Aquagram Standard Deviations of Moisture in Mixtures of Wet and Dry Corn

C. R. MARTIN,[1] Z. CZUCHAJOWSKA,[2] and Y. POMERANZ[1]

Cereal Chem. 63(5):442–445

ABSTRACT

The blending of high-moisture corn was determined by calculating aquagram standard deviations from patterns of millivolt signals recorded as the corn passed through a Tag-Heppenstall moisture meter. The higher the proportion of the wet corn or the higher the difference in moisture between the components of the mixture, the higher the standard deviation of the aquagram. Kernel size and shape, 3% broken corn and foreign material, or 10% mold and heat damaged kernels in the sample did not interfere with the detection.

We recently reported (Pomeranz and Czuchajowska 1986) a rapid and simple method for detecting large amounts of wet corn mixed with dry corn. The method is based on a comparison of moisture determined by the conductance Tag-Heppenstall (T-H) moisture meter and oven drying or between the conductance and other electrical methods. We now report on using one meter to determine the admixture amount of wet corn to produce a 15.5% moisture blend. The determination is based on the recorded signal from roll electrodes in the T-H meter (aquagram) and calculation of the standard deviation of the signal (aquagram standard deviation, AG-SD). For blends, the higher the proportion of the wet corn or the higher the difference between the components of the mixture, the higher the standard deviation. In sound samples, free of broken corn and foreign material (BCFM), blending in small amounts of wet corn can be detected. In that case, however, it may be difficult to ascertain whether the method measures admixture or variability in the bin or shipment.

MATERIALS AND METHODS

The studies were conducted with yellow dent corn samples obtained from three sources: commercial corn from Ohio, commercial corn from the Federal Grain Inspection Service (FGIS), and laboratory samples with known history (Table I). The 29 equilibrated commercial samples from Ohio differed widely in heat and mold damage levels from none to 25%. Some of the Ohio samples contained 8–10% BCFM. This corn was harvested in the fall of 1984, and the history of growing, harvesting, and drying is not known. However, the growing season ended with an early freeze that caused some corn to be harvested without full maturity. Rain and continued cold weather further limited the overall quality, causing much of the corn to be harvested and stored at moistures greater than 15.5% even after hot-air drying. Samples were obtained from individual truck loads received at a shipping terminal during early April 1985 and were stored seven months at about 2° C until this study began. The moisture levels of the Ohio samples ranged from 11.8 to 18.6%, but most of the samples used were about 15.0–15.5%.

Seven equilibrated samples of corn were obtained from FGIS; the moisture contents of the blend components ranged from 13.5 to 20.8%. One sample had an unknown amount of BCFM and another sample had an unknown amount of blue eye mold damage. The history and source of these samples were not known.

The 12 laboratory samples were harvested in 1984 and 1985 from farms near Manhattan, KS. The combine-harvested corn was ambient-air dried to 10.0–13.5% moisture and kept in jars at room temperature. The wet samples (about 20% mc) were kept in jars at about 2° C. All laboratory samples were essentially BCFM-free. Four laboratory samples were screened to produce corn fractions of fairly uniform size and shape (Pomeranz et al 1985). These samples were high in test weight and without damage from heat or visible mold.

Moisture was determined by three methods: the T-H conductance meter (Weston Electrical Instruments Corp., Newark, NJ), the Dickey-John GAC II dielectric meter (Dickey-John, Inc., Auburn, IL), and by the 72-hr, 103° C oven method (ASAE 1982). Test weight was determined by the Dickey-John GAC II.

In each sample, moisture and test weight were determined by the Dickey-John GAC II. Next, moisture was measured with the T-H meter (Weston model 8004 type 1 power roll electrode and model 8003 type 4 meter box panel). A Nicolet 4094 digital oscilloscope (Nicolet Instrument Corp., Oscilloscope Division, Madison, WI) with a magnetic disk memory recorded the signal from the roll electrodes. The oscilloscope was AC coupled with a scan time of 1 msec per point at a constant scale setting of 10 V. The recorded signal was analyzed to determine the standard deviation (SD) of the AC component generated during measurement using waveform analysis computer software supplied by Nicolet. Two SD measurements were made for each signal: a base SD was from the signal when no corn was between the electrodes, and mid SD was from the signal between the beginning and end effects of corn passing between electrodes (Fig. 1). A reference SD was needed to compensate for differences in AC carrier signal amplitude created by the several switch settings on the meter box panel and was calculated by

$$\text{ref SD} = 260 \times \text{mid SD}/\text{base SD}.$$

TABLE I
Corn Samples Used in the Study

Source	No.	Test Weight (lb/bu)	Oven Moisture (%)	Heat or Mold Damage (%)	BCFM[a] (%)
Commercial	29	47.6–57.7	11.8–18.6	2.0–25.5	2.0–10.0
FGIS[b]	7	54.6–57.9	13.5–20.8	...	...
Laboratory	12	52.6–61.8	10.0–21.5	...	...

[a] BCFM = broken corn and foreign material.
[b] FGIS = Federal Grain Inspection Service.

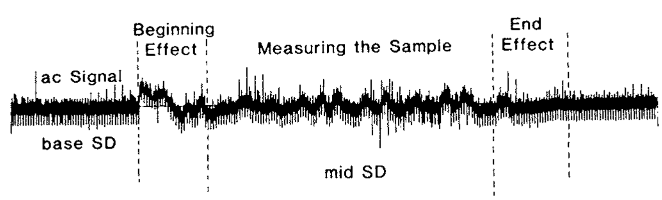

Fig. 1. An aquagram and its typical components.

[1] Agricultural engineer and research chemist, respectively, U.S. Grain Marketing Research Laboratory, USDA-Agricultural Research Service, Manhattan, KS 66502.
Mention of firm names or trade products does not constitute endorsement by the U.S. Department of Agriculture over others not mentioned.
[2] Research assistant, Department of Chemical Engineering, Kansas State University, Manhattan 66506.

For each measurement a 300-g sample was used in running three subsamples (Fig. 2). Each subsample required 2 to 3 sec to pass through the roll electrodes. Samples crushed by the roll electrodes were analyzed for moisture by the oven method.

RESULTS AND DISCUSSION

Corn with 12% or lower moisture content produced no difference in AG-SD between base and mid SD (Fig. 3). A very high SD was recorded from the signal of a 20.8% moisture sample that was presumed to have equilibrated after storage for several months at about 2° C. High-moisture corn produces a high conductance between the roll electrodes. The flow of current to the meter is regulated by switching more resistance into the circuit. The higher SD is the result of a larger voltage measurement across the meter resistors.

AG-SDs of equilibrated, about 15.5% moisture, corn samples are compared in Figure 4. The smallest SD was recorded for the sound, BCFM-free, laboratory samples of uniform size and shape. The SD increased somewhat in commercial samples containing 3% BCFM or 10% mold- or heat-damaged kernels. In no case did the SD of the equilibrated samples in this series of tests exceed 300 mV.

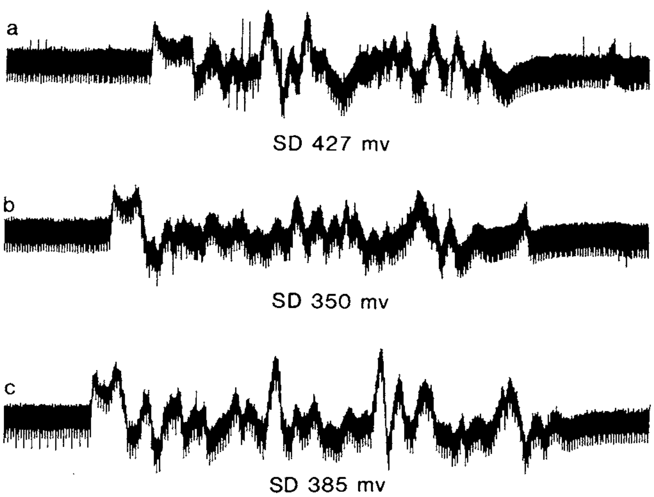

Fig. 2. Aquagrams of a blend; triplicate determinations on a single commercial sample.

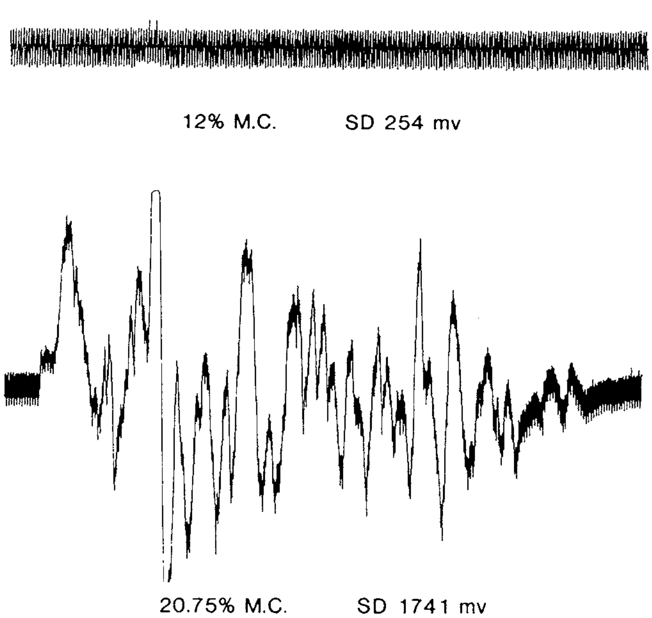

Fig. 3. Aquagram standard deviations of samples at 12.0% moisture (laboratory) and 20.8% moisture (Federal Grain Inspection Service).

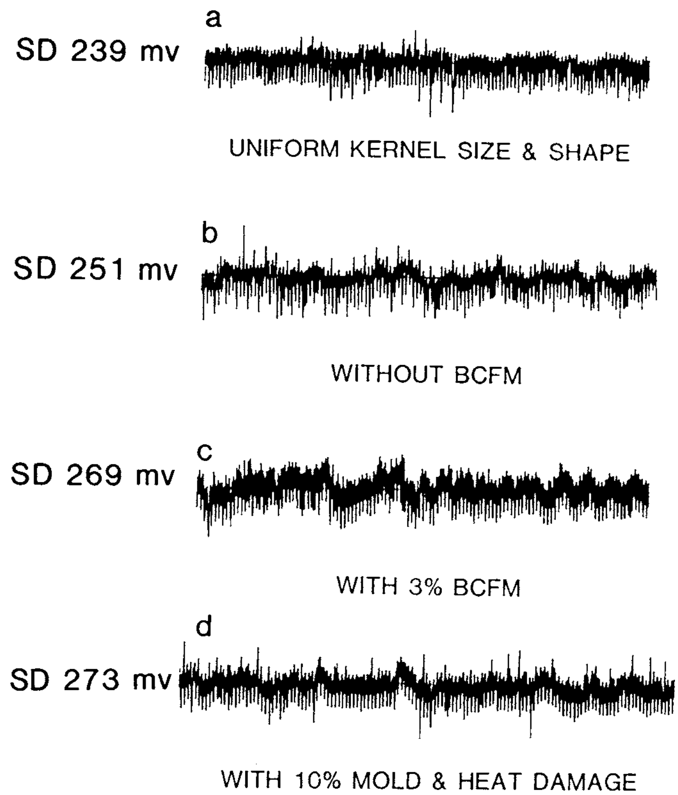

Fig. 4. Comparison of aquagram standard deviations of corn samples: **a,** uniform in kernel size and shape (laboratory); **b,** without broken corn and foreign material (commercial); **c,** containing 3% broken corn and foreign material (commercial); and **d,** containing 10% mold- and heat-damaged kernels (commercial).

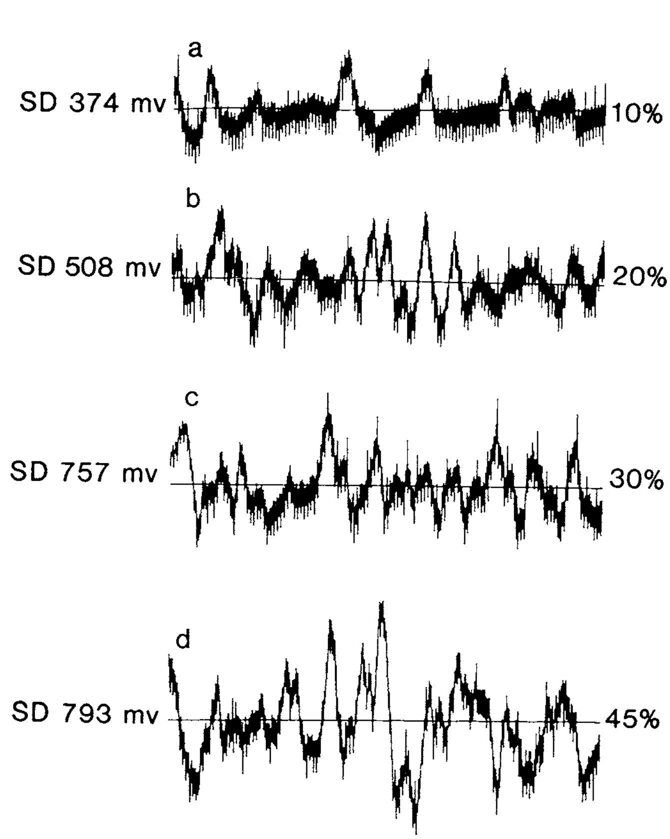

Fig. 5. Aquagram standard deviations of 12.0% moisture corn blended with 10, 20, 30, and 45% of 20.2% moisture corn (laboratory samples).

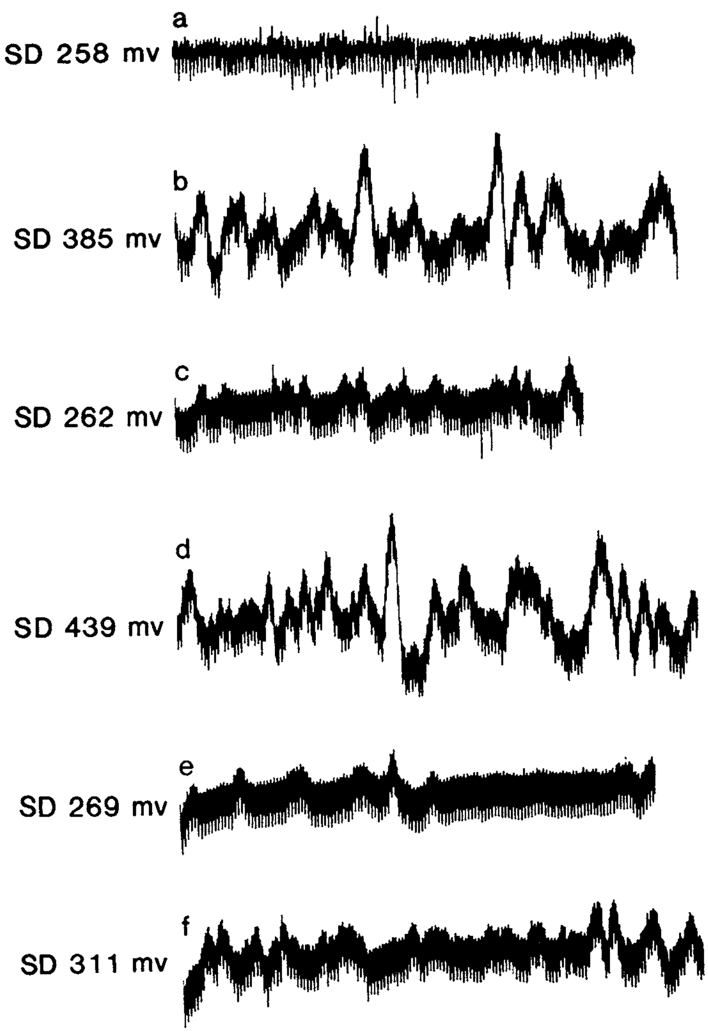

Fig. 6. Aquagram standard deviations of corn samples: **a,** equilibrated, commercial sample of 14.9% moisture; **b,** fresh Federal Grain Inspection Service (FGIS) blend of 65.0–13.6% moisture and 35.0–19.7% moisture corn (moisture of blend 15.7%); **c,** fresh FGIS blend of 92.2–13.5% moisture and 7.8–18.7% moisture corn (14.2%); **d,** fresh FGIS blend of 35.9–13.9% moisture and 64.1–19.6% moisture corn (17.5%); **e,** fresh FGIS blend of 92.2–13.5% moisture and 7.8–18.7% moisture corn (14.3%); and **f,** fresh FGIS blend of 25.0–13.6% moisture, 50.0–13.5% moisture, and 25.0–18.7% moisture corn (14.8%). All moisture levels were determined by oven drying.

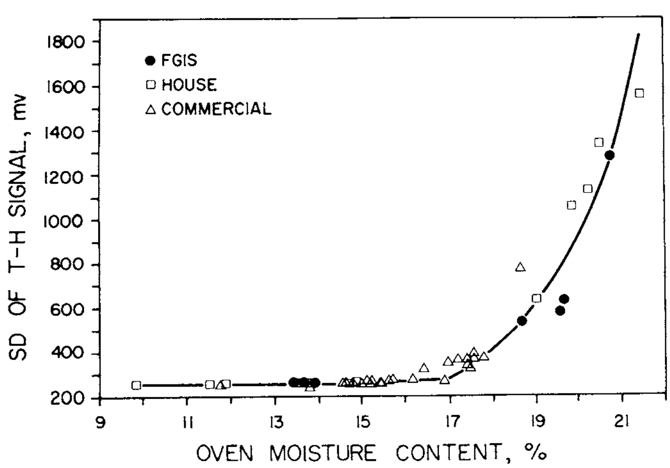

Fig. 7. A plot of the aquagram standard deviation for equilibrated commercial, Federal Grain Inspection Service, and laboratory samples vs. moisture determined by the oven method (**T-H** = Tag Heppenstall).

A blend of wet and dry corn presents a mixture of conductance values of which the signal SD is greater than the signal SD from kernels of uniform moisture content. The increase in the amount of high-moisture corn in a nonequilibrated blend is reflected by the increase in the AG-SD (Fig. 5). The high SD is probably the combined result of nonuniform moisture distribution in the kernel, redistribution after removal from the cooler, and effect of moisture on the instrument reading. For all practical purposes, however, it is of little consequence whether the moisture content of a sample is the result of blending or excessive moisture of a presumably equilibrated sample. Both are unacceptable in marketing channels. If required, it is possible to distinguish between these two causes by comparing the results from the Dickey-John and T-H instruments. In equilibrated high-moisture samples, both instruments give high readings and the discrepancy between them is small. In fresh blends, the Dickey-John reading is substantially lower than the T-H reading.

Examples of determining blend composition are illustrated by the AG-SD of the FGIS samples in Figure 6. The AG-SD of blends c and e was comparable to that of the equilibrated sample a. The moisture content of the latter (14.9%) was higher than of the blends c and e (14.2% and 14.3%). The AG-SD increased as the proportions and differences in moisture of the blend components

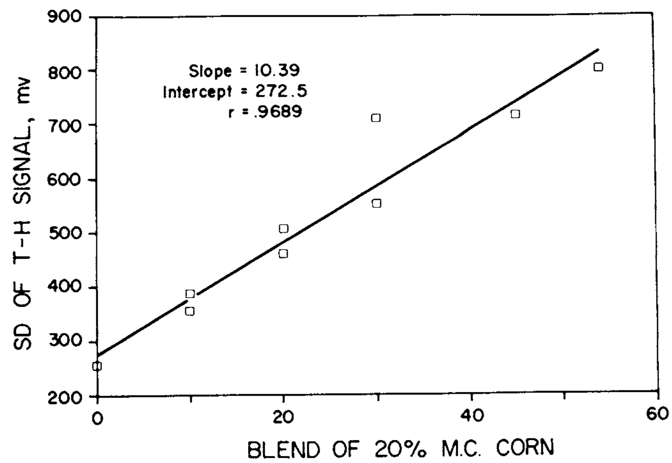

Fig. 8. Linear regression analysis of aquagram standard deviations for blends of two corn samples with 10.0 and 20.0% moisture; the values in the left corner denote slope, intercept, and correlation coefficient of the linear regression line. (**T-H** = Tag Heppenstall).

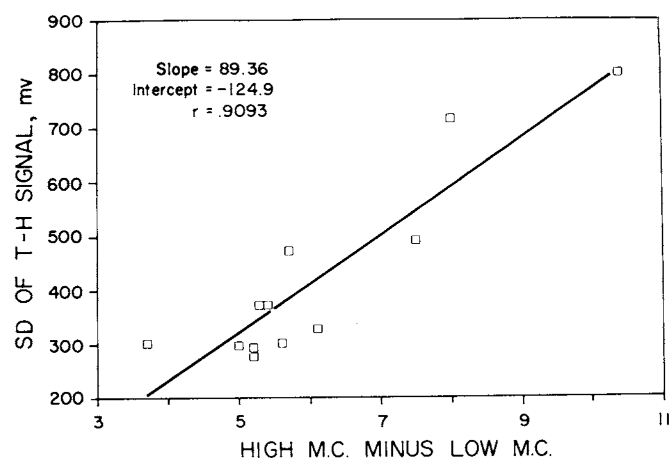

Fig. 9. Linear regression analysis of aquagram standard deviations for 1:1 blends of various corn samples that differed in moisture content between 3.7 and 10.5%. The samples were mixed to obtain blends with about 15.5% moisture; the values in the left corner denote slope, intercept, and correlation coefficient of the linear regression line (**T-H** = Tag Heppenstall).

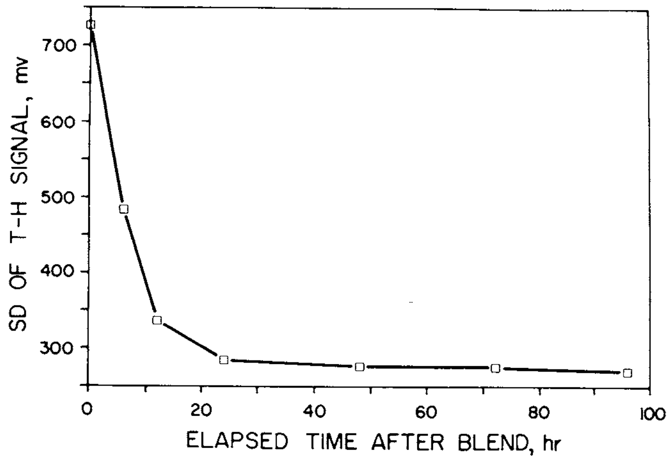

Fig. 10. Change in aquagram standard deviation of blends of 10 and 20% moisture corn samples held for 96 hr at 20° C. The samples were mixed to obtain blends with about 15.5% moisture (**T-H** = Tag Heppenstall).

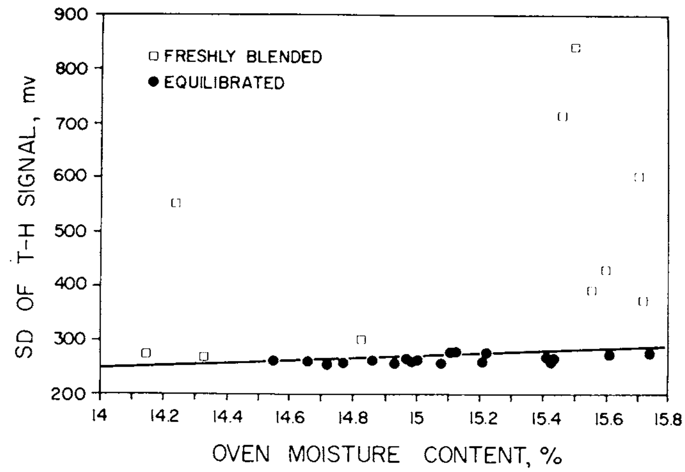

Fig. 11. Aquagram standard deviation of equilibrated and freshly prepared blends of corn samples varying in moisture content from 14.1 to 15.7% (**T-H** = Tag Heppenstall).

and the average moisture of the blend increased.

In equilibrated samples, the AG-SD was consistently below 300 mV for samples with a moisture content up to about 16%, and increased exponentially thereafter (Fig. 7).

In blends of two laboratory corn samples differing widely in moisture contents, the correlation coefficient between the AG-SD and percentage of the 20% moisture corn in the blend is as high as 0.969 (Fig. 8). The picture is more complex when blends of various corn samples are tested (FGIS samples, Fig. 9). It was difficult to ascertain the blending of samples differing in moisture up to 6% if the amount of the high-moisture corn was small (i.e., 7.8%) and especially if the average moisture of the blend was relatively low (14.2%). Preparation of such blends is rather uneconomical. In addition, it should be emphasized that the results were obtained for well blended mixtures in which there is a rapid exchange of moisture among the blend components. We are dealing with a complex biological system in which there is a microheterogeneity in moisture distribution within the kernel and macroheterogeneity as a result of blending or moisture migration during storage even in samples that equilibrate for a long time. It is impossible, at this stage at least, to establish with certainty whether moisture gradients result from natural variation or purposeful blending, especially when we deal with small differences and are measuring the effect of both factors combined. Finally, the presence of a very small amount of high-moisture corn, while undesirable, is not likely to create a large potential hazard when well blended with dry corn to yield a mean moisture of 14% or less. The nature of the dynamic and relatively rapid changes in well-mixed blends with a mean moisture of about 15.5% is illustrated in Figure 10. Similar rates of equilibration in well-mixed samples were reported by Sauer and Burroughs (1980) and by White et al (1972). The AG-SD after 12 hr was below 300 mV; indicative of the redistribution of moisture in the blend components. The AG-SDs of freshly blended and equilibrated samples, as related to the mean moisture content of the blends, are compared in Figure 11. Blends with an average moisture of 14.8% could be detected. If the average moisture of the blend exceeded 15.5%, a widely accepted limit for corn in marketing channels and for many years maximum for U.S. No. 2 corn (Anonymous 1978), the admixture of high-moisture corn could be established with certainty.

LITERATURE CITED

ANONYMOUS. 1978. The Official United States Standards for Grain. Federal Grain Inspection Service, Inspection Division, U.S. Department of Agriculture: Washington, DC.

AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS. 1982. Moisture measurement—grain and seeds. ASAE S-352. Page 347 in: Agricultural Engineers Yearbook. The Society: St. Joseph, MI.

POMERANZ, Y., and CZUCHAJOWSKA, Z. 1986. Rapid and simple detection of a mixture of wet and dry corn. Cereal Chem. 63:283.

POMERANZ, Y., CZUCHAJOWSKA, Z., MARTIN, C. R., and LAI, F. S. 1985. Determination of corn hardness by the Stenvert hardness tester. Cereal Chem. 62:108.

SAUER, D. B., and BURROUGHS, R. 1980. Fungal growth, aflatoxin production, and moisture equilibration in mixtures of wet and dry corn. Phytopathology 70:516.

WHITE, G. M., ROSS, I. J., and KLAIBER, J. D. 1972. Moisture equilibrium in mixing of shelled corn. Trans. ASAE 15:508.

[Received February 13, 1986. Revision received June 10, 1986. Accepted June 13, 1986.]