5

Marketing Research Report No. 631

STRESS CRACKS and BREAKAGE in ARTIFICIALLY DRIED CORN

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Transportation and Facilities Research Division

In cooperation with
PURDUE UNIVERSITY
Agricultural Experiment Station

SUMMARY

Shelled corn dried with heated air (140° to 240° F.) was two to three times more susceptible to breakage than the same corn dried with unheated air. Stress cracks (endosperm fissures), while practically nonexistent in crib-dried ear corn, were found in all samples of shelled corn dried artificially and accounted for much of the increased susceptibility to breakage. Such breakage contributes to downgrading of corn and to its susceptibility to molds and insect damage.

Other factors involved in breakage of corn, as indicated by laboratory breakage tests, are field shelling at high moisture levels and handling at low moisture levels or at low temperatures. Corn harvested at initial moistures near 30 percent broke easier than that harvested at 20-percent moisture. The amount of physical damage to the corn--broken, mashed, or scratched kernels--inflicted by the field sheller was higher in the wetter corn. Breakage increased as the amount of sheller damage increased.

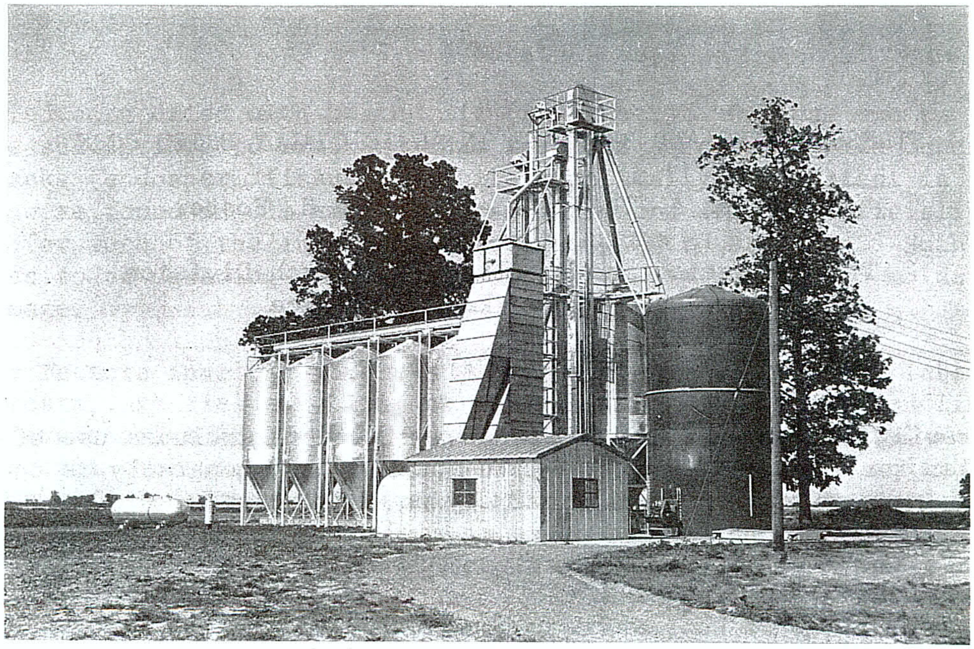
Drying speed, expressed in terms of moisture loss in percentage points per hour, was the most significant factor in stress-crack development. The number of stress cracks increased with increased drying temperatures and airflow rate, both contributors to drying speed. The amount of drying--the number of percentage points the moisture content is reduced--as well as the speed appears to affect stress-crack development. Puffing of kernels--more damaging than stress cracks--occurred, even though the number of stress cracks was reduced, when high-moisture corn was dried at drying speeds exceeding about 8 to 10 percentage points per hour. The crowns of puffed kernels were almost completely removed in breakage tests.

Most of the stress cracks were formed while corn was drying through the moisture range from 19 to 14 percent, according to laboratory and preliminary field tests. Rapid cooling of the dried corn added to the drying stress already present and increased the number of stress cracks.

Stress-crack evaluation can be useful not only in detecting corn that has been dried rapidly, but also in predicting increases in fine material that may be expected from breakage during handling.

Stress cracks in artificially dried corn are reduced (1) at slow drying speeds (especially through the range of 19 to 14 percent moisture) and (2) when cooling of the dried corn is delayed until after a tempering period.

No attempt was made to relate the results of laboratory breakage tests to the amount of breakage that might occur in handling operations common to the grain trade. However, the tests show that increased breakage may be expected if corn is (1) artificially dried with heat, (2) field shelled at high moisture levels, (3) handled at low moisture levels or at low temperatures.



BN-15829

Figure 1.--The experimental grain dryer used for "field tests."

The following variables were investigated in the field drying tests:

Drying treatment	Treatment level
Initial moisture content of corn, %	20
	30
Temperature of the drying air, °F	140
	190
	240
	290 (1962 tests only)
Airflow rate, cfm/bu	35 (1961 tests only)
	67
Drying method	Continuous flow
	Batch

The first year's tests were mainly exploratory and are not included in the table. Three commercial corn hybrids, all adapted to Indiana, were used for the tests. The corn was harvested with a field sheller, and dried to a final moisture content of about 14 percent.

Small samples of each test lot were also dried to about 14 percent in shallow screen-bottomed trays with forced air at room temperature. These samples, designated as initial or control samples, were used to evaluate the changes associated with the heated-air drying treatments.

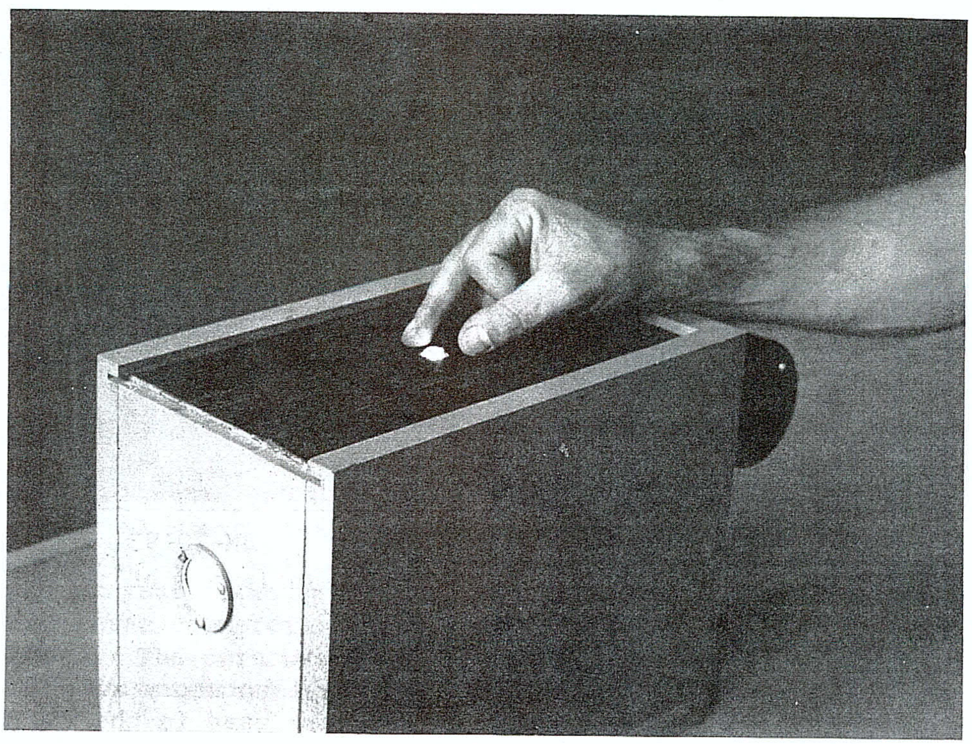
movement of the corn--were tested. Part of each sample was rapidly cooled with forced air and part slowly cooled in a vacuum bottle. Breakage tests and stress-crack evaluations were made on each sample.

Miscellaneous laboratory tests included a small test series comparing stress-crack development in corn dried on the ear with that in corn dried in shelled form. Other tests were made to explore treatments to reduce the development of stress cracks.

INCIDENCE OF STRESS CRACKS

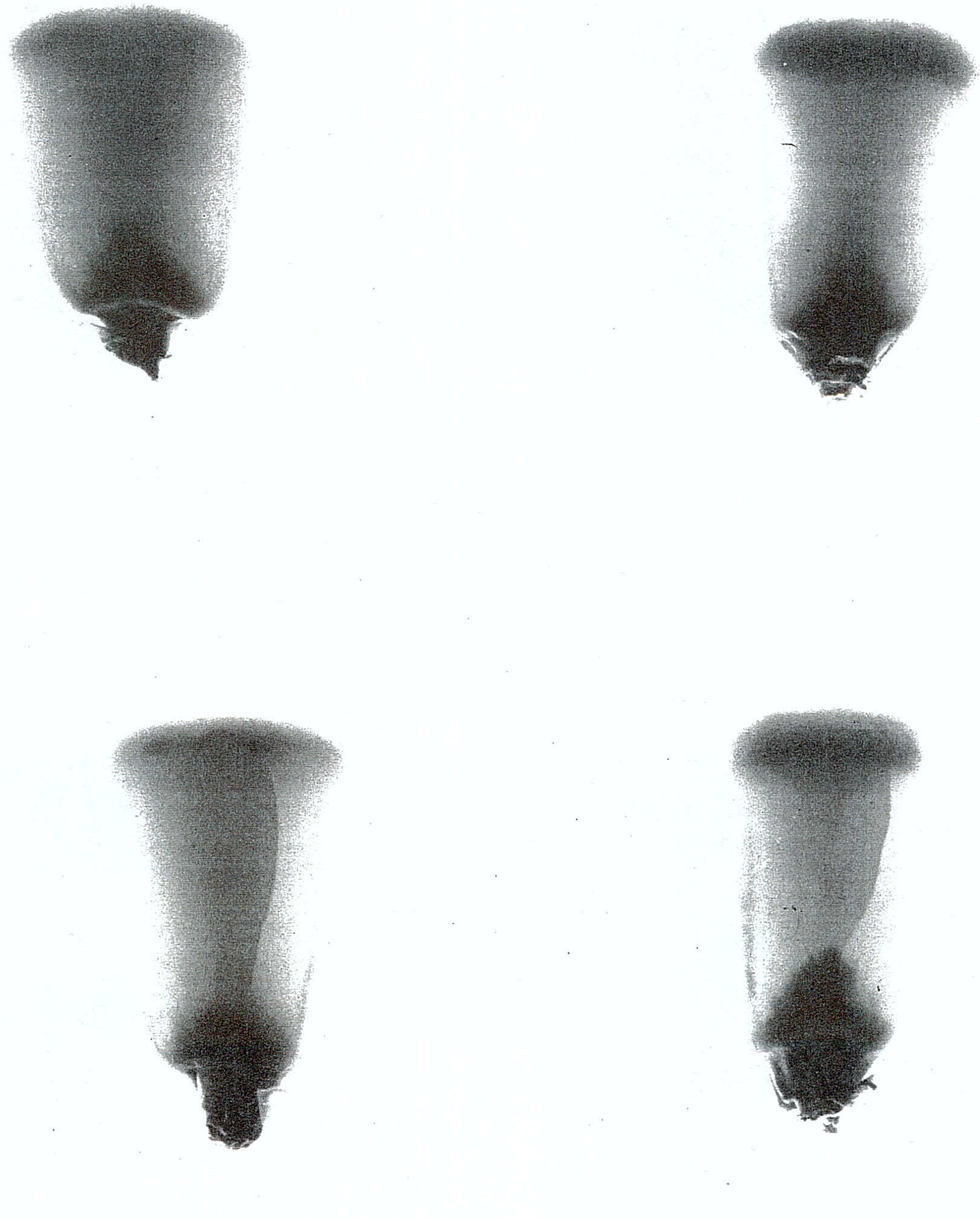
The shelled corn that was artificially dried exhibited characteristic cracks or checks. The cracks developed in the kernel endosperm; the seed coat was not ruptured. When the seed coat was removed by soaking or scraping, the endosperm broke easily at the stress cracks.

Stress cracks are readily visible under bright light and were evaluated in these tests by a simple candling process (fig. 3) (see appendix for details of procedure). The stress cracks were classified into single, multiple, or checked, according to the pattern formed in the kernel (fig. 4). The first indication of drying stress was a single crack, usually extending from the tip toward the crown of the kernel and visible on the side of the kernel opposite the germ. As stress increased, multiple cracks appeared, some kernels developing a checked or crazed appearance.



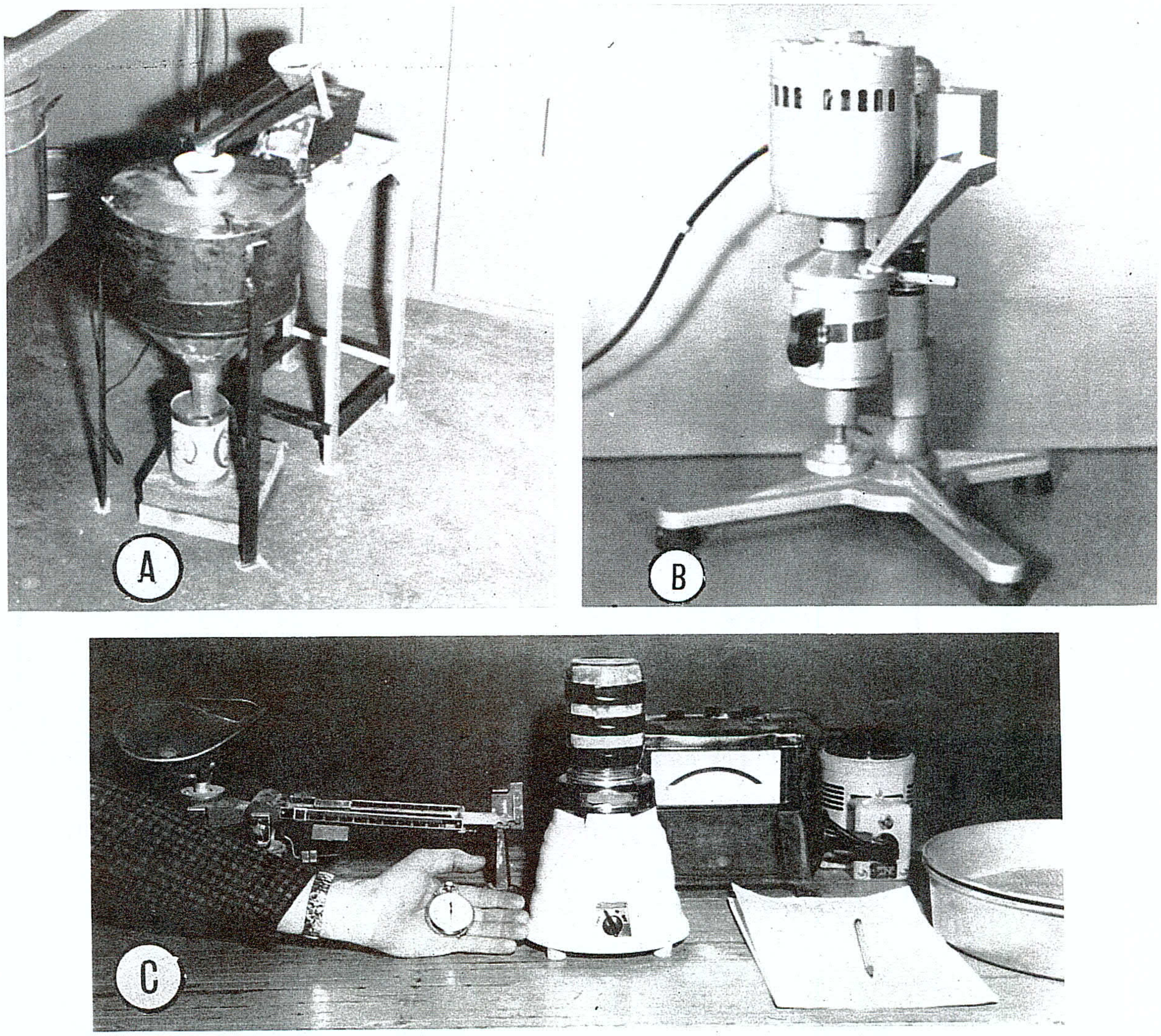
BN-20194

Figure 3.--The candling device used to examine corn for stress cracks.



BN-20201, 20202

Figure 4A.--Types of stress cracks in dried corn: Whole kernels (top); single stress cracks (bottom). See also figure 4B.



BN-20190, 20191, 20192

Figure 5.--The three breakage testers used: A. Modified peanut splitter. B. Commercially built tester. C. Modified food blender and accessory items.

Field Shelling Increases Breakage

For the corn field-shelled at 30-percent moisture, machine harvesting contributed about as much to the breakage as artificial drying. Over 2½ times as many corn kernels were damaged--broken, mashed, or scratched--when harvested at 30 percent moisture as when harvested at 20 percent. The relationship between the percentage of damaged kernels and the breakage after drying with unheated air is shown in figure 8. Fine material was removed from the test sample by screening with a 1/4-inch sieve before the breakage tests were made. The material removed averaged 3.5 percent in the 30-percent corn and 1.9 percent in the corn harvested at 20-percent moisture. This would normally be included in the breakage.

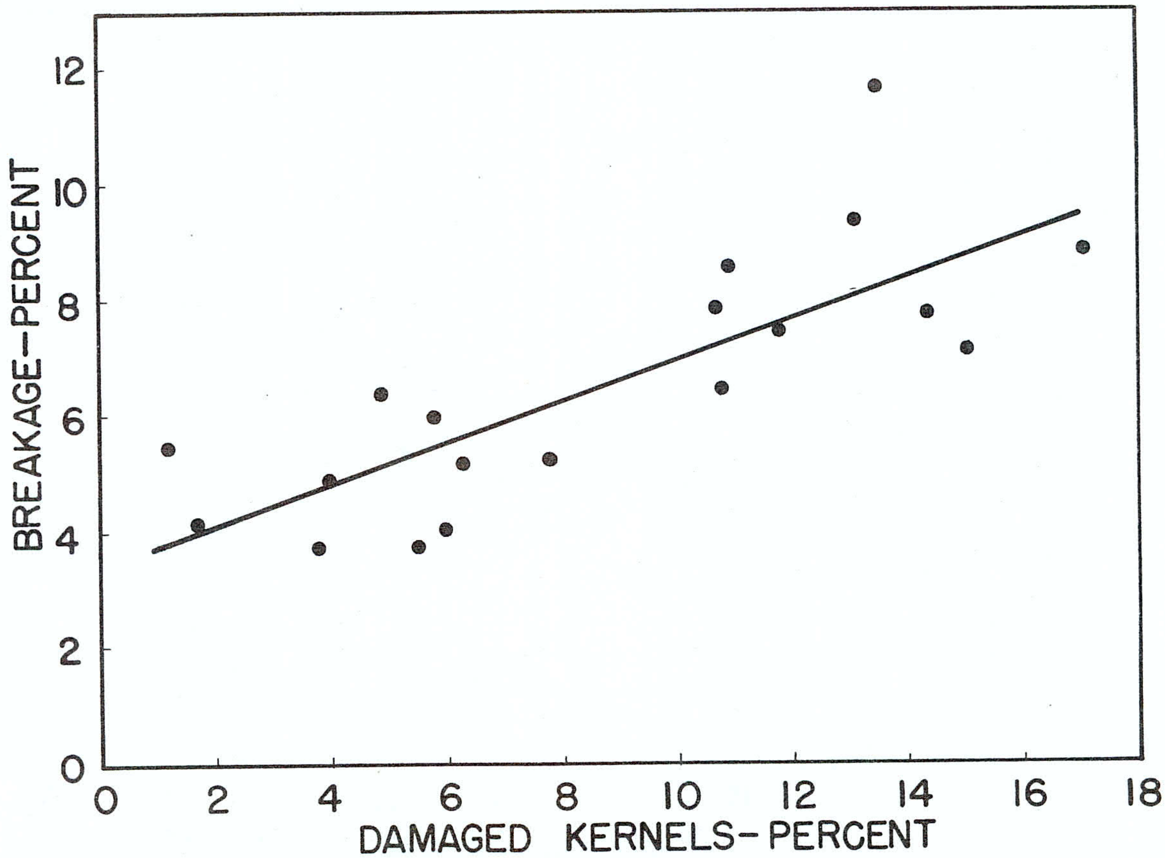


Figure 8.--Relation between sheller damage and breakage in corn dried with unheated air. The correlation coefficient between these two variables is 0.79 and the standard error from the regression is $\pm$ 1.35 (% breakage).

The effect of field shelling on breakage was confirmed also by comparisons of breakage in field-shelled corn with that in hand-shelled for some of the laboratory tests. Field-shelled corn had about twice the amount of breakage after drying.

RELATION OF STRESS CRACKS TO BREAKAGE

As the number of stress cracks in the corn increased, the susceptibility to breakage increased, as determined by the laboratory breakage tests. Figure 9 shows this relationship in terms of increase in breakage due to drying. The amount of breakage in the control sample dried with unheated air was subtracted from that in the sample dried with heated air, and the difference plotted against the percent of checked kernels. There are factors other than drying involved in corn breakage, as discussed earlier.

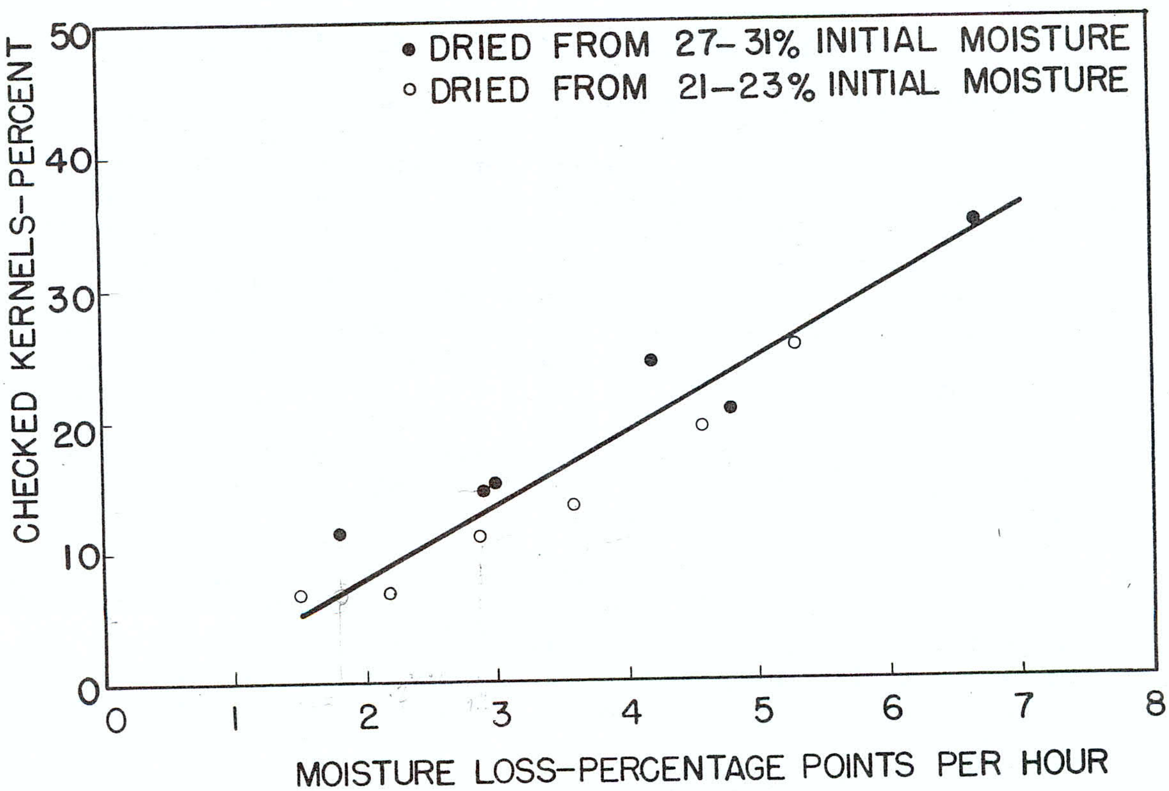


Figure 10.--Effect of drying speed on development of stress cracks in corn. The correlation coefficient between these two variables is 0.94 and the standard error from the regression was ± 2.90 (percent checked kernels).

A 1960 laboratory study compared stress-crack development during drying of ear and shelled corn from 20 to 14 percent, and demonstrated the importance of drying speed in stress-crack formation. The shelled corn dried 7 to 12 times faster than ear corn. When dried at 160° F., 100 percent of the kernels of shelled corn had multiple stress cracks, but only 3 percent of the kernels of ear corn had multiple cracks. In fact, more stress cracks formed in shelled corn dried at room temperature (80° F.) than in ear corn dried at 160° F.

Drying shelled corn with air temperatures of 290° F. resulted in puffing of the corn, as discussed in the section on breakage. The internal structure of the puffed kernel was changed sufficiently that the development of stress cracks was reduced. Three samples of 30-percent corn dried in the laboratory at 290° F. had only 10.7 percent checked kernels, while 6 samples dried at 240° and 190° F. averaged 43.8 percent checked kernels (see appendix table 3). The puffed samples had a test weight 5.5 pounds lower per bushel than the same corn dried with 140° F. air. When drying from initial moisture levels near 30 percent, puffing started at drying speeds of 8 to 10 percentage points per hour.

APPLICATIONS

Stress-Crack Determinations

Stress-crack evaluation is useful as a rapid method of detecting corn that has been artificially dried. The severity of the drying treatment is indicated by the number and type of stress cracks. As drying stress increases, single cracks develop into multiple cracks or checks.

None of the dried test samples had an equal distribution of single cracks, multiple cracks, and checked kernels. Large numbers of checked kernels and kernels with single or no stress cracks in the same lot might indicate that overdried and underdried corn were mixed.

There is some relationship between stress cracks and germination. A high percentage of checked or crazed kernels in a corn sample almost assures low germination. However, the absence of stress cracks does not assure high viability, since low germinating power may be caused by conditions other than those that cause stress cracks. Therefore, stress-crack determination may be used as a rapid method of detecting certain lots of corn unsuitable for commercial uses requiring corn with high viability. Dry millers expect less yield of large grits in dried corn with stress cracks. Small grits are less valuable than large grits.

Breakage Tests

The moisture content and temperature of the sample at the time the test is made influence the breakage perhaps even more than usual variations in the drying treatment. Figure 11 shows the effect of sample moisture on the tendency of shelled corn to break. The kernel became more friable as the moisture content was reduced. When moisture was reduced below about 13 percent, breakage increased rapidly. For this reason, all breakage comparisons were at moistures of approximately 13.5 percent. However, when breakage tests are used to indicate the breakage expected when the corn is handled commercially, the moisture level is an important test factor and should be representative of the lot of corn under consideration.

Lowering the temperature of the corn sample tested made it more brittle. When the temperature of some samples of corn was reduced from 84° to 42° F., the amount of breakage doubled. All the comparisons reported were made when the sample temperature was about 80° F. Here again, if the breakage test is used to predict breakage in a lot of corn to be handled, the test sample should be at the same temperature as the mass of corn to be handled.

CAN BREAKAGE AND STRESS CRACKS IN ARTIFICIALLY DRIED CORN BE REDUCED?

Test results indicated those factors in the artificial drying process that are related to physical changes in the corn kernel. Drying goes hand in hand with harvesting at high moistures. Mechanical damage during harvesting contributes to breakage and may be reduced by improving harvesters or by delaying harvest until corn is at a lower moisture level.

Avoiding overdrying and avoiding handling shelled corn while cold will reduce its susceptibility to breakage. Slow drying reduces stress-crack development. This applies particularly to drying through the moisture range from 19 to 14 percent.

Delaying cooling until after a tempering period appears beneficial. Applying steam to the corn immediately after drying apparently relieves the stress by wetting the outside of the kernel and making it less friable. Perhaps the hot corn provides its own steam during the tempering period. This steaming process may be more beneficial than the time delay in cooling.

Any pretreatment of the corn that will increase the ease of moisture transfer from the kernel to the drying air should allow the corn to be dried faster without increasing drying stress. Pretreatment should be investigated along with various posttreatments that will relieve drying stress before the stress cracks form.

APPENDIX

Stress-Crack Evaluation

A 50-gram sample of corn was prepared for stress-crack evaluation by first removing all foreign material. All broken, cracked, or otherwise physically damaged kernels were removed. Kernels with a "chalky" endosperm or other impairments that prevented the endosperm from being easily examined were also removed. Only those kernels that were not damaged and could be readily examined by candling were used.

The sample was examined for stress cracks by candling each kernel individually. The light for candling was passed through a small square glass-covered opening in a box containing a 150-watt incandescent lamp. The kernels were examined by holding the germ side toward the light source. It was often necessary to change the position of the kernel to see all the cracks. Samples usually contained from 130 to 150 whole kernels and took 15 or 20 minutes to inspect. As the sample was inspected, the kernels were sorted into three stress-crack categories--single, multiple, and checked. The percent of kernels in each category was then computed.

Breakage Determination

Samples of corn evaluated for breakage were first checked for moisture content with an electric meter. Whenever the samples were not at approximately 13.5 percent moisture content, they were conditioned in an atmosphere of about 80^{o} F. and 65 percent relative humidity. (Relative humidity was varied somewhat for corn dried at different temperatures.) Once the samples reached 13.5 percent, they were placed in plastic jars and sealed.

The conditioned samples were screened (with a 1/4-inch round-hole sieve) to remove broken kernels. The samples were then passed through a mechanical divider and reduced to 100 grams for the breakage test. After the prescribed time in the test device, the corn was removed and screened with a 12/64-inch round-hole sieve. The corn remaining on top of the sieve was weighed and the loss in weight calculated as the percent breakage.

Table 1.--Effect of artificial drying on breakage of shelled corn, field drying tests, 1960-62

Test factors compared	Average breakage	
	Control 1/	After drying
	%	%
Initial corn moisture		
17.5-23.2% (18 tests)	4.7	15.2
26.9-31.1% (18 tests)	9.8	20.1
Drying-air temperature		
140° F. (12 tests)	7.7	16.5
190° F. (12 tests)	7.2	17.1
240° F. (12 tests)	6.8	19.3
290° F. (4 tests-1962 only)	6.4	24.3
Drying method		
Continuous flow (18 tests)	7.5	18.1
Batch (18 tests)	6.7	17.2
Airflow rate (1961 tests only)		
32-37 cfm/bu. (11 tests)	8.2	15.8
62-72 cfm/bu. (12 tests)	7.9	16.4

1/ All control samples were dried in screen-bottomed trays with unheated air.

Analysis of variance showed the difference between the mean breakage after drying at the two moisture levels and the differences in the mean breakage among the three test years to be significant at the 1 percent level. Differences in the mean breakage among the three lower temperature levels and between the two drying methods were not significant at the 5 percent level.

Table 3.--Stress cracks and breakage in dried corn, 1962 laboratory tests 1/

Drying-air temperature	Initial moisture	Checked kernels: Cooled rapidly 2/	Checked kernels: Cooled slowly 3/	Breakage: Cooled rapidly	Breakage: Cooled slowly
°F.	%	%	%	%	%
290	30	4/ 10.7	0.1	16.7	6.4
	18	66.3	2.5	19.3	9.5
240	30	44.0	0.6	9.6	5.4
	18	45.1	3.2	15.3	10.8
190	30	43.7	2.4	8.8	4.2
	18	41.1	3.5	14.1	8.8
140	30	37.4	--	13.2	--
	18	18.2	4.7	14.2	10.7

1/ Average of three tests at each temperature and moisture level.
2/ Cooled immediately after drying with forced air at room temperature.
3/ Placed in vacuum bottle for 24 hours after drying.
4/ Kernels puffed from rapid drying.

NOTE: Corn used for 30% tests was hand-shelled and that used for 18% tests machine-shelled. Drying was stopped at about 14% moisture content.

Table 4.--Effect of artificial drying on stress-crack development in shelled corn, laboratory drying tests, 1961

Moisture reduction with 160° F. air 1/ from - -	Kernels with multiple stress cracks
%	%
22-18	5.0
22-16	86.9
22-14	100.0
22-12	98.2
22-10	98.1
21-16	94.0
19-14	97.5
17-12	89.1
15-10	23.1
14-12	26.4

1/ Initial moisture content of all samples before treatment was 22 percent. The samples listed in column 1 with initial moistures below 22 percent were dried to those initial figures by natural circulation of room air at about 80° F. and then were treated with 160° F. air. Similarly, all samples were dried to a final moisture of approximately 12 percent. Those samples listed in column 1 with final moisture contents above 10 to 12 percent were dried from the final figures shown to 12 percent by natural circulation of room air at about 80° F. after being treated with 160° F. air. Stress cracks were counted at the moisture level of 10 or 12 percent.