CORN QUALITY IN WORLD MARKETS

Highlights of an Interdisciplinary Conference for Researchers

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CAUSES AND CURES OF PHYSICAL DAMAGE TO CORN

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Physical damage is an important factor in corn quality, the subject of this conference. We often define physical damage in a negative sense—as being damage that is not from biological causes. It includes three main categories: (1) damage associated with harvesting, (2) damage associated with drying, (3) and damage from handling. Damage in any of the categories is not independent from that in the other categories; that is, the level of damage in one category may affect the level of damage in other categories. This will be discussed more fully later.

Another way of characterizing physical damage is in terms of its effect. Almost exclusively, physical damage to grain results in breakage and is manifested in terms of fine and broken material. Physical damage, especially that caused by harvesting and handling, is sometimes referred to as mechanical damage.

We now have a good idea of the cause and extent of physical damage to corn. However, the cure is not evident when one considers the constraints within which the problem must be solved. We could return to harvesting and handling corn on the cob and produce corn of near seed quality. But this would be a decided step backward in mechanization and would not permit the corn growers, who represent a relatively small percentage of our U.S. population, to produce the nearly 6 billion bushels of corn needed to satisfy our domestic market and to meet growing export commitments.

Damage Associated with Harvesting

The damage from harvesting is almost all physical damage, and most of the damage is caused by the shelling action of the field sheller. This problem has increased along with the increase in percentage of corn field shelled. If corn is field shelled at high moisture levels (above 25%), damage may be extensive.

The recent growth of field shelling in the central U.S. corn belt has been rather phenomenal. The percentage of corn that is field shelled increased from 12% in 1960 to 15% in 1966, and to near 75% in 1972.

Several reports have indicated the extent of damage associated with field shelling of corn. Studies at Ohio State University (3), although primarily concerned with the losses from field shelling, reported kernel damage in the form of broken material that would pass a 12/64-inch screen. Samples taken from the grain tank of farmers' combines averaged 1.5% broken material in 1964, 1.3% in 1965, and 2.3% in 1966. The range of broken material in individual samples was from 0.2% to 7.3%.

The Ohio field observations prompted a laboratory study by Hall and Johnson (9) to compare a combine cylinder sheller and an axial-flow sheller. Corn used in the test ranged in moisture content from 10% to 36%. Breakage was at a minimum at moisture contents between about 20% and 24% and was higher at moisture contents either above or below this range. Broken material increased as combine cylinder speed was increased from 400 to 600 r.p.m. Breakage with the axial-flow sheller fed at rates of 5 and 6 bushels per minute was less than the breakage from the combine cylinder.

Work by Waelti and Buchele (17) in Iowa showed that kernel damage was positively related to kernel moisture and that the relationship was logarithmic in the moisture range of about 15% to 38%. About 65% of the variation in sheller damage among varieties was accounted for by differences in moisture content. Earlier work by Johnson et al. (10) in Ohio, and by Burrough and Harbage (2) in Indiana also indicated increased damage with increasing moisture contents above 20%.

Kline (12) recently reported on machine damage to over 500 samples of shelled corn collected during the 1969, 1970, and 1971 harvests. Moisture content of the samples ranged from 16% to 32%. Seven makes of combines and one picker-sheller were used to harvest corn from which the samples were taken. Kline classified the damage in two categories. The broken corn he called "visible damage," which included all mashed and broken parts of kernels that were less than a whole kernel. Hidden damage was measured in the remaining whole kernels with the aid of green dye. Hidden damage in the form of hairline cracks and abraded pericarp was found in 40.5% of the corn. Only 5.5% of the corn was broken. The remaining 54% of the kernels were sound, without visible or hidden damage.

In connection with corn-drying research in Indiana, Thompson and Foster (16) reported on physical damage to corn caused by drying and by harvesting. Field-shelled corn had nearly twice as much breakage after drying as did hand-shelled corn. In corn harvested at 30% moisture content and then dried, field shelling contributed about as much to breakage as did artificial drying. Over 2 1/2 times more kernels were damaged in corn harvested at 30% moisture content than in corn harvested at 20% moisture content.

In more recent corn-drying tests conducted in Indiana by the author and co-workers, corn harvested with a field sheller was evaluated not only for the fine broken material separated by screening, but also for the percentage of damaged kernels. In crop years 1965 through 1968, the average moisture content at harvest varied from 19.6% to 32.4%. The percentage of mechanically damaged kernels ranged from 7.4% in corn having the lowest moisture content to 46.4% in corn having the highest moisture content. In 1969 the type of corn grown for the drying tests and the type of harvesting machine were both changed. Average moisture contents of various lots of corn harvested from 1969 through 1971 ranged from 20.6% to 26.5% and the percentage of damaged kernels ranged from 9.4% to 19.7%. These data are summarized in Figure 1 and show a positive correlation between moisture content at harvest and the percentage of damaged kernels. However, the obvious and distinct difference between the data from 1965-68 and from 1969-71 shows that factors other than moisture content, such as variety and machine type, also affect the amount of harvest damage to corn.

So there are at least three important contributing factors in physical damage to corn during harvest: (1) the moisture content at which the corn is harvested, (2) the machine type and method of operation, and (3) the type of corn or hybrid variety grown. In the machine factor, proper adjustment of the machine for the crop and weather conditions under which it is operating is

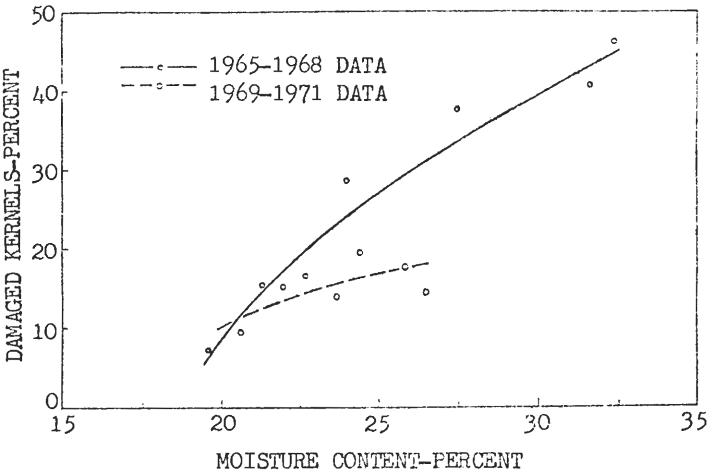

FIGURE 1: Damage vs. corn moisture at harvest.

equally as important as the type of machine. For example, the Ohio data referred to (9) show the adverse effect of operating combines at cylinder speeds higher than is necessary to remove kernels from the cob.

Damage Associated with Drying

Two types of damage are attributed to artificial drying, but only one type results in physical damage to corn. Brittleness caused by rapid drying is the most prevalent damage in artificially dried grain. The other type of drying damage, overheating, although indirectly contributing to the brittleness of dried grain, is characterized by scorching and discoloration of corn and by certain chemical changes in the protein which make starch and gluten separation difficult in wet milling.

Increased brittleness in artificially dried corn is manifested in stress cracks, or checking of the kernels. Stress cracks in corn are similar to the checks in rice that lead to reduced milling yields of whole kernel or head rice. Stress cracks form in the corn endosperm, but the seed coat or pericarp is not ruptured. However, when the seed coat is removed by soaking or scraping, the endosperm is easily broken at the stress cracks. Thus it appears that stress cracks in corn and checking in rice are similar, except that the corn pericarp is tougher and tends to hold the fissured endosperm intact.

Stress cracks in themselves are not bad, except possibly in corn for dry milling, but they lead to increased breakage when corn is handled. In our early work on corn drying, we showed (16) that shelled corn dried with heated air is two or three times more susceptible to breakage than corn dried with unheated air. The breakage, as determined in a sample breakage tester, was the percentage of the sample that passed a 12/64-inch round hole sieve after testing. As the number of checked kernels in the sample increased, there was a linear increase in breakage. However, a 10% increase in the percentage of checked kernels resulted in only about a 2% increase in breakage.

The number of stress cracks in corn increased with increased drying temperature and airflow rate, factors that contribute to drying speed. Stress cracks, although practically nonexistent in crib-dried ear corn, were found in nearly all samples of shelled corn that was dried artificially (16). There were more stress cracks in corn when drying started from high initial moisture levels; however, most of the stress cracks formed near the end of the drying period while the corn was drying through the moisture range of about 19% to 14%.

Ross and White (14) reported on stress cracking in white corn as affected by drying temperatures, cooling rates, and overdrying. Stress cracking increased as drying air temperature was increased from 130° to 220° F. Corn dried to final moisture levels of between 10% and 14% had 70-90% checked kernels.

When high-moisture corn is dried rapidly, the bulk density or test weight of the dried corn is reduced. In some of our laboratory tests, the test weight of corn dried from 25% to about 10% moisture content in an unheated room increased about 5 pounds per bushel. Similar corn dried with air heated to 200° F. increased in test weight less than 3 pounds during drying. Hall (8), in Illinois, found similar comparisons between corn dried with and without heat. He also reported a wide variation in the bulk densities of different hybrid varieties, both before and after drying.

Kline (12) reported on the breakage in samples collected before and after drying, in addition to the data reported on the damage from field shelling. The procedure for the breakage tests was similar to that described above. There was 5.5% breakage in the samples taken before drying, and 12.7% in the samples taken after drying.

To summarize, the physical damage associated with drying is largely in the form of stress cracks and breakage. Stress cracks directly affect the ability of millers to salvage intact endosperms and generally reduce the number of large, premium grits produced in dry milling. Stress cracks also contribute to the breakage in corn during its handling. Also associated with drying is the puffing or expansion of the corn, which reduces its bulk density. All of these types of damage are related to drying speed. Heat damage caused by excessive drying temperatures probably does not contribute directly to physical damage but does result in chemical and other changes that are undesirable.

Damage Associated with Handling

When corn is handled by elevators and conveyors, or by gravity, it tends to break. Most of the breakage is from impact; abrasion is little involved. In a study of breakage caused by commercial handling methods (7), a falling grain stream impacting the bottom of a grain bin caused more breakage than any other handling operation tested. In this study there were 160 tests with corn, in addition to tests with wheat, soybeans, and dry edible beans.

Corn used in the breakage study was grown in 1966 and 1967. Physical properties of the corn were judged to be similar to those of corn that had been mechanically harvested and artificially dried with heated air. The handling tests, conducted with full-scale equipment, included dropping grain in free-fall and through spouting, elevating it with a bucket elevator, and handling it with a grain thrower. Results were measured in terms of the amount of breakage removed by screening. The breakage removed was approximately the same as the fine and broken material that would be removed from a sample of grain when determining its grade according to U.S. Grain Standards.

Breakage in corn ranged up to 14% in tests in which the grain stream was dropped 100 feet and impacted on a concrete surface inclined 45°. Drop height was the most significant test variable in the free-fall drop test, and the average breakage in corn ranged from 2.5% at a drop height of 40 feet, to 10.2% at 100 feet. When the grain stream impacted the inclined concrete surface, the breakage averaged 7.7%, as compared with 6.0% when it impacted other corn.

Corn was dropped through vertical spouting with a 90° turn at the end that directed the stream against a vertical bulkhead located 20 feet from the spout. This arrangement simulated the handling operation involved in filling rail cars. Drop heights of 40 and 100 feet were used. The average breakage was 3.2% in 12 spouting tests, as compared to 6.3% average breakage in 18 free-fall tests. It was reasoned that the change of velocity in the 90° turn reduced impact and accounted for the reduced breakage in the spouting tests.

Breakage in corn handled with a grain thrower averaged about 1.6%, only half of that in the spouting tests, and one-fourth of that in the free-fall drop tests. The breakage increased from 0.8% to 2.4% when the belt speed was increased from 1,889 to 4,030 feet per minute (f.p.m.). The grain stream from the thrower impacted either a wood or steel bulkhead; the impact with the wood bulkhead resulting in slightly less breakage.

In the bucket elevator tests, only the damage occurring in the boot was measured. Breakage was less than in the other handling operations and was about the same at the two elevator belt speeds tested. A surprising result was that when the elevator was fed on the back or downleg side, the breakage was slightly less than when the elevator was fed on the front or upleg side. Apparently the breakage was caused by impact between the grain and the bucket, rather than from abrasion caused by dragging grain through the boot.

Of the two levels of corn moisture tested—about 13% and 15%—there was consistently less breakage at the higher moisture level. There was also less breakage when the corn was handled at temperatures above 70° F. than when it was below 50° F. Tests with a combination of the lower corn moisture and temperature resulted in five times as much breakage as in tests with a combination of the higher moisture and temperature.

One of the striking results from these tests was the effect of repeated handling. The amount of breakage was cumulative and remained about constant each time the same lot of grain was handled or dropped, up to four times. This was true regardless of whether or not the broken material was removed from the test lot before the second and subsequent handlings.

The grain stream and particle velocities were measured in some of the tests with a high speed motion picture camera. The velocity of the grain stream in free-fall exceeded the terminal velocity of individual seeds falling in air. Grain breakage was closely related to the velocity attained at impact and was found to be an exponential function of grain and stream velocity. For example, the velocity of the grain leaving the grain thrower operating at the highest belt speed was approximately that of a stream after falling 40 feet. Also, the breakage was approximately the same.

In pneumatic conveying systems, air velocities range from two to three times the terminal velocity of individual seeds. Velocities between 4,000 and 5,000 f.p.m. are common for handling grains. Chung and coworkers (4) reported on damage to corn from pneumatic conveying when conveying velocities ranged from 3,960 to 7,200 f.p.m. Breakage in corn conveyed at velocities up to 5,000 f.p.m. was less than 2% at conveying distances up to 1,600 feet. At conveying velocities of 7,200 f.p.m., the breakage ranged up to 22% in 12% moisture corn. The corn used was harvested by combine but was not dried with heat. The tests were conducted in a laboratory conveying system of 200 feet total length constructed from 2-inch pipe having 24-inch-radius elbows. The grain was decelerated in a cyclone separator and passed through the conveying device repetitively to accomplish conveying distances greater than 200 feet. Under these conditions, breakage at conveying velocities of 4,000 f.p.m. was only one-tenth that in free-fall tests in which the velocity of the corn was near 4,000 f.p.m. at impact. Corn used in the free-fall tests was heat dried and more brittle than the corn used in the pneumatic tests. This difference in brittleness probably accounted for part of the difference in breakage levels.

Keller et al. (11) reported on corn kernel damage from high velocity impact. They used hand-shelled corn dried with room air. The corn was accelerated in a pneumatic system and directed toward an impact surface contained within a mesh enclosure from which the treated sample was recovered. Variables tested included kernel velocity, moisture content, impact surface, angle of impact, and size and shape of corn kernel. Kernel velocity contributed more to kernel damage than any of the other variables tested. Corn having moisture contents below 15% had greater damage levels than did more moist corn. With a urethane impact surface, kernel damage was one-fifth that with a steel surface, and one-sixth that with a concrete surface. Reducing the angle of impact from 90° to 45° also reduced the damage. The damage was measured in terms of cracked kernels and broken kernels, but did not include a separate category for breakage separated by screening.

Sands and Hall (15) reported on damage to shelled corn during transport in a screw conveyor. They used corn dried with both ambient air and air that was heated to 240° F. They found that when a screw conveyor was operated at full capacity, it caused negligible damage (less than 0.1% breakage) to dry shelled corn. When it was operated at one-fourth capacity, corn breakage ranged from about 0.1% at 275 r.p.m. screw speed to about 0.7% at 865 r.p.m. Only when the conveyor was transporting heat-dried corn at one-fourth capacity for the full distance of 150 feet did the breakage exceed 1%.

To summarize, the damage associated with handling of corn appears to be caused principally by impact. The more abrasive action that occurs when corn moves through auger conveyors or through pneumatic conveying systems does not cause extensive damage as compared with that when falling grain streams impact solid surfaces. It is also evident that the brittleness of corn contributes to the resulting breakage. In all comparisons made, the handling of heat-dried corn resulted in more breakage than the handling of corn dried without heat. There was also more damage in corn handled at lower moisture contents and lower temperatures.

Approaches to Reducing Physical Damage

Some of the causes of physical damage suggest appropriate cures. Obvious approaches are to have tougher corn or to handle it more gently, or both. The question is how to best accomplish these objectives. It is also obvious that the causes of physical damage are interrelated. Damage done by harvesting machines may show up when the corn is handled, but only after it is made more brittle by artificial drying.

Considerable progress has been made and promising leads developed on methods to reduce physical damage. Iowa researchers (5) and others have shown that hybrid varieties differ in their adaptability to mechanical harvesting. Size of the cob and its tendency to break up in the combine cylinder are factors affecting the amount of damage in field shelling. I am sure that plant breeders are capable of improving shelling characteristics of hybrid corn. Use of shorter-season hybrids, a practice which is gaining favor—particularly now with the shortage of fuel for drying, will permit harvesting corn at lower moisture contents with less physical damage.

There is also the possibility of a break-through in shelling technique. Iowa engineers (1) have been exploring the use of rubber rolls and belts to accomplish shelling, as well as attempting to analyze the shelling action in conventional combine cylinders. In one study (13), it was shown that ears oriented such that they rolled into the cylinder with the ear axis parallel with the cylinder axis suffered only half as much damage in shelling as those that entered the cylinder tip and first. Regardless of ear orientation, the moisture content for minimum damage was between 20% and 22%.

Brittleness imparted to corn by rapid drying can be relieved by modifying drying procedures. Our recent work in Indiana in cooperation with Purdue University was directed toward methods of limiting damage from high-temperature drying of field-shelled corn. This work has been reported in summary form (6).

The dryeration process was the result of our first effort to reduce brittleness in heat-dried corn. Key to this process is a tempering period following heat drying. The corn is then cooled slowly by aeration. Dryeration prevents most of the stress cracks associated with rapid drying and reduces the breakage tendency of the corn by about 50%. Dryeration has been widely adopted by grain firms involved with export corn that must be handled repetitively. Farmers and commercial grain people find dryeration an advantage if they have a special market or need to produce corn that is less brittle. The extent to which dryeration and other modifications of the drying method can reduce the brittleness of dried corn is shown in Table 1.

We can also handle corn more gently. Impact forces can be reduced either by reducing the velocity of the grain at impact or by using more resilient impact surfaces. The effectiveness of urethane surfaces in reducing impact damage was shown by Keller et al. (11). Lining impact areas with resilient material appears to be a practical solution to part of the problem. Use of spout flow retarders, bin ledges, or other means of reducing drop heights will lower grain velocities and thus reduce impact forces. Evaluation of these types of devices, along with other more novel methods of reducing grain velocity and impact damage are currently under study at the Grain Marketing Research Center in Manhattan, Kansas.

It will likely be impractical to eliminate all of the breakage in corn and other grains. How best to cope with the remaining breakage in terms of its distribution within the grain bulk and its effect on storage conditions, particularly those related to conditioning processes in which air is passed through grain, is also under study at the Grain Research Center.

I think that the greatest current need is for practical methods of evaluating physical damage and factors such as brittleness that lead to breakage. We cannot adequately reward producers and handlers of quality grain unless we can measure physical damage and other quality factors. Such measures must be accurate and fast enough to apply at appropriate points in the marketing chain. Given this measuring ability, rapid development of less damaging harvesting methods and equipment, drying regimes, and handling systems would surely follow.

TABLE 1: Effect of drying method on brittleness of dried corn.[a]

Drying Method	Sound Kernels (without stress cracks)	Breakage[b]
	Percent	Percent
Conventional continuous-flow	8.8	11.3
Dryeration	60.6	6.7
Two-stage dryeration	72.0	7.0
Partial heat drying	82.2	3.9
Unheated air	93.3	1.6

a. This summary includes more than one year of research. Tests of the first three drying methods were conducted in 1964 with corn at 25% initial moisture content. The other two methods were tested in 1968 with 23% moisture content corn and in 1969, with 26% moisture content corn in the partial heat drying tests; 20% moisture content corn was used in the unheated air drying tests. In partial heat drying, heated air was used to dry the corn to about 20% moisture, followed by cooling and completion of drying by aeration. Data are averages of three tests for each of the first three drying methods, and of eight tests for the last two methods listed.

b. Breakage as determined in a sample breakage tester and defined as broken parts of kernels that will pass through a 12/64-inch round-hole screen.

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