Texture (Hardness and Softness) Variation Among Individual Soft and Hard Wheat Kernels

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Cereal Chem. 63(6):479–484

ABSTRACT

The texture of individual kernels of soft and hard wheat cultivars was measured by grinding individual kernels in ethanol in a blender jar and subsequently determining median particle size by laser light scattering. This method parallels the production and measurement of break-flour yield of bulk wheat samples. There was a large variation in individual kernel texture within a cultivar (approximately one-half of the texture range of all kernels of the respective wheat class). Most variation in kernel texture of a particular cultivar was observed among the kernels of a single wheat rachis (head), probably resulting from different maturation times of kernels on a wheat rachis. The influence of kernel weight, and indirectly, size, on the measurement of kernel texture was small enough to allow good separation of soft and hard wheat texture data. Estimates of the kernel texture/weight relationship were sufficiently precise to reduce the overlapping of soft and hard wheat data from 6% without consideration of kernel weight to 1.5% when weight was included in the regression. Many hundreds or thousands of kernels were required to statistically differentiate between two samples containing mixtures of hard and soft wheat kernels that have mixture ratios as close as 2%. Overlapping of soft and hard wheat data greatly increases the number of kernels required but is a consequence of a single-kernel method that has a strong relationship with kernel weight, size, and density. If these factors are considered by least squares regression, overlapping may be reduced.

The relative texture (hardness or softness) of wheats has much practical significance in grading and classifying wheats in various marketing channels and therefore in breeding and quality evaluation programs. Texture evaluation is one tool with which to distinguish among wheats by class and to a lesser extent (due to variability) by cultivar.

Soft wheats are expected to have a softer texture than hard wheats. In the marketplace the classification of wheat by texture is determined using bulk samples. Proper classification of bulk samples becomes increasingly difficult, however, if two or more wheat classes are mixed. A bulk textural method that differentiates well among hard and soft wheats becomes ineffective when hard and soft wheats are mixed (Pomeranz et al 1985a). New methods that evaluate the texture of individual kernels may be effective for determining the mixture percentage of mixed wheat samples (Lai et al 1985). In developing such methods it is first necessary to determine whether individual kernels from hard and soft wheat classes exhibit a statistical mean, range, and variance of kernel texture that would allow reliable estimates of class mixture percentages based on the textural assessments of individual kernels within the mixed sample.

Therefore, it is useful to think that kernels are predisposed toward having a certain type of texture. The scientific challenge is, then, to accurately measure and express that texture. The problem is that texture is defined by the method used to measure it. Because statistical variance usually decreases as accuracy increases, a method must be chosen that accurately reflects the predisposition of kernel texture. Such a method should be little influenced by other factors, such as kernel size or weight.

Bulk methods of wheat texture measurement were reviewed by Obuchowski and Bushuk (1980). Methods to measure individual kernel texture have been reported by Harper and Peter (1904), Newton et al (1927), Smeets and Cleve (1956), Katz et al (1959), Gasiorowski and Poliszko (19797), and Lai et al (1985). Those methods either measure the resistance of the endosperm to indentation with a hard instrument or the resistance of the entire kernel to cracking, breaking, or crushing resulting from a single brief application of force. Each report suggests that kernel size, weight, or density has an influence on hardness measurements.

In bulk methods, it is easy to overcome the effect of natural variation in texture among individual kernels by establishing a sample size sufficient to "average out" those influences. Depending on the particular measurement, bulk methods usually require at least 10 g (300–500 kernels). Bulk or individual kernel textural measurements are expressed as resistance to various energy inputs. These inputs range from minor deformation (mild compression, penetration, or impact) to various magnitudes of disintegration (tissue disruption). Most bulk methods require extensive tissue disruption and, therefore, it is likely that the best expression of the predisposition of individual kernel texture may also be achieved by measuring the effects of extensive tissue disruption.

Extensive tissue disruption occurs during milling kernels into flour. That process is greatly affected by wheat texture and probably lends the most sensitive definition of bulk sample texture, e.g., the amount of break flour produced during milling. Break-flour yield is a function of the number of particles passing through the flour sieve during the first three or four break-roll passes. If the wheat is soft, more particles pass the flour sieve during the break passes.

It is probable that a sensitive and accurate expression of the texture of individual wheat kernels will result from determining the size and number of particles generated by extensive tissue disruption. This study employs such a technique with the objective of determining if the statistical variation in the texture of individual kernels of hard and soft wheats is sufficiently small to allow accurate statistical estimates of mixtures of hard and soft wheats based on individual kernel texture alone. Are some kernels of hard wheats actually softer than some soft wheat kernels? If so, to what magnitude, and how would it affect texture-based methods of wheat class differentiation?

MATERIALS AND METHODS

Wheats

Thirty-three wheats from three wheat classes (soft red winter, hard red winter, and hard red spring) were evaluated for bulk and individual hardness. Wheats are listed by class in Table I. Unless otherwise stated, all wheats were at 12.0 ± 0.5% moisture content. An additional six wheats were harvested by hand as wheat rachises (heads) with kernels attached. Two heads of each cultivar were harvested from separate plants located approximately 3 m apart. The heads were harvested at approximately 15% moisture content and slowly dried at room temperature and humidity until the attached kernels had a moisture content of 10.0 ± 0.5%.

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Bulk Sample Texture Measurement

The texture of bulk samples (10 g) of kernels was determined as softness equivalent (SE), which is the break-flour yield obtained on a Quadrumat Junior mill as described by Finney and Andrews (1986).

Individual Kernel Texture Measurement

Single kernels were weighed and processed in 200 ml of 99% ethanol for 1 min in a sealed, metal 500-ml blender jar (Eberbach model 8520) by a two-speed blender (Waring model PB-5) operated at high speed (15,000 rpm). After processing, the contents were poured into a nonrecirculating small volume sample cup of the Microtrac particle size analyzer model 7991-0 (Leeds and Northrup Instruments). The blender jar was rinsed with approximately 10 ml of ethanol, and the rinsing was also poured into the cup. The contents of the cup were immediately analyzed on the Microtrac and data were expressed as median volume diameter, i.e., the particle diameter at cumulative 50% of the volume of the sample particles analyzed. The Microtrac range was 1.9–176 μm.

RESULTS AND DISCUSSION

Reproducibility of Individual Kernel Texture Measurements

Individual kernels were ground in ethanol in a blender jar to create extensive tissue disruption, to meet the methodology objectives outlined. To express kernel texture, the particles generated in the blender jar were analyzed for median volume diameter (MVD), a function of both the size and number of particles. Although the entire process (including cleaning and preparation for the next kernel) took 10 min per kernel, it had acceptable reproducibility for the objectives of this study. To estimate statistical variability of the procedure, 10 hard and 10 soft wheat kernels were cut in half along the crease with a razor blade. Each kernel half was processed individually in the blender jar and analyzed by the Microtrac separately. The least significant difference derived for the variance between the two halves was 6.7 μm, and the pooled standard deviation was 12% of the expected range of kernels within a cultivar and 8% of the range of hard or soft wheat classes. The pooled standard deviation among the weights of the two half kernels was 12% of the mean half kernel weight.

TABLE I
Wheat Class, Crop, Year, Certification, Bulk Sample Texture, and Individual Kernel Texture and Weight of 19 Soft Wheats and 14 Hard Wheats

Class/ Cultivar	Crop Year	Certification[a]	Bulk Sample (10 g) Softness Equivalent (%)	Individual Kernels[b] Mean MVD (μm)	MVD Range (μm)	Mean Weight ($g \times 10^{-2}$)	Weight Range ($g \times 10^{-2}$)
Soft red winter							
Pike	1985	C	67.5	35.6	22.1	3.23	2.87
Caldwell	1985	C	62.7	36.2	4.7	3.61	2.34
Caldwell	1985	C	62.1	35.2	8.4	2.61	2.13
Tyler	1985	C	61.6	38.4	8.6	2.74	1.32
Tyler	1985	C	60.9	36.6	8.3	2.72	2.22
Test line	1982	B	58.5	39.5	16.6	3.43	1.62
Titan	1985	C	56.5	37.6	12.5	3.46	1.53
Hart	1985	C	54.8	39.8	19.2	3.55	1.98
McNair 1003	1983	B	54.0	42.9	11.9	4.86	1.47
Titan	1985	C	53.8	45.3	21.5	3.00	2.01
Adena	1985	C	53.2	41.5	16.3	2.89	1.43
Wheeler	1982	B	52.4	45.9	19.6	4.42	1.33
Adena	1985	C	52.3	42.0	13.2	3.64	1.06
Hart	1985	C	52.1	45.8	14.8	3.89	2.00
Tyler	1982	B	51.7	49.4	17.4	3.71	1.80
Argee	1982	B	50.7	48.3	19.5	4.27	2.42
Arthur	1985	C	48.6	42.0	25.0	3.87	2.83
Arthur	1985	C	48.2	38.0	11.6	3.62	2.60
Stacy	1982	B	47.5	54.0	10.6	4.55	1.84
Class mean	...	...	55.2	41.8	14.8	3.58	1.94
Hard red winter							
Newton	1985	R	49.9	67.2	15.1	2.90	1.75
TAM-105	1985	R	45.7	75.5	19.2	3.26	1.70
Newton	1985	C	45.5	70.0	17.8	3.30	2.23
Arkan	1985	C	45.0	65.8	17.3	8.04	1.30
Vona	1985	R	43.6	72.2	17.8	3.04	2.30
Triumph 64	1985	R	43.3	67.2	9.6	3.71	2.27
Commercial mix	1978	...	43.1	68.4	17.9	3.66	2.13
Arkan	1985	C	41.5	62.5	16.4	3.15	1.82
Shawnee	1982	B	40.4	76.9	31.3	3.59	2.52
Class mean	...	...	44.2	69.5	18.0	3.27	2.00
Hard red spring							
PR-2369	1985	C	37.1	79.1	17.5	3.72	1.86
Stoa	1985	C	36.2	73.3	31.2	2.77	1.02
Butte	1985	C	35.8	84.1	7.9	3.44	1.98
Marshall	1985	C	35.5	75.9	12.9	3.74	0.60
Wheaton	1985	C	33.0	73.1	28.4	3.97	1.37
Class mean	...	...	41.1	72.2	18.6	3.33	1.78

[a] B = breeders sample, C = Certified, R = registered.
[b] Mean and range of 10 kernels. MVD = mean volume diameter.

Individual Kernel Texture of Soft and Hard Wheat Classes

The frequency distribution of kernel texture (MVD) of soft and hard wheat kernels showed the hard wheat kernels to have a fairly symmetrical distribution around their mean (Fig. 1). The texture distribution of soft wheat kernels was skewed toward the hard wheats. Without adding the effect of kernel weight (discussed later), that may suggest that harder kennels of soft wheats may be responsible for the 6% overlap of the 330 soft and hard kernels evaluated.

To compare the measurement of individual kernel texture with that of bulk samples, the texture of the 330 kernels was plotted against the texture (SE) of bulk samples of the 33 cultivars (Fig. 2). The MVD of kernels of hard wheats was usually larger than 60 μm and, except for the Newton cultivar, was below 46% SE. The analyses of individual kernel texture were more effective at distinguishing the Newton hard wheat cultivar from soft wheats than was the bulk sample analysis. Two separate regression lines for the soft and hard wheat classes show the relative influence of kernel weight on the analyses of individual kernels. The lower and upper lines represent kernels having 0.01 and 0.05 g, respectively Individual kernels of the hard wheat class were not significantly correlated with kernel weight, whereas larger soft wheat kernels tended to be harder in texture ($r = 0.38$, $P = 0.01$). Also, larger kernels were associated with harder bulk sample texture (SE) measurements, $r = -0.43$, and -0.25 for soft and hard wheats, respectively. (Harder wheats have a lower SE value.)

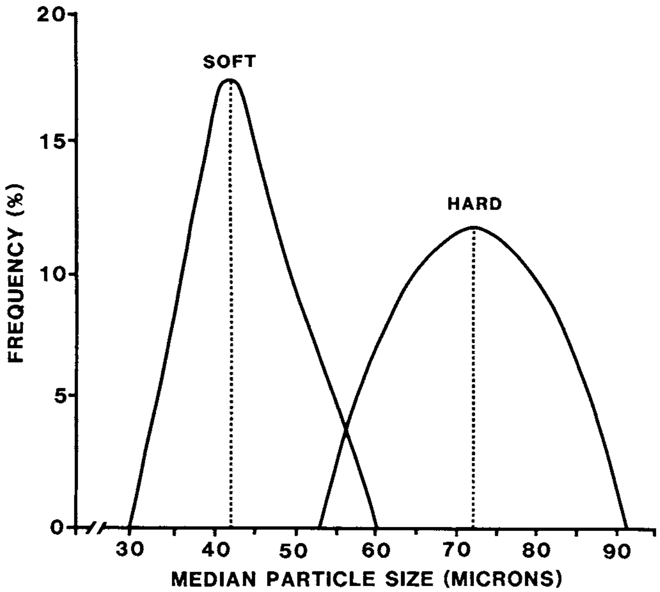

Fig. 1. Frequency distribution curves of the texture of 190 soft wheat and 140 hard wheat kernels. Dotted lines indicate sample population means.

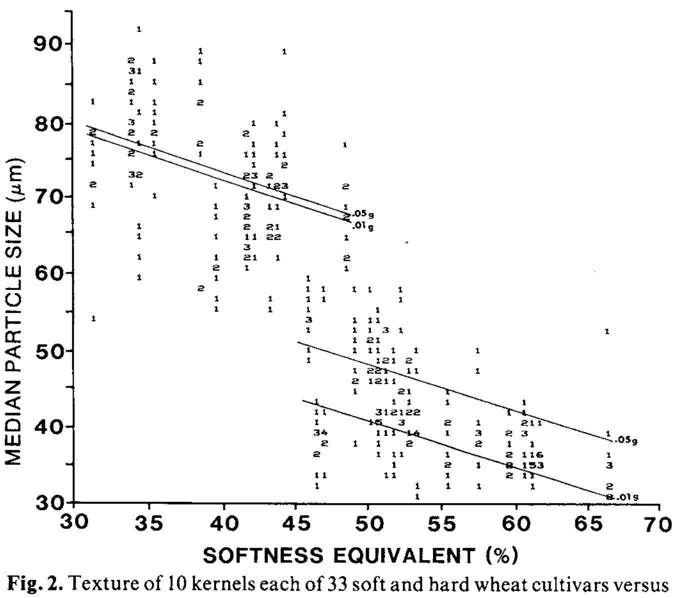

Fig. 2. Texture of 10 kernels each of 33 soft and hard wheat cultivars versus a bulk sample texture measurement of each cultivar. Dotted lines represent multiple regression lines for kernel weights of 0.01 and 0.05 g. Hard wheats are upper left and soft wheats are lower right.

Texture Range Within a Cultivar

Most cultivars had a 15–20 μm range in the MVD of individual kernels, which was approximately half of the total range of the soft and hard wheat classes. As the range was easily evidenced from only 10 kernels of every cultivar studied and did not significantly change when up to 50 kernels of one cultivar were evaluated, this common range in kernel texture from all bulk lots of any origin might be more a function of the position of the kernel in each wheat rachis than of factors such as macro- or microvariation in agronomic growing conditions. Testing that theory, the kernels of the intact heads of six soft wheat cultivars were evaluated for texture (Fig. 3). Position number one is the top kernel in the head, and increasing numbers represent the next kernel lower down a vertical row of kernels to the bottom of the head. Dotted lines in Figure 3 link the numbers of smaller tertiary kernels (which develop between primary rows when environmental conditions are favorable). With the exception of the Adena cultivar, the centrally located kernels tended to be larger and harder than those at the top and bottom of the rachis. It is well known that the central positions of the rachis flower, develop, and mature faster than the top and bottom. Environmental conditions such as crop year or rainfall and drainage, in particular, are known to affect texture measurements of bulk samples (Miller et al 1984, Pomeranz et al 1985b), but only by a relatively small percentage of the entire range of wheat class texture and not the 50% variation observed among

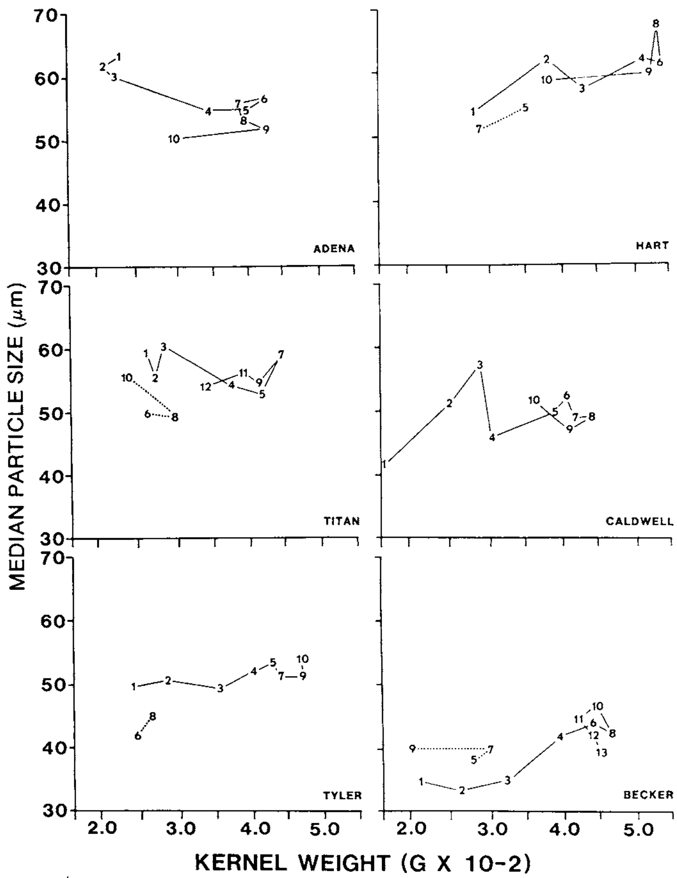

Fig. 3. Texture versus weight of kernels from a vertical row on the rachises (heads) of six soft wheat cultivars. Numbers connected by solid lines indicate the position in the row of each kernel beginning with number one at the top of the rachis. Dotted lines connect tertiary growth kernels. Values are means of two rachises.

individual kernels. Therefore, it is likely that most of the range in individual kernel hardness results from differences within each wheat rachis.

The range in texture of kernels within a particular cultivar (or even within each rachis) could also be related to differences in moisture content among kernels. Six bulk samples of Caldwell cultivar, a soft red winter wheat, were adjusted to six moisture levels and equilibrated overnight in sealed glass jars. The texture of 10 kernels was evaluated at each moisture level (Fig. 4). From 8.6 to 15.1% moisture there was a 5.5% increase in SE of the bulk samples, yet there was no significant correlation between individual kernel texture and kernel moisture content. This evaluation was made on the assumption that at a particular moisture content of the bulk samples, all of the kernels were actually at the moisture level. Figure 4 shows that the influence of kernel weight of this cultivar (at 0.01 and 0.05 g) on kernel texture was much greater than that of moisture content. Newton et al (1927) also concluded that kernel moisture had little influence on individual kernel texture. However, tempering is known to soften kernel endosperm (as measured by resistance to indentation), but the response to tempering can be greatly affected by cultivar differences (Smeets and Cleve 1956).

Kernel density, vitreousness, and protein content have been variously linked to the texture of individual wheat kernels. Vitreous kernels have been observed to have a harder endosperm than starchy appearing kernels (Newton et al 1927, Gasiorowski and Poliszki 1977). It was also observed that vitreous kernels have a slightly higher protein content and greater density. Judging the intensities of electrophoretic patterns produced by individual kernels, Lookhart et al (1985) suggested that protein content may affect the values obtained from the measurement of the texture of individual kernels.

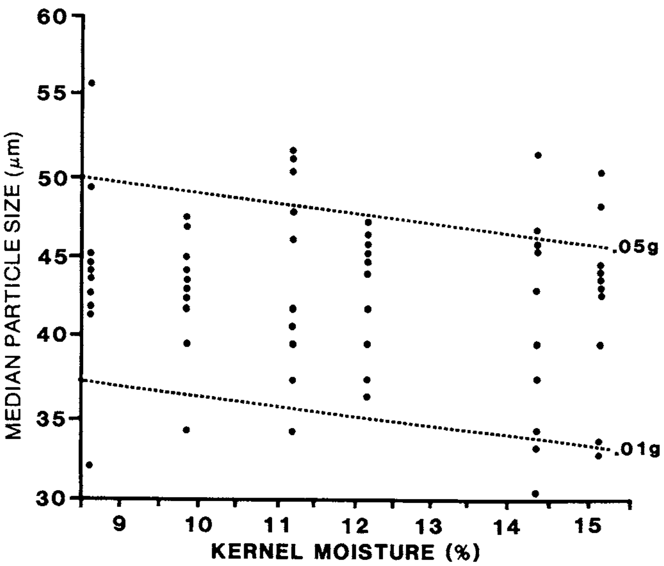

Fig. 4. Individual kernel texture of Caldwell soft wheat cultivar at six levels of moisture content. Dotted lines represent multiple regression lines for kernel weights of 0.01 and 0.05 g.

Effect of Kernel Weight on Kernel Texture Measurements

The effect of kernel weight on kernel texture is shown in Figure 5. The top and bottom regression lines are for hard and soft wheats, respectively. The larger kernels tended to be harder in texture, although as discussed above and as the slopes of each line indicate, the influence of weight was greatest among the soft wheats. Miller et al (1981) also observed that bulk samples of a hard wheat cultivar become increasingly softer as kernel size is reduced by screening. The dashed line represents a regression that is the mathematical mean of the hard and soft wheat regression lines. Only three hard wheat kernels are below the mean regression line, and only two of the soft wheat kernels are above that line. Those five kernels are only 1.5% of the sample population of 330 kernels. Incorporating texture as a function of weight results in an improved distribution over the 6% overlap of hard and soft wheat kernels observed in Figure 2, in which kernel weight was not considered.

The frequency distribution of the individual kernel weights of hard and soft wheats (Fig. 6) shows that soft wheat kernels in this study had a greater overall range, greater mean weight, and a relatively symmetrical frequency curve. The hard wheat distribution showed a pronounced tailing off of the larger kernels and a definite lack of small kernel weights, with no kernels below 0.02 g. Therefore, it is unlikely that the weight distribution of hard and soft wheats in a given mixture would be the same.

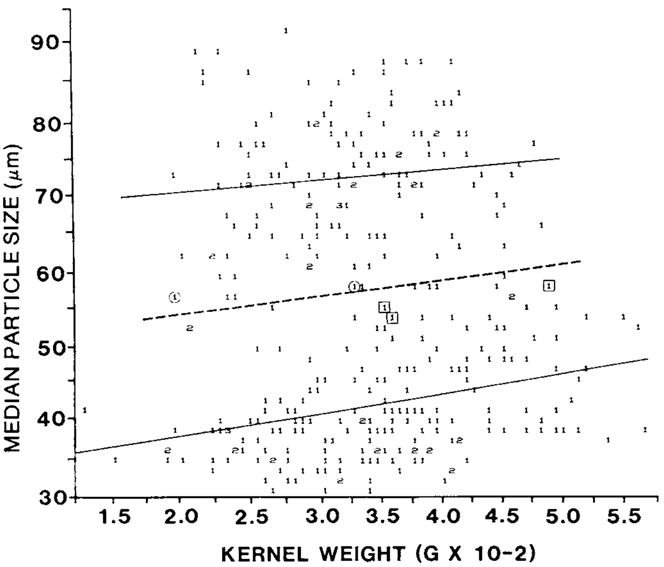

Fig. 5. Texture versus weight of 190 kernels of soft wheat and 140 kernels of hard wheat. Upper regression line is for hard wheats and lower line is for soft wheats. Dashed line is the mathematical mean of the hard and soft wheat regression lines. Hard wheat kernels below the dashed line are indicated by squares. Soft wheat kernels above the dashed line are indicated by circles. Hard wheat mediam volume diameter (MVD) = 68.49 + 112.1 (weight); soft wheat MVD = 30.74 + 308.2 (weight); dashed line MVD = 49.62 + 210.2 (weight).

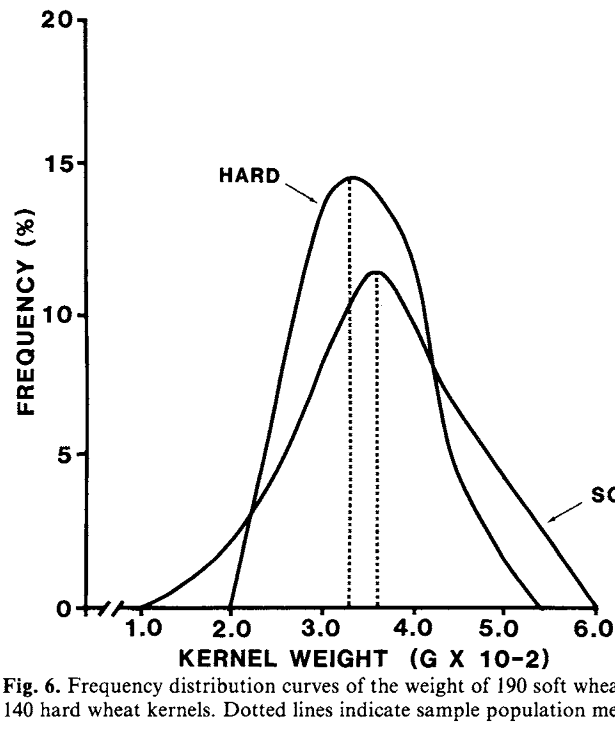

Fig. 6. Frequency distribution curves of the weight of 190 soft wheat and 140 hard wheat kernels. Dotted lines indicate sample population means.

Effect of Overlap of the Texture of Hard and Soft Wheats on Determining Class Mixture Percentages

The overlapping texture measurements of soft and hard wheat kernels (whether resulting from the actual kernel texture or artificially created by methodology) greatly complicate the problem of statistically estimating the ratio of soft and hard wheat kernels in a given mixture. Given that a bulk container of mixed classes of wheat is probably never uniformly mixed, sampling error makes the task even more difficult. Figure 7 shows the number of kernels that must be analyzed at various ratios of number of kernels of soft and hard wheat, at 0 to 25% overlap of soft and hard wheat data, to be 95% certain that the ratio is not ±2% different, e.g., that a 95:5 ratio is not 93:7 or 97:3.

Even with no overlap of kernel texture, sampling error requires up to 2,401 kernels if the mixture ratio is increased up to 50:50. The numbers of kernels required increase greatly when overlap is included, up to 9,604 kernels at 25% overlap and a 50:50 mixture ratio. Such high numbers will require practical methodologies of kernel texture measurement that are highly automated and that take only a very few seconds to accomplish. For instance, a continuous methodology that can distinguish between a 95% and a 97% mixture by measuring a kernel every 10 sec will require 1.2, 2.8, 5.0, 8.1, 13.1, and 21.2 hr at 0, 5, 10, 15, 20, and 25% overlap, respectively. Paradoxically, it is likely that a measurement of kernel texture that takes 10 sec or less to cycle will probably measure the resistance to crushing, cracking, or breaking. Those are measurements that are usually subject to significant influence by kernel weight, size, and density, creating relatively high overlap between hard and soft wheat classes and requiring larger numbers of kernels, and thus more time, for statistical difference. Those considerations are supported by the work of Roberts (1910) who concluded that 250 kernels were required just to accurately estimate the texture of a given bulk sample of wheat using a crushing point measurement of individual kernels. Additionally, Newton et al (1927) found that 350 kernels were required to estimate the texture of a bulk sample of wheat by measuring the resistance to cracking individual kernels.

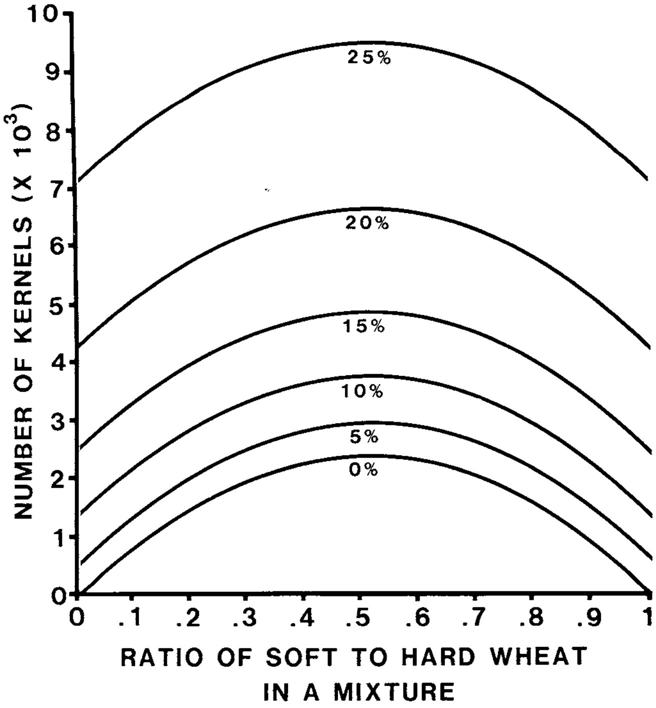

Fig. 7. Number of kernels required for individual kernel texture measurement to be 95% certain that a given ratio of a mixture of soft and hard wheat kernels is not ±2% different using texture measurement methodologies that produce 0–25% overlap of soft and hard wheat kernel texture data.

$$n = \frac{1.96\ R(-R) + P(1-P) - 4[P(1-P)R(1-R)]^2}{0.2(1-2P)}$$

where: n is the number of kernels, R is the ratio of soft to hard wheat expressed in decimal form, and P is the percent overlap of texture of hard and soft wheat kernels.

CONCLUSIONS

The texture of individual kernels was measured by particle size reduction and assessment of the number and size of particles generated. Such measurements parallel the production of break flour, a sensitive measurement of bulk sample kernel texture. The mean, range, and standard error of measurement of individual kernel texture are greater for hard wheats than for soft wheats. Larger (heavier) kernels of individual and bulk soft wheat kernels and bulk samples of hard wheats tend to be harder, although the influence of kernel weight is greatest among soft wheats.

The range in individual kernel texture of a particular soft or hard wheat cultivar is approximately one-half the range of all kernels of that wheat class. Much of the range of texture among individual kernels of a cultivar results from the variation in texture found among kernels of an individual wheat rachis. The range is not a function of differences in the moisture content of bulk samples, but may result from differences in the protein content of individual kernels that arise from differences in maturation of the kernels on the rachis.

There is a small overlap (6%) of individual kernel texture data from hard and soft wheat kernels based on texture measurement alone. Much of this overlap results from the influence of kernel weight, size, and density on texture (as measured). When the relationship between kernel texture and weight is considered, the overlapping of raw texture data among soft and hard wheat kernels is greatly reduced. Therefore, with appropriate consideration of kernel texture along with kernel weight, size, and density, it is possible that a method of individual kernel texture measurement may be developed that will produce very little or no overlapping of soft and hard wheat data.

Depending on the particular methodology of individual kernel texture measurement (and thus the amount of overlapping of raw data that results), many hundreds or thousands of kernels are required to differentiate on the basis of kernel texture between two mixtures of soft and hard wheats that are 2% different in mixture ratios. This may require several hours or days per mixture ratio determination, even with fast, automated procedures taking only a few seconds per kernel. The future development of techniques to determine wheat class mixture ratios by measuring the texture of individual kernels should, therefore, be very rapid and should either not be influenced by or should include kernel weight, size, or density data.

ACKNOWLEDGMENT

The author is very grateful for wheat samples from the Kansas Wheat Quality Council, the Minnesota Crop Improvement Association, Ohio Seed Improvement Association, Howard N. Lafever, Ohio State University, and the USDA Soft Wheat Quality Laboratory. The author also wishes to thank Bert L. Bishop, Statistics Laboratory, O.A.R.D.C., Ohio State University, for deriving the formula for Figure 7.

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[Received May 5, 1986. Revision received July 11, 1986. Accepted July 18, 1986.]