered and milled separately, the patent flour yields calculated from the cumulative ash curves were 63.6% for wheat sample I and 44.1% for wheat sample II. To wheat sample I an increase of 6.1% of patent flour could be obtained. On the contrary, to the wheat sample II 4.4% of patent flour could be lost. When the cumulative ash curves of different milling systems are compared, it can be seen that for wheat sample I (Fig. 9)

the cumulative ash curve of the milling system C is lower than the other two. Therefore, such a conclusion can be reached that the milling system C is better than the system A and system B in terms of low ash flour yield. However, when the same comparison is made on the curves of wheat sample II (Fig.11), a contrary conclusion is obtained.

When different size wheat kernels are milled separately as is done in the milling procedure C (Fig.4), it is technically possible to increase the cumulative break releases of the early break systems and the sizing production of small wheat kernels in the break system by adjusting the technical specifications of the rolls. If proper technical specifications of mill stands and optimum tempering can be chosen to accommodate the differences of each wheat size group, there should be a possibility to increase the yield of low ash flour from each size group by employing the milling procedure C. Throughout this experiment the constant technical specifications of break mills (roll gap, speed ratio of rolls, corrugation of rolls, feeding rate etc.) were used for both sample I and sample II. When the break release data (Table 3) are compared, it can be seen that the break releases of the first breaks assume higher for the wheat sample I than for the wheat sample II. Because of the low break releases of the first break for wheat sample II, the three size groups lost the chance to yield high quantity of good sizings in this break

system and left more stock to be sent to the late break systems. The improper low first break release might be partly responsible for the less low ash flour of the wheat sample II milled with the procedure C. The milling procedure C may be a prospective milling alternative way for milling. Nevertheless, research work is needed to find out the corresponding optimum technical specifications for each wheat size group and economically evaluate this practice.

The negative relationship between the wheat kernel size and the flour ash content found in this experiment confirms the early statement made by Pence(7), Chuey(47), and Gilles(8) that the ash content of flour increases as the wheat kernel size decreases. The cumulative ash curves of the three size groups shown demonstrate the detailed information on the degree of the deterioration in the flour quality with the decrease of kernel size of the wheat kernels in the same batch of commercial wheat.

The minerals, or ash, in flour result from those present in the endosperm of wheat kernels and the bran powders unavoidably mixed into flour during milling process. Therefore, the ash content in flour can be influenced by both the ash level of the endosperm and the milling process. Whether the ash level of the endosperm of small kernels is higher than that of large kernels can not be judged just according to the negative relationship between the flour ash content and the wheat kernel size.

The higher ratio of the total bran volume to the total kernel volume that smaller kernels have than large kernels might be the main reason for the high wheat ash content of small wheat kernels since the bran is the component containing the highest ash in wheat kernels.

The simple correlation coefficients between physical tests, stock distribution in break system, cumulative break releases, straight grade flour yield, milling rating, and milling value are presented in Table 6.

Since a high percentage of large wheat kernels in a wheat sample accompanies a high test weight and one thousand kernel weight, the correlation coefficients between test weight (or one thousand kernel weight) and the criteria listed approximately indicate the strength of the relationship between the wheat size distribution and these criteria.

The data of protein content, wet and dry gluten yield of the flours are presented in Table 7. The flour of medium size wheat kernels gives highest protein content in sample I and the same level of protein as small kernels in sample II. The finding confirms the conclusion made by early researchers that flour milled from small wheat kernels contains a higher level of protein than that of the flour of larger wheat kernels.

It can be seen in Table 7 that the flours from different size wheat kernels differ in their gluten yields. A

Table:6 SIMPLE CORRELATION COEFFICIENTS

	TEST WEIGHT	THOUSAND KERNEL WEIGHT
PEARLING VALUE	-0.9831	-0.8803
SIZING YIELD	0.6077	0.7009
MIDDLING YIELD	-0.5777	-0.6342
FINE STOCK YIELD	-0.9384	-0.9329
BREAK FLOUR YIELD	-0.1389	-0.1698
STRAIGHT GRADE FLOUR	0.9784	0.9660
MILLING RATING	0.8849	0.9056
MILLING VALUE	0.8557	0.8820
I BK RELEASE	0.9875	0.9876
II BK RELEASE	0.9195	0.9187
III BK RELEASE	-0.1160	-0.1862
IV BK RELEASE	-0.3747	-0.3525
CUMU. I BK RELEASE	0.9891	0.9883
CUMU. II BK RELEASE	0.9908	0.9901
CUMU. III BK RELEASE	0.5710	0.5231
CUMU. IV BK RELEASE	0.7838	0.7884

* Correlation coefficient of $R > 0.576$ is required for 0.05 level of significance. Correlation coefficient of $R > 0.708$ is required for 0.01 level.

* Cumu. ---- Cumulative.

Table:7 PROTEIN CONTENT AND GLUTEN YIELD
OF STRAIGHT GRADE FLOUR

	Large	Medium	Small	Sys.A	Sys.B
(Sample I)					
Protein (%)	9.5 ^a	10.0 ^b	10.0 ^b	9.5 ^a	9.4 ^a
Wet Glu. (%)	26.2 ^a	27.2 ^b	26.2 ^a	26.3 ^a	26.2 ^a
Dry Glu. (%)	9.2 ^a	9.5 ^b	9.2 ^a	9.3 ^a	9.2 ^a
(Sample II)					
Protein (%)	9.5 ^a	10.2 ^b	9.8 ^c	9.7 ^{ac}	9.9 ^c
Wet Glu. (%)	23.9	24.5 [*]	23.4	23.7	23.9
Dry Glu. (%)	9.7	10.1 [*]	9.8	9.6	9.7

- * The values designated by different letters are significantly different from the corresponding values at the 5% level.
- * The value designated by "*" is significantly greater than the corresponding values at 10% level.
- * All values are expressed on 14.0 % moisture base.
- * Results are averages of triplicate experiments.

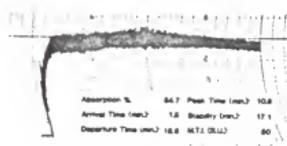
significant high gluten yield was found in the flours milled from medium wheat kernels. The higher flour protein content of medium kernels relatively to the other flours may contribute to the corresponding high gluten yield.

The farinograph mixing curves of straight grade flours milled from different size wheat kernels and different milling systems are presented in Fig. 12 and 13. The statistic treatment on the data from these curves is performed and results are summarized in Table 8 and 9. It can be seen that the flour of large wheat kernels had a higher water absorption, and a longer peak time than the flours of small and medium wheat kernels. The flour of small wheat kernels shows a greater mixing stability than the flour obtained from large and medium wheat kernels.

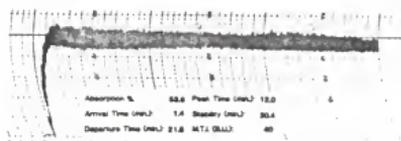
In Fig. 12 (sample I) two peaks were obtained on the farinograph curves of the flour from medium size wheat kernels and the flours from milling procedure A and C. However, this two peak phenomenon could not be seen on the curves of the flours of small and large wheat kernels. The both Fig. 12 and 13 it can be seen that the curves of the flour of the medium wheat kernels are similar to the curves of the flours of the "original" wheat milled in milling procedure A and C. Interestingly, if the curves of the flours from large are superimposed on the curves of the flours from small wheat kernels, the curves produced are quite similar to the corresponding curves of the flours from

Figure: 12 FARINOGRAPH MIXING CURVES
(SAMPLE I)

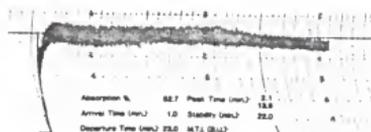
FARINOGRAPH MIXING CURVES (SAMPLE I)



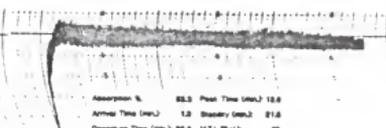
FLOUR OF LARGE KERNELS



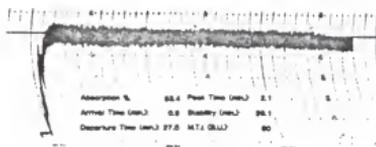
FLOUR OF SYSTEM A



FLOUR OF MEDIUM KERNELS



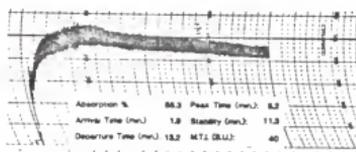
FLOUR OF SYSTEM B



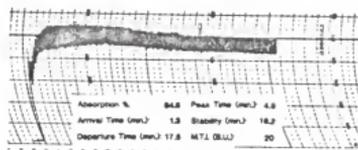
FLOUR OF SMALL KERNELS

Figure: 13 FARINOGRAPH MIXING CURVES
(SAMPLE II)

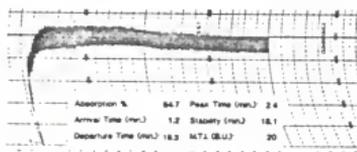
FARINOGRAPH MIXING CURVES (SAMPLE II)



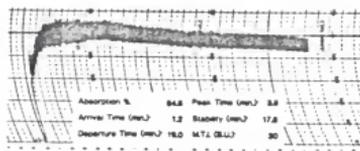
FLOUR OF LARGE KERNELS



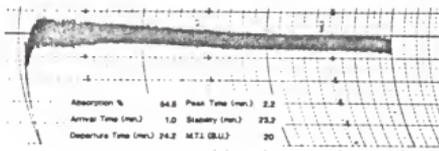
FLOUR OF SYSTEM A



FLOUR OF MEDIUM KERNELS



FLOUR OF SYSTEM B



FLOUR OF SMALL KERNELS

Table:8 THE FARINOGRAPH READINGS
(Sample I)

	Large	Medium	Small	Sys. A	Sys. B
Absorption (%)	54.7 ^a	52.76 ^b	53.4 ^c	53.6 ^c	53.3 ^{bc}
Arrival Time (min.)	1.5 ^a	1.0 ^b	0.9 ^b	1.4 ^{ac}	1.3 ^c
Departure Time (min.)	18.6 ^a	23.0 ^b	27.0 ^c	21.8 ^b	22.8 ^b
Stability (min.)	17.1 ^a	22.0 ^b	26.1 ^c	20.4 ^c	21.5 ^c
Peak Time (min.)	10.8 ^a	13.1 ^b	2.1 ^{cd}	12.0 ^d	12.6 ^d
M.T.I. (B.U.)	50	60	20	40	30

* Values designated by different letters are different from the corresponding values at 5% level.

Table:9 FARINOGRAPH READINGS
(Sample II)

	Large	Medium	Small	Sys. A	Sys. B
Absorption (%)	55.3 ^a	54.7 ^b	54.5 ^b	54.6 ^b	54.6 ^b
Arrival Time (min.)	1.9 ^a	1.2 ^b	1.0 ^b	1.3 ^c	1.2 ^c
Departure Time (min.)	13.2 ^a	19.3 ^b	26.2 ^c	17.5 ^b	19.0 ^b
Stability (min.)	11.3 ^a	18.3 ^b	23.2 ^c	16.2 ^b	17.8 ^b
Peak Time (min.)	5.2 ^a	2.4 ^b	2.2 ^b	4.9 ^c	3.8 ^d
M.T.I. (B.U.)	40	20	20	20	30

* Values designated by different letters are significantly different from the corresponding values at 5% level.

medium wheat kernels.

The rheological disagreement of the flours from different size wheat kernels indicates the potential difference in their baking qualities. Because of the poor relationship between the farinograph mixing behavior of flours and their baking quality, further baking test will be necessary to determine their breadmaking characteristics (gassing power, water absorption, mixing time, loaf volume, and crumb grain etc.).

The milling procedure B (Fig.4) was designed to investigate the effect of the uneven moisture distribution at the early stage of wheat tempering among different size wheat kernels on milling. By comparing the presented experimental data of the milling procedure B with the milling procedure A, no significant improvement can be found in flour quality, quantity, and the wheat milling behavior when the milling procedure B was employed. Therefore, it may be concluded that the uneven moisture distribution phenomenon at the early stage of wheat tempering does not affect the milling process, the final flour yield, and the flour quality if no stratification and separation occur during tempering.

The influence of wheat kernel size on the moisture readings of the MOTOCOM moisture tester was checked with the blends of wheat containing different ratios of three size groups. The experimental results are presented in Table

Table: 10 THE EFFECT OF WHEAT KERNEL SIZE
ON MOISTURE TESTER READINGS (DRY WHEAT)

CLASSIFIED WHEATS AND BLENDS TESTED			MOTOMCO MOISTURE TESTER READINGS	
LARGE %	MEDIUM %	SMALL %	SAMPLE I ^a	SAMPLE II ^b
100	0	0	12.49	11.50
0	100	0	13.11	11.89
0	0	100	13.10	11.92
80	10	10	12.36	11.50
60	20	20	12.53	11.53
40	20	40	12.80	11.45
20	20	60	12.94	11.76
10	10	80	13.10	11.70
40	40	20	12.55	11.50
20	60	20	12.76	11.45
10	80	10	12.96	11.50
-0.9054	0.3350	0.5644	DEPENDENCY	
-0.6041	0.0597	0.5405	DEPENDENCY	

- 1) $a/R^2 = 0.84$ $b/R^2 = 0.44$
- 2) Moisture readings of the moisture tester are averages of triplicate experiments.
- 3) Moisture levels (AACC Air - Oven method 44-15A)

	large	medium	small
Sample I	12.77	12.84	12.66
Sample II	12.80	12.66	12.49

10. The data in Table 10 show that the higher the percentage of large wheat kernels in the samples tested, the lower the moisture readings on the MOTOMCO moisture tester will be. This finding indicates that the MOTOMCO moisture tester is sensitive to the size distribution of the sample tested.

The mechanism used in the MOTOMCO moisture tester is based on the relationship between the capacitance of wheat and the moisture content of the wheat itself. However, beside the moisture content, the capacitance of the sample in the sensing element can be influenced by some other factors (55). The different packing densities in the sense element of the samples differing in the kernel size distribution might be the reason causing the different responses of moisture readings in this experiment. Because of the higher ratio of length to width, small wheat kernels tend to auto-orient themselves to form a dense integral when they drop into the sensing element. On the contrary, the incorporation of large wheat kernels increases the void in the integral formed in the sensing element. It may be the change of the void with the change of wheat kernel size distribution that results in the different responses of moisture readings on MOTOMCO moisture tester.

Through MOTOMCO moisture tester is calibrated to test different classes of wheat, the effect of the change of wheat size is still a factor that has not been put into consideration.

SUMMARY AND CONCLUSIONS

The wheat size distribution plays an important role in influencing the wheat physical test results. Large wheat kernels give higher values of test weight, one thousand kernel weight than small wheat kernels. It is found that the smaller the wheat kernels, the higher the pearling value. This tendency indicates that pearling values of wheats are comparable only when their kernel size distributions are similar.

As wheat kernel size increases, the ash content and protein content of the wheat decrease. When different size groups of wheats are milled under the same milling conditions, the protein content of the flour milled from smaller wheat kernels is higher than that milled from larger wheat kernels. At a given ash content the same quantity of large wheat kernels can yield more flour than small wheat kernels. The yield of straight grade flour increases as wheat kernel size increases.

Wheat kernels differing in size show a great difference in the amount of water absorbed even when they are tempered with limited water. The amount of water absorbed is negatively related to the wheat kernel size. The higher ratio of surface to volume that small kernels have than large kernels is believed to contribute to the difference in the amount of water absorbed.

A moisture equilibration process occurs during the time after tempering. A moisture migration can be observed from small wheat kernels to large wheat kernels. To the two hard red winter wheat samples tested it takes about 10 hours and 4 hours respectively for the moisture content of different size wheat kernels to be equalized. It is believed that the small wheat kernels offer a greater resistance to the water diffusion into the endosperm than large wheat kernels. The uneven moisture distribution in different size wheat kernels at early stage of wheat tempering does not significantly affect the wheat milling behavior, final flour quality, and flour yield if no stratification and separation occur during the time after tempering.

Milled with fixed milling systems, different wheat kernels behave quite differently in the break system in terms of break releases, cumulative break releases and the yield of different size intermediate milling stocks. It was observed that the larger the wheat kernels, the higher the break releases in the early break systems. Large wheat kernels tend to release more milling stocks in the early break systems than small wheat kernels. The high sizing yield is thought to be favorable to the yield of low ash flour. A positive relationship exists between the wheat kernel size and the sizing yield.

The flour milled from large wheat kernels has a higher water absorption and shows a longer peak time than the

flour milled from medium and small wheat kernels on the farinograph curves. Of the flours from different size groups of wheat, the flour of small wheat kernels has the greatest mixing stability. The flours milled from different wheat size groups differ in the yield of wet and dry gluten. The flour of medium wheat kernels significantly yields a greater amount of wet and dry gluten than that of large and small wheat kernels.

The rheological disagreement of the flours from different size wheat kernels might suggest the possible difference in the chemical composition of the flour protein and the quality for bread-making among them.

The distribution of wheat kernel size also significantly affects the moisture readings of the MOTOMCO moisture tester. The increase of large wheat kernels in the sample tested lowers the moisture readings on the MOTOMCO moisture tester.

The uniformity of wheat kernel size plays an important role in the milling stability. From the millers' stand point view, the wheats that are uniform in kernel size are desirable in terms of the employment of technical specifications of milling equipment and the consequent economic benefits. It is suggested that the wheat kernel size distribution should become one of the wheat grading criteria.

SUGGESTIONS FOR FUTURE WORK

The present study was designed to investigate the effect of kernel size on the millability of the hard red winter wheat. The possibilities for future work may include the continuation of this research with emphasis on the following:

- 1). Differences in water absorption was found in the different size wheat kernels of the hard red winter wheat during tempering. The results obtained also shown that there was a moisture equalization process happening during the time after tempering. The problem remains, whether or not there is a similar process occurring in other wheat classes.
- 2). The present study showed that flour of small wheat kernels had much higher ash content than that of large wheat kernels. This finding, however, is based on the flour produced by roll milling that can cause partial involvement of wheat bran into flour. The measurement of ash level of pure endosperm of different size wheat kernels will be helpful to figure out the reason for the high ash level in flour from small kernels. Hand-dissection method is suggested for this determination.
- 3). In the present study a break system possessing fixed technical specifications was used in milling procedure C for

different wheat size groups. Since the sizing yield is changeable by using different technical specifications in the break system, there should be a possibility to increase the low ash flour yield of medium and small wheat kernels by choosing the optimum milling specifications for each wheat size group. Since the break release of the first break system is believed to be crucial to the whole break system. Therefore, it might be suggested to study the adoption of using individual first break passages for each size group.

4). It will be valuable to establish a standard procedure and the corresponding criteria for the determination of wheat millability. The flour yield and the flour ash, the tempering response, behaviors in milling break systems, the intermediate milling stock yields, flour color, and milling energy consumption should be included in these criteria.

5). More detailed flour composition analysis of the flours from different size wheat kernels could be helpful to clarify the different behaviors of farinograph curves found in the present study.

6). Experimental baking test should be conducted to investigate the different bread-making quality of the flours from different size wheat kernels.

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THE INFLUENCE OF KERNEL SIZE
ON THE MILLABILITY OF WHEAT

by

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ABSTRACT

Wheats differing in kernel size can also differ in obtainable flour yields, flour quality, and milling behaviors. This fact is of considerable commercial and technological importance.

The objective of this study is to investigate the behaviors of different wheat size groups in milling process. This includes the response to tempering, break releases cumulative break, release in the break systems, flour extraction, and the intermediate milling stock distribution in the break systems. In addition, the effect of wheat kernel size on the physical and rheological properties of the flours from different wheat size groups are studied. This study is taken as an attempt to establish a standard procedure and the corresponding criteria to evaluate wheat millability.

Three different milling systems are employed for this purpose. 1. Different wheat size groups are tempered and milled all together. 2. Different wheat groups are tempered separately and milled together. 3. Different wheat size groups are tempered separately and milled separately. Two commercial hard red winter wheats are used in this experiment.

It is found that the test weight and one thousand kernel weight have a positive relationship with wheat kernel size.

The pearling value of wheat, however, is negatively related to the wheat kernel size.

Small wheat kernels contain a higher protein and ash content than larger wheat kernels. The yield of straight grade flour of large wheat kernels is higher than that of small wheat kernels. The cumulative ash curves of the flours milled from different size wheat kernels show that at a given ash content, large wheat kernels can yield more flour than small wheat kernels.

A great difference is found in the amount of water absorbed by different size wheat kernels during tempering. A moisture migration process can be observed from small wheat kernels to large wheat kernels during the time after tempering. This uneven water distribution at the early tempering stage does not affect the milling process, flour quality, and quantity if the different size wheat kernels can be well mixed during the time after tempering.

Experimental data show that the larger the wheat kernels, the higher the break releases in the early break systems. Large wheat kernels tend to release more milling stock than small wheat kernels in the early break systems. A significantly high sizing yield can be obtained from milling large wheat kernels.

The flour milled from the large wheat kernels has a higher water absorption and shows a longer peak time than the flours milled from the the medium and small wheat kernels on

the farinograph curves. Of the flours from different size wheat groups, the flour from the small wheat kernels has the longest mixing stability.

To evaluate the millability of wheats, multiple criteria should be considered. The sizing yield and the cumulative break release in the break systems indicate the ease with which the endosperm can be detached from wheat bran.