NOTE

Evaluation of Digitally Filtered Aquagram Signals of Wet and Dry Corn Mixtures

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ABSTRACT

Standard deviations (AG-SD) of recorded signals from the Tag-Heppenstall (T-H) moisture meter for equilibrated and fresh blends of corn depended both on the quantity of wet corn in a blend and the difference in moisture contents of the blend components. The signals were subjected to Fourier transformation and digitally filtered. The correlation coefficient between the logarithm of the AG-SD of the filtered signal and the oven moisture content was 0.975 for equilibrated corn, free of broken corn and foreign material (BCFM) and damaged kernels. The AG-SD value for such corn at the 15.5% moisture level (the accepted upper limit for commercial corn) was up to 63 mV. In the presence of BCFM and damaged kernels in equilibrated corn, the AG-SD deviation increased at 15.5% moisture to 78 mV. No freshly blended samples had AG-SDs below 63 mV; in corn with an oven moisture up to 17.0%, the AG-SD of equilibrated samples increased to about 150 mV in the presence of heat- or mold-damaged kernels. Above 17.0% moisture, BCFM also increased the AG-SD. The correlation coefficient between AG-SD of the T-H signal and calculated standard deviation was 0.895. Moisture equilibration in well-mixed blends, as determined by AG-SD values, approached equilibrium at an exponential rate within two days at room temperature.

Electronic meters can provide a measure of the moisture content of a grain sample. However, the variability of the moisture in a measured sample may bias the average moisture reading when compared to the standard oven method (Pomeranz and Czuchajowska 1986). The Tag-Heppenstall (T-H) moisture meter can yield erratic readings caused by the nonuniform moisture among kernels within a sample, and the recommended procedures include tempering time of 24 hr for samples that are suspected to be nonuniform. This sensitivity to nonuniform moisture has been utilized to identify the blending of wet and dry corn by examination of aquagrams. An aquagram is a recorded millivolt signal from the T-H meter that shows the variability of signal values in a grain sample (Martin et al 1986).

The standard deviation of an aquagram (AG-SD) is a statistical measure of the variability of that signal. Fresh blends of grains with different moistures produce larger standard deviations in the AG-SD signals than well-equilibrated samples (Martin et al 1986).

The T-H moisture meter was selected for this study because it measures, continuously, the conductivity of 10 to 16 corn kernels while providing a signal during the scanning of a crushed sample. This feature averages signal variations among continuous small groups of kernels, thus minimizing the effects of kernel size and shape variations. However, the circuitry within the T-H meter panel imposes several harmonic frequencies that significantly mask the effect of signal variation below moistures of about 16%. Different switch settings compound the problem by changing the amplitude of these harmonic frequencies. These harmonics can be eliminated by digital filtering so that the nature of the AG-SD can be studied. This report describes a procedure for identifying the blending of wet and dry corn on the basis of AG-SD of digitally filtered signals of conductivity measurements.

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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 house samples with known history. The samples were described by Martin el al (1986).

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 oven drying at 103°C for 72 hr (ASAE 1983).

In each sample, moisture and test weight were determined by the GAC II. Next, moisture was measured with a Weston moisture meter (formerly T-H) 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 range setting of 10 V. The recorded signal was analyzed using computer software waveform analysis supplied by Nicolet Instrument Corp. to determine the standard deviation of the AC component generated during measurement. Two calculations were made for each signal: a) base SD was from the signal with no corn between the electrodes and b) mid SD was from the signal between start and stop end effects of corn passing between electrodes (Fig. 1). A fast Fourier transformation was obtained from 2.048 sec of the mid SD of a signal; all frequencies greater than 30 Hz were deleted, and an inverse function reconstructed the digitally filtered signal. A base SD compensated for differences in AC carrier signal amplitude created by the switch settings on the meter box panel and was used in calculating the AG-SD as follows:

$$\text{AG-SD} = 260 \times (\text{filtered mid SD}) / \text{base SD}.$$

For each measurement, a 300-g sample was used in running three subsamples. Each subsample (about 100 g) required 2–3 sec to pass through the roll electrodes. Samples crushed by the roll electrodes were analyzed for moisture by the ASAE oven method.

RESULTS AND DISCUSSION

Original and digitally filtered signals for a corn sample are compared in Figure 1. Filtering reduced the AG-SD from 260 to

65. Figure 2 shows AG-SD of duplicate determinations (digitally filtered signals) of two fresh blends and two equilibrated samples containing 14.2–14.5% moisture. The AG-SD of the two equilibrated samples averaged 44 and 42 and of the fresh blends 84 and 96.

The relation between expected SD for various combinations of blend ratio and point difference in moisture is shown in Figure 3. The SD depended both on the ratio of wet corn in a blend and the difference in moisture contents of the blend components.

An analysis of variance showed a linear relationship between oven moisture content (mc) and the natural logarithm of the filtered SD signal for all samples considered to be equilibrated and free of BCFM and damaged kernels ($r = 0.975^{**}$ for 22 samples; AG-SD = exp [mc × 0.560 − 4.53]). Figure 4 shows that the SD, like the conductance, of corn increases exponentially with increase in moisture content. Using the regression equation and a moisture content of 15.5%, an SD value of 63 mV was found as the upper limit for equilibrated corn free of mold or heat damage and with BCFM removed. A similar analysis for equilibrated samples containing damaged kernels or BCFM is summarized in Table I. The lowest mean values were for the samples of uniform size and shape, which are shown as four points near 15% moisture. The presence of BCFM and damaged kernels increased the mean AG-SD level at 15.5% moisture to 78–80 mV.

The AG-SD of equilibrated and freshly blended samples as related to average oven moisture are compared in Figure 4. There was a distinct differentiation between blended and equilibrated corn at 15.5% moisture, based on the AG-SD value of 63 mV. Three equilibrated samples with AG-SD values greater than 63 but with moisture below 15.5% were highly damaged field samples.

No freshly blended samples had AG-SDs below 63. In corn with an oven moisture up to 17.0%, AG-SDs of equilibrated samples increased to about 150 in the presence of heat- or mold-damaged kernels. Above 17.0% moisture, BCFM also increased the AG-SD.

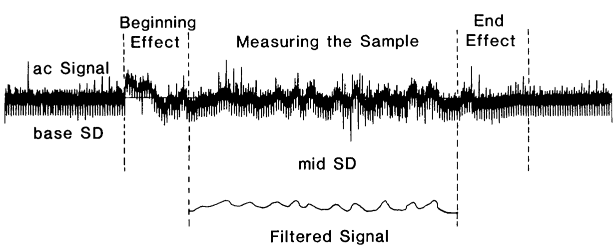

Fig. 1. Comparison of original and digitally filtered signals of aquagram standard deviations of a corn sample.

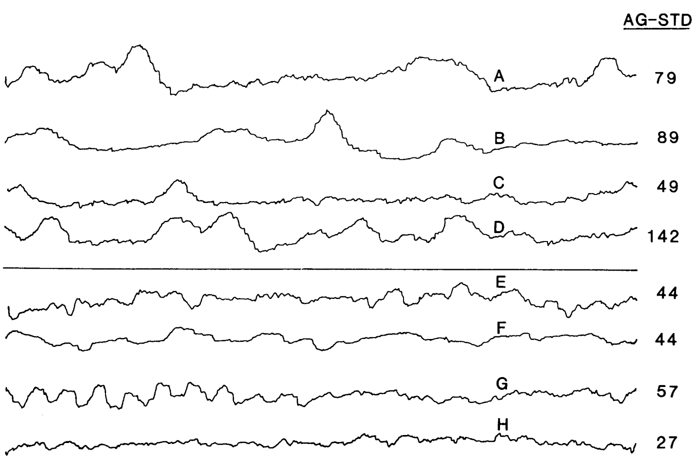

Fig. 2. Aquagram standard deviations of fresh blends (**A–D**) and equilibrated corn samples (**E–H**). **A** and **B** = duplicate runs of a 14.3% moisture corn sample blended from 92.2% corn of 13.5% mc and 7.8% corn of 18.7% mc. **C** and **D** = duplicate runs of a 14.2% moisture corn sample; blended from 92.2% corn of 13.5% mc and 7.8% corn of 18.7% mc. **E** and **F** = duplicate runs of an equilibrated 14.5% mc corn. **G** and **H** = duplicate runs of an equilibrated 14.5% mc corn.

TABLE I
Comparison of Aquagram Standard Deviation (AG-SD) Values for Samples Containing Broken Corn and Foreign Material (BCFM) or Damaged Kernels (DM)

Description of Corn Samples	Number of Samples	AG-SD at 15.5% mc (mV) Mean	SD
Uniform kernel size and shape	12	53	15
Hand harvested	2	60	9
Without BCFM and DM	66	66	23
With BCFM	33	73	32
With DM	12	80	30
With BCFM and DM	24	78	29

It should be emphasized, however, that the moisture content of BCFM differs widely from that of the corn even in "equilibrated" samples (*unpublished data*). The results point to the desirability of removing BCFM before the determination of moisture by the T-H method. Alternatively, large differences in moisture before and after removal of BCFM indicate incomplete equilibration.

The linear correlation coefficient between the logarithm of the filtered AG-SD and the SD of the calculated moisture content was 0.895^{**} for 18 fresh blends (AG-SD = exp [mc SD × 0.540 + 3.94]). The intercept of this equation (SD = 0) was 51 mV, which was close to the mean value of 53 mV for equilibrated samples of uniform

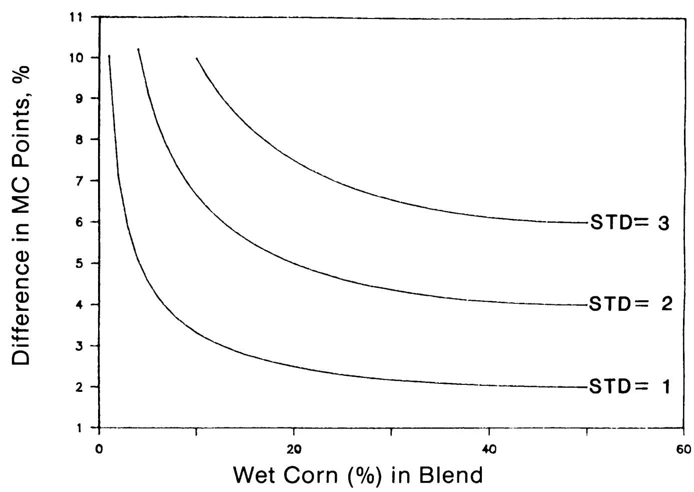

Fig. 3. Standard deviations of blends of wet and dry corn as affected by differences in moisture contents and ratio of components of wet and dry corn blends.

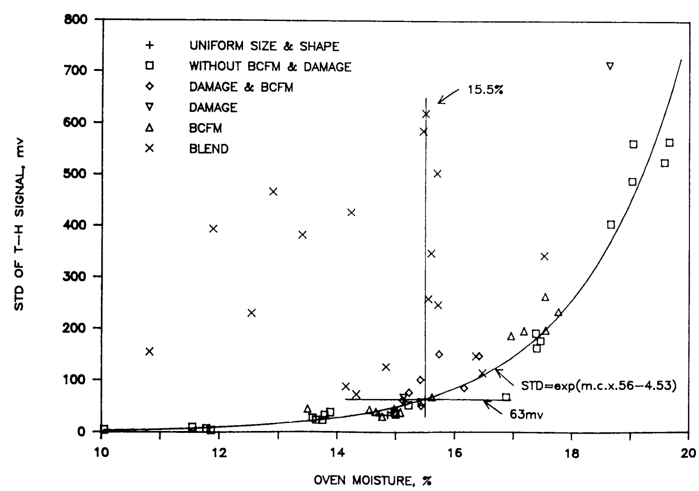

Fig. 4. Relation between standard deviation of the Tag-Heppenstall signal and oven moisture for fresh blends and equilibrated corn samples with uniform kernel size and shape, without broken corn and foreign material (BCFM) and damage, with BCFM, with damage, and with BCFM and damage. Points are averages of three measurements.

size and shape. For an AG-SD up to about 63 mV, the SD of the calculated blend moisture was comparable to that resulting from the presence of BCFM and damaged kernels. For average (oven) moistures between 10 and 17%, the difference between the measured SD and the expected SD (calculated from the regression equation) increased as AG-SD increased.

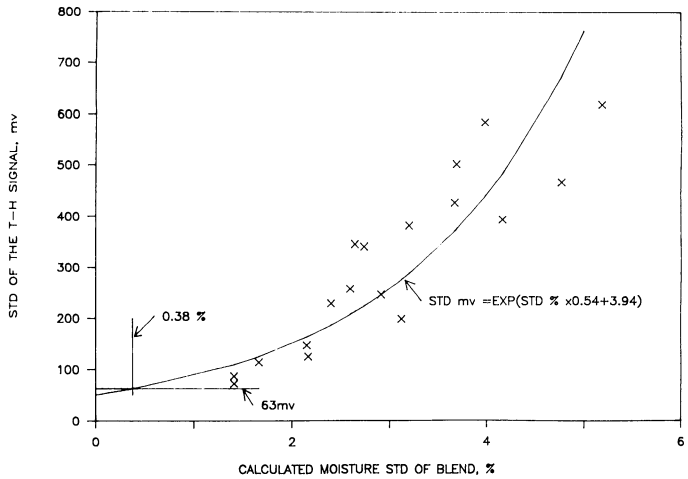

Fig. 5. Relation between standard deviation for the Tag-Heppenstall signal and calculated moisture standard deviation of fresh blends. Points are averages of three measurements.

Figure 5 shows the relation between AG-SD of the T-H signal and calculated moisture SD for fresh blends. The means of samples of uniform size and shape (53 mV) and of hand-harvested, clean, and sound samples (60 mV) of various sizes and shapes fall between 51 and 63 mV. The means of damaged samples and samples with BCFM fall between 63 and 150 mV.

Freshly blended samples approached equilibrium at an exponential rate (data not shown). After two days at room temperature, the AG-SD value was less than 63 mV for samples stored in small jars.

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