# Air-Aspirated Wheat Cleaning in Grading and in Separation by Functional Properties[1]

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**ABSTRACT**

Thirty-seven commercial wheat samples (17 soft white and 20 hard red) were graded by State of Washington/U.S. Dept. of Agriculture-Federal Grain Inspection Service inspectors for dockage and foreign material. The clean grain and dockage were recombined, mixed, and separated by the Carter dockage tester and the Kice dockage tester DT4 (KDT). The KDT operates on the principle of air aspiration. Results from the KDT apparatus at a low airflow were highly correlated ($r = 0.889$) with the results of the Federal Grain Inspection Service separation. At high airflow, the KDT also separated whole kernels of various densities. The separated kernels significantly differed in 1,000-kernel weight, ash, near-infrared hardness, and protein content from the portion of the sample passing through the system. The hard wheat samples also differed in kernel density (determined by helium pycnometer) between these fractions. Separated fractions were milled experimentally and evaluated in cookie making. The less dense fraction exhibited higher flour ash, protein, and mixograph absorption but lower flour yield and cookie diameter.

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One of the main complaints of buyers of U.S. wheats concerns the high percentage of foreign material. The problem is complicated by the fact that the determinations of foreign material by the U.S. Department of Agriculture's Federal Grain Inspection Service (FGIS) differ from those of inspection services in the buying countries.

The objectives of evaluating wheat of a certain class and type for milling are to determine the percentages of 1) sound, plump, whole kernels; 2) broken, shriveled, shrunken, and damaged wheat kernels; 3) other grains or grain of contrasting classes; and 4) foreign material. Kernels can be damaged by insects, sprouting, frost, mold, or heat. Foreign material includes weed seeds, ergot, smutty kernels, chaff, and nongrain material.

There are two basic standards to evaluate a wheat sample: the "Official United States Standards for Grain" (FGIS 1984) and "Standards of the International Association of Cereal Chemistry" (ICC 1972). Under the official U.S. wheat standards, "dockage" is all material that can be readily removed from wheat by prescribed mechanical means (Zeleny 1971). In wheat, the weight of dockage is deducted from the total weight of the marketed grain. For each of the five grades, the standards set maximum limits on defects and on wheat of other classes (total and contrasting). Defects include wheat kernels that are shrunken and broken or damaged (by heat, sprouting, or insects) and foreign material. Foreign material is all material other than wheat (nonwheat material) that is not separated in the determination of dockage.

In ICC standards, the term "*Besatz*" encompasses all components of a wheat sample that differ from the normal basic variety (ICC Standards 1972). *Gesamtbesatz* (total extraneous material) is classified into *Kornbesatz* (millable grain extraneous material), and *Schwarzbesatz* (nonmillable foreign extraneous material).

The results from evaluation by the two systems differ widely. Both are designed to determine the amount of sound millable wheat. In addition, it is necessary to measure in both methods the small amounts of objectionable material that may be present. The dockage test (FGIS 1984), rapid and well-adapted to routine evaluation, has been criticized because it does not measure the total amount of nonmillable material. The ICC *Besatz* test, on the other hand, is time-consuming, somewhat subjective, and subject to errors because of the small sample used for testing. The use of air classification in combination with sifting and the trieur separator have met those difficulties to only a limited extent (Seibel 1985, Scotti 1985).

The use of image analysis in discrimination among various types of cereal grains (Lai et al 1986, Zayas et al 1986a) and among wheat classes and varieties (Zayas et al 1985) has been previously described. Zayas reported on use of this technique to determine the amount of whole wheat and the presence of foreign material, in general, and weed seeds, in particular (Zayas et al 1986b).

A variation of air classification was employed (Katz et al 1954) to separate insect-damaged grain (*Kornbesatz*) from sound grain. This system accelerated wheat using conveyor belts and projected the wheat into bins along the wheat's trajectory at increasing distances. This "grain spectrometer" was successful in removing internally infested wheat from sound wheat, as whole, more dense wheat fell into bins farther away from the launch point than did the damaged wheat. This system used air resistance as well as gravity to classify wheat kernels of varying density.

Recently, new mechanized equipment became commercially available for the separation of foreign material. This study was designed to determine whether the equipment is more effective in removing foreign material from wheat than the conventional Hart Carter dockage tester. In addition, little is known about the value in milling and baking of the wheat separated by air cleaning systems.

A relationship between test weight and flour yield ($r = 0.824$) and between 1,000-kernel weight and percent endosperm content ($r = 0.963$) has been shown to exist (Swanson 1943). The test weights were obtained from conventionally cleaned wheat, and the endosperm content and 1,000-kernel weights were obtained from a wheat maturity study. In another study, test weight and flour yield correlated at $r = 0.75$ (Shuey 1960). That study also indicated that the size ratios of the wheat were more highly correlated with flour yield ($r = 0.982$) than was test weight. Those studies showed a general relationship between kernel weight and the quality parameter of flour yield.

In recent years, there has been concern voiced over the quality of wheat being produced in terms of flour texture (Faridi et al 1987) and protein content (Noguchi 1978, Sasaki 1984, Yates 1988). The wheat fractions separated by air aspiration in this study were evaluated in terms of their relative value in milling and baking and in terms of their physical characteristics. The benefits of cleaning wheat have been recently reviewed (Anonymous 1988): Cleaning reduces storage problems from mold and insects, reduces transportation costs by removing costs to transport nonwheat material, produces a relative increase in storage capacity, improves marketability, and provides a more favorable public image.

## MATERIALS AND METHODS

This study consists of three parts. The first part concerns the

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evaluation of a Kice (Kice Metal Products Co. Inc. Wichita, KS) air cleaner's ability to remove dockage from a sample of wheat relative to a Hart Carter dockage tester. The second part of the study examines various density and quality factors of whole wheat kernels removed by a Kice air-aspirating dockage tester at high airflows. The third part examines functional differences between the wheat kernels that are removed by the air stream relative to the kernels that pass through the system.

For the first part of this study, 37 commercial wheat samples were obtained; they consisted of 17 soft white and 20 hard red wheats. Each sample was processed by the FGIS, which removed the dockage from the samples with a Hart Carter dockage tester using standard sieves and FGIS procedures, and weighed and packaged it with the remaining samples in separate envelopes.

The samples were reblended with their dockage and these "reconstituted" samples were processed by air classification with the Kice 6DT4 dockage tester (KDT) and by screen with a Hart Carter dockage tester (CDT) as methods of wheat cleaning. The KDT was operated at 0.7 and 0.9-in. water column (WC) of static pressure for purposes of this portion of the study. The CDT differed from the FGIS standard setup in that the middle sieve was no. 3 (0.1875-in. round) instead of no. 2 (0.078-in. round) and the bottom sieve was no. 5 (0.070 × 0.5-in. slot) instead of no. 2 (0.078-in. round). The air setting in both cases was 4 and the feed rate was 6 for the FGIS analysis and 3 for the laboratory setup. This setup is used routinely in our laboratory to clean the wheat prior to experimental milling.

When the KDT operated at 0.9-in. WC, wheat kernels were removed in addition to the dockage. The reason for these kernels being removed was investigated. Ten wheats (5 soft white and 5 hard red) were selected from the original 37 commercial wheats for density analysis. They represented high, medium, and low dockage weight samples as determined by the FGIS. The dockage was separated from the whole kernels and the latter were analyzed. Test weight, ash, near-infrared reflectance (NIR) hardness, and protein determinations were performed according to AACC approved methods 55-10, 8-01, 39-70, and 46-12, respectively. Kernel density was determined with a Quantachrome gas pycnometer (model SPY2) using helium (Thompson and Isaacs 1967, Chang 1988). The samples were purged three times with helium and allowed to equilibrate 5 min before density determination.

In the third part of this study, two commercial lots of soft white wheat were obtained. One sample was received from a grain elevator (St. John, WA), and one was a composite of export cargo samples. The wheats were passed through the KDT at 0.9-in. WC and the liftings and throughs were collected. Each lifted portion was sorted by hand, and whole, unbroken kernels were used in the analytical part of the study. Additionally, the St. John elevator supplied a sample of wheat cleaned with a newly installed large-scale air cleaner that operates on the same principle as the KDT, the associated liftings, and the original uncleaned sample.

The resulting wheat samples (fractions) were milled on a modified Quadrumat Senior milling system (Jeffers and Rubenthaler 1977, Bequette 1966) and flour yield was calculated. The resulting flour was tested for moisture, ash, and protein (AACC methods 44-16, 8-01, and 46-12, respectively). A 10-g mixograph evaluation (AACC 54-40) was performed to obtain water absorption and dough-mixing properties. A cookie-baking evaluation was performed (AACC 10-52) to determine cookie spread (in centimeters).

## RESULTS AND DISCUSSION

### Cleaning Wheat with the CDT and KDT

For the first part of the study, the correlations between various wheat cleaning methods were compared. The amount of dockage in the wheat samples, as graded by FGIS, ranged from 1.6 to 14.9 g/1,000 grams (Table I). At 0.7-in. WC, the KDT correlated with the FGIS dockage weight at an $r = 0.889$ level. The KDT removed slightly more material than did the FGIS method (8.3 vs. 6.9 g, on average), and most of this additional material was in the form of broken kernels that the FGIS method did not remove as dockage. The KDT lifted these broken kernels out because they presented a larger, rougher surface area to the airflow than did the whole wheat kernels. The KDT correlated with the CDT at $r = 0.682$. This could be due to the nonstandard sieves routinely used in the laboratory CDT for preparation of material for experimental milling. The laboratory CDT correlated with FGIS dockage weight (also obtained with a Hart Carter dockage tester, but with different sieves) at $r = 0.670$. The laboratory CDT removed many more shriveled and broken kernels than did the KDT or FGIS methods. This resulted in the laboratory CDT removing a greater weight of sample than did either the FGIS or KDT methods.

Nonwheat components with a density near that of wheat, such as corn or lentils, were not lifted out by the airflow in the KDT. Additionally, dense, short joints of straw fell through the system with the wheat. When these nonwheat products were separated out with a 5-W screen (0.168-in. openings), the correlation between FGIS and KDT dockage at 0.7-in. WC was increased from $r = 0.889$ to 0.914. At 0.9-in. WC, the FGIS and KDT dockage correlation improved from $r = 0.779$ to 0.789. The relationship between the KDT and the CDT was not improved.

When the airflow in the KDT was increased to 0.9-in. WC, some of the less dense whole wheat kernels (about 2% of the total sample) were lifted out in addition to the dockage. At this airflow, the KDT correlation with FGIS dockage weight dropped to $r = 0.779$ because some wheat was removed with the dockage. The KDT weight correlated with the CDT at $r = 0.644$, and the correlation did not improve by increasing the airflow. The correlation between the KDT(0.7-in. WC) and the KDT(0.9-in. WC) was $r = 0.872$. The increase in airflow did not improve the relationship between the KDT and the more conventional FGIS methods of wheat cleaning in grading. However, at the 0.7-in. WC level of airflow, the KDT was able to replicate the FGIS dockage weight determination ($r = 0.889$).

### Characterization of Wheat Kernels Separated by the KDT

The second part of the study focused on the reasons for removing whole wheat kernels by the KDT at 0.9-in. WC. At this level of airflow, some whole, fairly plump kernels are lifted out in addition to more shrunken and broken kernels. At 0.9-in. WC versus 0.7-in. WC an average additional 18.4 g/1,000 g was removed. This prompted the question of why some were lifted out by air when other kernels of similar size fell through? A difference in density would seem to be the answer. Test weight, 1,000-kernel weight, and density (as determined by a helium pycnometer) were used to analyze the wheat kernels lifted out at 0.9-in. WC. Only whole, unbroken, plump kernels (of the same dimensions as those not lifted out by the KDT) were analyzed.

Thousand-kernel weight and density were significantly different between the portion that was lifted out by the KDT and the portion that passed through the separation system (Table II). When hard and soft wheat were considered separately and combined, the difference in 1,000-kernel weights between the fraction lifted out compared to that passing through was significant. In the case of the density determined by the pycnometer, there was a significant difference when all samples were considered. When soft and hard wheats were considered separately, density was not significantly different in soft wheats. However, in all cases the kernels lifted out by the KDT were less dense than the kernels dropping through the system.

**TABLE I**
**Comparison of Dockage Amount Measured by Different Dockage Tests**

| Method[a] | Grams of Dockage per 1,000-g Sample Average | Range | SD |
|---|---|---|---|
| Official FGIS (Hart Carter) | 6.9 | 1.6–14.9 | 2.39 |
| Laboratory (Hart Carter) | 29.2 | 13.7–41.2 | 6.81 |
| Kice (0.7-in. WC) | 8.3 | 2.5–17.8 | 2.82 |
| Kice (0.9-in. WC) | 26.7 | 7.1–57.0 | 9.03 |

[a] FGIS = Federal Grain Inspection Service; WC = water column.

NIR hardness between the lifted and passed-through fraction was significantly different. Both the hard and soft wheats passing through the KDT were harder than the corresponding wheats being lifted out. In hard wheats, the throughs were 11 arbitrary NIR units higher in hardness than the lifted kernels. In soft wheats, the difference was less at 5 units but still significant. Wheat ash was significantly different when all samples were considered (averaging 1.57% in the liftings vs. 1.48% in the throughs) as well as when hard and soft wheats were considered separately. The same pattern held true regarding wheat protein. The average difference in hard wheats of 0.6 versus 1.4% in soft wheats indicates that some separation of wheat by protein is possible with the KDT. The protein separation was consistent in every sample. The protein and ash were higher, and density, 1,000-kernel weight, and hardness were lower in the lifted wheat than in the wheat passed through the KDT.

**Quality Differences in Wheats Separated by the KDT**

The third part of the study explored differences in milling, physical dough testing, and cookie making in wheat separated by air-cleaning devices. Two soft white wheat samples were passed through the KDT in the laboratory at 0.9-in. WC, and the wheat kernels from the lifted and passed-through fractions were evaluated for milling, physical dough testing, and cookie-making potential. Two additional samples included in this part of the study were from an air-cleaning process at a commercial grain elevator. The soft white wheat was passed through the commercial air-aspirated grain cleaner, and the wheat in the liftings, that which passed through (cleaned), and the original uncleaned wheat samples were evaluated.

These samples followed the same pattern of differentiation as the laboratory-separated samples. The differences were clear-cut and consistent. Wheat ash and wheat protein were higher in the lifted sample than in the sample that passed through; test weight, 1,000-kernel weight, hardness, and flour yield were lower. Ash, protein, and mixograph absorption were higher in the flour produced from the lifted wheat kernels; cookie diameter was lower (Table III). Relative to the experimental error, all of these differences are significant.

Average flour yield was 4.5% lower in the lifted samples than in the passed-through samples. Because kernels that were lifted out by the KDT were lower in density than those that pass through the system, it seems apparent that the starchy endosperm ratio is lower in these kernels. Additionally, protein in the lifted kernels averaged 1.9% higher than protein in the kernels that passed through.

Lowered cookie diameter reflects the increased level of protein in the lifted kernels in that the flour produced from the lifted kernels produced a smaller cookie (8.95 vs. 9.20 cm, on average) than the flour from the kernels that fell through. Mixograph absorption also reflected a higher level of protein, probably in addition to differences in pentosan content (not determined). The flour produced from the lifted kernels averaged 2.5% higher in absorption than the flour from the passed through kernels.

The functional quality of the wheat lifted out of the sample by the KDT is lower than that of the wheat passing through in terms of flour yield. If protein content is taken into account, the other

**TABLE II**
**1,000-Kernel Weight, Density, Hardness, Ash, and Protein in 10 Wheat Samples Separated by the Kice Dockage Tester at 0.9 in. Water Column**

| | 1,000-Kernel Weight (g) | | Pycnometer Density ($g/cm^3$) | | Relative Hardness | | Ash (%) (14% mb) | | Protein (%) ($N \times 5.7$ 14% mb) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Type | L[a] | T[b] | L | T | L | T | L | T | L | T |
| Soft | | | | | | | | | | |
| | 24.1 | 35.5 | 1.392 | 1.395 | 26 | 31 | 1.69 | 1.56 | 11.0 | 9.7 |
| | 26.1 | 35.0 | 1.410 | 1.415 | 29 | 32 | 1.48 | 1.33 | 11.3 | 9.8 |
| | 26.4 | 35.3 | 1.403 | 1.414 | 30 | 34 | 1.44 | 1.38 | 11.0 | 10.2 |
| | 29.5 | 47.8 | 1.415 | 1.420 | 30 | 40 | 1.77 | 1.58 | 12.3 | 10.9 |
| | 24.1 | 33.3 | 1.401 | 1.406 | 23 | 30 | 1.48 | 1.36 | 11.2 | 9.6 |
| Hard | | | | | | | | | | |
| | 24.2 | 28.5 | 1.405 | 1.415 | 69 | 76 | 1.59 | 1.55 | 13.0 | 12.9 |
| | 24.5 | 30.1 | 1.398 | 1.412 | 67 | 82 | 1.57 | 1.49 | 13.7 | 12.7 |
| | 22.9 | 29.6 | 1.406 | 1.417 | 59 | 71 | 1.60 | 1.49 | 11.7 | 11.0 |
| | 23.8 | 28.1 | 1.409 | 1.420 | 62 | 73 | 1.52 | 1.47 | 12.5 | 11.9 |
| | 24.9 | 34.4 | 1.402 | 1.418 | 65 | 73 | 1.59 | 1.54 | 14.1 | 13.5 |
| Averages | | | | | | | | | | |
| Total | 25.1 | 33.8 | 1.404 | 1.413 | 46 | 54 | 1.57 | 1.48 | 12.2 | 11.2 |
| Soft | 26.0 | 37.4 | 1.404 | 1.410 | 28 | 33 | 1.57 | 1.44 | 11.4 | 10.0 |
| Hard | 24.1 | 30.1 | 1.404 | 1.416 | 64 | 75 | 1.57 | 1.51 | 13.0 | 12.4 |
| Experimental error | 0.15 | | 0.006 | | 2.22 | | 0.006 | | 0.19 | |

[a] L = Liftings.
[b] T = Throughs.

**TABLE III**
**Ash, Protein, Flour Yield, Cookie Diameter, and Absorption in Wheats and Wheat Flours[a]**

| | Wheat | | | Flour | | | |
|---|---|---|---|---|---|---|---|
| Wheat Description | Ash (%) | Protein (%, $N \times 5.7$) | Flour Yield | Ash (%) | Protein (%, $N \times 5.7$) | Cookie Diameter (cm) | Mixograph Absorption (%) |
| Composite soft | | | | | | | |
| Original | 1.32 | 10.0 | 68.9 | 0.39 | 8.6 | 9.38 | 53.0 |
| Lab Kice clean | 1.31 | 9.9 | 69.1 | 0.38 | 8.4 | 9.27 | 52.5 |
| Kice liftings | 1.44 | 11.1 | 65.7 | 0.42 | 9.8 | 9.12 | 54.0 |
| Elevator | | | | | | | |
| Original | 1.21 | 11.0 | 70.0 | 0.39 | 9.6 | 9.25 | 55.0 |
| Commercial clean | 1.19 | 11.1 | 70.1 | 0.40 | 9.7 | 9.08 | 54.0 |
| Commercial lifts | 1.47 | 13.5 | 62.0 | 0.44 | 12.0 | 8.68 | 57.5 |
| Lab Kice clean | 1.20 | 11.0 | 70.0 | 0.38 | 9.4 | 9.25 | 54.0 |
| Kice liftings | 1.44 | 13.0 | 67.9 | 0.44 | 11.1 | 9.04 | 56.5 |
| Lab Carter clean | 1.24 | 10.9 | 70.0 | 0.39 | 9.6 | 9.13 | 54.5 |

[a] All results expressed on a 14% mb.

measured quality factors (cookie diameter and mixograph absorption) are comparable. The less dense kernels appear, therefore, to be less fully filled with starch than the heavier kernels.

## CONCLUSIONS

In cleaning wheat for grading, the KDT can replicate the results of the standard FGIS method for wheat cleaning and grading. The addition of a screen to sieve out large, nonwheat material of density similar to that of wheat improves the KDT's cleaning ability for laboratory milling purposes and improves its correlation with standard cleaning methods for grading (increasing $r$ from 0.889 to 0.914 at 0.7-in. WC).

The KDT offers several advantages over the CDT in a laboratory setting despite the fact that some nonwheat components are not separated by the system: a) the KDT is faster than the CDT in processing samples; b) the KDT is quieter than the CDT; c) the KDT is easily adjusted to extract various amounts of material from the sample since no sieves are involved; and d) a sample sufficiently clean for laboratory milling can be obtained with less effort than with the CDT.

Air-aspirated cleaning of samples can produce fractions of differing parameters when the airflow is adjusted to remove whole wheat kernels with the dockage. Thousand-kernel weight, hardness, ash, and protein are all significantly different between the lifted and passed-through fractions of wheat sample (at 0.9-in. WC). Density is significantly different in hard wheats, but not in soft wheats.

Functional properties differ between the lifted portion of sample and the portion passed through a commercial air cleaning system. The pattern follows that of the laboratory separation with either the KDT or the CDT. In addition, flour protein, flour ash, flour yield, and cookie diameter were all different for the two fractions. Differences in flour protein and pentosans could cause the differences in cookie diameter and mixograph absorption. Results for milling and baking support the value of removing the light kernels by air separation to improve product quality and to reduce bulk and transportation costs.

The speed, quietness, and easy adjustment of the laboratory model of the KDT make it an alternative to the laboratory model of the CDT in preparation of samples for milling. Additionally, the ability of air aspirators to separate wheat of varying quality could eventually prove to be a bonus in marketing. Because less dense wheat—of higher protein and ash and lower flour yield and cookie baking potential—can be separated from the rest of a sample (about 2% of the total), improved flour quality can be obtained for end users. The separated fraction with its higher protein could be used as a high-protein feed grain.

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