AN ELECTRONIC METHOD FOR THE MEASUREMENT OF HEAT-DAMAGE IN ARTIFICIALLY DRIED CORN[1]

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ABSTRACT

Recent work by several investigators has shown that shelled corn dried in air at 180°F. or higher is damaged with respect to its commercial use. Many chemical and physical properties of corn have been examined in an attempt to find one or more properties which would serve as an index of damage in corn dried at excessive temperatures. A method based on measurement of moisture distribution within the corn kernel has been studied and found both accurate and rapid as an indication of damage by drying. Moisture distribution measurements were made indirectly by determining the electrical capacitance and d.c. resistance of the corn. Two sets of artificially dried samples on which the prime starch yields had been determined were tested for their capacitance-resistance relationships. Results showed the capacitance-resistance measurements are an accurate index of drying damage. Glutamic acid decarboxylase activity of these samples also showed a highly significant correlation with the capacitance-resistance measurements.

In recent years the trend toward increased artificial drying of corn has presented new problems to the corn processing industries, particularly when drying temperatures have been excessive. Corn, when damaged by overheating, yields less starch, with higher protein content (1,2,3,4,5,6). Excessive drying temperatures increased the friability of corn (1,3), resulting in more breakage of the grain during handling, thereby lowering the grade on account of cracked corn. Reduction in nutritional value of overheated corn also has been reported (1,4,7,8). In addition, germination is reduced severely when corn is overheated.

Watson and Sanders (9) studied the steeping characteristics of thin sections of the horny endosperm of corn grains and found that drying-damaged sections retained more starch, presumably because the protein matrix containing the starch grains was denatured by heat and hence less soluble in the sulfur dioxide steep liquor.

MacMasters and co-workers (2) recently published extensive data showing that shelled corn dried in air at 180°F. or higher was damaged with respect to its use in starch production. Damage to corn was indicated by reduced starch yield and increased protein content in the recovered starch.

Many attempts have been made by various investigators to find a property of corn which is affected by drying and which could be

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adapted to a quick test for assaying damage done to corn by excessive heat. However, none of the work reviewed has indicated any property which appears to be adaptable to an accurate and rapid method for practical use.

The method presented in this paper for assaying damage in corn from overheating during artificial drying is based on determination of moisture distribution in the kernel. This was done by relating total moisture of the kernel to surface moisture content. Previous investigators (2,3,4,6,9) have indicated that one of the primary effects of drying damage is the denaturation of the proteinaceous material in the horny endosperm. Since denaturation reduces the water-binding capacity of proteins, it follows that the water-binding capacity of this material would be related to the severity of the drying damage. If the water content of the horny endosperm is reduced, it is reasonable to assume that other areas of the corn kernel would be higher in moisture content in relation to the total moisture content. One area which has greater moisture content and which is readily accessible for measurement is the outer surface of the kernel. Both total moisture content and surface moisture content can be determined by electrical measurement, since total moisture content is closely related to the electrical capacitance of the kernel and surface moisture is inversely related to the logarithm of the d.c. resistance of the kernel surface (10).[3]

Materials and Methods

Source of Corn Samples. Two sets of shelled corn samples were used. The first set consisted of 16 samples dried in a laboratory batch dryer and one sample dried in the field at North Carolina State College during the fall of 1963. The laboratory-dried samples varied in initial moisture content from 19 to 33% and were all reduced to 12% final moisture content and then stored in sealed containers at 40°F. until ready for use. The drying treatments are given in Table I. The field-dried sample was harvested at 13% moisture, and this also was stored at 40°F. in a sealed container.

The second set was processed at Purdue University during the fall of 1963 and consisted of 13 samples dried in a commercial-type dryer, a control sample dried at ambient temperatures, and one sample dried on the cob. All of the Purdue samples had an initial moisture content of 25%, except the cob sample which was not measured initially. The samples dried with heated air were reduced to moisture contents between 14% and 18% and then subsequently dried to 14% with room

[3] It was assumed in this study that the resistance was primarily related to the surface moisture, although it is entirely possible that the resistance was affected to some degree by the moisture deeper within the corn kernel. The surface moisture, however, had the greatest influence on the resistance when measurements were made with the type of electrode and circuitry used in this study.

TABLE I

DRYING DATA OF THE NORTH CAROLINA SAMPLES WITH CORRESPONDING DISPLACEMENT VALUES, STARCH YIELDS, AND GLUTAMIC ACID DECARBOXYLASE ACTIVITIES

Sample No.	Drying Temperatures	Initial Moisture	Displacement Value	Prime Starch	Glutamic Acid Decarboxylase Activities
	°F.	%		%	mm. ethyl lactate
Field-dried	ambient	..	6.5	61.5	15.2
Lab. 2	ambient	33	7.5	61.4	15.2
Lab. 5	ambient	29	5.5	61.2	15.2
Lab. 7	ambient	25	1.5	62.8	19.0
Lab. 9	ambient	19	0	62.0	19.0
120–2	120	33	11.0	59.6	9.0
120–5	120	29	6.0	61.3	16.4
120–7	120	25	4.5	61.5	18.8
120–9	120	19	0	62.8	18.5
160–2	160	33	17.0	46.7	3.5
160–5	160	29	13.0	58.0	7.0
160–7	160	25	6.5	61.4	15.0
160–9	160	19	2.5	62.5	19.0
200–2	200	33	19.0	46.0	3.0
200–5	200	29	12.5	51.4	7.9
200–7	200	25	9.0	60.5	11.8
200–9	200	19	6.5	61.3	15.0

air. Three of the drying tests were repeated. Table II gives the drying treatments for these samples.

Instrumentation. Two types of electronic instruments were used in making the moisture distribution measurements. A capacitance-type moisture meter was employed to obtain the electrical capacitance of

TABLE II

DRYING DATA OF THE PURDUE SAMPLES WITH CORRESPONDING DISPLACEMENT VALUES, STARCH YIELDS, AND GLUTAMIC ACID DECARBOXYLASE ACTIVITIES

Sample No.	Drying Temperatures	Final Moisture	Displacement Value	Prime Starch	Glutamic Acid Decarboxylase Activities
	°F.	%		%	mm. ethyl lactate
Air-dried on cob	ambient	..	0	72.8	18.0
Check — 1963	ambient	14	4.0	73.8	15.8
100	140	18	7.3	73.5	14.8
101	190	18	10.0	66.4	11.5
102	190	16	8.0	73.2	13.2
102R	190	16	8.5	73.5	11.3
103	190	14	9.5	71.6	11.7
105	240	18	11.0	70.1	9.2
106	240	16	12.0	67.8	8.5
107	240	14	15.0	67.6	6.0
109	290	18	14.0	66.0	6.8
109R	290	18	13.5	67.5	6.7
110	290	16	12.5	63.5	5.2
110R	290	16	13.5	65.2	6.1
111	290	14	14.0	63.5	6.1

the sample, and a highly sensitive, wide-range ohmmeter with a specially designed electrode was used in making the d.c. resistance measurements (Figs. 1 and 2).

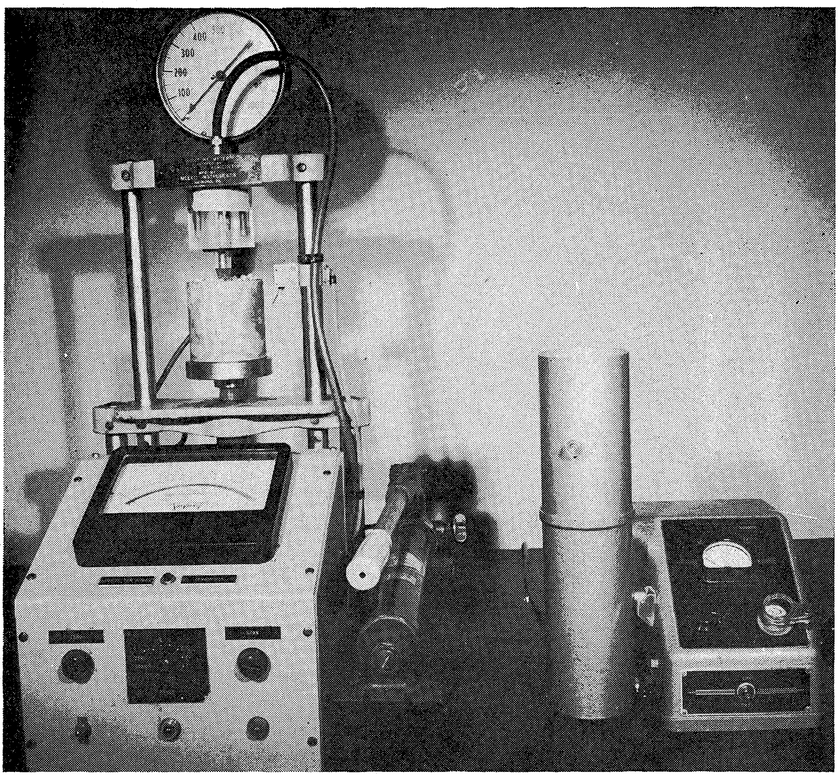

Fig. 1. Ohmmeter (left) used in making the resistance measurements. Moisture meter (right) used in making the capacitance measurements.

Capacitance-Resistance Method. The testing procedure involved making three capacitance readings, then immediately making the three resistance readings of a well-mixed 250-g. sample. The three readings for each instrument were averaged and the averaged readings plotted on a semilogarithmic graph. Total time required to make a test from the mixing of a sample to completion of the meter readings was about 4.5 min. Since single readings on each instrument would suffice for routine testing, only about one-third this time would be required for testing a sample.

Prime Starch Determinations. Prime starch determination, based on a method worked out by Watson and co-workers (6,9), involved steep-

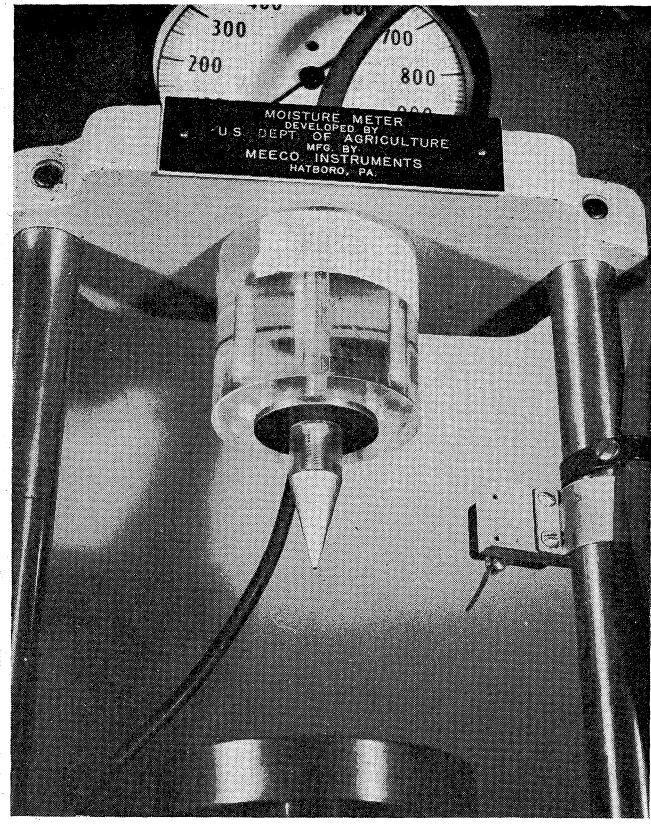

Fig. 2. The electrode used in conjunction with the ohmmeter.

ing 250 g. (dry weight basis) of corn in dilute solution of lactic acid and sulfur dioxide at pH 4 for 48 hr. at 49°C. The steeped corn was ground 1 min. in a Waring Blendor equipped with a dull blade and operated at 85 volts. To separate the mixture of starch and protein from the coarser fragments, the milled grain was screened and washed on silk bolting cloth stretched over a shaker frame. The filtrate was then passed over slightly finer cloth to remove fragments escaping the first screen. Yields of dry, prime starch were calculated as a percentage of the 250-g. dry weight of corn.

Glutamic Acid Decarboxylase Activity. This test was developed by Linko and co-workers (11) and is a measure of the enzymatic activity of the corn. It involves the measurement of the quantity of carbon dioxide evolved from a mixture of 30 g. of ground corn and 15 ml. of a dilute solution of buffered glutamic acid maintained at 30°C. for 30 min.

Results and Discussion

Relation between Capacitance-Resistance Measurements and Damage. The relation between electrical capacitance and d.c. resistance measurements on a series of 25 undamaged samples with moisture contents from 10 to 20% was linear when plotted on semilogarithmic graph paper (Fig. 3). The correlation coefficient for the two variables was +0.998. The plot of the values for the samples damaged by drying (Fig. 3), on the other hand, showed significant negative displacement from the regression line of the undamaged samples. The magnitude of this displacement, or the displacement value (DV), showed a direct relationship to the degree of damage by drying.

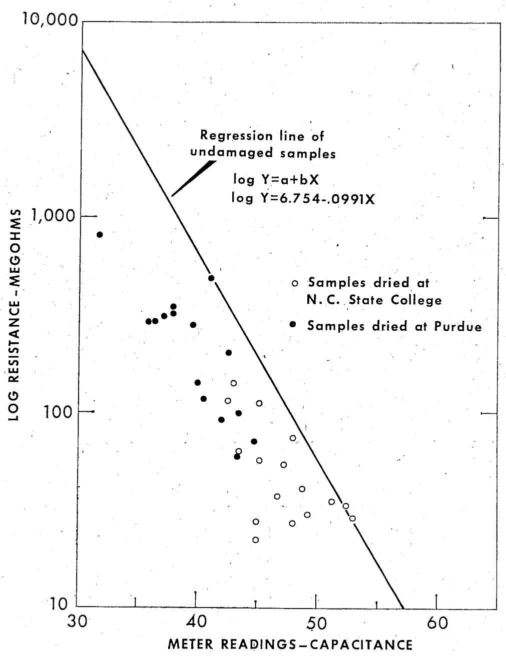

Fig. 3. Regression line of undamaged samples and scatter diagram of samples from N.C. State and Purdue.

The severity of the damage, or the DV, can be determined, therefore, by measuring the number of graph divisions along the capacitance axis from a plot of the capacitance-resistance values of a sample to the regression line of the undamaged samples.

Over a range of 70° to 90°F. no correction was needed for temperature, presumably because the temperature variations affected both parameters to approximately the same degree within this temperature range. Sudden changes in temperature of the sample environment, however, were found to cause errors in the resistance measurement that were due to sweating of the sample and migration of the moisture within the sample.

In some samples there was a gradual increase in DV with time. Even under refrigeration a few samples showed a slight increase. The damaged samples appeared to show greater increase than the undamaged samples in most cases. Further study will be necessary to elucidate this phenomenon.

Effect of Drying Temperatures and Initial Moisture Contents on Displacement Values. The DV's for the corresponding drying temperatures for both the N.C. State and Purdue samples (in Tables I and II) clearly show that the greater DV's occur at the higher drying temperatures. Only differences of little significance were found in the DV's, however, in drying down to different moisture levels, except at the drying temperature of 240°F.

Perhaps the most significant factor as a cause of damage due to drying, other than the drying temperature, is the moisture content of the corn before drying. The samples from North Carolina, which were dried from four different moisture levels, demonstrate this effect. Figure 4 shows that the greatest damage, as shown by the DV's, occurred

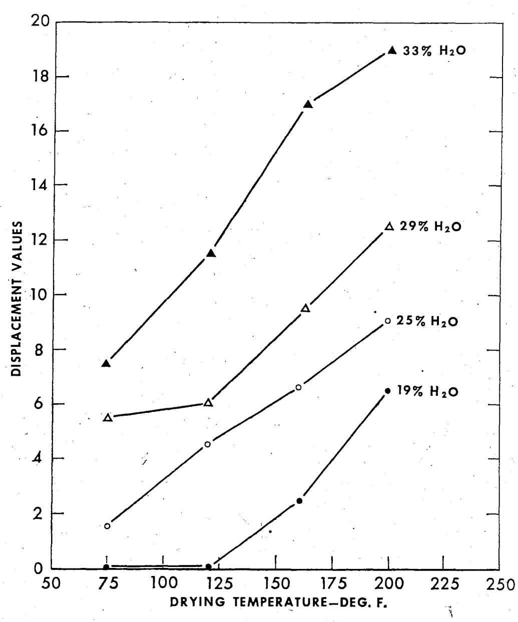

Fig. 4. Effect of drying temperature on displacement value at four different initial moisture contents.

in those samples with the highest initial moisture content. More damage occurs at drying temperature of 120°F. and 33% moisture than at drying temperature of 200°F. and 19% moisture.

Effect of Drying Temperatures and Initial Moisture Content on Prime Starch Yields. The reduction in prime starch yield of corn dried at temperatures above about 180°F., which was shown by previous investigators (2,3,4,5,6,10), was corroborated by the findings of this study. Other factors, however, are also important in the reduction of starch yields. Figure 5 shows the marked degree to which the moisture content before drying affects the prime starch yield. Watson (6) found

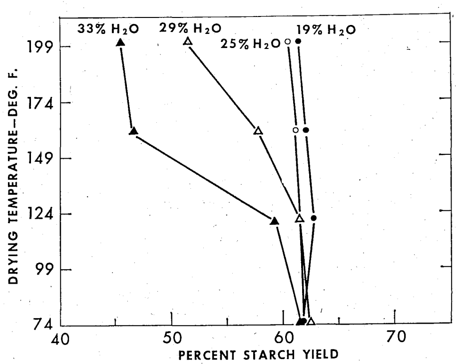

Fig. 5. Effect of drying temperature on starch yields at four different initial moisture contents.

that very high relative humidity (40%) of the drying air also tended to decrease starch yields at 180°F.

Relation between Displacement Values and Prime Starch Yields. Prime starch yields show an inverse relationship to the DV's (Fig. 6). Between the DV's of 0 and about 9 or 10 there is little or no reduction in starch yield. Above a DV of about 9 or 10 the prime starch yield declines sharply. Between 0 and 10.0 DV it may be assumed that only the initial stage of the denaturing process has taken place, and therefore the walls of the endosperm cells are not sufficiently hardened to prevent dissolution by the sulfur dioxide steep liquor.

Relation between Displacement Values and Glutamic Acid Decarboxylase Activities. Linko (12) showed that the correlation coefficient between the log of the glutamic acid decarboxylase activities (GADA) and germination is highly significant at the 5% level. Figure 7 shows the relation between GADA and the DV for the 32 samples from N.C. State and Purdue. The coefficient of correlation is +0.967, which is highly significant at the 5% level. In the statistical analysis, the rela-

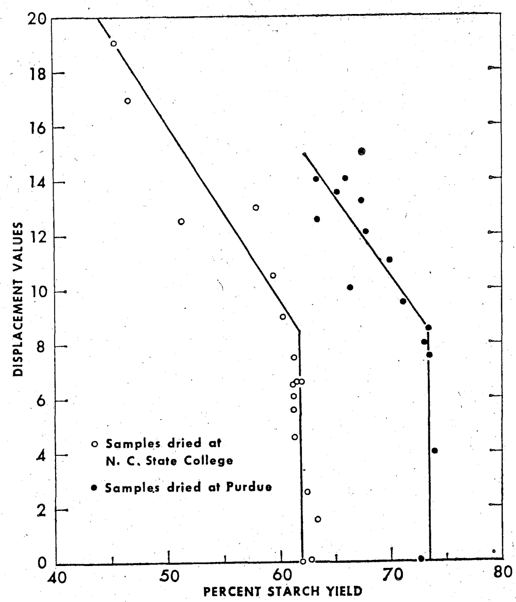

Fig. 6. Relation between starch yields and displacement value.

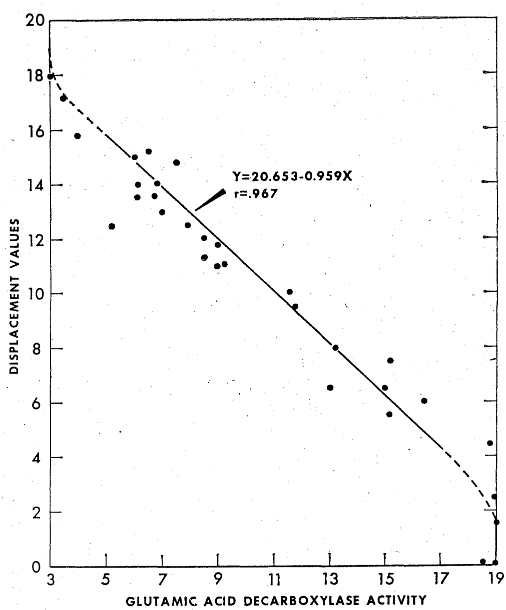

Fig. 7. Relation between glutamic acid decarboxylase activity and displacement value.

tionship was assumed to be linear, although it was noted that the points at the upper and lower ends of the graph appeared slightly curved. Only two different corn hybrids were involved in this study, and probably other hybrids will have a different activity for a given displacement value.

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