CORN DRY-MILLING: A COMPARISON OF SEVERAL PROCEDURES FOR TEMPERING LOW-MOISTURE CORN[1]

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ABSTRACT

In pilot-plant tests, corn (12–13% moisture content) from a single lot was degerminated in a studded-cone mill after being tempered by one of five procedures: 1) dry corn given a second temper, 2) pretempered corn, 3) pretempered corn with a second temper, 4) pretempered corn with both first and second tempers, and 5) corn given conventional first and second tempers. Degermination was moderate to good for each procedure. Although the conventional temper gave the highest degerminator throughput, the other procedures gave the best yield of flaking grits and total grits. With dry corn, oil recovery was appreciably lower. Results demonstrate that any one of the tempering procedures can be used. The choice depends upon various cost and process factors, such as product yields, degerminator throughput, tempering facilities, and dryer capacity, and the relative weight given to each factor. The results also point to the need for ascertaining the effect of moisture addition and movement upon the development of stresses within the corn kernel during tempering.

Although corn dry-milling is an old industry, the various aspects and limitations of tempering have not been fully established. A better understanding is needed of the principles involved. The miller hopefully looks for improved tempering and degerminating procedures to give him higher yields of prime goods, better product characteristics, reduced load on product dryers, a shorter temper time, or lower operating costs. Previous research at our laboratory has demonstrated the pronounced differences in degerminator response as moisture level and rest time are varied in the tempering of corn of 13% initial moisture content (1).

Further knowledge of how tempering affects degerminator response has been gained from a study of five different tempering procedures.

Materials, Equipment, and Methods

Materials. Yellow dent hybrid corn, grade No. 1, field- and crib-dried, from the 1962 crop was processed 13 to 24 months after harvest. This corn (P.A.G. Hybrid 444) had been grown on brown silt soil with 400–475 lb. per acre of ammonium sulfate plowed under and 165 lb. per acre of mixed fertilizer (65 lb. of potash and 100 lb. of diam-

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monium sulfate) applied when the corn was planted. At the time of processing, the corn varied in moisture content between 11.9 and 12.9%. It contained (% d.b.) oil 4.70; crude fiber 1.93; ash (600°C.) 1.48; and protein 9.90. Test weight at 12.0% moisture content was 59.0 lb. per bu. with 5, 46, 61, and 99% (weight) of kernels retained on round-hole perforated sieves, 24-, 21-, 20-, and 17/64-in. diameter, respectively. The corn was of "average" hardness according to the floaters test (2).

Processing Equipment. A 16-bu.-capacity, rotating, double-cone batch grain mixer equipped with nozzles for spraying temper water onto the corn during mixing was used for the pretemper and first-temper steps. Second-temper water was sprayed onto the corn as it moved through two 5-in.-diameter, 12-ft.-long screw conveyors to the degerminator supply hopper. The degermination was conducted in a No. 0 Beall degerminator fitted with a "blunt"-studded rotor and three screens having 14/64-in.-diameter, round-hole perforations.

Experimental Operation. In tempering sublots of the corn by the five procedures, various combinations of pretempering, first temper, and second temper were employed, all at room temperature. In the pretemper step, sufficient tap water was sprayed onto the corn to raise its moisture content to 15–16%; it was then given a rest period of 9 to 43 hr. Strictly speaking, a pretemper is the first temper, because moisture is being added for the first time. However, pretempering is the term used among industrial operators, because in mill operation pretempering is usually done before the corn is washed.[2]

In our first-temper step, the corn was brought to a moisture content of 21% and the rest period approximated 2¼ hr. From 7 to 30 min. were required for the addition of water in both the pretemper and first-temper steps, depending upon the quantity of corn being tempered. For the second temper, approximately 3% more water was added about 20 min. before the corn was degerminated. The specific tempering combinations used for the five procedures, along with average temper times and moisture levels for each step, are shown in Fig. 1.

For the degermination step, the Beall rotor was always in the 50% closed position and operated at 850 r.p.m. with the motor load approximating 13.4 kw. or almost 18 h.p. The V-notched slide used for a tailgate was adjusted to obtain 2% of recycle stock based on gross, air-dried products (range was 1.1–3.3%) for the first three tempers listed

[2] During a normal year, millers process corn ranging from about 20 to 13% in initial moisture content. First the corn is cleaned by screening and aspiration and then, if necessary, by washing and whizzing. The wet-cleaning step often adds about 3% moisture. Although tempering conditions vary from mill to mill, corn of 15–16% moisture content generally is given a first temper to 21% for ½ to 2 hr. With the longer temper time, a second temper is often used, consisting of 2–3% moisture addition about 10 min. before degermination. Pretempering is used infrequently.

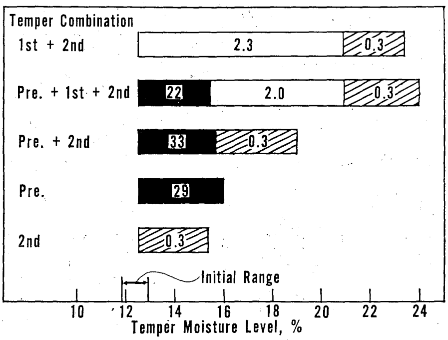

Fig. 1. Average moisture level (%) and holding times (hr.) (numerals within each bar), for five experimental procedures used in tempering corn preparatory to degermination.

above. For tests employing only a pretemper or a second temper, the recycle level was 5% (range was 4.2–5.8%).

The degerminator product streams (throughs and tailings) were combined, sampled, air-dried, and fractionated into grits of various sizes, fines, germ, and hull fractions by a laboratory procedure employing screening, aspiration, and flotation. Various details of the pilot-plant installation, fractionation procedure, and analytical methods have been reported previously (1,3,4).

Results and Discussion

Data on degerminator performance for each tempering procedure are given in Table I, including the number of tests used in calculating the averages. Each value in the table is accompanied by a plus-minus factor for determining the 95% confidence interval.

Comparison of Tempering Procedures. In general, all five tempering procedures produced −3½+16 grits of good-to-moderate oil content, but some of the −16+25 grits had an undesirably high oil content. Variations in the tempering procedures had the following effects on degerminator performance and on products:

A. Tempering to higher moisture levels as in the procedures employing a first temper:

1) Gave the highest degerminator throughput;

2) Produced lowest amount of both −3½+25 and −4+6 grits; the −4+6 grits were considerably higher in oil content than grits from the other procedures, whereas the −8+16 and −16+25 were lower;

3) Produced the lowest amount of undesirable fines and fines of lowest oil content;

4) Produced largest amount of hull fraction, and these hulls were of best purity as judged by oil content;

TABLE I

PRODUCT YIELDS, PRODUCT OIL CONTENTS, AND CORN DEGERMINATOR THROUGHPUT

Throughput and Product Characteristics	Temper Treatment				
	First + Second	Pretemper + First + Second	Pretemper + Second	Pretemper	Second
Degerminator throughput, bu./hr. (15% m.c.)[a]	42.0 ±2.3[b]	25.7 ±2.6	18.9 ±3.0	16.4 ±3.6	19.4 ±3.6
Yields, % n.p.:[c]					
−3½+25 Grits	63.0 ±1.0	65.4 ±1.1	65.3 ±1.3	69.8 ±1.6	64.4 ±1.6
−25 Fines	10.9 ±0.7	12.1 ±0.8	14.6 ±0.9	13.1 ±1.1	17.0 ±1.1
Germ fraction	19.7 ±1.3	16.5 ±1.5	14.5 ±1.7	15.1 ±2.1	13.2 ±2.1
Hull fraction	6.2 ±0.2	6.1 ±0.3	5.5 ±0.3	2.0 ±0.4	5.6 ±0.4
−3½+4 Grits	2.3 ±0.8	6.7 ±0.9	4.3 ±1.1	4.0 ±1.3	5.2 ±1.3
−4+6 Grits	29.7 ±2.7	45.4 ±3.0	45.7 ±3.5	46.4 ±4.3	47.4 ±4.3
−6+8 Grits	23.3 ±2.2	9.2 ±2.5	12.0 ±2.8	14.4 ±3.5	8.2 ±3.5
−8+16 Grits	5.6 ±0.9	2.6 ±1.0	2.2 ±1.1	3.4 ±1.4	2.3 ±1.4
−16+25 Grits	1.9 ±0.4	1.5 ±0.5	1.2 ±0.5	1.8 ±0.6	1.3 ±0.6
Recoverable oil, lb./net bu.[d]	1.29±0.06	1.36±0.06	1.22±0.08	1.27±0.09	0.96±0.09
Oil contents, % d.b.:[e]					
−3½+25 Grits[f]	0.79±0.06	0.50±0.07	0.52±0.08	0.64±0.09	0.54±0.09
−25 Fines	5.07±0.40	6.67±0.45	7.98±0.52	7.12±0.64	9.88±0.64
Germ fraction	17.05±1.25	20.09±1.40	20.43±1.62	20.26±1.98	18.50±1.98
Hull fraction	1.97±0.34	2.45±0.38	3.60±0.44	3.95±0.53	4.52±0.53
−3½+4 Grits	1.12±0.16	0.55±0.18	0.35±0.20	0.70±0.25	0.58±0.25
−4+6 Grits	0.74±0.06	0.40±0.07	0.41±0.08	0.44±0.10	0.41±0.10
−6+8 Grits	0.72±0.08	0.62±0.09	0.62±0.10	0.80±0.12	0.68±0.12
−8+16 Grits	0.88±0.08	1.00±0.09	1.17±0.11	1.33±0.13	1.44±0.13
−16+25 Grits	1.79±0.21	1.84±0.24	3.13±0.28	2.94±0.34	2.59±0.35
−4+6 Grits with attached hulls, % (wt.)	0.6 ±0.5	0.5 ±0.6	1.3 ±0.7	97 ±1	5 ±1
Yields, lb./bu.:					
Fines, −16 m.[g]	7.2	7.6	8.8	8.3	10.2
Fines, −25 m.	6.1	6.8	8.2	7.3	9.5
Germ, −3½+25 m.	11.0	9.2	8.1	8.5	7.4
Germ, −3½+8 m.	6.6	5.8	5.4	5.9	4.7
−16 m. Fines, % oil, d.b.[g]	4.49	6.05	7.58	6.56	9.30
No. of tests averaged	5	4	3	2	2

[a] Moisture content.

[b] Plus-minus factor for determining 95% confidence interval. When the upper and lower limits for two values do not overlap, they differ significantly. Example: 39.7 (i.e. 42.0−2.3) and 28.3 (25.7+2.6) differ significantly; 18.9±3.0 and 16.4±3.6 do not.

[c] Net product basis, i.e., gross product less 3½-mesh recycle stock.

[d] Calculated yield based on germ cake containing 5% oil, d.b.

[e] Dry basis.

[f] Weighted average.

[g] Germ and hull removed from −16+25 fraction.

5) Placed maximum load on dryers.[3]

B. Use of a pretemper (comparison made with 1st + 2nd temper):

1) Reduced the degerminator throughput;

2) Increased the yield of $-3\frac{1}{2}+25$ grits by about one-twentieth and of $-4+6$ grits by about one-third; also, the latter were much lower in oil content;

3) Reduced the yield of $-6+8$ grits with no definite effect on their oil content;

4) Produced a germ fraction higher in oil content and lower in yield with no reduction in yield of recoverable oil. When the first temper was omitted, the drying load was considerably smaller.

C. Milling corn given only a second temper (comparison made with 1st + 2nd temper):

1) Reduced the degerminator throughput;

2) Produced quite good degermination, hull removal, and grit yield;

3) Produced an excessive amount of fines high in oil content;

4) Produced less germ fraction and considerably less recoverable oil;

5) Reduced the drying load to a minimal level.

The results from degermination of dry corn (average of two tests — data not included in Table I) were generally like those for dry corn given a second temper. In a comparison of the two, yield of $-3\frac{1}{2}+25$ grits was $3\frac{1}{2}$ percentage points more for dry corn and of $-4+6$ grits almost 3 points less. Oil content of grits in the $-3\frac{1}{2}+8$ range ran about 0.1 percentage point higher. Attached hull count for the $-4+6$ grits climbed to 64, and hull recovery fell to 2.6%.

The $-3\frac{1}{2}+25$ grits fraction is a miller's major source of prime goods (grits, meal, and flour). Economically feasible process conditions leading to greater yields of these grits of adequate quality and to more recoverable oil are always being sought. If product yields and characteristics obtained by use of a first plus a second temper are taken as the datum level, the differences as tabulated in Table II and the data in Table I can serve as a basis for discussion.

Use of a pretemper plus a first and a second temper increased the yield of $-3\frac{1}{2}+25$ grits by 2 percentage points and the fines fraction by 1 point. This increase occurred entirely at the expense of the germ fraction; however, oil recovery did not suffer, because pretempering produced a purer germ fraction as obtained by the laboratory flotation procedure; that is, a germ fraction less contaminated by endosperm fragments. Removal of the endosperm fragments to produce the purer germ fraction presumably resulted in simultaneous abrasion of the germ, with germ fragments then appearing in the fines fraction and raising its oil content. At the same time, better degermination as indi-

[3]Moisture content of the degerminator products fed to the dryers varies with the moisture level to which the corn is tempered. Depending upon moisture level and amount of surface moisture, a small and variable amount of this moisture is lost in the degermination step through evaporative cooling. The degerminator stock is dried down to 15–17% for the multistep milling operations that follow, and the final products are dried to about 13% for packaging and storage.

TABLE II

COMPARATIVE DIFFERENCES IN PRODUCT YIELDS AND OIL CONTENTS

Characteristics of Milled Corn Fractions	Temper Treatment				
	First + Second	Pretemper + First + Second	Pretemper + Second	Pretemper	Second
Yields, % n.p.:	Datum level or 0				
$-3\frac{1}{2}+25$ Grits		+2	+2	+7	+1
-25 Fines		+1	+4	+2	+6
Hull fraction		0	−1	−4	−1
Germ fraction		−3	−5	−5	−7
$-3\frac{1}{2}+6$ Grits		+20	+18	+18	+21
Oil contents, % d.b.:					
-25 Fines		+2	+3	+2	+5
Germ fraction		+3	+3	+3	+1
Hull fraction		0	+2	+2	+3

cated by oil content was obtained for the $-3\frac{1}{2}+8$ grits, which represented about 60% of the total products.

Omission of the first temper increased the yield of fines and decreased the yield of germ. Without a first temper, slightly poorer degermination also resulted, as judged by oil content of grit fractions in the $-8+25$-mesh range.

Omission of the second temper gave more $-3\frac{1}{2}+25$ grits but largely at the expense of lower hull recovery (see data for corn given only a pretemper). Consequently, a very high percentage of the grits had attached hull fragments.

The larger amount of fines produced upon degermination of corn given only a second temper and the increase in their oil content again occurred at the expense of the germ fraction. The decreased yield of germ far overbalanced the slight increase in its oil content, with a correspondingly large decrease in quantity of recoverable oil.

The yield of germ and fines is partially interrelated, one increasing at the expense of the other. A summation of yields of fines and germ fractions is fairly constant for the five tempering procedures and totals 28 to 31%. Similarly, totals for the grits and hull fractions range between 72 and 69%. This interrelationship between yield of germ and fines fractions confirms a supposition made earlier (1) and provides an insight as to where efforts should be made to improve the tempering step.

From a material balance calculation for distribution of oil among the four major product groups, i.e., $-3\frac{1}{2}+25$ grits, fines, hull, and germ, for each of the five tempering procedures (Table III), there appears little likelihood of substantially reducing oil content of the grits. However, the wide variation in total oil content of the fines, ac-

TABLE III
DISTRIBUTION OF OIL AMONG PRODUCT GROUPS

FRACTION	TEMPER TREATMENT				
	First + Second	Pretemper + First + Second	Pretemper + Second	Pretemper	Second
	Based on 100 lb. corn[a]				
	lb.	*lb.*	*lb.*	*lb.*	*lb.*
$-3\frac{1}{2}+25$ Grits	0.45	0.30	0.31	0.40	0.31
-25 Fines	0.51	0.73	1.05	0.85	1.51
Germ	3.12	3.07	2.76	2.84	2.22
Hull	0.11	0.13	0.18	0.07	0.22
Total[b]	4.19	4.23	4.30	4.16	4.26
	Based on percentage of total oil				
	%	%	%	%	%
$-3\frac{1}{2}+25$ Grits	10.8	7.0	7.1	9.6	7.3
-25 Fines	12.1	17.3	24.5	20.4	35.5
Germ	74.4	72.6	64.2	68.3	52.1
Hull	2.7	3.1	4.2	1.7	5.1

[a] Assuming recycle stock has same oil content as whole corn.
[b] Oil content of corn containing 12% moisture and 4.7% oil (d.b.) = (100) (1.00—0.12) (0.047) = 4.136 lb. Average of totals for five procedures is 4.23 lb.

companied by corresponding changes in oil content of the germ fraction, points to this as one area in tempering and degerminating for potential improvement. If such improvements could limit the fines production to 10% and their oil content to 1.5%, then the germ fraction ($-3\frac{1}{2}+25$ m., as recovered by the laboratory flotation procedure) would contain about 85% of the oil present in the corn kernel.[4] By comparison, the germ fraction from experiments made with a first plus a second temper contained 74% or less of the total oil, and this figure was higher than for any of the other four procedures. Conceivably, an entirely new approach may be needed to produce a germ fraction containing 85% of the total oil. If a procedure meeting these specifications should be developed, then the fat content would be less of a limiting factor for use of these fines in various food and industrial applications.

Millers recover few germ particles finer than 12-mesh and prefer particles coarser than 8-mesh.[5] Among the five procedures there was only a small variation in the proportion of larger particles. Of the total germ recovered ($-3\frac{1}{2}+25$), the proportion retained on an 8-mesh sieve varied between 61 and 70% or 6.6 to 4.7 lb. per bu. (Table I).

Product Temperatures. Temperatures of the degerminator throughs

[4] Ten pounds of fines containing 10% moisture and 1.5% oil (d.b.). (10) (1.00—0.10) (0.015) = 0.135 lb. oil in fines fraction. 0.135 ÷ 4.23 = 0.032 or 3.2%. Germ and fines fractions contained 88.3% of total oil (av. for five tempering procedures). 88.3—3.2 = 85.1% for germ fraction.
[5] Private communication from Hans Wanzenried, The Buhler Corporation, July 1965.

and tailing streams varied somewhat with the moisture level attained in tempering the corn (see table below).

Temper			*Total Moisture Content*	*Temperature*[a]	
				Throughs	*Tailings*
			%	°F.	°F.
. . .	1st	+2nd	23.4	98	103
Pre	+1st	+2nd	24.0	106	109
Pre	. . .	+2nd	19.0	116	126
Pre			16.0	116	122
. . .	. . .	2nd	15.3	117	127

[a] Approximate temperatures as measured by insertion of a thermometer into solids upon completion of test.

Higher moisture levels resulted in lower temperatures for stock leaving the degerminator. The more moisture available, the greater was the evaporative cooling effect which helped limit product temperatures.

The higher temperatures obtained when a pretemper was used for a portion of the 24% temper indicate that less cooling occurred by evaporation compared with corn given the conventional first plus second temper. The longer temper period permitted some of the added moisture to migrate further into the kernel, leaving less near the exposed surfaces for evaporative cooling. This effect is in agreement with millers' observation that moisture recently added to the corn is most readily removed when the degerminator stock is dried.

Hull Removal. For the tempering procedures investigated, it was necessary, for good hull removal, to have adequate surface moisture on the corn at time of degermination. At the higher levels of temper moisture, possibly less than 3% moisture was needed as a second temper, but for dry corn given only a second temper probably more than 3% should have been added.

Tempering and Kernel Stress. In this study pretempering had three noticeable effects. As described previously, it lowered the degerminator throughput, increased the yield of −4+6 grits by one-half and of −3½+25 grits by about one-twentieth, and lowered the oil content of the −4+6 grits drastically and of the −3½+25 grits significantly. The causes of these changes are not yet definitely known.

Current work, to be reported later, indicates that during cold-tempering an increase in moisture content directly from 12–13 to 21% creates much stress within the corn kernel, and consequently, an appreciable portion of the kernels develop internal fissures or "stress cracks." It follows that less power would be needed to break open the kernels and that degerminator throughput would increase accordingly. Also, the highly stressed kernels, if not already fractured, undoubtedly break into smaller fragments and the yield of large grits suffers. Although a previous study (5) indicated that a 50% increase in throughput had little effect on oil content of the large grits, the poorer degermination obtained with the first plus second temper procedure possibly may result from the weakened kernels fracturing and moving out of the degerminator before the endosperm was adequately rubbed free of adhering germ.

Addition of moisture in increments, as is done in pretempering corn, probably has two effects. With less moisture added in any one step, less stress is created within the kernel and fewer kernels develop stress cracks. Secondly, because corn swells when it absorbs moisture (as in steeping for wet-milling), corn at the 15.5% moisture level is less dense and thus possibly absorbs water more readily than corn at a lower moisture level.

Conclusions

In this study of various tempering conditions, a broad range in both temper time and temper moisture level has been covered. Each of the five tempering procedures had some merit. All produced good degermination of $-3\frac{1}{2}+25$ grits and moderate-to-good results in other respects.

The results also demonstrate the need for an "adequate temper" if good oil recovery is desired. The miller has some choice of tempering conditions, but data from this study indicate that for low-moisture corn either a high temper-moisture level or an extended temper time through use of a pretemper is needed. Furthermore, the results point to the need for ascertaining what effect moisture addition and movement during tempering of low-moisture corn have upon the development of stress within the corn kernel, its related effect upon ease of fracturing the kernel, size of endosperm fragments produced upon fracturing, and the concurrent germ release obtained.

From a processing standpoint, a miller has considerable leeway as to his choice of tempering conditions for corn of the type used. His selection depends, therefore, upon the relative weight he places upon factors such as degerminator throughput, yield of total grits, oil content and other characteristics of the products, tempering capacity, drying load, and oil recovery. From an over-all view, a combination of pretemper plus a second temper seems favorable. With this combination a high yield of both total grits and flaking grits and good degermination were obtained, along with a smaller drying load. One potential disadvantage is the longer temper time. This could be a handicap when low levels of microorganisms are desired in the products and no sanitizing agents are used. However, it could prove advantageous if such agents are added to the temper waters and the pretempering conditions bring about germination of the spores. The resultant vegetative cells then become more susceptible to the action of the sanitizing agents.

Acknowledgments

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