# Quality and Classification of Hard Red Wheat

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**ABSTRACT**

Twelve quality assessments of hard red spring and hard red winter wheat were evaluated over a three-year period to determine which could best fulfill the intent of the U.S. Grain Standards Act of 1916 and the U.S. Grain Quality Improvement Act of 1986 in determining market class. The study indicated that of the 12 quality evaluations, protein content and kernel hardness were the best suited to be used as classification tools for differentiating hard red spring and hard red winter wheat and that other quality assessments not as well suited also were highly correlated with protein content. A classification model based on protein content and wheat hardness successfully classified 92.7% of the hard red winter wheats and 91.5% of the hard red spring wheats over the three years studied, when changes in growing conditions were incorporated into the model. A hardness and protein index was defined as a possible means of implementing in a single score the quality characteristics of a hard wheat sample.

Official grain standards for the marketing of United States wheat have been established, beginning with the U.S. Grain Standards Act of 1916 and, more recently, supplemented by the U.S. Grain Quality Improvement Act of 1986. The purpose of these standards is to facilitate the marketing of grain through the development of descriptive nomenclature, offering the best possible information from which the end product yield and quality can be determined, and to provide the framework necessary for grain markets to establish quality improvement incentives. Unfortunately, the practice currently employed by the Federal Grain Inspection Service of identifying wheat by its morphological characteristics is limited in its ability to provide information on the quality of the grain and does not contribute much of an incentive for quality improvement.

The United States Department of Agriculture (USDA) has experienced difficulties in identifying the market classification of some wheat varieties almost since the initial implementation of the Grain Standards Act of 1916 (Phillips 1940). The use of morphological traits (e.g., kernel shape) in the inspection of wheat has been further degraded by the efforts of wheat breeders to improve characteristics such as yield and pest resistance, which are not strongly tied to the morphological features of wheat. For example, a new hard red winter (HRW) wheat variety named Arkan was released in Kansas in 1982 and in Nebraska in 1983 (Mattern 1988). Arkan was the result of breeders crossing the HRW variety, Sage, and a soft red winter (SRW) wheat variety, Arthur. Arkan had the end product characteristics of the HRW classification while possessing (under certain environmental conditions) the morphology of the SRW parentage. The difficulty arises when a visual method, based on kernel morphology, is used to assess the market classification or end product characteristics of a wheat variety such as Arkan. Furthermore, crossbreeding between wheat classes to obtain a desired trait is not uncommon, especially between hard red spring (HRS) and HRW germ plasms.

The objective of this study was to determine whether any of the wheat quality assessments currently in practice could be used as a means of establishing grain standards that better represent wheat quality. Specifically, this study was designed to examine the feasibility of replacing subjective morphological methods of classifying wheat with objective and quantitative quality assessments. This study attempted to identify distinguishing features of the HRS and HRW wheat classes that can be applied directly toward providing the best possible information on the end product quality. The term "class" was defined in this study as the market class for wheat (e.g., hard red winter, hard red spring, soft red winter, white, and durum) currently used by the Federal Grain Inspection Service to implement the U.S. Grain Standards Act of 1916 and the U.S. Grain Quality Improvement Act of 1986.

## MATERIALS AND METHODS

More than 2,000 samples of U.S. HRW and HRS wheat were collected and evaluated over a three-year period (1987, 1988, and 1989). The wheat samples were collected by Doty Laboratories, Kansas City, MO (a division of Caleb Brett USA). The samples were collected from a 10-state region ranging from Texas in the south to Montana in the north. The wheat samples were collected by individuals from Doty Laboratories during the peak of harvesting activity at local grain elevators throughout the 10-state

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region. The sample collectors began in the southern states and moved northward as the harvest season progressed.

The wheat samples were evaluated using a wide array of tests to determine which test of wheat quality best described the market classification or end product characteristics of each of the two wheat classes (HRW and HRS). Twelve tests of wheat quality were conducted on all samples over the three-year study. The battery of tests consisted of evaluations of wheat at all phases in its processing, ranging from whole wheat kernels (e.g., test weight) to the final baked product (e.g., crumb texture).

When applicable, analyses were done using the official methods of the American Association of Cereal Chemists (AACC 1983). The analyses for wheat hardness were done at the USDA Instrumentation and Sensing Laboratory, Beltsville, MD; all remaining analyses were done by Doty Laboratories. Three analytical tests were performed on each of four phases of wheat processing (whole kernels, ground kernels, wheat flour, and baked product).

Analyses performed on whole wheat kernels included: test weight (lb/bu, AACC method 55-10), 1,000-kernel weight (mass in grams of 1,000 kernels), and percent moisture content (AACC method 44-11).

Analyses performed on ground wheat kernels included: protein content (12% moisture basis) for HRW (AACC method 46-11A) and HRS (AACC method 46-10), hardness (near-IR AACC method 39-70A), and sedimentation (cubic centimeters, AACC method 56-61).

Analyses performed on wheat flour included: farinograph (AACC method 54-21) absorption (percent), peak time (minutes), and tolerance (minutes).

Analyses performed on the baked product included: loaf volume (cubic centimeters, average volume of duplicate loaves measured by rapeseed displacement); crumb grain (visual comparison of bread grain against known standards where 5 = very open, 6 = open, 7 = slightly open, 8 = close even, and 9 = slightly tight); and crumb texture (visual comparison of bread texture against known standards where 5 = harsh stressed, 6 = harsh, 7 = slightly harsh, 8 = silky good, and 9 = silky excellent).

## RESULTS

The sample means, standard deviations, and coefficients of variation of each quality measurement are shown in Table I. The data were segregated into traditional HRS and HRW wheat classes and analyzed for each of the three years (1987, 1988, and 1989). In addition, the Mahalanobis distance (Mahalanobis 1936) between the mean values of each quality measurement for HRS and HRW wheat classes also is shown. The Mahalanobis distance provides a means of comparing the "distance" (adjusted for different measurement units and standard deviations) between wheat classes among the different quality measurements. The number

**TABLE I**
**Summary of Wheat Quality Factors**

| | Winter Wheat[a] | | | Spring Wheat[b] | | | |
|---|---|---|---|---|---|---|---|
| Quality Factor | Mean | SD | CV | Mean | SD | CV | Mahalanobis Distance[c] |
| 1987 | | | | | | | |
| Protein | 11.9 | 1.0 | 8.7 | 14.4 | 1.0 | 7.3 | 2.4 |
| Moisture | 12.1 | 1.1 | 8.7 | 12.1 | 1.0 | 8.3 | 0.0 |
| Hardness | 61.3 | 9.3 | 15.2 | 76.9 | 7.5 | 9.7 | 1.8 |
| Test weight | 58.9 | 2.3 | 3.9 | 59.7 | 2.7 | 4.5 | 0.3 |
| Kernel weight | 26.4 | 2.8 | 10.6 | 27.4 | 3.9 | 14.2 | 0.3 |
| Sedimentation | 42.7 | 12.8 | 30.0 | 66.5 | 9.0 | 13.5 | 2.1 |
| Absorption | 59.9 | 2.4 | 4.0 | 64.7 | 2.4 | 3.7 | 2.0 |
| Tolerance | 10.3 | 2.8 | 27.8 | 15.2 | 5.6 | 37.2 | 1.1 |
| Peak time | 5.0 | 1.8 | 35.6 | 8.3 | 3.1 | 37.5 | 1.3 |
| Loaf volume | 819.1 | 67.7 | 8.3 | 939.4 | 75.1 | 8.0 | 1.7 |
| Crumb grain | 7.4 | 0.7 | 9.6 | 6.9 | 0.8 | 11.4 | 0.6 |
| Crumb texture | 7.5 | 0.7 | 9.2 | 8.0 | 0.7 | 8.8 | 0.7 |
| 1988 | | | | | | | |
| Protein | 12.6 | 1.4 | 11.4 | 16.1 | 1.4 | 8.5 | 2.5 |
| Moisture | 10.4 | 1.5 | 14.8 | 10.9 | 1.3 | 12.1 | 0.3 |
| Hardness | 63.4 | 8.5 | 13.3 | 82.5 | 8.6 | 10.4 | 2.2 |
| Test weight | 59.3 | 2.3 | 3.8 | 59.0 | 2.2 | 3.7 | 0.1 |
| Kernel weight | 24.1 | 3.0 | 12.8 | 25.1 | 4.1 | 16.5 | 0.3 |
| Sedimentation | 47.8 | 11.0 | 22.9 | 66.2 | 6.7 | 10.1 | 1.9 |
| Absorption | 61.4 | 2.6 | 4.2 | 67.0 | 2.2 | 3.4 | 2.3 |
| Tolerance | 9.8 | 2.9 | 29.2 | 16.4 | 6.0 | 36.4 | 1.6 |
| Peak time | 5.7 | 1.8 | 32.5 | 9.1 | 3.1 | 33.9 | 1.5 |
| Loaf volume | 817.8 | 84.2 | 10.3 | 962.8 | 66.2 | 6.9 | 1.8 |
| Crumb grain | 7.3 | 0.7 | 10.2 | 6.6 | 0.9 | 14.4 | 0.9 |
| Crumb texture | 7.6 | 0.8 | 10.1 | 8.0 | 0.8 | 9.5 | 0.5 |
| 1989 | | | | | | | |
| Protein | 13.7 | 1.3 | 9.5 | 15.8 | 1.2 | 7.7 | 1.7 |
| Moisture | 12.0 | 1.3 | 11.0 | 11.4 | 1.4 | 11.9 | 0.5 |
| Hardness | 67.7 | 8.1 | 11.9 | 87.3 | 8.3 | 9.5 | 2.4 |
| Test weight | 59.1 | 1.8 | 3.1 | 60.1 | 1.8 | 3.1 | 0.5 |
| Kernel weight | 26.1 | 2.6 | 9.9 | 26.1 | 3.5 | 13.3 | 0.0 |
| Sedimentation | 64.4 | 9.5 | 14.7 | 64.6 | 6.4 | 9.9 | 0.0 |
| Absorption | 62.7 | 2.7 | 4.3 | 66.9 | 2.3 | 3.5 | 1.5 |
| Tolerance | 11.4 | 3.7 | 32.5 | 17.6 | 6.6 | 37.3 | 1.2 |
| Peak time | 6.5 | 1.9 | 29.4 | 9.3 | 3.2 | 34.6 | 1.1 |
| Loaf volume | 826.5 | 93.5 | 11.3 | 875.8 | 71.6 | 8.2 | 0.6 |
| Crumb grain | 7.9 | 1.0 | 12.9 | 7.2 | 0.9 | 12.5 | 0.7 |
| Crumb texture | 7.4 | 0.8 | 10.9 | 7.7 | 0.6 | 7.4 | 0.4 |

[a]There were 381 observations of winter wheat in 1987, 462 in 1988, and 384 in 1989.
[b]There were 333 observations of spring wheat in 1987, 224 in 1988, and 250 in 1989.
[c]Between means of hard red winter and hard red spring wheat.

of samples varied from 224 in 1988 for HRS to 462 for HRW in the same year. Some of the year-to-year variability may have been attributable to differences in environmental conditions. For example, in 1988, the weather conditions in the HRS growing regions were unusually dry and hot, inducing early crop maturity. The hot dry weather probably accounts for the decrease in production and the increase in protein content in the HRS wheat from 1987 to 1988. Although the HRW growing regions also experienced unusually hot and dry conditions during the spring and summer, the crop was sufficiently developed before then to be less adversely affected than the HRS crop.

The large number of samples collected provides a high degree of statistical power to differentiate between the mean values of any of the quality measurements conducted on the two classes of wheat. This is demonstrated by the fact that with the exception of moisture content in 1987, test weight in 1988, and kernel weight in 1989, all other measurements have a significantly ($\alpha = 0.01$) different value for HRS wheat than for HRW wheat. Some of these comparisons may reveal more about the local growing environment than about quality differences that are genuinely characteristic of the two classes. For example, in 1988, HRS wheat had a significantly ($\alpha = 0.01$) higher average moisture content than HRW wheat, whereas in 1989 HRW wheat had an average moisture content that was significantly ($\alpha = 0.01$) higher than that of HRS wheat. In both of these cases, the difference in moisture content may be of little practical significance.

With this note of caution, the following characteristics of the HRS and HRW wheat classes were observed during the three-year study. On the average, HRS wheat had higher protein, hardness, farinograph absorption, tolerance and peak time, loaf volume, and crumb texture than HRW wheat in all three years of the study. HRW wheat had a higher crumb grain rating, on average, than HRS wheat. Further analysis of crumb scores indicated that more than 55% of the HRW wheat had "close even" or better crumb grain, whereas only 26% of the HRS wheat had a similar crumb grain rating. At the same time, more than 74% of the HRS wheat had a "silky good" or better crumb texture, whereas only 56% of the HRW wheat had a similar crumb texture rating. Moisture, test weight, and kernel weight were more or less equivalent between the two classes. In all three years, sedimentation had a higher coefficient of variation for HRW than for HRS, whereas farinograph tolerance had a higher coefficient of variation for HRS than for HRW in all three years.

Table II shows the simple correlations between the quality assessments in each of the three years. Protein content is better and more consistently correlated with a higher number of other quality assessments than any other measurement. Hardness, sedimentation, loaf volume, farinograph absorption, and peak time are also well correlated with other quality assessments. Of the quality assessments made in this study, protein content, hardness, sedimentation, loaf volume, farinograph absorption, tolerance, and peak time have greater Mahalanobis distances (Table I) between wheat classes than the other measurements. Of these, protein content, hardness, and farinograph absorption appear to be the best criteria for classifying wheat into HRS or HRW categories.

**TABLE II**
**Correlation Between Wheat Quality Factors**

| Correlation ($r$)[a] | Protein | Moisture | Hardness | Test Weight | Kernel Weight | Sedimentation | Absorption | Tolerance | Peak Time | Loaf Volume | Crumb Grain | Crumb Texture |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | | | | | | | | | | | | |
| Protein | 1.0 | | | | | | | | | | | |
| Moisture | −0.07 | 1.0 | | | | | | | | | | |
| Hardness | 0.58 | 0.22 | 1.0 | | | | | | | | | |
| Test weight | 0.01 | −0.16 | 0.30 | 1.0 | | | | | | | | |
| Kernel weight | −0.01 | 0.05 | 0.30 | 0.35 | 1.0 | | | | | | | |
| Sedimentation | 0.85 | −0.12 | 0.60 | 0.14 | 0.04 | 1.0 | | | | | | |
| Absorption | 0.73 | −0.13 | 0.62 | 0.23 | 0.18 | 0.72 | 1.0 | | | | | |
| Tolerance | 0.53 | −0.05 | 0.32 | −0.03 | −0.02 | 0.54 | 0.40 | 1.0 | | | | |
| Peak time | 0.63 | −0.07 | 0.43 | 0.07 | 0.12 | 0.60 | 0.55 | 0.80 | 1.0 | | | |
| Loaf volume | 0.76 | 0.05 | 0.53 | 0.04 | 0.01 | 0.70 | 0.52 | 0.36 | 0.46 | 1.0 | | |
| Crumb grain | −0.37 | −0.03 | −0.25 | −0.01 | 0.07 | −0.33 | −0.25 | −0.16 | −0.22 | −0.42 | 1.0 | |
| Crumb texture | 0.42 | 0.02 | 0.23 | 0.01 | 0.00 | 0.41 | 0.25 | 0.25 | 0.28 | 0.52 | −0.22 | 1.0 |
| 1988 | | | | | | | | | | | | |
| Protein | 1.0 | | | | | | | | | | | |
| Moisture | −0.19 | 1.0 | | | | | | | | | | |
| Hardness | 0.71 | 0.13 | 1.0 | | | | | | | | | |
| Test weight | −0.22 | −0.12 | 0.01 | 1.0 | | | | | | | | |
| Kernel weight | −0.21 | 0.32 | 0.12 | 0.55 | 1.0 | | | | | | | |
| Sedimentation | 0.78 | 0.10 | 0.64 | −0.09 | −0.06 | 1.0 | | | | | | |
| Absorption | 0.85 | −0.15 | 0.75 | −0.12 | −0.06 | 0.72 | 1.0 | | | | | |
| Tolerance | 0.63 | 0.04 | 0.48 | −0.23 | −0.15 | 0.61 | 0.53 | 1.0 | | | | |
| Peak time | 0.70 | −0.08 | 0.54 | −0.18 | −0.14 | 0.66 | 0.65 | 0.79 | 1.0 | | | |
| Loaf volume | 0.80 | −0.15 | 0.57 | −0.20 | −0.21 | 0.69 | 0.65 | 0.52 | 0.58 | 1.0 | | |
| Crumb grain | −0.52 | 0.11 | −0.31 | 0.13 | 0.15 | −0.42 | −0.41 | −0.27 | −0.30 | −0.57 | 1.0 | |
| Crumb texture | 0.40 | −0.11 | 0.28 | −0.15 | −0.18 | 0.36 | 0.30 | 0.32 | 0.35 | 0.50 | −0.35 | 1.0 |
| 1989 | | | | | | | | | | | | |
| Protein | 1.0 | | | | | | | | | | | |
| Moisture | −0.21 | 1.0 | | | | | | | | | | |
| Hardness | 0.58 | −0.09 | 1.0 | | | | | | | | | |
| Test weight | −0.20 | −0.36 | 0.24 | 1.0 | | | | | | | | |
| Kernel weight | −0.32 | 0.29 | −0.05 | 0.36 | 1.0 | | | | | | | |
| Sedimentation | 0.48 | 0.14 | 0.08 | −0.33 | −0.08 | 1.0 | | | | | | |
| Absorption | 0.70 | −0.35 | 0.71 | 0.14 | −0.20 | 0.22 | 1.0 | | | | | |
| Tolerance | 0.48 | −0.17 | 0.41 | −0.02 | −0.25 | 0.23 | 0.24 | 1.0 | | | | |
| Peak time | 0.54 | −0.15 | 0.44 | −0.01 | −0.20 | 0.32 | 0.41 | 0.75 | 1.0 | | | |
| Loaf volume | 0.64 | −0.01 | 0.29 | −0.29 | −0.27 | 0.44 | 0.48 | 0.25 | 0.38 | 1.0 | | |
| Crumb grain | −0.46 | −0.10 | −0.23 | 0.16 | 0.05 | −0.31 | −0.24 | −0.20 | −0.25 | −0.53 | 1.0 | |
| Crumb texture | 0.28 | 0.11 | 0.16 | −0.09 | −0.06 | 0.14 | 0.11 | 0.17 | 0.16 | 0.43 | −0.43 | 1.0 |

[a]Correlations of $0.09 < |r|$ are significant at $P < 0.01$, $0.07 < |r| < 0.10$ are significant at $P < 0.05$, all others are not significant.

In an attempt to model the quality differences between HRS and HRW wheat classes, a coded wheat class variable was introduced and a stepwise multiple linear regression procedure (using main effects only) was used to identify suitable quality assessments. Because of the known differences in environmental conditions for the three-year period, the year of sample collection was entered as a block effect in the model. The next parameter entered into the model was hardness ($r^2 = 0.52$). The third parameter entered into the model was protein ($r^2 = 0.63$), the fourth was farinograph tolerance ($r^2 = 0.66$), the fifth was kernel weight ($r^2 = 0.67$), and the sixth was farinograph absorption ($r^2 = 0.67$). This analysis indicated that the majority of the variation could be accounted for by a model with the hardness and protein parameters and that a model with additional quality assessment did not greatly increase the effectiveness of the model.

The analysis of variance for the full model of year, hardness, protein, and their interactions is shown in Table III. This analysis shows that each of the main effects and all the interactions are significant ($\alpha = 0.01$) and that the full model has a coefficient of determination of $r^2 = 0.68$. The addition of other quality assessments to this model did not substantially improve its ability to account for additional variation.

To reduce a model of wheat quality to practice, a classification system must be developed based on information from the model. As a first step in evaluating the feasibility of using this model in a classification system for HRS and HRW wheat, a discriminant analysis procedure based on the Bayesian probability theory was used (Lachenbruch 1975). To perform this analysis, the data set was randomly split into two subsets of equal size. The first subset was used in calibration as a training set and the second subset was used to verify the effectiveness of the model. The results from applying the discriminant analysis to the verification subset using the model developed in step one are shown in Table IV. The results presented in Table IV are tabulated in a gridlike manner with the rows representing the "true" classification of the wheat and the columns representing the resulting classification if the model were employed. For example, the protein model was evaluated using a total of 615 HRW wheat samples. Of these the model "correctly" classified 485 (or 78.9%) as HRW and "erroneously" classified 130 (or 21.1%) as HRS. The last row for each section of Table IV lists the total error rate for the proposed classification model for each class independently and an error rate for both classes overall.

To illustrate the effectiveness of protein and hardness measurements in distinguishing between HRS and HRW wheat classes, classification models were developed for protein and hardness (both separately and combined) with and without the blocking effect of year in the model. Adding the year of analysis into the model reduced the total error rate by 2–5%; protein was more heavily influenced by yearly variation than hardness. In the three years of this study, yearly variation in protein influenced the error rate in classification of HRW more than of HRS, whereas yearly variation in hardness influenced the classification of HRS more than of HRW. When a classification model was developed using protein, hardness, and year, the total error rate for the model was 7.9%, where 8.5% of the HRS samples were misclassified and 7.3% of the HRW samples were misclassified. Adding other quality assessments to the classification model using protein and hardness did not substantially improve the total error rate; the only effect was to shift the number of misclassified samples from one class to the other.

**TABLE III**
**Analysis of Variance for Hard Red Wheat Model[a]**

| Source | df | Sum of Squares | Mean Square | *F* Value |
|---|---|---|---|---|
| Year | 2 | 7.31 | 3.65 | 46.99**[b] |
| Protein | 1 | 243.54 | 243.54 | 3,131.26** |
| Protein × year | 2 | 6.17 | 3.08 | 39.64** |
| Hardness | 1 | 57.77 | 57.77 | 742.82** |
| Hardness × year | 2 | 3.14 | 1.57 | 20.21** |
| Protein × hardness × year | 3 | 9.00 | 3.00 | 38.55** |
| Error | 2,002 | 155.71 | 0.08 | |
| Corrected total | 2,013 | 482.63 | | |

[a]Predicted variable: wheat class.
[b]Significant at the $\alpha = 0.01$ level.

**TABLE IV**
**Wheat Quality Classification Models**

| "True" Classification[a] | Wheat Samples Classified by Model as: Winter Wheat | Spring Wheat | Total Samples |
|---|---|---|---|
| **Protein Model** | | | |
| Winter wheat | 485 | 130 | 615 |
| (Percent) | (78.9) | (21.1) | (100) |
| Spring wheat | 65 | 325 | 390 |
| (Percent) | (16.7) | (83.3) | (100) |
| Total | 550 | 455 | 1,005 |
| (Percent) | (54.7) | (45.3) | (100) |
| Total error rate | 21.1[b] | 16.7[c] | 18.9[d] |
| **Hardness Model** | | | |
| Winter wheat | 525 | 94 | 619 |
| (Percent) | (84.8) | (15.2) | (100) |
| Spring wheat | 59 | 335 | 394 |
| (Percent) | (15.0) | (85.0) | (100) |
| Total | 584 | 429 | 1,013 |
| (Percent) | (57.7) | (42.4) | (100) |
| Total error rate | 15.2[b] | 15.0[c] | 15.1[d] |
| **Year & Protein Model** | | | |
| Winter wheat | 527 | 88 | 615 |
| (Percent) | (85.7) | (14.3) | (100) |
| Spring wheat | 56 | 334 | 390 |
| (Percent) | (14.4) | (85.6) | (100) |
| Total | 583 | 422 | 1,005 |
| (Percent) | (58.0) | (42.0) | (100) |
| Total error rate | 14.3[b] | 14.4[c] | 14.3[d] |
| **Year & Hardness Model** | | | |
| Winter wheat | 524 | 95 | 619 |
| (Percent) | (84.7) | (15.4) | (100) |
| Spring wheat | 41 | 353 | 394 |
| (Percent) | (10.4) | (89.6) | (100) |
| Total | 565 | 448 | 1,013 |
| (Percent) | (55.8) | (44.2) | (100) |
| Total error rate | 15.4[b] | 10.4[c] | 12.9[d] |
| **Protein & Hardness Model** | | | |
| Winter wheat | 538 | 77 | 615 |
| (Percent) | (87.5) | (12.5) | (100) |
| Spring wheat | 49 | 341 | 390 |
| (Percent) | (12.6) | (87.4) | (100) |
| Total | 587 | 418 | 1,005 |
| (Percent) | (58.4) | (41.6) | (100) |
| Total error rate | 12.5[b] | 12.6[c] | 12.5[d] |
| **Year & Protein & Hardness Model** | | | |
| Winter wheat | 570 | 45 | 615 |
| (Percent) | (92.7) | (7.3) | (100) |
| Spring wheat | 33 | 357 | 390 |
| (Percent) | (8.5) | (91.5) | (100) |
| Total | 603 | 402 | 1,005 |
| (Percent) | (60.0) | (40.0) | (100) |
| Total error rate | 7.3[b] | 8.5[c] | 7.9[d] |

[a]As determined by Doty Laboratories.
[b]For winter wheat class.
[c]For spring wheat class.
[d]For both classes.

TABLE V
Summary of Hardness- and Protein-Index Scores

| Year | HRW Wheat[a] Mean | HRW Wheat[a] SD | HRS Wheat[b] Mean | HRS Wheat[b] SD |
|---|---|---|---|---|
| 1987 | 60.4 | 9.6 | 74.5 | 7.8 |
| 1988 | 63.2 | 9.1 | 81.5 | 9.2 |
| 1989 | 68.1 | 8.6 | 83.2 | 8.7 |

[a] Hard red winter wheat.
[b] Hard red spring wheat.

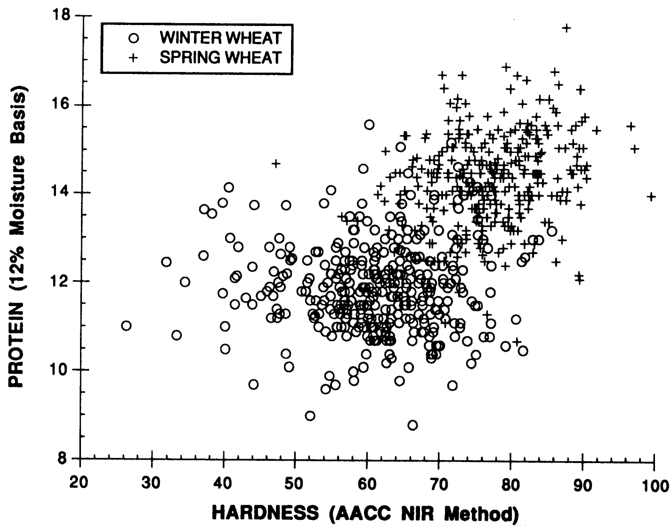


**Fig. 1.** Relationship between protein, hardness, and wheat class for the 1987 harvest.

One possible means of implementing a quality assessment based both on hardness and protein would be to define a hardness and protein index (HPI) as the weighted linear combination of protein and hardness content. The HPI is defined as:

$$\text{HPI} = 1/2[\text{hardness} + (5 \times \text{protein})]$$

where hardness is determined by AACC method 39-70A and protein is expressed at a 12% moisture basis. This definition of HPI was selected because near-IR hardness scores fall in the range of 0–100 and are approximately five times the protein content. The HPI has an expected range of 0–100. The mean and standard deviation of HPI for HRS and HRW wheat classes over the three years of this study are shown in Table V. The basis for defining HPI in this manner is shown graphically in Figure 1 for the 1987 season.

When a classification model was developed for HPI using the Bayesian probability theory, the classification results were similar to those obtained from the model with separate hardness and protein elements (see Table IV). One of the advantages of the HPI is that it can be determined rapidly (in less than 5 min) using the AACC method 39-10 for protein at the same time as the near-IR hardness is being determined. This means that the HPI assessment can easily be determined in USDA field offices using low-cost near-IR instruments and minimally skilled personnel.

## DISCUSSION

More than 2,000 samples of HRS and HRW wheat were collected and evaluated over a three-year period (1987, 1988, and 1989). Twelve quality assessments were conducted on each sample and included tests made on whole kernels, ground kernels, wheat flour, and the final baked product. The different quality assessments were compared to determine which were best suited to be used as quantitative and objective assessments of wheat quality. The quality assessments were selected because of their ability to better fulfill the intent of the U.S. Grain Standards Act of 1916 and the U.S. Grain Quality Improvement Act of 1986 than the current practice of using a subjective assessment of the morphological characteristics of the grain to identify its market class.

The study indicated that of the 12 quality evaluations, protein content and kernel hardness were the best suited to be used as classification tools for differentiating HRS and HRW wheat. Further, the study indicated that many of the other quality assessments (e.g., farinograph absorption) were highly correlated with protein content and did not improve the ability to classify HRS and HRW wheat. The use of hardness and protein for classification of HRS and HRW wheat has the additional benefit that both measurements can be conducted using AACC near-IR analysis techniques, which are much more rapid and simpler to implement than many of the other methods. Discriminant analysis indicated that using protein and hardness as inputs to a classification model based on the Bayesian probability theory successfully classified 87.5% of the HRW wheat and 87.4% of the HRS wheat studied. When the effect of changes in growing conditions was incorporated into the model, the classification results improved to successfully classify 92.7% of the HRW wheat and 91.5% of the HRS wheat over the three years studied.

An HPI was defined as a possible means of implementing in a single score the quality characteristics of a wheat sample. For this study, HRW wheat had a mean HPI score of 64 and HRS wheat had a mean HPI score of 79. The HPI assessment also may be of use for soft wheats, because the protein content of soft wheats is typically lower than hard wheats and together with their lower level of hardness would typically produce an HPI score in the 10–50 range.

The main disadvantage of using the HPI score for classifying wheat is that the current technology for near-IR analysis uses a 15-g bulk sample of wheat, and thus the HPI score represents the average assessment over multiple wheat kernels. For HPI to be developed into a fully viable alternative for classifying wheat, a means of determining the hardness and protein of individual wheat kernels must be developed to enable the detection of mixtures of wheat of different classes. Overall, the HPI score provides a rapid and objective means of assessing the quality of an HRS or HRW wheat sample.

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