CORN DRY-MILLING: EFFECT OF TEMPER TIME AND MOISTURE LEVEL ON DEGERMINATOR PERFORMANCE[1]

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ABSTRACT

In pilot-plant tests, yellow dent hybrid corn from a single lot was tempered to moisture levels of 18, 21, and 24% at room temperature and processed in a degerminator of the studded-cone type. Temper time ranged from 0.3 to 8 hr. As temper time increased regardless of the moisture level, degerminator throughput climbed sharply to a maximum in 2 to 3 hr. and then fell off; yield of $-4+6$ grits dropped sharply and then climbed slowly; fat content of these grits climbed and leveled off; and yield and oil content of -16-mesh fines fell rapidly during the first 3 hr. As the moisture level was increased for temper times beyond 1 hr., degerminator throughput increased; yield of $-4+6$ grits decreased while the effect on their fat content was indefinite; also effect on yield of -16-mesh fines was indefinite although their fat content decreased. Data were also obtained on degree of hull release and oil recovery.

Since millers prefer short temper times and minimum moisture addition and since no single set of conditions is known to give optimum degerminator performance, the data developed will help a miller select the most practical conditions for his operations.

Both residence time and the moisture level attained in tempering corn before degermination have a definite effect on degerminator performance. Despite their importance, no published information is available on the concurrent effect of these two variables. Accordingly a study was undertaken to learn more about the interrelated effect of these two variables on degerminator operation and on product yields and characteristics. The findings should be of value in plant operation. Also, some of the results point to the need for a better understanding of what occurs within the corn kernel as tempering proceeds.

In commercial dry-milling of corn the temper times employed range from 15 min. to 3 hr. The corn is tempered in one, two, and sometimes three stages to a moisture level in the 18 to 24% range. Millers would like to operate with minimum moisture addition and minimum temper time, but conditions must often be adjusted to meet product requirements and to fit the corn being processed.

Materials, Equipment, and Methods

Materials. Yellow dent hybrid corn, grade No. 1, field- and crib-

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dried, from the 1961 local crop was processed about 18 months after harvest. This corn was grown without commercial fertilizer and its average moisture content at the time it was processed was 13.2% (range 12.7 to 13.7). It contained (% d.b.) oil, 4.56; crude fiber, 2.03; ash (600°C.), 1.18; and protein, 9.13. Test weight at 13.2% moisture content was 59.0 lb. per bu. with 2, 17, 62, and 96% (wt.) of kernels retained on 24-, 21-, 20-, and 17/64-in. round-hole perforated sieves, respectively. The corn was of "average" hardness according to the floaters test (1).

Processing Equipment and Evaluation Method. A No. 0 Beall degerminator was fitted with three screens having 14/64-in. round-hole perforations. It had a "blunt" studded rotor which was operated in a 50% closed position and driven at 840 r.p.m. by a 15-h.p. motor. While the manufacturer recommends using a 10-h.p. motor for a degerminator of this size, oversized motors are often used in commercial operation. A V-notched slide gate was installed above the rotor shaft in place of the conventional hinged gate for the tail stock discharge (2).

Other details of the pilot-plant installation, laboratory fractionation procedure for determining product yields, and analytical methods used have been described previously (3,4), with three exceptions. A sodium nitrate solution of 1.30 sp. gr. was substituted for the toluene-carbon tetrachloride mixture of 1.27 gravity in the germ flotation step. The higher gravity assured essentially complete removal of free germ (some floury endosperm fragments were also removed) from grit fractions coarser than 25-mesh, and besides, the sodium nitrate solution did not extract any oil. For oil analysis, the germ fraction was ground more satisfactorily when passed through a coffee mill and then twice through a roller mill having smooth rolls. This new procedure eliminated the gumming occasionally encountered when the germ fraction was ground in a laboratory sample mill. Also, a wattmeter was installed for recording the motor load for each test.

Experimental Operation. Corn was tempered to moisture levels of 18, 21, and 24% (first temper only) for periods varying from approximately 1 to 8 hr. and then processed in the Beall degerminator. In addition, two tests were made on corn tempered to the 21% level for periods of 0.3 and 0.6 hr. Both corn and the tap water used for tempering it were at approximately 70°F.

The time interval starting with introduction of temper water on the corn and ending with start of the degerminator test was taken as the temper time. One sublot was tempered and degerminated for the 18% temper level series (five tests). Three sublots were processed for the 21% series (six tests) and three for the 24% series (five tests).

Average electrical input to the degerminator motor for the series was 13.38 kw.; i.e., almost 18 h.p.

The tailgate was adjusted for each test to obtain an average recycle level of 5.4% of the gross feed stock (GFS). The recycle range was 2.6 to 8.0%.

Results

Experimental data obtained from varying the tempering conditions have been grouped so as to show the effect of tempering on degerminator performance. These groups in their order of presentation are: degerminator throughput; yield and oil content of various endosperm fractions of progressively smaller particle size; germ, oil, and hull recovery data; and finally, polish of the −4+6 grits.

Each point on the curves and in Table I represents the value from one test. In more recent experiments involving several groups of replicated tests (usually paired groups) the coefficient of variability was in the 5 to 10% range. Exceptions were: 2% variability for yield of −3½+16 grits, and 10 to 25% variability for yields of recycle stock and −4+5 grits and for oil contents of −3½+4, −4+6, −8+16 grit fraction and hull fraction. The coefficient was not calculated for the attached hull count.

Degerminator Throughput. Both temper time and moisture level had a pronounced and interrelated effect on degerminator throughput. At the 18% level, the throughput rose from 23 to 27 bu. per hr. as temper time was increased from 1.0 to 2.0 hr. Beyond 2.5 hr. the throughput fell off with increasing time and at 8.2 hr. the throughput was down to 16 bu. per hr. (Fig. 1). All throughputs are net (i.e., gross throughput less the recycle fraction) and are based on product weights adjusted to 15% moisture content.

With 21% temper and a 0.3-hr. temper time, the throughput was 18 bu. per hr. In the interval between 1 and 2 hr. the throughput rose sharply, reached a maximum of 40 bu. per hr. at about 2.5 hr., and then fell, not as steeply as it rose, but more so than for the 18% temper. With the 24% temper, higher throughputs were attained and a maximum of 44 bu. per hr. was reached at about 2.5 hr. An increase in temper moisture from 18 to 21% boosted the throughput by over 13 bu. per hr. at the 2.25-hr. temper, but a further increase in the moisture level to 24% brought about a much smaller increase, only 4 bu. per hr., in throughput.

−3½+16 Grits. Temper time had no noticeable effect on yield of −3½+16 grits, but for temper times beyond 3 hr. the average yield

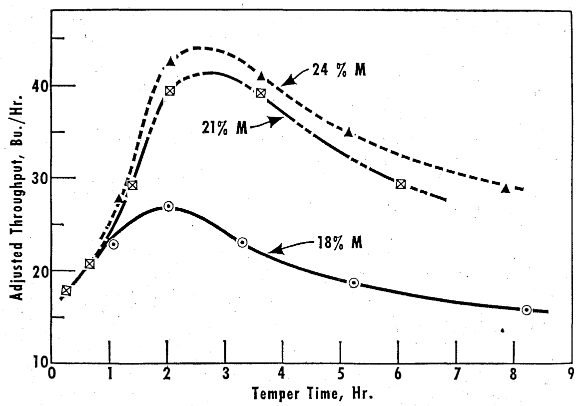

Fig. 1. Effect of temper time and moisture level on degerminator capacity. Key for all figures: M = moisture; MFB = moisture-free basis; GFS = gross feed stock; NFS = net feed stock.

decreased from 64, to 61, to 59% as moisture level was increased from 18, to 21, to 24% (Table I). A maximum yield of grits in this range is sought because they, along with recovered corn oil, constitute the most valuable products in terms of over-all return.

−3½+4, −4+6 Grits. In many cases the miller also prefers maximum yield of −3½+4 and −4+6 grits. In the current series the yield of −3½+4 grits remained essentially constant during the first 2 hr. and then decreased with time as the moisture level was increased (Table I). The best yield of −4+6 grits was with the shortest temper time. Yield fell rapidly during the first 2 hr. and then increased slowly after passing a minimum (Fig. 2). As temper level was increased from 18, to 21, to 24%, this minimum fell from 38, to 30, to 29% and the time for reaching this minimum shifted from 2.5, to 4.5, to 4.75 hr.

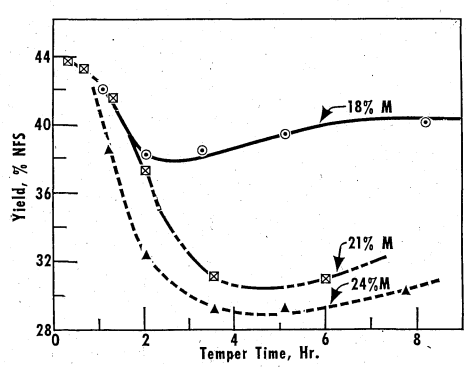

Fig. 2. Variation in yield of −4 + 6 grits with temper conditions.

TABLE I

YIELDS AND OIL CONTENTS OF VARIOUS CORN FRACTIONS

	Temper Moisture Level															
	18%					21%						24%				
Temper time, hr.	1.0	2.0	3.2	5.1	8.2	0.3	0.6	1.3	2.0	3.6	6.0	1.2	2.0	3.6	5.1	7.7
Recycle, % GFS[a]	5	6	6	7	4	7	7	5	3	3	8	4	4	6	6	6
Yields, % NFS[b]																
−3½ + 16 Grits	61	63	65	66	63	60	59	62	62	61	61	59	61	59	58	59
−3½ + 4 Grits	7	8	8	6	5	7	6	8	6	4	4	8	8	6	3	2
−4 + 5 Grits	9	7	9	7	7	7	9	8	6	4	4	7	4	4	4	4
−5 + 6 Grits	33	31	29	32	34	36	34	33	31	27	26	31	28	25	26	26
−6 + 8 Grits	9	12	13	14	12	8	8	10	15	19	19	10	16	17	18	20
−8 + 16 Grits	3	5	6	7	5	2	2	3	4	7	8	3	5	7	7	7
Oil contents, % d.b.																
−3½ + 4 Grits	0.65	1.10	1.14	1.22	0.92	0.53	0.55	0.81	0.85	1.12	1.66	0.51	1.37	1.52	1.42	1.23
−4 + 6 Grits	0.40	0.43	0.54	0.45	0.52	0.35	0.31	0.40	0.51	0.46	0.50	0.38	0.52	0.58	0.48	0.43
−6 + 8 Grits	0.69	0.61	0.64	0.64	0.60	0.62	0.62	0.59	0.63	0.57	0.57	0.59	0.61	0.60	0.59	0.44
−8 + 16 Grits	1.17	1.01	1.01	1.11	0.94	1.16	1.06	0.90	0.87	0.82	0.68	0.84	0.78	0.75	0.72	0.67
Germ fraction	19.81	18.62	17.29	19.96	18.74	19.64	19.91	21.24	21.19	20.21	19.21	18.36	18.35	18.15	18.83	19.57
Hull fraction	3.36	3.40	3.49	3.90	3.54	3.70	3.21	3.17	2.56	3.10	2.75	4.49	3.23	2.06	2.16	2.43

[a] Gross feed stock.
[b] Net feed stock, i.e., gross less +3½-mesh recycle. Yields are on air-dry basis, i.e., containing 5 to 12% moisture with specific fractions varying 2 to 4% in moisture content.

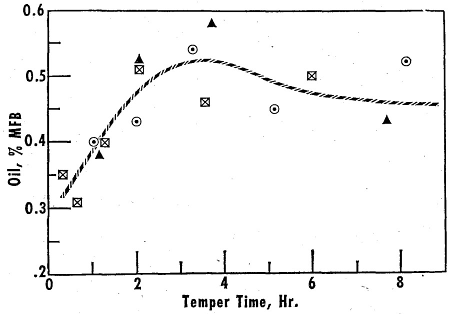

Fig. 3. Effect of temper conditions on oil content of −4 + 6 grits.

Here again the largest change occurred as the temper level was raised from 18 to 21%.

Oil content of −4+6 grits increased steadily during the first 2.5 to 3 hr. of temper time, dropped slightly, and then leveled off (Fig. 3). Moisture content had an indefinite effect on oil content of these grits. For the −3½+4 grits, oil content was lowest with the shortest temper time and, again, the effect of moisture level was not apparent (Table I).

−6+8, −8+16 Grits. Yield of both −6+8 and −8+16 grits increased with time. Use of either the 21 or 24% temper level also increased the yield of −6+8 grits, but largely at the expense of −4+6 grits. Oil content of −6+8 grits remained at or near the 0.60% level for all tests. As temper time and moisture level were increased, oil content of −8+16 grits generally decreased (Table I).

Fines. Amount of undesirable fines (−16-mesh) was quite high for the shortest temper time. It fell sharply during the first 2 hr. and then climbed after passing through a minimum (Fig. 4). An increase

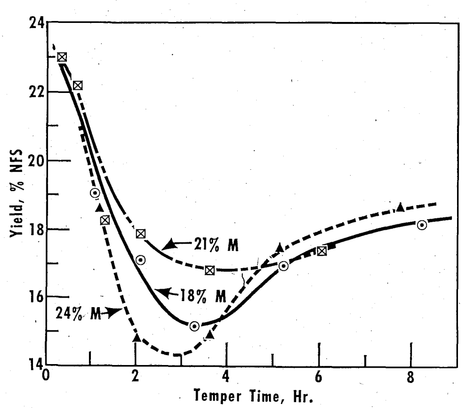

Fig. 4. Relationship between yield of −16-mesh fines and temper conditions.

in the moisture level from 18 to 21% produced more fines, whereas a further increase to 24% gave the least amount for temper times up to 4 hr. With temper times beyond 5 hr. there was no difference in production of fines for the 18 and 21% moisture levels, with about 0.5% more at the 24% level. Dislocation of the 21% curve appears related to germ recovery. Fines produced with the shortest time were high in oil content, almost 9%. As temper was prolonged up to 2 hr., the oil content fell steadily and after 3 hr. it leveled off at successively lower levels for progressively higher levels of temper moisture (Fig. 5).

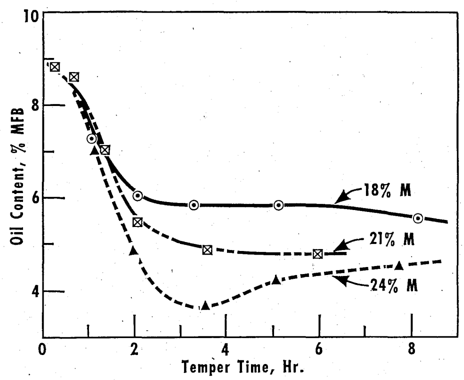

Fig. 5. Effect of temper time and moisture level on oil content of −16-mesh fines.

Germ and Oil Recovery. Amount of germ recovered from −3½+25-mesh fractions increased with time during the first 4 hr. (approx.) and then generally leveled off (Fig. 6). As a consequence, the quantity of recoverable oil also increased during the first 4 hr. (Fig. 7) because neither time nor temper level had a consistent effect on oil content of

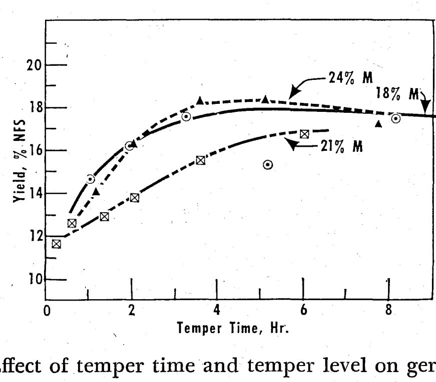

Fig. 6. Effect of temper time and temper level on germ yield.

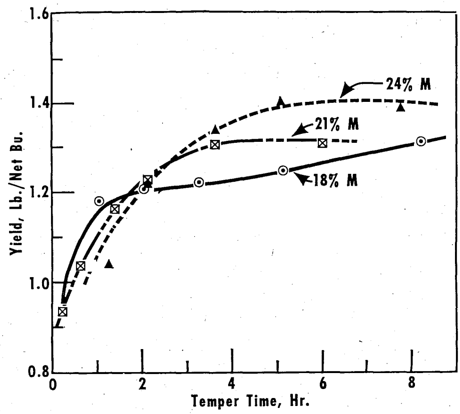

Fig. 7. Recoverable oil vs. temper time and moisture level.

the germ fraction (Table I). After 4 hr. the quantity of oil was fairly constant for the 21 and 24% temper, whereas that for the 18% temper continued to increase but at a slower rate. Only during the interval from about 3.5 to 7 hr. did oil recovery increase as temper moisture was raised. (Calculated quantity of recoverable oil, expressed as lb. per net bu., was based on quantity of recovered germ and its oil content and a 5% residual oil content, d.b., in the germ cake.)

Hull Recovery and Polish of —4+6 Grits. After the first hour, yield of free hull decreased with time for the 18 and 24% tempers, whereas it increased slightly for the 21% temper up to 4 hr. before declining (Fig. 8). Beyond 1 hr., hull yield increased progressively

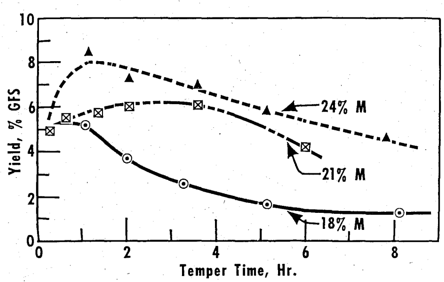

Fig. 8. Variation of hull yield with temper conditions.

with higher temper levels, and beyond 2 hr. the hull fraction was progressively cleaner as judged by its decreasing oil content (Table I).

As determined by percentage of —4+6 grits with attached hull fragments, excellent polish was obtained as long as adequate moisture was present on or near the kernel surface. As surface moisture was absorbed, polish was impaired. For an attached hull count not exceeding 5%, temper times would be limited to about 1, 2.5, and 3.5 hr. for temper levels of 18, 21, and 24%, respectively (Fig. 9).

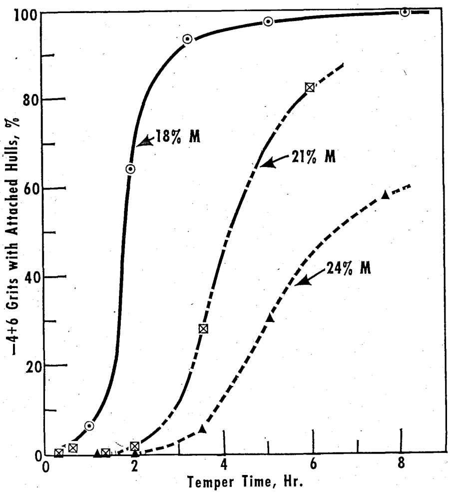

Fig. 9. Effect of first temper time and temper level on attached hull count.

Discussion

Apparently a 21% temper level and a 2-hr. temper time gave the best results over-all for this lot of corn to achieve a high throughput, hull and germ release, oil recovery, and polish for large grits and low fines production. Increasing the temper level to 24% and extending the time to 3 to 4 hr. or more, or both, improved some of the results but to a much smaller degree. Because these additional improvements were comparatively small, the miller probably would not consider the added expense warranted, except under special circumstances.

Tempering to 21% moisture for 2 hr. was not the best for production of flaking grits (i.e., $-3\frac{1}{2}+6$). A short temper time, 1 hr. or less, and an 18% temper moisture were better for producing a maximum amount of large grits and for lowering their oil content. Major drawbacks of the shorter time and temper were reduced throughput and oil recovery. While fines production was increased with short temper time, only part, possibly one-half, was at the expense of $-3\frac{1}{2}+16$ grit production from which the miller obtains prime goods. The other half resulted from germ being ground into fine particles. This reduction in germ yield was reflected in an increased oil content of the fines. Further evidence of the relation between germ recovery and fines production arises from dislocation of the 21% curve in both Figs. 4 and 6.

Several fundamental questions arise from this investigation. The low oil content obtained in $-3\frac{1}{2}+4$ and $-4+6$ grits with short temper times was unexpected and indicates that these grits must have been comparatively free of attached germ fragments. Apparently a 2- and 3-hr. temper for absorbing an appreciable quantity of moisture by the germ was not necessary for good degermination. Adequate temper did swell the germ and make it rubbery; as a result, it better withstood the abrasion and scouring to which it was subjected within the degerminator. This condition is reflected by the increases noted in oil recovery and concurrent decreases in oil content of the fines. However, while adequate tempering increased the germ and oil recovery, it did not necessarily increase the relative amount of large germ particles as might be expected. The percentage of germ particles retained on U.S. No. 8 and coarser sieves during initial screening of degerminator products and subsequently recovered by flotation averaged about 54% for 0.3- to 1.2-hr. tempers, regardless of temper level. As temper time was extended to 6 and 8 hr. the percentage retained increased by about 10 points for the 18% temper, remained essentially constant for the 21% temper, and fell off about 9 points for the 24% temper.

Concurrent increases in oil content of the large grits and in oil recovery seem inconsistent. A search for a plausible explanation leads to the aleurone layer, which is high in oil and protein. MacMasters (5) indicates that much of the aleurone layer is removed in dry-milling. It appears that much of it was removed with the 0.3- and 0.6-hr. tempers but not with the longer tempers.

For the first 3 hr. of tempering there appears to be an inverse relationship between degerminator throughput and yield of $-4+6$ grits. Swelling and softening of various portions of the corn kernel by the added moisture undoubtedly brought about both of these effects. For temper times beyond 2 to 4 hr., reversals noted in throughput, yield of $-4+6$ grits, and in fines production were unexpected. Presumably further weakening of the endosperm and other components proceeded at a much slower rate or stopped entirely. After the surface moisture had disappeared, the throughput decreased. This change may have resulted from more friction between the kernels. The increased fines production after 3+ hr. for 18% temper series resulted from a lower recovery of hull fraction and $-3\frac{1}{2}+16$ grits, and in the 24% temper series, from decreased amounts of hull and germ.

On the basis of progressive decreases in yield of $-4+6$ grits with time and with the higher temper levels (for tempers beyond 1 hr.), it is assumed that a part of the temper moisture must have worked its way into the horny endosperm. No explanation is evident for the much smaller differences noted in both throughput and −4+6 grit yield when the temper was increased from 21 to 24% as compared with the differences in going from 18 to 21%.

The objective in tempering corn differs from that in conditioning wheat for flour milling in one major respect. In degerminating corn, as in milling wheat, good removal of both germ and bran and maximum recovery of the endosperm portion are wanted. The wheat miller wants the endosperm to crumble easily for flour production. In contrast, the corn dry-miller needs the endosperm in a tough and rather vitreous state for maximum production of $-3\frac{1}{2}+16$ grits; any endosperm that goes into fines is essentially a loss item.

Possibly more strongly than many may have realized, this experimental work confirms and points out the pronounced effect of tempering upon degermination performance, as well as upon product yields and characteristics — at least for some lots of corn. The studies also emphasize the need and opportunities for improving the tempering step. Some of the results appear quite logical on the basis of our current knowledge. Others point to the need for more research on the fundamentals of moisture movement (rate and distribution) within the corn kernel and on subsequent effects upon various components as tempering proceeds.

Acknowledgments

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