밀의 硬度測定 方法의 새로운 開發에 關한 研究

A Development of New Technique for Measuring Wheat Hardness

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摘　要

밀의 硬度測定은 제분 또는 다른 과정에서 밀의 기계적 物理的 性質을 研明하는데 必要하며 곡류의 등급, 분류, 대조등에 널리 이용되고 있다. 파쇄, 절단, 마모, 펄링(pearling), 자국(indenting) 등의 곡물에 대한 기계적 처리의 저항력 또는 파쇄입자의 특성등으로 경도를 결정하려고 기도되여 왔으나 滿足스러운 結果를 얻지 못하였었다. 이 研究는 現在 존속하는 測定技術의 문제점을 把握하여 새로운 測定方法을 開拓하는데 있었다. 이 연구에서, 현존하는 方法中에서 가장 좋다고 認定되는 펄링기계에 偶力測定 裝置를 設置하여 펄링이 進行될 때의 그 系의 時間經過에 따른 偶力變化를 連續的으로 記錄하는 펄로그래프 (pearlograph)를 開發하였으며 이 펄로그래프의 特性을 밀의 경도와 관련시킬수 있었다. 그 結果는 다음과 같이 요약된다.

(1) 펄링과정에서 어느 瞬間의 pearlograph chart height는 pearler 속에 남아있는 物質의 量에 比例한다.
밀의 경도를 가장 알맞게 表示해 주는 것은 pearlograph 曲線以下의 面積이였다.

(2) 밀의 粒子分布가 다를때 pearlograph 曲線은 그 自體에서 補正되는 特性이 있어서 다른 測定方法에서 가장 문제되든 밀의 穀粒子의 分布의 差異에 대한 영향을 거의 무시할 程度로 적게 만들수 있었다.

(3) pearlograph 曲線以下의 面積은 밀의 含水量에 多少의 영향을 받으나 全般的으로 적은편이며 pearling 時間을 80秒間으로 잡으면 含水量의 영향을 가장 적게 하면서 밀의 경도를 잘 區分함으로 이 시간을 최적시간으로 決定하였다.

Summary

The pearlograph curve, produced from the pearlograph developed during this investigation was analyzed. The physical meaning of the quantities derived from the pearlograph curve was explained. Based on experimental evidence of the effect of material factors on the pearlograph curve, the quantity that shall be proposed for routine measurement of wheat hardness were determined. The conclusion of the study was as follows:

1. The pearlograph chart height at any instant during pearling process indicates the material remaining within the pearler. The best measure of wheat hardness can be obtained from the chart area.
2. By the compensating characteristics of the pearlograph curve for the different kernel distributions, it is possible to make the kernel size effect very small.
3. The pearlograph chart area is affected by the variation of grain moisture in such a way that, as grain moisture is increased in the range of 7 to 15%, the area for the hard wheat decreased rapidly, the area for the soft wheat is slightly incereased, and the area for the intermediate hardness wheat is relatively insensitive.
4. The optimum pearling time, for which the pearlograph chart area is integrated and used for rating wheat hardness was determined as 80 seconds duration. The basis for the decision

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was the maximum ratio of the average effect of variety to that of grain moisture.

Introduction

Grain is a complex capillary-porous body consisting of natural polymers. Grain hardness is an important physical property of wheat; it depends upon the heterogeneity of grain structure, variable chemical composition and grain moisture, and affects largely the processing properties of grain, e.g., the behavior of grain during processing and also the quality of the final procuct.

A classification of the wheat according to softness or hardness prior to purchase, milling, or the other processing would serve to identify the type of wheat for a particular purpose. For instance, hard-textured wheats are customarily. used for bread and soft wheats for pastry purposes A very hard wheat requires extra grinding power and an elaborate milling procedure. A very soft wheat also requires alteration of the mill flow to reduce the quality of break flour. Commercial mill thus grind blends of different wheats. The proper level of tempering wheat for optimum milling conditions is of great importance to the commercial and experimental millers. All of these considerations point out the need for hardness measurement.

The problem of testing wheat hardness dates back almost to beginning of milling. As a primitive test, wheat hardness was measured from the reactions of humann sense to hard or soft kernels by chewing small samples. Such physiological reactions are too crude and inconsistent, although it is still quite a convenient means for a rough estimate.

Numerous methods for the quantitative measurement of grain hardness have been suggested. The underlying principles vary in accordance with the mechanical treatment of grain such as crushing, cutting, pearling, grinding, and indenting. Actual measures of grain hardness vary to a greater extent than the measuring techniques, as a result of processing and manupulating the observed data. In spite of considerable research efforts, a satisfactory hardness measurement has not been developed.

Objective for this study was to develop a new system by modifying the pearling technique of wheat hardness measurement. The characteristics of the system response are explained on the basis of the material response to the functional elements of the system.

The effects of material factors (variety, grain moisture, and kernel size) are investigated in an attempt to develop a mean for estimating and correcting for kernel size and grain moisture effects.

Literature review on the pearling test

The pearling test for the determination of kernel hardness of wheat was developed by Taylor, Bayles and Fifield(6). The machine, classified as the Strong-Scott barley pearler, consists of a carborundum wheel coupled to an electric motor: the wheel rotates in a closed case which provides an abrasive action to the charge of wheat. The kernels whirl around between the pearling stone and the sieve mantle, the motion of kernels being due to the transversal grooves in the stone and circular motion of air currents within the case. The kernels bounce against the stone and the mantle: the abrasive action that occurs is due to the impact and the acquired relative velocity between the stone and wheat kernels. The wheat charge is treated for a definite time, and the resulting product is sifted over the 20-wire screen to remove powdered material. The percentage of material retaining on the screen is defined as the pearling index. It has been found that as the grain harder, less material is removed in pearling or the greater the pearling index.

McCluggage(4). proposed a standard technique for the determination of the pearling index based upon his experimental work. He investigated the factors affecting the pearling index. Temperature of wheat and the pearler did not affect the pearling index. The size of charge greatly affected the amount of wheat pealed off but the relative differences among varieties did not change. To test the effect of the screen that enclosed the carborundum wheel. 10-mesh and blank screens were compared. Based on the evidence that the pearled-off material was much greater for the 10 mesh screen, he concluded that the greater part of the grinding action was due to the screen rather than the stone. No. significant differences of the pearling index were observed due to the varied moisture and carborundum wheel speed within the limits tested.

Kramer and Albrecht(2). utilized the pearling test that was standardized by McCluggage. They adjusted the charge and the period of operation so that tests from a smaller sample could be comared with the standard one, in case the quantity of wheat available for such test was limited. A method of adjusting the pearling indexes was proposed and the usefulness of the procedure was discussed. In connection with this work, they investigated several basic characteristics among the pearling variables. They found a linear relationship between sample size and the pearling indx, irrespective of the pearling time or variety. In addition, there was a distinct tendency for variability or standard error to increase as the charge was reduced and for coefficients of variation to decrease with longer pearling. They also found that in mixtures of soft and hard wheats each component of the mixture retains its own pearling index, the index of mixture being the weighted average according to proportions of mixtur constituents. They reported no significant differences between pearling indexes from single and fractional pearlings. Here, fractional perarling refers to the pearling of each sample in successive time increments (20 seconds increments up to 3 minutes intheir work); single pearling is performed in a single operation for the corresponding period of time. The authors also reported that the pearling index decreased as moisture content increased, this was particularly evident for soft wheats. The results contradict the work done by McCluggage. He concluded no significant moisture effect within the comparable moisture range. In a recent work. (4) Mepplink found that in the range of 8 14% moisture content the pearling index decreased linearly by about 1.4% per 1% change of moisture content. He also indicated that there was a discontinuous region or an obvious shift on the pearling index versus moisture content regression line ; he attributed this to the tempering process.

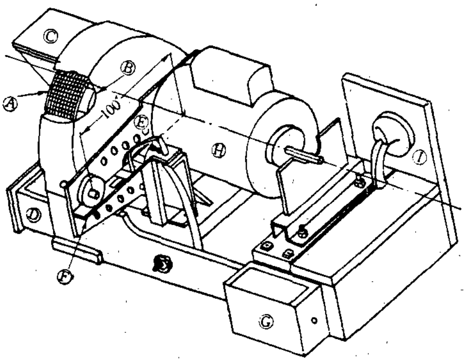
One of the most undesirable points in the pearling test was indicated by Mepplink as the influence of the size and / or shape of wheat kernels. The perling index showed the greatest kernel size effect among all the existing techniques of hardness measurements. The pearling indexed for the different sizes of a given variations between different varieties which were supposedly to have a considerable hardness defference.

It may be interesting to note that no one ever attempted to improve the Strong-Scott barley pearler to overcome the disadvantages of the device. Due to its simplicity and performance, it has become a standard for laboratory work and practical use. However, the following inadequacies are known; First, its test results varyed greatly among laboratories(3)(6). Second, the range of the pearling indexes from the hardest to softest wheats is relatively narrow with great variation due to size factor of kernels. It is also konwn that pearling index data will not separate clearly the harder classes(5). Third, the machine itself may not be designed so as to give data as consistant as is possible. Observation may reveal that some of the materials remain on the screen mantle or between wires of the screen after operation. Another possibility of error is in the slot opener design. A slight movement of the slot opener due to kernel impact may allow kernel escape out of the screen mantle enclosure.

Development of the pearlograph

The barley pearler was modified to develop a new sysem for measuring wheat hardness. The purpose of the pearler modification was to allow a torque measuring device on the barley pearler. The original pearler from the manufacturing company was utilized except for the driving unit and the base for supporting the entire unit. The drive motor was replaced by a double-ended shaft motor with the same operating speed. Ball bearings were mounted on the motor shaft and fastened to stands. A longer base, made of wood, was constructed to accommodate the extended length necessary to support the stands. For convenience of operation, tha pearler timer was mounted to the side of the extended base. The pearler and motor shafts were connected, in-line, by a jaw type flexible connector. To retain the lateral position of the rotating wheel while pearling, the jaw connector was wrapped firmly with a flexible clothe tape.

Torque transmission to the pearler was measured by utilizing the dynamometer principle. A coupling arm was extended from the frame of the drive motor. A cantilever beam was used to restrain the reaction force resulting from the torque of the cradled motor. A ball bearing was mounted to the end of the coupling arm to allow concentrated contact on the restraining beam with a small friction al effect. The schematic drawing of the modified-pearler is shown in Fig 1.



Ⓐ Pearler enclosure screen
Ⓑ Carbonundum wheel
Ⓒ Wheat input gate
Ⓓ Particle collecting box
Ⓔ Loading arm
Ⓕ Cantilever beam transducer
Ⓖ Wiring connector enclosure
Ⓗ Electric motor
Ⓘ Timer

Fig 1. Schematic drawing of the modified barley pearler

Two strain gages were mounted at the center of the restraining beam, one on the upper surface and another on the lower. To improve bridge sensitivity and bridge null-balance, two more indentical gages were later mounted adjacent to the gages of the first set. The physical and electrical arrangements of the four active gages are shown in Fig 2.

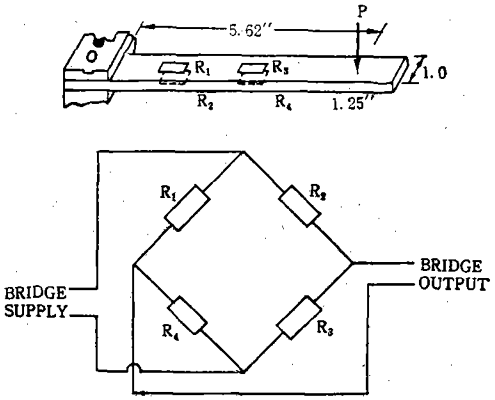


Fig 2. Strain gage location and wiring diagram used for sensing torque in the pearlograph

Strain gages used for sensing torque output from the hardness measuring machines were connected to a strain gage amplifier-indicator. The electric signal from the Daytronic system was fed into a X-Y recorder, the Beckman Model 100,500, which utilyzes a standard 10 inch cartesian coordinate recording chart. The recorder was equipped with an integrator unit. An overall view of the Daytronic amplifier-indicator and the Beckman recorder systems is shown in Fig 3. The curve produced during pearling by this modified system was termed as the pearlograph curve.

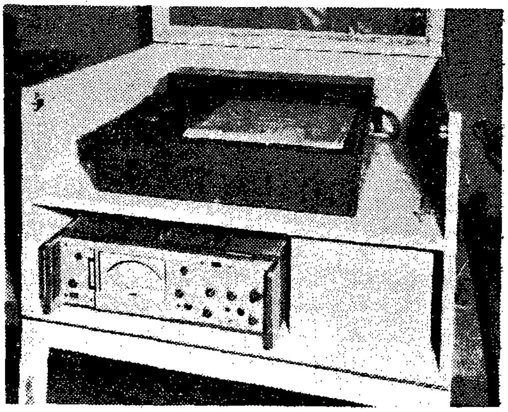


Fig 3. The Daytronic Model 300 D transducer amplifier-indicator (Lower) and Beckman Model 100,500 Recorder(upper)

Characteristics of the pearlograph curves

The pearlograph curve produced during pearling showed a wellbehaved curve. The pearlograph chart height reaches its peak at the beginning stage of pearling and gradually reduced as the pearling proceeded. Fig. 4 shows a typical example of the pearlograph designed and some of the terminology used. It also includes the integrator pen trace by which the area underneath the curve was counted.

The basic quantities of the pearloraph curve are the chart height and the pearling time. There are a number of secondary quantities which can be obtained by combining these two quantities. The values for integration beneath the curve and differentitation of the curve at a given time are examples of secondary quantities.

The following hypothesis was used as the basic approach for analyzing chart height versus time: "The pearlograph chart height except for the initial peak is proportional to the mass of wheat within the pearler"

The beginning of the curve (up to 12 seconds) was excluded because the peak formed due to a sudden input of wheat may be too sensitive to the initial condition of the pearler system or the manner of introducing the wheat.

Since the opening of enclosure screen is equivalent to that of a No. 10 Tyler sieve, the hypothesis can be tested by correlating the curve height with the amount of wheat remained on the No. 10 sieve.

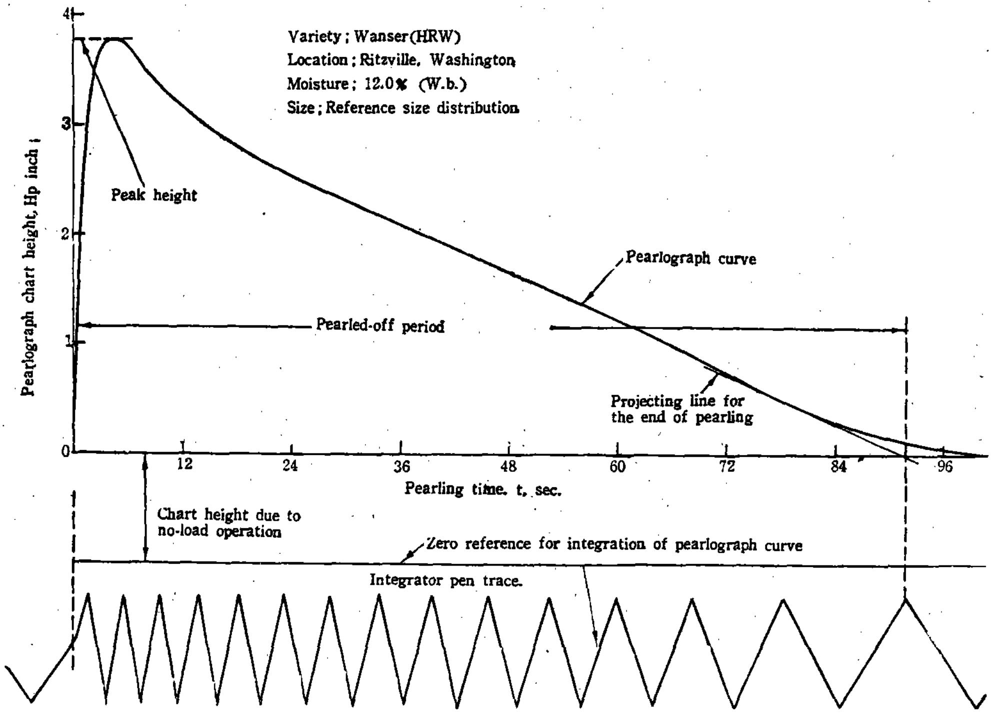


Fig 4. A typical pearlograph curve and integrator pen trace.

A series of tests was conducted in the pearlograph with wheat varieties of Moro, Reed, Wanser, and Wells Durum. For each variety, two fractional kernel sizes within the ranges of a Tayler sieve No. 6 to 7 and No. 7 to 8 were tested. For a pearling time of about 12 seconds, the outlet of the pearler was opened and the ground material was sieved to obtain the amount of material retained on the No. 10 sieve. The indicated chart height at the time when the slot was opended could be obtained from the chart. The same test was repeated increasing the pearling time to 18, 30, 40 seconds and so on until the chart height reduced to the no-load operation.

The cumlative material over the No 10 sieve is related to the pearlograph chart height as shown in Fig. 5. The data points include results for the size, variety, and different stages of pearling. The correlation coefficient of 0.97 indicates that two quantities are highly correlated and the hypothesis stated above is acceptable.

In spite of this high correlation coefficient, a wide scattering of data points was observed, especially in the higher range of the chart height. The higher chart height occurs when the kernel size is larger and the individual kernel is heavier. However, such a contribution may be too small to compare with the amount of wheat in pearling process as the main factor.

The implication of the test results is that the pearlograph chart height produced from pearling of any variety of wheat at any stage of pearling process is the direct reflection of the material remaining within the enclosure screen of the pearler and not a positive indication of wheat hardness itself.

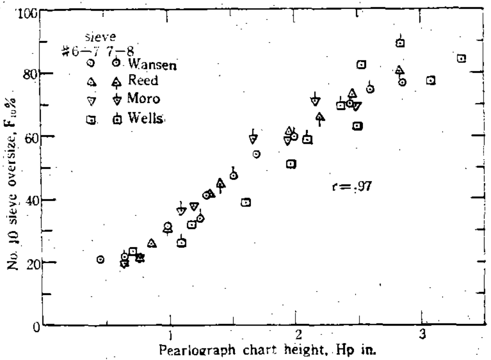


Fig 5. The relation between the No. 10 sieve oversize of the pearled wheats and the pearlograph chart height.

A considerable difference in shapes of pearlograph curves was produced from different varieties. Generally speaking, softer wheat shows an exponential decay, while harder wheat is approximately a constant rate decay. A complete description of the pearlograph curves by a mathematical model may need several pararmeters, as does the time rate of the chart height. This complexity comes from the time dependence of the rate of the chart height. An attempt to make use of the rate of change of chart height (differentiation of chart height with respect to time) for rating wheat hardness may cause a problem: At what particular pearling time should the value of differentiation be made? The integration operation accommodates the time dependence of the differentiation by summing up the whole variation of the curve during any particular time. Therefore, the integrated area under the pearlograph curve measures the strength or weakness of wheat to the pearling action not just for a particular stage, but for the entire process, in other words, the hardness for a whole kernel, hull and endosperm, which is coarse enough to remain within the system.

Based on the analysis, it seems reasonable to conclude that the chart area is the best quantity for indicating wheat hardness. However, a question may be raised as to whether the chart area for the pearled-off time or for a specific fixed time limit shall be used for rating wheat hardness in routine measurement. The solution to this problem shall be given in the following section.

The pearlograph curves as affected by kernel size and moisture content

Kernel size and moisture content are two physical characteristics which receive special attention in many existing techniques associated with measurement of wheat hardness. The principal problem has been a sensitive response of measuring scale due to the variation of these two factors.

To simplify and clarify te problem, the following assumption was made on testing the effect of kernel size on the pearlograph curve:

> "The hardness of healthy, sound grains with the same variety, locality and history of growth are the same regardless of their sizes"

The literature survey indicated that researchers have never given clear statements with respect to this assumption. However, their efforts to detect, correct, or reduce the kernel size effect on hardness measuring devices indirectly admitted the problem. The assumption is a necessary condition which must be made in order to detect and correct any undesirable response of measuring system which is in its develeping stage. Based on the assumption, the reference sizes were selected and tested on the pearlograph.

For grain moisture effect, a completely different conception is necessary, because there is reason to believe that the mechanical strength of grains change with moisture level. Therefore, attempts to develop a testing machine that is insensitive to moisture change may be regarded as conceptionally misleading. Since the prime importance of handness measurement of wheat is to identify varieties of wheats in reference to their hardness, it is desirable for grain moisturee effect to be as small as possible.

Characterizing kernel size distribution

Although wheat kernels consist of comparatively uniform sizes, researchers have indicated that the effect of the size variability on the hardness output of measuring device may not in general be neglgible. Variety, locality and history of growth may cause differences in kernel size distribution. Kernel size analysis showed considerable differences in size distribution even with the same variety for which the location and history of growth were altered.

Sizes of wheat kernels are conveniently measured by sieving. Particle shape is usually too complex to be described in standard terms of geometry. The sieve range used for kernel size analysis was from No. 5 to 10 in the Taylor sieve series. For most of the wheat tested, which covered a wide range of varieties and localities, a large portion of the kernels was petained between the No. 6 and No. 8 sieves. With this apparent uniformity of kernel sizes, an attempt to represent the kernel size distribution of wheat by a single parameter was made. The parameter was difined as the mean diameter corresponding to fifty percent of cumulative fractional weight.

The kernel size distributions for 82 different wheats were analyzed. The mean size of the distribution was obtained by plotting percent passing versus logarithmic size in mm. The gradation curves for two extreme varieties, the lowest and highest mean sizes, are shown in Fig 6.

Selection of reference size

To determine the kernel size effect on a wheat hardness index, it is necessary to have a reference size for which the comparisons within a variety or among varieties can be made. One of the techniques used by researchers(4), is to select the kernel fractions contained in the two adjacent sieves, such as kernels between No. 6 and 7 or No. 7 and 8 sieve. The hardness index for fractional kernels enclosed within the other adjacent sieves. This technique allows the detection of the kernel size effect with in a variety and to compare size effect with those for the corresponding fractional sizes among varieties. It may be, however, impractical to estimate or correct the undesirable response of size effect for the measuring system which deals with a variety of composite kernel sizes that is generally encountered in routine measurement of grain hardness.

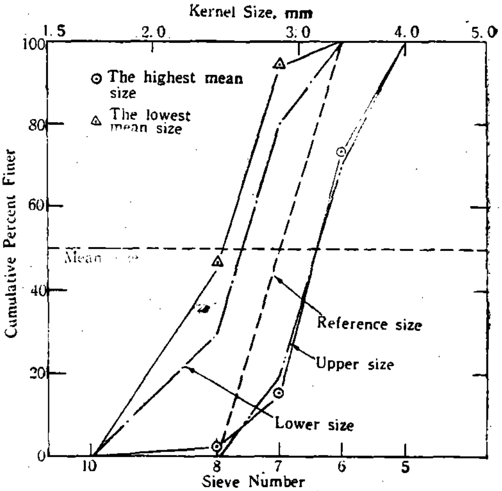


Fig 6. Wheat kernel size distributions and selection of reference size distributions.

Thus, the reference size in this study was selected by a composite of fractional sizes such that it is very close to the most probable size distribution of wheat samples. The most probable mean size was obtained from the average of the mean sizes which characterize wheat kernel distributions. A statistical analysis* shows that:

Mean of the mean size, $\bar{x}=2.82$ mm.

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* A complete analysis is given in the reference.

Standard error of the mean sizes. $S\bar{x}=0.184$.

It may be seen that the most probable mean size obtained is vary close to the No. 7 sieve opening size, 2.84 mm., which was taken for convenience as the mean size for the reference size distribution. With this mean size, a number of kernel size distribution can be obtained by altering fractional weights retaining on sieves. For convenience and reasons given earlier, equal proportions of fractional weights from sieve rangs No. 6 to 7 and No. 7 to 8 were used to make up the refer ence size distribution.

Any hardness index corresponsing to the reference size distribution shall be the reference hardness index against which the kernel size effects for different size distributions may be compared. Two other size distributions to be compared with the reference distribution are defined in Table 1. It may be observed that these distributions have mean sizes approximately equal to $\bar{x}\pm1.55\ S\bar{x}$ with the same slopes of the cumulative distribution curves as the reference distribution, as shown in Fig 6.

Table 1.

Percent fractional weights for the reference sizes used for determining the kernel size effect.

	sieve range				Mean size (mm.)
	5-6	6-7	7-8	8-10	
Reference size distr.	0	50	50	0	2.84
Upper reference size distribtuion	30	50	20	0	3.14
Lower reference size distribution	0	20	50	30	2.56

The varieties used for testing the kernel size effect on the pearlograph curve were selected so that they represented wheat hardness, ranging from one of the softest to one of the hardest. Because of the difficulty in obtaining both upper and lower reference sizes from limited amounts of a pure variety, it was possible to test only one of either upper or lower size distrition against the reference one, except for wells durum.

Experimental results of kernel size effect

Variations of the pearlograph curves due to the effect of different kernel size distribution for two representative samples may seen from Fig 7. The common characteristics of the kernel size effect that was observed, may be summerized as follows:

The larger the kernel sizes within a variety, the higher the chart height in the beginning stage of pearling. This difference of the chart height for the initial pearling time decreased continuously as the pearling preceeded. There was a time after which the response was reversed. In other word, the chart height for the smaller kernel size become greater than one for the larger size in later stage of pearling.

The same tendency was observed for all varieties tested and for either upper or lower kernel size distributions, even though the degree of response differences and the time at which inversion occured varied for varieties.

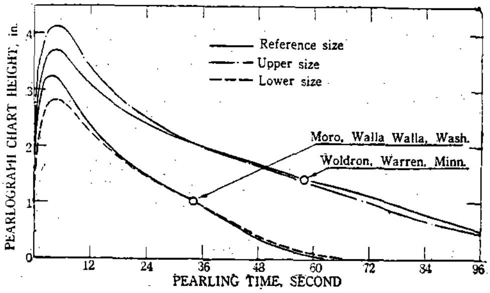

Fig 7. Effect of kernel sizes on the Pearlograph curves

This nature clearly indicates that the effect of kernel size on the pearlograph curve is compensated to a certain degree if the area underneath the curve is considered. Therefore, it is necessary only to study the common characteristics of the compensation so as to determine the pearling time that should give a minimum kernel size effect. For this reason the areas underneath the pearlograph curves for the distict sizes were obtained for various peiods of pearling. For a given variety and pearling time, the area between curves for the upper or lower size and the reference one was compared. The degree of kernel size effect was defined and evaluated by the following equation:

$$R_s(t)=\frac{S(t)-S_o(t)}{S(t)}\times 100 \qquad (1)$$

where $R_s(t)$ = the relative kernel size effect in at any given pearling time

$S_o(t)$ = the area underneath the pearlograph for the pearling period t for the reference size

$S(t)$ = the area for either upper or lower size distribution at the same period of time

The relative size effects either a positive or negative sign depending upon the magnitude of S(t) in reference to So(t). The equation also defines a common base for obtaining a general pattern of kernel size effects of all the varieties tested. The relative size effect vs. pearling time for all the varieties and moisture contents tested is shown in Fig 8.

In reviewing the kernel size effects, two important patterns should be noticed: the larger effect in the initial stage of pearling tails off as the pearling preceeds. And some of the relative size effects of the initial stage of pearling are so rapidly compensated by those of the later stage that a change of the direction takes place. Which ever the case is, the relative size effects are very small after certain period of pearling, For instance the relative size effect at the 72 seocnds pearling time is about 12% at maximum and is generally less than 7%. However, the maximum effect reduces to less than 10% at the 90 second. If the end of pearling times for all the varieties and moisture contentsare considered, the relative size effects are getting reduced.

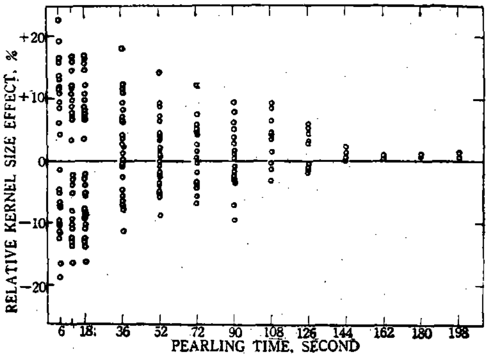

Fig 8. The variation of the relative kernel size effects for different stages of pearling

Experimental results of grain moisture effect

In general, as grain moisture increased, the pearlograph chart area for the harder wheat decreased mainly because of the shortened pearled-off period, while that for soft wheat increased because of a long pearled-off period. In contrest to this, intermediate hardness wheats were quite insensitive to moisture variation.

The overall picture of these moisture effects for different varieties may be observed by plotting the pearlograph chart area versus the grain moisture for which the charts were produced. A number of such plots can be obtained by chosing different pearling times. Fig 9 and 10 show graphically the effect of grain moisture on the pearlograph chart area. Each point in the plot represents the average of both the reference and upper or lower kernel size distribution within a variety.

Let us examine first the case of the pearled-off period. The range of pearlograph chart area, as a measure of wheat hardness, for different varieties is narrower as the moisture increases. The range for two extreme varieties at about 8% moisture content shrinks to less than a quarter of the range at about 15% grain moisture. For the intermediate hardness wheats, the pattern is rather indefinite; some of curves characterising the grain moisture effect within the same variety cross each other at lower or higher moisture levels. However, it is evident that the effects for these intermediate hardness wheats vary within a relatively small range of the pearlograph chart areas. For instance, the average change of the chart area per one percent moisture increment within the limit of moisture tested shows 1.83 square inchess for Leed durum (hard wheat) in contrast to 0.30 square inches for Era (intermediate hardness wheat).

A very significant point regarding the grain moisture effect may be observed in the soft wheats such as Reed and Moro varieties, whose pearlograph areas increase as the grain moisture increases.

The trend contrasts completely with that of hard wheat. This is an uncommon phenomena for the other machines(4) which have been used to test the influence of grain moisture on wheat hardness. The moisture effects that were observed from these machine indicated variated in the same direction regardless of varieties. No attempt was made to determine the reason for this particular phenomenon.

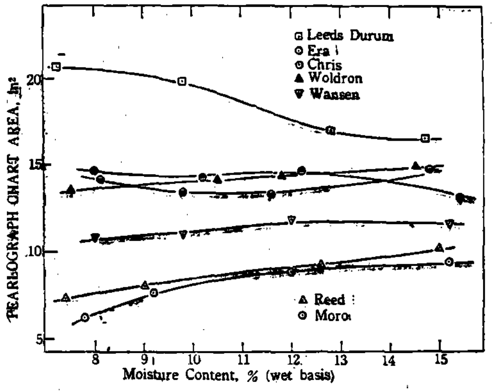

Fig 9. Effect of grain moisture on the pearlograph chart area for the 72 second pearling time.

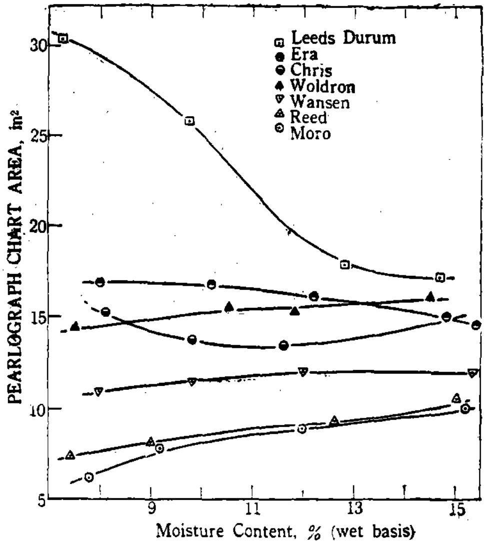

Fig 10. Effect of grain moisture on the pearlograph chart area for the pearled-off pearling time.

A desirable device for the routine measurement of wheat hardness should be relatively insensitive to variation of grain moisture, since the prime objective of the hardness measurement is to identify the hardness characteristic of different wheat varieties. In this sense, the pearlograph chart area could provide this requirement. The higher rate of grain moisture effect, especially in the hard wheat with low moisture content, can be reduced to a greater extent by sacrificing a little of the differentiating ability of variety difference. This fact can be illustrated by comparing Fig 9 with Fig 10. As the pearling time was reduced, the corresponding chart areas that were integrated within the reduced time limit were smaller in particular for the hard wheat and to a small extent for the intermediate hardness wheat. In this way, it is possible to surpress and stabilize the effect of grain moisture on the chart area throughout the range of grain moistures that is comonly encountered in the routine hardness measurements. The selection of a particular pearling time, for which ihe pearlograph chart areas are counted, should be based on overall considertion of the entire effects (variety, kernel size, and moisture).

Optimum pearling time as determined from the combined material effects

Effects of the grain moisture and kernel size on the pearlograph curves are in general significant as indicated in the sections preceeded. However it may be necessary to justify the extent of these effects on the basis of their contribution to the total variation of data. In other words, these effects may not be considered important if they are relatively small as compared to the other contributing effects. To investigate this matter, an analysis of variance was performed on the data of the pearlograph chart areas which wereobserved by varying variety, moisture, and kernel size. However a more important point for performing the analysis of variance was not simply to test the significance of effects by a proposed hypothesis against an alternative, but to study the variation of major effects as the pearling time was varied and to determine an optimum pearling time such that the contribution of variety effect to the total variation of the chart area would be the largest.

The pearlograph areas used for the analysis were those integrated for 54. 72, 80 seconds pearling times and the pearled off period.

The analysis of variance was performed by the computer program via AARDVARK and the result for different pearling times are shown in Table 2.

Table 2.

The analysis of variance for the data that were taken from different pearling times

A. Analysis of variance for 54-second pearling time

Source of Variation	Sum of Squares	DF	Mean Square	F
Variety(V)	955. 508	8	119. 438	1011. 24
Moisture(M)	11. 308	3	3. 769	31. 91
Kernel Size(S)	1. 243	1	1. 243	10 53
V×M	130. 401	24	5. 433	46. 00
M×S	1. 010	3	0. 337	2. 85
V×S	21. 989	8	2. 748	23. 27
V×M×S	5. 314	24	0. 221	1. 87
Error	8. 504	72	0. 118	
Total	1135. 277	143		

B. Anlysis of variance for 72-second pearling time

Source of Variation	Sum of Squares	DF	Mean Square	F
V	1720. 313	8	215. 039	1442. 846
M	8. 089	3	2. 686	18. 092
S	0. 689	1	0. 689	4. 622
V×M	242. 626	24	10. 109	67. 831
M×S	2. 913	3	0. 971	6·516
V×S	19. 206	8	2. 400	16. 109
V×M×S	6. 539	24	0. 272	1. 828
Erpor	10. 730	72	0. 149	
Total	2011. 108	143		

C. Analysis of variance for90 Seconc pearling time

Source of variation	Sum of Squares	DF	Mean Square	F
V	2535. 650	8	316. 956	1864. 357
M	24. 103	3	8. 034	47. 268
S	1. 192	1	1. 191	7. 010
V×M	447. 382	24	18. 641	109. 647
M×S	2. 391	3	0. 797	4. 688
V×S	15. 161	8	1. 895	11. 148
V×M×S	10. 659	24	0. 444	2. 612
Error	12. 241	72	0. 170	
Total	3048. 780	143		

D. Analysis of variance for the pealed-off period

Source of variation	Sum of Sqvares	DF	Mean Square	F
V	4690. 227	8	586. 278	3377. 030
M	247. 503	3	82. 501	475. 215
S	2. 547	1	2. 547	14. 669
V×M	1415. 630	24	58. 98	339. 758
M×S	2. 326	3	0. 775	4. 467
V×S	14. 676	8	1. 834	10. 567
V×M×S	11. 523	24	0. 480	2. 766
Error	12. 500	72	0. 174	
Total	6396. 937	143		

Let us first examine the analysis of variance for the pealed-off period. As the mean squares indicated, the average contribution of the main effects and their interactions to the variation of data are largely variable. It is no doubt that most of the variation is due to variety effect. However, considerble variations also come from moisture effect and the interaction between variety and moisture effects. Compared to these effects as mentioned, the other interactions and kernel size effect are exceedingly small. For different pearling times, the trend is generally the same. To compare the relative significance among the main contributing effects as pearling time varies, the ratio of the variety mean sauare to the moisture mean square was considered.

As seen in Table 3. the variation of the ratio to the pearling time is a quadratic. A maximum value of the ratio may occur somewhere between 72 and 90 seconds but close to the former. Based on the evidence, it was finally decided 80 seconds as the optimum pearling time. It may be expected that the pearlograph chart area up to 80 seconds of pearling time gives an adequate measure of wheat hardness without significant effect of kernel size and with allowing a slight moisture effect.

Table 3.

The ratio of the variety to moisture mean squares for different pearling times

Pearling time sec.	54	72	90	Pearled-off
Variety M.S. Moisture M.S.	31.6	79.8	3.95	7·12

Repeatability of Measurements

From the error mean square given in Table, it is possible to estimate the repeatability of measurement or the average variation between replications. The coefficient of variation was used to estimate the repeatability and tomake comparisons for different pearling time. The coefficients of variations for the four different pearting times are given in Table 4.

Table 4.

The coefficient of variations for the pearlograph chart areas for different pearling times

pearling time(second)	54	72	90	End
wean	14.22	16.50	17.89	19.24
Standard deviation	0.344	0.386	0.412	0.417
Coefficient of variation	2.42	2.34	2.31	2.17

The table shows that as the pearling time is increased, coefficient of variation for the corresponding pearlgraph chart areas decreases. Satisfactory accuracies could be obtained for any of the pearing times since they all have low coefficients of variation(less than 2.6 percent).

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