Effect of Drying Method on Grain Corn Quality

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Cereal Chem. 56(6):529-532

ABSTRACT

Grain corn of five hybrids, harvested at different moisture contents, was dried by three methods. The drying methods were the high-temperature crossflow batch method, dryeration, and low-temperature in-bin drying. The laboratory quality measures of (a) test weight, (b) viability, (c) amount of kernel stress cracking, and (d) steeping performance, derived from visual examination of steeped kernel sections, were determined for grain dried with each treatment. Low-temperature drying consistently produced grain with high steeping index and test weight and a negligible amount of kernel stress cracking. Although low for all grain, viability was preserved most effectively by treatments involving drying air temperatures of 60°C or lower. Kernel stress cracking was prevalent in all batch-dried grain, regardless of the drying temperature. Dryeration was superior to the normal high-temperature batch drying method in the amount of kernel stress cracking and in the steeping performance and test weight of dried grain. Viability, test weight, and the amount of kernel stress cracking were correlated with the steeping index of corn, but the association was not close enough to permit prediction of steeping performance from these factors alone.

Improper artificial drying reduces the value of shelled corn for wet milling. Excessive drying-air temperatures and high initial grain moisture percentages increase the degree of damage to corn kernels in the normal one-pass high-temperature grain dryer (Gustafson et al 1976, Peplinski et al 1975, Watson 1960). Solubility of corn proteins in the steep solution is reduced in grain that has been overheated (McGuire and Earle 1958), resulting in a low yield of starch and poor starch quality (Vojnovich et al 1975, Watson and Hirata 1962). Kernel stress cracks caused by abusive drying techniques increase the amount of breakage that occurs when grain is handled, causing a loss of millable material (Freeman 1973).

Several quality criteria can be applied to commercial shelled corn to estimate the degree of grain damage caused by artificial drying. Corn with a high percentage of viable kernels is usually suitable for wet milling (Watson and Hirata 1962). The test weight of grain is routinely used for grade designation and quality assessment (Canadian Grain Commission 1975). Stress-crack analysis is indicative of the amount of breakage to be expected in handling artifically dried corn (Thompson and Foster 1963) and may also reflect internal or chemical grain damage. Laboratory steeping or milling studies (Watson et al 1951, 1961) best indicate actual milling performance, but they are too lengthy and involved for rapid quality determination.

Some criteria for estimating quality may be misleading when applied to corn dried with other than the typical high-temperature, one-pass method. Dryeration reduces the degree of stress cracking associated with artificial drying (Foster 1973), but internal grain damage may still occur. If mold growth can be prevented, low-temperature drying (Shove 1970) should produce corn with the high quality of naturally dried grain. Our study was initiated to determine the effects of three grain drying methods, involving corn harvested at different initial moisture contents, on several rapidly determined estimators of quality for milling. Millability of grain was measured using an index of steeping performance.

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0009-0352/79/000084$3.00/0

MATERIALS AND METHODS

Grain of five commercial corn hybrids, ranging from 20 to 30% (wet basis) moisture content, was harvested by combine for the study. A pilot-scale crossflow dryer described by Meiering et al (1977) was used for batch drying and for the pretempering stage of dryeration treatments. Air plenum temperatures of 45, 60, and 80°C were used for each of the batch drying treatments and, with an airflow rate of 23.3 m^3/min/m^2 of column, drying time ranged from 1 to 4 hr for the different grain lots.

Drying temperatures were increased to 60, 80, and 100°C for each of the dryeration treatments. Grain was transferred hot from the dryer at an average moisture content of 17% to one of a series of small (200 L) insulated ventilation bins and the bin was sealed. Following a tempering period of 12 hr, the lid was removed from the bin and the grain was cooled to ambient temperature with an airflow rate of 1.1 m^3/min/tonne of grain. Each dryeration treatment, including tempering and cooling, required 16 to 20 hr to complete.

The small bins were also used for the low-temperature drying treatments; however, the airflow rate was increased to 11 m^3/min/tonne of grain. Two banks of electrical resistance heaters under humidistatic control were installed in the supply airstream to maintain the relative humidity of drying air at or below 70%. The temperature of the drying air ranged from 3 to 18°C during the low-temperature treatments, varying with ambient conditions. Freshly harvested grain of each lot was placed in one of the bins and aerated until the average moisture content was 14–15%. Drying time for the different grain lots ranged from 3 to 9 days depending on the initial moisture content and the ambient air conditions.

The moisture content of grain samples taken during the drying treatments was determined with a Model 919 moisture meter[4]. Four samples of 4 kg each were taken from the grain of each treatment for quality analysis once drying was complete, and the moisture content was calculated from the weight loss in drying 50-g subsamples for 72 hr at 103°C in an air oven. Final moisture content for all treatments was 15 ± 1% (wet basis).

Quality Analysis

Viability of the samples was determined by counting the number of sprouted kernels after incubating 100-kernel subsamples in a germination cabinet at 27.5°C for five days (Corn Industries Research Foundation 1975). Test weight was measured in accordance with procedures outlined by the Canadian Grain Commission (1975). The degree of stress-crack formation was assayed by a technique similar to that of Thompson and Foster (1963). Individual kernels were examined visually on all sides over a fluorescent light source and categorized as: 1) kernels with no stress cracks, 2) kernels displaying a single crack, and 3) kernels with multiple cracks. The number of cracked kernels in each category was reported as percentage of 100-kernel subsamples.

Suitability for Wet Milling

A "steeping index" derived from visual examination of steeped kernel sections was determined for the grain of each treatment. Treatment subsamples were placed in tubes of stainless-steel screen and suspended within the bed of grain in full-scale steep tanks at the Canada Starch Company plant at Cardinal, Ontario. The corn was steeped for 32 hr (cover time) at a solution temperature of 52°C. Steeped kernels were sectioned longitudinally (parallel to the germ), examined visually, and classified into one of three categories: 1) horny endosperm intact and tough, protein matrix intact; 2) kernel softened but retains dented appearance and dry interior, protein matrix partially disrupted; 3) kernel fully swollen and wet internally, protein matrix dispersed. Steeping index was formulated as: Steeping index = (number of kernels in category 1) + (2 × number of kernels in category 2) + (3 × number of kernels in category 3). With 100-kernel samples, a steeping index of 300 indicated that all kernels were fully steeped, whereas the lowest index of 100 denoted that all kernels retained intact horny endosperm and were inadequately steeped.

The reliability of the steeping index in estimating wet-milling performance of corn was investigated at the plant. The steeping index of grain and the starch recovery rate upon milling were recorded for 33 full steeps involving different lots of corn.

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RESULTS AND DISCUSSION

Viability

Analysis of variance showed significant differences among the grain drying treatments and grain lots (ie, grain of five corn hybrids harvested at different initial moisture contents) in viability of the dried grain (Table I). viability of grain was markedly reduced by any of the treatments involving drying temperatures above 60°C (Table II). The rest of the drying treatments, including low-temperature drying, did not differ significantly in their effect on viability. Grain lots dried with either dryeration or the batch method at a common air temperature did not differ significantly. Grain lots harvested at low initial moisture (20 or 21%) retained a higher percentage of viable kernels after drying than the lots that were wetter at harvest. The five grain lots differed in genetic composition as well as initial moisture content. The differences observed among lots may have arisen from differences in the stage of maturity at harvest or from mechanical damage to kernels, particularly at the higher moisture levels.

Test Weight

Drying treatment and grain lot were both significant in their effect on the test weight of dried grain. All of the corn dried had a test weight greater than the minimum value of 68 kg/hl required in the statutory definition of grade Number 1 Canada Eastern Corn by the Canadian Grain Commission. The highest test weight within each lot of grain occurred with low-temperature drying (Table III) although it was not always significantly higher than that of the moderate high-temperature treatments. The test weight of corn lots dried with both the batch and dryeration methods tended to decrease as the drying temperature was increased, particularly in lots harvested at 28 and 30% moisture. Differences among grain lots were not consistent indicating that the variety of corn, as well as the initial moisture content, had a significant effect on final test weight. The effects of variety and moisture content at harvest (Duncan et al 1972) could not be separated in this experiment.

Stress Cracking

There were significant differences among grain lots and drying treatments for the frequency of stress crack formation (Table IV). Grain dried with the low-temperature system had a negligible

TABLE I
Mean Squares from Analysis of Variance for Quality Factors

Quality Factors	Mean Squares: Drying Treatment	Grain Lot	Drying Treatment × Grain Lot Interaction	Sampling Error
Viability	4,293.61	2,670.60	90.04	83.57
Test weight	16.96	45.53	1.69	0.13
Stress cracks				
Single	2,315.36	210.34	30.45	12.13
Multiple	3,808.98	885.04	94.52	15.11
Total	7,457.87	1,255.11	126.47	23.56
Steeping index	2,642.98	12,944.97	735.56	94.96
Degrees of Freedom	6	4	24	105

TABLE II
Effect of Drying Treatment on Viability of Artificially Dried Shelled Corn

Drying Treatment	Grain Lot (% Initial Moisture): I (20)	II (21)	III (26)	IV (28)	V (30)	Drying Treatment Means[a]
Low-temperature	74.7	75.8	53.7	36.2	47.1	57.5a
Batch 45°	61.4	84.9	52.7	43.5	55.5	59.6a
Batch 60°	57.2	58.5	40.3	49.5	17.4	44.6a
Batch 80°	28.9	48.4	12.4	6.6	2.7	19.8b
Dryeration 60°	66.4	64.1	35.3	33.7	41.4	48.2a
Dryeration 80°	19.4	28.9	8.4	9.2	2.2	13.6b
Dryeration 100°	20.3	24.6	4.1	6.1	3.9	11.8b

[a]Means subtended by the same letter do not differ significantly at the 0.05 probability level (Duncan's NMRT using interaction as error).

amount of kernel stress cracking. Dryeration treatments also caused little stress cracking, especially when the initial drying stage was conducted at temperatures below 100°C. Batch-dried grain contained many more stress-cracked kernels, frequently with multiple cracks (Table V). The grain lot harvested at 26% moisture had fewer stress-cracked kernels after batch drying treatments than the other lots, even those of lower initial moisture content. The differences among grain lots for both batch and dryeration treatments were not consistent; however, there was a discernible trend toward increased stress cracking in the lots harvested at higher moisture levels. The variability in the results suggests that there may be a varietal effect as well as an effect of initial moisture content contributing to the susceptibility to stress-crack formation with high-temperature drying for the grain lots.

Steeping Index

There was a highly significant correlation between steeping index of corn and the starch recovery rate upon wet milling (Fig. 1). From regular observations taken over several years of normal plant operations, corn with a minimum steeping index of 200 was found to give satisfactory milling performance and normal starch-gluten separation.

All grain dried by the low-temperature method yielded a steeping index greater than the minimum value of 200 required for satisfactory milling performance (Table VI). Grain lots harvested at less than 28% moisture were all satisfactory in this respect regardless of drying treatment. All high-temperature drying treatments for the grain lot harvested at 30% moisture produced an unsatisfactory steeping index. As drying temperature increased with both batch and dryeration treatments, the steeping index tended to decline. Dryeration usually caused an improvement over corresponding batch treatments at the same drying temperature. The treatment means were not significantly different when tested using interaction as error (Table VI); however, it is probable that the true error is overestimated with this approach.

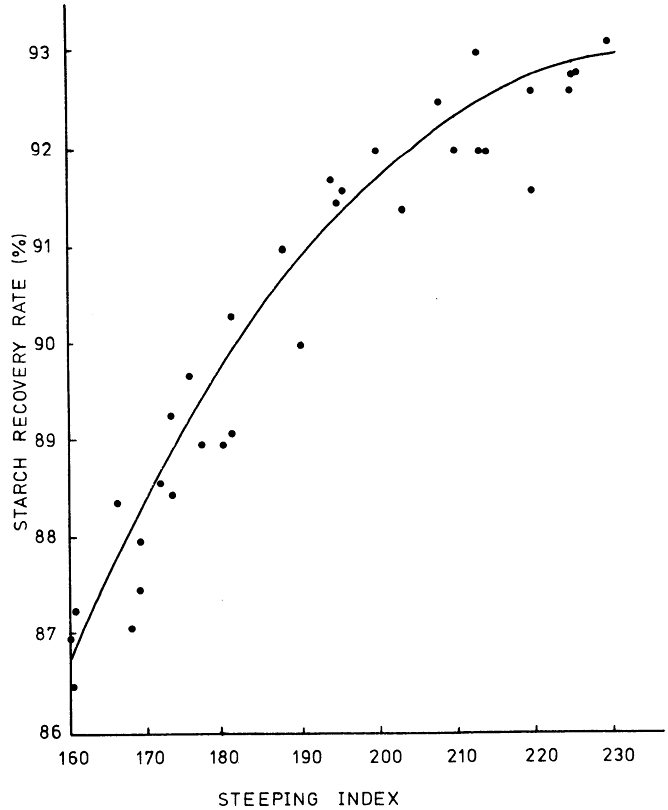

Fig. 1. Regression of starch recovery rate of steeping index of artificially dried shelled corn. $y = 22.75 + 0.566X - 0.0012X^2$, $r = 0.97$, s.e. = 0.51.

TABLE III
Effect of Drying Treatment on Test Weight (kg/hl) of Artificially Dried Shelled Corn

Drying Treatment	Grain Lot (% Initial Moisture) I (20)	II (21)	III (26)	IV (28)	V (30)	Drying Treatment Means[a]
Low-temperature	73.2	75.1	73.2	72.3	73.9	73.5a
Batch 45°	72.4	73.8	71.2	70.6	71.5	71.9abc
Batch 60°	71.5	73.7	71.3	71.3	69.4	71.4bc
Batch 80°	71.0	73.2	71.5	69.2	68.3	70.6c
Dryeration 60°	72.9	74.2	72.4	71.1	72.2	72.6ab
Dryeration 80°	72.3	73.9	71.1	70.3	71.0	71.8abc
Dryeration 100°	71.7	73.8	71.0	69.8	71.0	71.5bc

[a]Means subtended by the same letter do not differ significantly at the 0.05 probability level (Duncan's NMRT using interaction as error).

TABLE IV
Percent Stress-Cracked Kernels in Artificially Dried Shelled Corn

Drying Treatment	Grain Lot (% Initial Moisture) I (20)	II (21)	III (26)	IV (28)	V (30)	Drying Treatment Means[a]
Low-temperature	0.4	3.1	1.0	1.2	1.3	1.4a
Batch 45°	45.0	73.7	36.7	68.8	63.2	57.5c
Batch 60°	52.8	63.6	37.4	78.9	69.3	60.4c
Batch 80°	59.3	73.3	28.5	77.3	79.1	63.5c
Dryeration 60°	3.2	12.7	8.5	9.6	16.2	10.0ab
Dryeration 80°	6.3	14.9	5.6	22.3	16.3	13.1ab
Dryeration 100°	19.5	8.0	4.5	22.5	30.0	16.9b

[a]Means subtended by the same letter do not differ significantly at the 0.05 probability level (Duncan's NMRT using interaction as error).

TABLE V
Stress Crack Development in Batch-Dried Corn

Drying Temperature	Stress-Crack Category	Grain Lot (% Initial Moisture) I (20)	II (21)	III (26)	IV (28)	V (30)	Drying Treatment Means
45°	Single	24.2	28.3	23.4	27.2	30.7	26.8
	Multiple	20.8	45.3	13.3	41.6	32.5	30.7
	Total	45.0	73.6	36.7	68.8	63.2	57.5
60°	Single	26.6	31.2	22.9	32.5	34.2	29.5
	Multiple	26.2	32.4	14.5	46.4	35.1	30.9
	Total	52.8	63.6	37.4	78.9	69.3	60.4
80°	Single	29.2	23.2	17.2	27.8	20.1	25.5
	Multiple	30.0	50.1	11.3	49.5	49.0	38.0
	Total	59.2	73.3	28.5	77.3	79.1	63.5

TABLE VI
Effect of Drying Treatment on Steeping Index of Artificially Dried Shelled Corn

Drying Temperature	Grain Lot (% Initial Moisture) I (20)	II (21)	III (26)	IV (28)	V (30)	Drying Treatment Means[a]
Low-temperature	249	217	219	226	247	232a
Batch 45°	235	232	221	221	186	219a
Batch 60°	250	207	213	204	177	210a
Batch 80°	229	199	204	201	156	198a
Dryeration 60°	252	222	224	210	186	219a
Dryeration 80°	244	209	231	201	180	213a
Dryeration 100°	250	197	208	192	157	201a

[a]Means subtended by the same letter do not differ significantly at the 0.05 probability level (Duncan's NMRT using interaction as error).

Relations Among Quality Factors

The steeping index is useful in estimating the wet-milling performance of grain corn. Because the steeping process must be duplicated for each sample, however, the procedure is too complex for routine corn quality analysis. The relations of the other quality factors, which can be evaluated more readily, with the steeping index were investigated. The steeping index of dried grain decreased nearly linearly with increasing percentage of stress-cracked kernels (Table VII). There was also a linear relation between grain viability and steeping index. Although each factor was correlated with the steeping index, the standard error of estimate associated with each regression equation was too large for a practical application. The test weight of dried grain also was correlated with steeping index; however, the standard error of estimate again was large (Table VII).

CONCLUSIONS

Viability of the dried corn was low except for the lots harvested at 20 and 21% moisture and dried by either the low-temperature method or the batch method at 45°C. Corn lots harvested at 26% moisture or more and dried with either batch or dryeration methods retained very few viable kernels. The millability of dried corn, as indicated by the steeping index, was satisfactory except for the lot harvested at 30% moisture and dried with any of the high-temperature treatments. The value of corn for wet milling may be underestimated if high viability is a major criterion in quality evaluation, especially if the corn was dried with dryeration.

With the exception of viability, the quality of corn dried with dryeration was improved to some extent over that of corresponding batch treatments.

Kernel stress cracking was much more severe in batch-dried grain than in grain dried with the other methods.

TABLE VII
Relation Between Selected Grain Corn Quality Factors

Quality Factors	Correlation Coefficient	Regression Equation	Standard Error of Estimate
Steeping index vs. kernel stress cracks	0.47[a]	$y = 234 - 0.61X$	22.62
Steeping index vs. viability[b]	0.54[a]	$y = 185 + 0.80X$	21.37
Steeping index vs. test weight	0.57[a]	$y = -13{,}900 + 385X - 2.60X^2$	21.13

[a]Significant at 1% probability level.

The inclusion of a stress-crack determination as part of the routine quality assessment procedure may help identify grain lots that are susceptible to abnormally large breakage and material losses during normal handling and processing operations.

Viability, test weight, and stress crack analysis of dried grain alone did not accurately predict wet-milling performance of corn. taken together, however, these quality factors can detect damage levels in corn, which will adversely affect the wet-milling process.

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[Received December 28, 1978. Accepted May 30, 1979]