DRYING MARKET CORN

by G. H. FOSTER [1]

(Reprinted from the Proceedings of the 20th Annual Hybrid Corn Industry-Research Conference 1965)

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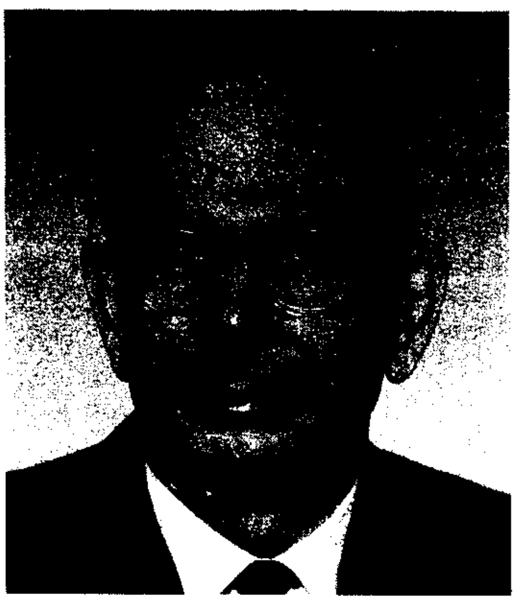
LARGE VOLUMES OF CORN are harvested by field shellers or corn combines at moisture contents considerably above those acceptable for market or storage. Field shelled corn, especially that harvested at high moisture levels, is susceptible to rapid deterioration and must be dried within a few hours after harvest. The deluge of wet shelled corn, with its increased perishability, has strained the capacity of drying facilities, both on the farm and at the elevator. The kernel damage from shelling at high moisture makes it more difficult to produce dried corn of acceptable market quality.

From a market quality standpoint, there are two main areas of concern when drying corn. The first is brittleness or breakage susceptibility. Nearly all buyers of market corn, particularly the dry miller and the exporter, are concerned about brittleness. The second is related to the temperature the corn reaches during drying and is of principal concern to wet millers. Except for livestock feed manufacturers, the wet process millers are the largest users of market corn. They separate and refine the corn into starch, syrup or sugar, and oil. If the corn has been damaged by overheating, the separation becomes more difficult, if not impossible. The dry miller is more concerned with brittleness since it is difficult to produce large premium grits from brittle corn full of stress cracks. The exporter's problem stems from the number of times the corn must be handled from its point of origin to its point of use. Each handling adds to the amount of fine material, and it is almost impossible to deliver some artificially dried corn in satisfactory condition.



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The wet milling quality of artificially dried corn has received the most publicity and has been the subject of previous research. MacMasters and co-workers, working principally with corn dried in the laboratory by Ramser (2) at the University of Illinois, showed that drying temperatures in the range of 120° to 200°F. had a significant effect on important wet milling properties (3). On the basis of recovery and quality of starch, acceptable processing of corn was obtained in the laboratory when the grain had reached a temperature as high as 160°F. The authors stated that "drying conditions were such that the corn doubtless reached the temperature of the drying air," but no corn temperatures

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were reported and the grain-air volume ratio used in drying was not specified. Control samples were dried with room air. The difference in starch recovery between the control samples and those dried with heat was significant (five per cent level) in only one of the five crop years covered by the tests. However, variation among years was significant in both starch recovery and in the percentage of protein mixture in the starch. Also, the trend of starch recovery was downward with increasing drying temperatures, with a marked and significant difference between samples dried at 180° and 200°F.

S. A. Watson, after reviewing work of others and citing laboratory milling tests from corn dried in a small-scale continuous column dryer, concludes that corn heated above 140°F. is undesirable for milling by the wet process (5). He states that overheating corn will result in a lower yield of starch with higher protein mixtures because the protein matrix holding the starch in the endosperm cells will not soften in steeping and will not release starch on milling. Further, corn heated to the starch gelatinization temperature of 160°F. causes serious impairment of fiber screening and starch separation processes in wet milling, even though such corn is present in small amounts.

DRYING TESTS CONDUCTED

A series of drying tests were designed to investigate the principal controllable variables in the drying process and to determine their effect on (1) drying capacity and efficiency and (2) the quality of the dried grain.

The results from 52 drying tests in a field-scale dryer and eight drying tests in a laboratory dryer conducted over a four-year period, 1960-63, inclusively, are used as a basis for this report. Variables studied in the drying process included:

Drying air tempertures—140, 190, 240, and 290°F.

Initial corn moistures—20-30 per cent.

Drying methods—batch and continuous-flow.

In addition, single year tests were made to compare two types of batch dryers, and to compare two different airflow rates and drying speeds.

This paper reports the effect of drying on wet milling properties and reviews the previously published material on the effect of drying on the brittleness of corn. The tests differed from those of MacMasters (3) in these ways:

1. Drying was done both in a full-scale dryer under field conditions and in the laboratory.

2. Higher drying air temperatures were used for some of the tests.

3. The actual corn temperature was measured along with the air temperature entering and leaving the dryer.

4. The corn was harvested with a field sheller.

5. The volume of air used in the field tests was typical of that used under practical drying conditions.

All the corn for the tests was grown on the Purdue Agronomy Farm near Lafayette, Indiana, under essentially the same cultural practices. For any one year's tests, the corn used was all the same hybrid. A different hybrid was used each of the four years.

Field-Scale Drying Tests

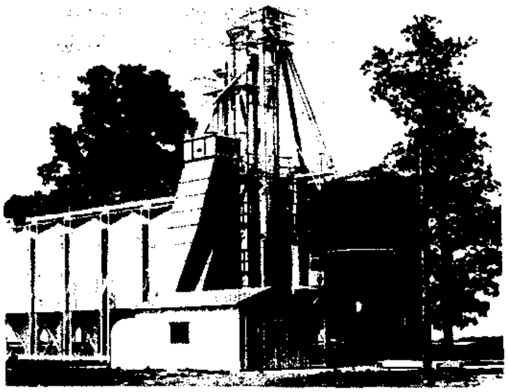

Figure 1

The Experimental Grain Dryer Used for the "Field-Scale Tests."

The field-scale tests were made at an experimental drying facility located on the Purdue University Agronomy Farm (Figure 1). The dryer was a continuous-flow tower type dryer typical of those used at country elevators. The drying section held about 200 bushels and the cooling section about 165 bushels. The grain moved down through the dryer past alternate rows of intake and exhaust air ducts spaced on one-foot centers. A metering device at the bottom controlled the grain flow rate and was set according to the moisture to be removed and the drying potential of the input air. Heated air was supplied at a nominal rate of 70 cubic feet per minute (CFM) per bushel.

The temperature of the drying air was measured as it entered and left the dryer by a system of thermocouples. The corn temperature was measured as the hot corn was discharged past a grid of 18 thermocouples positioned where there was negligible air movement.

The corn was dried to a moisture content of near 14 per cent. The test lots of corn varied in size from 200 bushels in some of the batch tests of 400 bushels in some of the continuous-flow tests. Samples from each test lot were removed as the wet corn entered the dryer, at three to five intermediate points in the dryer and as the dry corn was discharged. Three sets of samples were taken, each representing approximately each third of the test lot. The moisture and temperature of each sample were measured. The wet samples were then dried to 14 per cent with room air and all samples stored for subsequent quality evaluation.

Laboratory Tests

Laboratory drying tests were included in 1962, and the corn used was from the same lot as that used in the field-scale tests. The corn was stored at 40°F. and the laboratory tests were made during the winter following harvest.

The corn was dried by forcing air through samples in screen-bottomed trays in a laboratory dryer. The drying air temperatures used in the laboratory tests were the same as those used in the field-scale tests. However, the ratio of heated air volume to grain volume was much higher in the laboratory tests, a difference that will be discussed more fully later.

Evaluation of Wet Milling Properties

The suitability of the dried corn for milling by the wet process was evaluated by laboratory milling tests. The components of the corn were separated and their yield and purity determined. The procedure followed was essentially that used by MacMasters (3), except that the separation of the starch and gluten fractions was by tabling rather than by centrifuging.

TABLE 1

Starch yield as related to drying temperature, drying method and initial corn moisture level.

Corn Moisture %	Drying Method	Drying Temperature °F.	1960 %	Starch Yield—% of Dry Corn Weight 1961 %	1962 %	Average %
30	Continuous Flow	140	62.3	62.1	57.3	60.6
		190	62.6	63.0	56.6	60.7
		240	61.6	60.0	54.5	58.7
30	Batch	140	66.2	60.6	58.0	61.6
		190	......	63.6	55.9	59.8
		240	58.5	59.0	52.8	56.8
30	Control Samples	Room Air	64.4	63.5	60.3	62.8
20	Continuous Flow	140	60.9	63.4	62.0	62.1
		190	62.9	63.5	56.0	60.8
		240	60.9	60.6	50.3	57.3
20	Batch	140	62.4	63.3	56.2	60.6
		190	......	64.2	54.2	59.2
		240	60.0	58.7	53.3	57.3
20	Control Samples	Room Air	65.0	63.6	59.1	62.5

The wet milling procedure and the analysis of fractions were carried out by a private chemical laboratory under a research contract.

QUALITY EVALUATION OF DRIED CORN

Presented first are the results of the wet milling evaluation of corn from the drying tests that were repeated in each of the first three years of the test period. The results of tests run on a single year basis are presented next, followed by a discussion of the relationship of corn temperature to drying air temperature. The discussion on the brittleness of dried corn is based in part on tests made in 1963.

Results of Wet Milling Tests

Starch Yield: Starch and its derivatives are the main products of the corn refining industry, and the effect of drying practices on the starch yield and purity is of concern to corn millers.

The starch yields from corn dried in tests conducted over the three-year period, 1960-62, are given in Table 1. The average starch yield from all the drying tests was near 60 per cent. The control samples dried without heat yielded from 59 to 65 per cent starch with an average of 62.6 per cent.

The drying air temperature was the only variable that significantly affected starch yield. There was no difference in the starch yield of corn dried from 30 per cent initial moisture and that of corn dried from 20 per cent. The difference in starch yield between the corn dried by the batch and that dried by the continuous method was less than one per cent.

Since the treatment variables other than temperature did not significantly affect starch yield, the temperature effect will be discussed on the basis of averages of all tests from the three years. Compared to the control samples with an average starch yield of 62.6 per cent, drying at 140°F. resulted in a reduction in starch yield of 1.4 per cent. At 190°F. drying temperature, the starch yield averaged 60.2 per cent, a further reduction of 1.0 per cent from that in the tests at 140°F. The starch yield from corn dried at 240°F. averaged 57.5 per cent, 2.7 per cent lower than at 190°F., a difference that was statistically significant according to Tukey's significant difference procedure.

The starch yields from the samples from the 1960 and 1961 tests were about the same, but those from the 1962 tests were significantly lower. In 1962, the milling quality tests were run at a different location under conditions somewhat different than in the previous two years. It is not known how much of the reduction in level of starch yield in 1962 can be attributed to measurement technique and how much to the growing conditions for that crop year.

Protein Mixture: Excessive protein in the starch is indicative of poor separation of the gluten and starch fractions in milling. Temperature was the only drying treatment that adversely affected protein mixture. The protein mixture in the control samples averaged 0.38 per cent, a value considered normal for corn of good milling quality. With drying air temperatures of 140° or 190°F., only one test produced milled starch with a protein mixture above 0.41 per cent. At 240°F., protein mixtures in the starch ranged from 0.33 to 0.86 per cent, with only the corn from the 1961 tests at or below the average for the control samples.

Batch or continuous drying methods had no consistent effect on the protein in the starch and there was no difference in the corn dried from 30 and 20 per cent initial moistures.

Starch in Fiber: Excessive starch attached to and separated with the fiber is considered by millers as indicative of poor milling. The starch in the fiber fraction separated by laboratory milling of the test lots of dried corn varied from 7.6 to 44.6 per cent and averaged 22 per cent of the total weight of the fraction. The six control lots averaged 16 per cent. Despite the dried lots' having more starch in the fiber, there was no consistent relationship with drying temperature or initial corn moisture. Comparing drying methods, the batch-dried corn had 1.4 per cent more starch in the fiber in the 30 per cent tests, and 6.9 more in the 20 per cent tests.

Oil Yield: Corn oil has increased in value with the recent increased demand for fats high in unsaturated fatty acids. The yield of oil from corn averages about 1.5 pounds per bushel, or about three per cent of the corn dry weight.

The corn heat-dried from 30 per cent initial moisture had an average oil yield of 2.7 per cent of the corn weight, compared to 3.1 per cent for the control samples dried without heat. Dried from 20 per cent initial moisture, the oil yield of the heat-dried samples averaged 2.9 per cent and the control samples averaged 3.0 per cent.

In the tests with 30 per cent corn there was some reduction in oil yield as drying temperature was increased. This trend was reversed in the corn dried from 20 per cent moisture, with 0.1 to 0.2 per cent higher oil yields at the higher drying temperatures.

None of the relationships between oil yield and drying treatment were significant at the five per cent level.

Tests at Higher Temperatures

Since the effect of drying air temperature on milling quality was not as pronounced as expected in the tests in 1960 and 1961, tests with 290°F. air temperature were added in 1962. Figure 2 shows the three-year average starch yield for drying at room temperature, at 140°, 190°, and 240°F., and the yield in 1962 for drying at 290°F. The 290°F. tests included two continuous and two batch tests. The starch yield for the four tests averaged 48.8 per cent, nearly nine per cent less than the three-year average for the 240°F. tests but only four per cent less than the 240°F. tests in the same year. The protein mixture in the starch increased threefold, and the starch in the fiber increased from 30 to 41 per cent when the drying temperature was increased from 240° to 290°F. There was no reduction in oil yield at the higher drying temperature.

Other Batch Drying Tests

In the 1960 season, a conventionally designed portable batch dryer was used to verify the results obtained with batch operation of the tower dryer. Conditions were the same for the two series of batch tests, except that the drying air supplied was about 70 CFM per bushel in the tower dryer and about 45 CFM per bushel in the portable dryer.

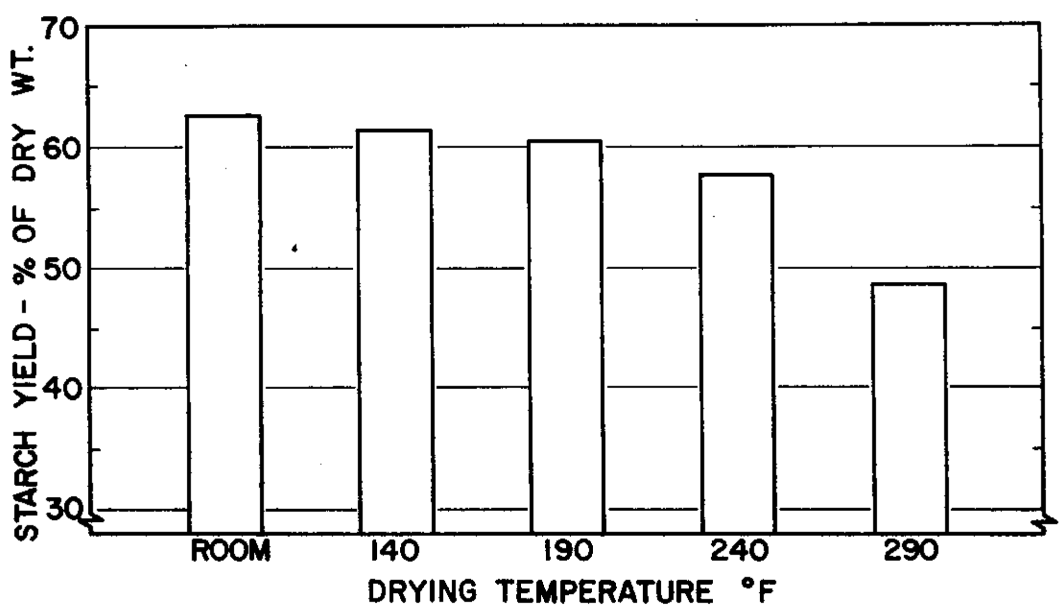

Figure 2
Effect of Drying Temperature on Starch Yield.

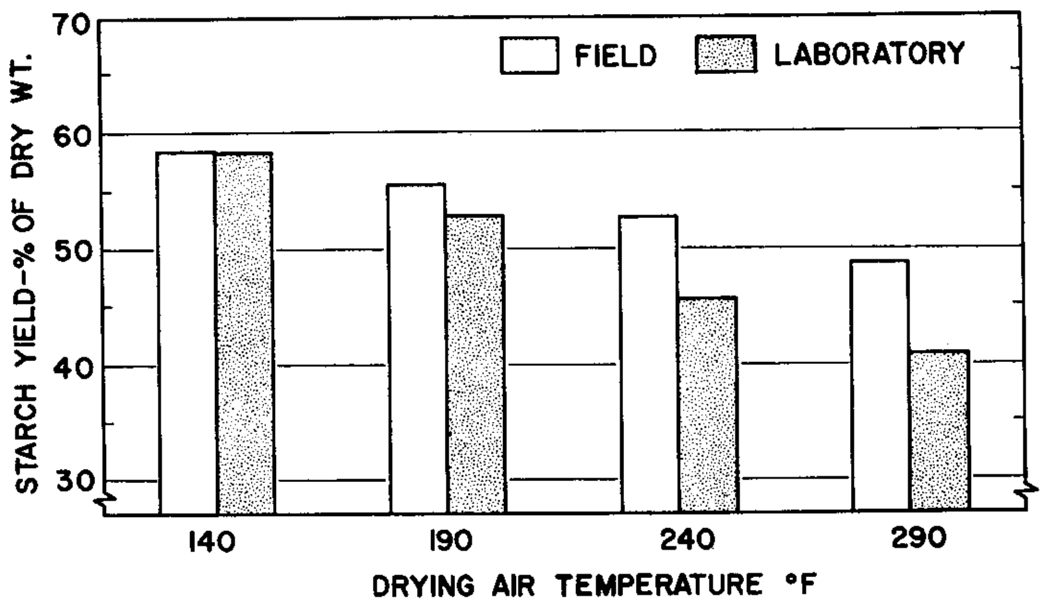

Figure 3
Comparison of Starch Yield from Corn Dried in the Field and in the Laboratory—1962.

Laboratory wet milling analyses were made on samples from four of the tests with the portable batch dryer. The starch yield of the corn from the four tests averaged 60.6 per cent, about one per cent above the three-year average for the batch tests but about one per cent below the batch average in 1960.

The protein mixture in the milled starch was equal for comparable tests in the portable batch and the tower dryer. The amount of starch in the fiber was higher in the portable batch when compared to equivalent tests in the tower dryer in 1960, but was about equal to the three-year average for all batch tests.

From these results, it was concluded that batch operation of the tower dryer produced dried corn of milling quality similar to that produced in conventional portable batch dryers.

Slower Drying

In 1961, each of the continuous drying tests was repeated at reduced speed. The airflow through the grain was reduced from about 72 to 37 CFM per bushel, the retention time in the dryer was increased to obtain the same final grain moisture and the resulting drying speed and capacity was about 60 per cent of that with the higher air volume.

The reduced air volume gave no increase in starch yield. The protein in the starch was not reduced, and the starch in fiber was only about two per cent less in corn dried at slow speed.

More Milling Damage in Corn Dried in the Laboratory

The starch yield of corn dried in the laboratory was lower than that dried in the field-scale dryer (Figure 3). While the yield was about the same at a drying temperature of 140°F., it dropped at a faster rate in the laboratory tests as the drying air temperature was increased. At 290°F., the reduction in starch yield in the laboratory-dried corn was double that in corn from the field dryer.

The laboratory samples were dried in screen-bottomed trays one foot square. Approximately 50 CFM of drying air was forced through 1,800-2,000 grams of wet corn. The airflow rate was equivalent to about 750 CFM per bushel (10 times that used in the field-scale dryer). The drying time in the laboratory ranged from 12 minutes for the 20 per cent corn dried at 290°F. to four and a half hours for the sample of 30 per cent corn dried with air at 140°F. The range of drying time in the field-scale tests for the same conditions was from one to five hours.

These results suggest that as airflow rate is increased and the drying rate approaches the maximum that can be obtained with air at a given temperature, greater damage to milling quality can be expected.

It is difficult to conduct laboratory tests with small samples at air-flow rates equivalent to those used in conventional dryers. For example, to dry a one-pound sample of corn at airflow rate equivalent to 56 CFM per bushel requires only one CFM. Such low air volumes are difficult to measure and control without sophisticated equipment.

RELATIONS OF CORN TEMPERATURE TO DRYING AIR TEMPERATURE

The test results reported have been in terms of drying air temperature—that is, the temperature of the air first entering the corn. However, it is the corn kernel temperature that is critical in preventing milling damage.

There are several factors to be considered in relating air temperature and kernel temperature in drying. Air volume, amount of moisture removed, final moisture level and the method of exposing the corn to the drying air all influence this relationship. Most dryers do not dry all the grain uniformly, and the desired final moisture level is achieved with a blend of overdried and underdried grain. The temperature of the overdried grain approaches the entering air temperature, while the wetter grain remains cooler.

For the field-scale tests, the average temperature of the corn at the end of the heating period for each of the input air temperatures is shown in Figure 4. Starting with the 140°F. test series wherein the corn temperature was 120°F., each increase of 50°F. in air temperature resulted in an increase of about 25°F. in corn temperature. At an average drying air temperature of 286°F., the average temperature of the corn leaving the dryer was 198°F., nearly 90°F. cooler than the drying air. The relatively small decrease in milling quality reported for a 50°F. increase in drying temperature may be partly explained by the corn temperature increasing only half as much.

The results shown in Figure 4 are based on a total of 20 continuous-flow tests—six each at 140, 190 and 240°F., and two at 290°F. drying temperature. The final moisture content in the 20 tests averaged 14 per cent, but varied in individual tests from a low of 11.2 to a high of 15.3 per cent. In 1960 and 1961, there was less than one°F. difference in the final temperature of the corn dried from 30 per cent and that dried from 20 per cent. In 1962, the corn in the 20 per

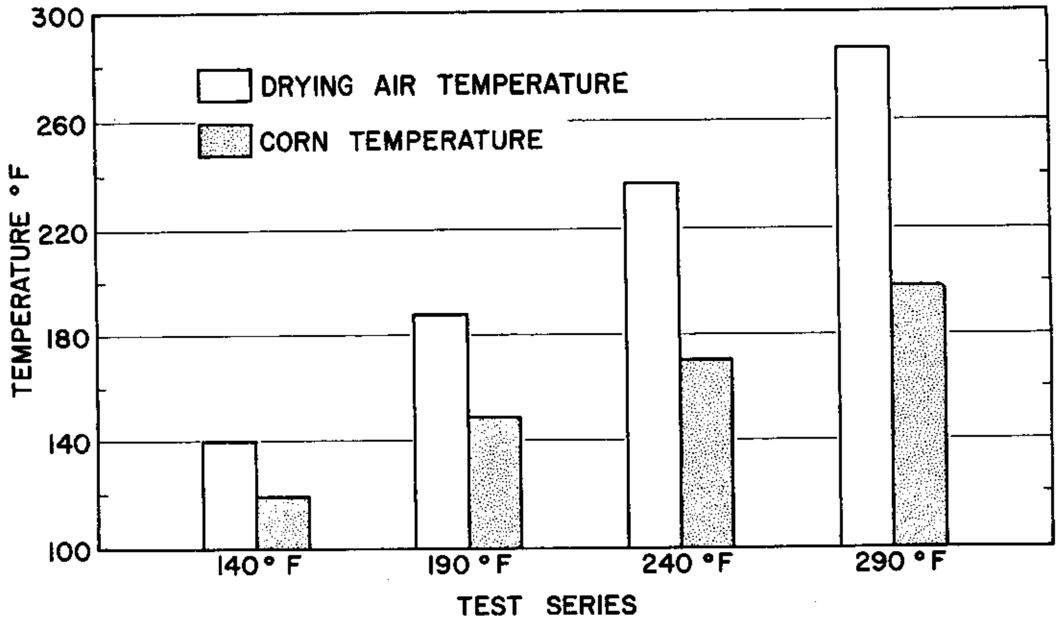

Figure 4
Relation of Corn Temperature to Drying Air Temperature in Continuous-Flow Drying Tests.

cent tests was dried to an average moisture of 12.4 per cent, and the resulting corn temperatures were 17°F. higher than those in the four 30 per cent tests wherein the final moisture averaged 14.5 per cent. Other than the drying air temperature, the final moisture level—not the initial—was the controlling factor in the corn temperature reached during drying.

The test setup did not provide for routine measurement of average corn temperatures in the batch tests. Special measurements taken in the two tests indicated that the average corn temperature at the end of the heating period was about the same in the batch tests as it was in the continuous tests.

The corn dried in the laboratory reached a temperature much nearer that of the drying air. At 140°F., the corn was within two°F. of the drying air temperature. At 290°F., the corn reached a maximum temperature of 258°F., 60°F. higher than in the field-scale tests. The higher corn temperatures are related to the higher air-flow rates used in the laboratory tests and were probably responsible for the greater milling damage.

This discusson of temperature relationships in drying does not intend to imply that damage to milling occurs only in the final stages of drying or when corn is overdried. Evaluation of intermediate samples that were only partially dried show that milling damage occurs during the first stages of drying if the corn temperature is high enough. However, it should be emphasized that overheating is most likely to occur during the final stages of drying when the moisture removal slows down and cooling from evaporation is lessened.

THE BRITTLENESS PROBLEM

The observations made on the brittleness of artificially dried corn in these tests were published in October, 1963 (4). Summarizing, increased breakage may be expected if corn is (1) artificially dried with heat, (2) field-shelled at high moisture levels or (3) handled at low moisture levels or at low temperatures. For corn harvested at 30 per cent moisture, the field-shelling contributed about as much to the breakage as artificial drying. Over two and one-half times as many kernels were damaged—broken, mashed or scratched—when harvested at 30 per cent moisture as when harvested at 20 per cent.

The formation of stress cracks that lead to breakage when the corn is handled increased as drying speed increased. Most of the stress cracks formed in the later stages of drying and during cooling.

These observations led to research on methods of reducing brittleness by delaying the cooling of heat-dried corn until after a tempering period. The final two percentage points of moisture can be removed during the cooling if it is done slowly over a 10- to 12-hour period. A drying process called "Dryeration" incorporating these practices was found to reduce the brittleness of corn by 50 per cent. A progress report describing Dryeration was published in April, 1964 (1).

SUMMARY

Drying tests with field-shelled corn were conducted both in a field-scale and in a laboratory dryer. The controllable variables in the drying process were evaluated in terms of their effect on corn quality, especially as related to wet process milling. The principal variables studied were (1) drying air temperature, (2) initial corn moisture and (3) drying method—batch or continuous. The milling quality was assessed in terms of starch yield, protein mixture in milled starch, starch loss in fiber fraction and oil yield.

The test data show, as drying air temperatures were increased from 140° to 290°F., that starch yield was reduced, that the reduction was gradual with no clearly defined temperature limit, that differences in starch yield related to the crop year were sometimes as great as those resulting from the drying variables, and that there were no differences in batch and continuous drying methods for drying corn of 20-30 per cent moisture.

The amount of protein mixture in the separated starch was not affected by drying air temperatures up to 190°F., and only slightly increased at 240°F.

Heat drying lowered the recovery of oil from corn, especially that harvested and dried from 30 per cent moisture. There was no relationship between oil yield and the drying temperature or the drying method used.

Reducing airflow rates below about 70 CFM per bushel and thereby increasing the retention time in the dryer did not appreciably increase corn quality and was not justified under the conditions tested.

The reduction in milling quality was greater in corn dried in the laboratory than in corn dried at the same temperature in a field-scale dryer. The airflow rate through the small laboratory samples was 10 times that used in the field dryer and resulted in faster drying and higher corn temperatures.

The average corn kernel temperature at the end of the heating period was lower than the input heated air temperature. In the field-scale dryer, each 50°F. increase in air temperature resulted in about a 25°F. increase in corn temperature.

In general, these results confirm previous investigations, but point to the need for establishing safe temperature limits for drying market corn on the basis of measured corn kernel temperature. Minimal milling damage occurred at corn temperatures up to 150°F. The brittleness of artificially dried corn can be reduced by eliminating overdrying and by delaying the cooling of hot corn until after a tempering period.

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