Single-Stage Short-Duration Tempering of Corn for Dry-Milling

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ABSTRACT

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Pilot-scale dry-milling runs were conducted to study the feasibility of using a short-duration single-stage tempering procedure for the tempering-degerminating system, instead of the 17.8–21.5 hr of conventional three-stage tempering procedures reported in the scientific literature. Using a Beall degerminator No. 0, pilot-scale dry-milling experiments were conducted at 10 tempering levels: 0, 5, 10, 15, 30, 45, 60, 120, 180, and 240 min. Variation in moisture content of through- and tail-stock fractions, degerminator throughput, ratio of tail- to through-stock, yields of different sized grits from tail- and through-stock fractions, and the recovery of germ and pericarp were used to compare tempering periods. A decrease in the milling action was observed for tempering durations >30 min. A tempering period of 15 min gave the highest grit recovery and a 30-min tempering period resulted in the highest germ and pericarp recovery. Based on these results, it was concluded that short tempering periods of 10–30 min as compared to 17.8–21.5 hr could be used for the tempering-degerminator system.

Originally all corn milled was ground whole into meal by mortar and pestle or millstones (Kumar, 1972). The oil-bearing germ was not removed, which limited the shelf life of the meal due to rancidity and spoilage. The turn of the 20th century brought about the development of a tempering-degerminating system that removed the pericarp, germ, and tip cap, resulting in the production of low fat grits, meal, and flour (collectively referred to as prime products), and hominy feed and oil (Brekke 1970a). Presently, a large number of small mills grind whole corn directly for the production of whole fat corn meal and grits, but most of the large modern mills use a degerming-roller milling process to separate the germ and the pericarp from the endosperm (Hill et al 1991).

The machine that first made the tempering-degerminating system possible was the Beall degerminator, patented in 1905. According to Brekke (1970a), this degerminator is essentially an attrition device built in the form of a cone mill, where the product leaves in two distinct streams: 1) tail stock or the hominy stock consisting of large particles that leave the degerminator by passing through a weighted gate on the end-plate side of the cone, and 2) through stock consisting of finer particles of broken corn, pericarp, and germ that pass through the perforated screens encasing the cone. Approximately 40% of the corn exits as tail stock, with the remainder being through stock. About 90% of the corn dry-milled in the United States is degerminated by the Beall degerminator.

The efficiency of the tempering-degerminating process depends on the specific tempering procedure used and on degerminator settings. Tempering involves the addition of a controlled quantity of moisture to the corn kernel as cold or hot water or steam in one, two, or three stages with appropriate tempering periods for each stage (Brekke 1970a). The addition of moisture to the corn kernel results in an increase in the volume due to swelling. The protoplast within the germ cells constitutes a hydrophilic colloidal system with a greater swelling capacity than that of the endosperm cells (Kumar 1972). Therefore, the moisture uptake capacity and the rate of moisture absorption by the germ exceeds that of the other corn components (Shelef and Mohsenin 1966). Under certain conditions, this leads to differential moisture distribution resulting in swelling forces of several thousand pounds (White 1966). These swelling forces are dependent upon the initial corn moisture, the amount of water added, and the tempering period. Under optimum conditions, these forces make the germ and pericarp readily separable from the endosperm with minimum damage.

Tempering in the scientific literature is generally considered as a three-stage procedure: 1) pretempering to elevate the kernel moisture to ≈16% overnight (16–18 hr); 2) first tempering to raise moisture to 21% with a rest period varying between 1.75 and 3.25 hr; and 3) second, or dehulling, tempering ≈5–15 min before degermination to raise the moisture to 24% (Brekke 1970b; Brekke et al 1971, 1972, 1973; Manoharkumar et al 1978; Peplinski et al 1984; Kirleis and Stroshine 1990; Peplinski et al 1992; Mistry and Eckhoff 1992). This tempering procedure is contrary to the conclusions made by Brekke (1967) that a two-stage tempering procedure (pretemper followed by second tempering) was quite satisfactory and practical as compared to pretempering, and a first and second tempering combination. Surprisingly, discussions with the corn dry-milling industry indicate that the multiple-stage tempering procedure used in past research studies is not used and has not been used for a long time. Rather, a single-stage tempering procedure is used to raise the moisture content by 6–8% points with a tempering period of 10–20 min.

Pretempering is the longest stage in the three-stage tempering procedure. Elevating the corn moisture to only 16% during pretempering as compared to 20–24% in single-stage tempering, results in a reduction in the magnitude of the moisture gradients inside the corn kernel. Ekstrom et al (1966) reported that stress crack formation was related to the moisture and thermal gradients present inside the corn kernel. Furthermore, dry-milling of corn with higher stress cracks results in poor degermination performance (Brekke 1968). A long overnight rest period following the addition of water during the pretempering stage results in an even distribution of the moisture. Sarwar and Kunze (1989) reported that no stress cracks were observed for kernels at initial moisture of 15% or higher, subjected to any humidity conditions. Therefore, further addition of water, either during the first or second tempering period, does not have any effect on stress crack formation.

Multiple-stage tempering procedures can be justified on the basis of stress crack formation but also imply poor utilization of the initial swelling stresses, which are beneficial for a purer separation, during degermination. Corn at a higher initial moisture subjected to a moisture increase has a reduction in swelling stresses as compared to corn at a lower initial moisture (Kumar 1972). Furthermore, during the initial period of water sorption by the kernel, the unidirectional swelling per unit thickness is higher for the germ as compared to that of the endosperm (White 1966). The higher swelling of the germ as compared to the endosperm helps

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in the separation of germ from the endosperm. But with increase in the temper period the swelling of the germ and endosperm equalizes, and the benefits associated with tempering of corn are diminished.

Corn tempered in a single stage at 12–14% to a moisture at 20–21% develops more swelling stresses when compared to that pretempered to 16%. If degermination were done before the development of stress cracks by the swelling stresses, then these stresses could be utilized for a better separation of the germ from endosperm. A short-time temper scheme would result in a drastic reduction in processing time from 17.7–21.5 hr to 10–50 min. Peplinski et al (1984) compared the three tempering procedures (single-, double-, and three-stage) using a horizontal drum degerminator and concluded that the best results were achieved by the use of a three-stage tempering procedure, but that the results were equaled by single-stage tempering at a final moisture of ≥17%.

The discrepancies between the procedures reported in the scientific literature and the commercial practice and the lack of literature on the role of single-stage tempering on product recovery initiated this study. The objectives were to verify the hypothesis that corn subjected to single-stage tempering could be efficiently milled, to observe the influence of tempering period on degerminator performance, and to determine the optimum tempering period.

MATERIALS AND METHODS

A single lot of medium soft endosperm corn (FR1064 x LH59), at an initial moisture content of 12–13% (wb), was degerminated in 40-kg lots using a Beall degerminator No. 0, after being tempered to ≈20% moisture content. The influence of the tempering period on the quantity of product recovered after degermination was studied at 10 tempering levels: 0, 5, 10, 15, 30, 45, 60, 120, 180, and 240 min. Before the milling for each experiment, 40 kg of corn was weighed and stored in 68-L (18-gallon) plastic containers at room temperature (≈30°C) for a period of at least three days to ensure a uniformity in temperature during tempering and degermination. All runs were randomized and duplicated, and later Duncan's multiple range test was conducted to compare the throughput and product yields.

Tempering

Dry corn lots (40 kg) were placed in a ribbon blender (40-kg capacity, 0.914 × 0.305 × 0.356 m), equipped with spray nozzles. A specific quantity of water was added to elevate the corn moisture to ≈20% (wb). After blending the corn for a maximum of 15 min (for tempering periods <15 min, the corn was blended for the entire duration of the tempering period), the corn was allowed to remain in the blender until the completion of the tempering period (defined as the period beginning from the time when water is added to the corn), after which the corn was removed from the mixer and placed into a spiral-screw auger (model No. 4C8, S. Howes Co.) that fed the degerminator. The moisture content of corn with and without surface water (surface water was absorbed by placing the corn on a tissue paper) was determined using the Method 44-15A (AACC 1995) to observe the variation in moisture with time.

Degermination

Degermination was performed using a Beall degerminator (model No. 0, Union Iron Works) fitted with two 0.0056-m (14/64-in) round-hole perforation screens. The blunt studded rotor was operating at a 50% open position and was driven by a 11.2 kW (15 hp) motor. A hinged gate with 192-g weight was installed above the rotor shaft to serve as the tail-gate discharge. The feed rate to the degerminator was adjusted to maintain ≈40 amperes going to the motor; higher amperage consumption (>50 amperes) resulted in an overload condition, causing the circuit to trip. The tail- and through-stock fractions were collected for ≈2 min after the steady state was achieved, and they were used to compute the ratio of tail- to through-stock and the degerminator throughput. The moisture content of the stocks was measured using forced-air ovens to dry the stocks at 49°C overnight, followed by drying at 135°C for 2 hr (AACC 1995).

Fractionation

Dried stocks were thoroughly mixed and three 500-g subsamples were collected from the tail- and through-stocks for fractionation on a laboratory sifter (model 130-11, Great Western). Tail stock was sifted over 3.5, 4, 5, and 6 mesh (M) screens and through stock was sifted over 6, 10, and 22 M screens. The weight of each fraction was recorded and averaged over the three samples. Pericarp was separated using a laboratory-scale aspirator, (model 6DT4, Kice) and the weight of the pericarp removed was recorded. Germ was manually separated from the tail-stock fraction –5+6 M (indicates that the fraction passed through a 5 M screen but was retained over a 6 M screen), and from through-stock fractions +6 M (indicates that the fraction was retained over a 6 M screen) and–6+10 M. The weight of germ recovered was recorded.

RESULTS AND DISCUSSION

Moisture Content

The moisture content of corn both with and without surface moisture for untempered corn (tempering period equals zero) was significantly lower than that of the tempered corn (Table I). The difference in the moisture content of the corn with and without surface moisture was within 1% for tempering periods of 10 min or longer. Furthermore, for the tempered corn, no significant change in either moistures was observed with a change in the tempering period. The moisture content of corn with surface water present was always higher than without surface moisture, though the difference between the two, in general, decreased with tem-

TABLE I
Variation in Moisture of Corn with Tempering Period[a]

	Moisture Content (%, wb)				
Tempering Period (min)	**With Surface Moisture**	**Without Surface Moisture**	**Tail Stock**	**Through Stock**	**Difference Between Tail and Through Stock**
0	14.38b	14.38b	14.71d	14.74b	0.03b
5	20.38a	18.98a	15.74cd	19.48a	3.74a
10	20.57a	19.72a	15.61cd	19.73a	4.11a
15	20.87a	19.84a	16.39c	20.47a	4.08a
30	20.97a	19.85a	16.66c	20.47a	3.81a
45	20.40a	19.69a	18.42b	20.90a	2.49a
60	20.30a	19.75a	18.30b	20.88a	2.58a
120	21.01a	20.32a	19.96a	20.56a	0.60b
180	20.15a	19.86a	19.69ab	20.29a	0.60b
240	20.43a	20.10a	20.13a	20.42a	0.29b

[a] Values in the same column with different lowercase letters are statistically different at the 5% level.

pering period, implying that though the moisture was available on the surface for absorption, it was not being absorbed by the kernel. This could be explained by the fact that moisture is absorbed by the kernel through the tip cap, and the surface water present on the pericarp is not absorbed by the kernel due to the impervious nature of pericarp. Therefore, no significant change in the kernel moisture was observed for tempering periods longer than 10 min.

Tail-Stock Fraction

Percent tails recovered for untempered corn was ≈77% (Table II). The effect of tempering period can be summarized in two groups. The tail-stock fraction of the first group consisted of tempering periods varying between 5 and 60 min and was significantly lower compared to that of the untempered corn. Except for tempering periods of 5 and 30 min, nonsignificant differences were observed within this group. The second group consisted of tempering periods of 120 min and longer and had a tail-stock fraction that was statistically similar to that of the untempered corn. The tail-stock percentage for 180 and 240 min tempering periods was significantly higher than that for 120 min.

Flaking grits. Dry-milling of untempered corn resulted in ≈21% yield of flaking grits (-3.5+6 M) from the tail stock (Table II). The influence of tempering period can be divided into three groups. Group 1 had tempering periods between 5 and 15 min had a total variation in the flaking grit yield of >1%. The flaking grit yield was highest for 10 min of tempering and was statistically similar to that of 5 and 15 min of tempering. Compared to the untempered corn the yield of flaking grits was significantly higher. Group 2 had tempering periods between 30 and 60 min with no significant difference in flaking grit yield. The yields were significantly higher compared to that of the untempered corn but were significantly lower compared to group 1, except at 45 min of tempering, for which the yields were statistically similar to the 5 and 15 min of tempering. Group 3 had tempering periods of 120 min and longer. The flaking grit yield was significantly lower for this group as compared to groups 1 and 2. Within group 3, the yield of flaking grits was significantly higher for 120 min of tempering compared to that of 180 and 210 min.

+3.5 M Fraction. This fraction retained over a 3.5 M screen is generally composed of whole kernels subjected to little or no milling action. Therefore, an increase in the fraction of +3.5 M indicates a reduction in the milling action. The yield for untempered corn was ≈52%. The effect of tempering can be divided into two groups. Group 1 had tempering periods between 5 and 60 min and the percentage of material retained over a 3.5 M screen was significantly lower than that for the untempered corn. Nonsignificant differences were observed within this group, with the exception that the yield for 30 min was significantly lower than that for 60 min of tempering. Group 2 had tempering periods between 120 and 240 min. A significantly higher percentage of the +3.5 M fraction was recovered for 180 and 240 min of tempering as compared to that of the untempered corn, indicating a significant reduction in the milling action for longer tempering periods.

–3.5+4 M Grits. The yield of –3.5+4 M grits varied <3%. Nonsignificant differences were observed for all tempering periods, with the exception that the yield for 120 min of tempering was significantly higher than that for the untempered corn and for 30 min of tempering (Table II). This implies that the yield of –3.5+4 M grits was independent of the tempering period.

–4+5 M Grits. The recovery of -4+5 M grits for untempered corn was –12% (Table II). Recovery of -4+5 M grits increased with tempering period and a maximum recovery was observed for 10 min of tempering, after which a decrease was observed. This trend is in agreement with Brekke (1965) for the tempering periods investigated in this study. The yield of –4+5 M grits can further be divided into three groups. For group 1 with tempering periods between 5 and 15 min, the yield of –4+5 M grits was significantly higher as compared to the other groups and nonsignificant differences were observed within this group. Group 2 consisted of tempering periods between 30 and 60 min and resulted in the yield decreasing with an increase in tempering period. The yield for 45 min of tempering was statistically similar to both 30 and 60 min of tempering, though the yield for 30 min was significantly higher than that for 60 min of tempering. Group 3 had tempering periods between 120 and 240 min. The yield for 120 min of tempering was statistically similar to that for the untempered corn but was significantly higher compared to that of 180 and 240 min of tempering.

–5+6 M Grits. Total variation in –5+6 M grits with tempering periods was <3% (Table II). The yield was ≈3% for untempered corn, and the difference in the yields for untempered corn and for tempering periods between 0 and 30 min was nonsignificant. The yield was highest for 60 min of tempering and was statistically similar to that observed for 45 min. The recovery for 180 min of tempering was statistically similar to that for 120 and 240 min, but the yields for 120 and 240 min were significantly different.

–6 M Grits. The yield of grits passing through a 6 M screen for untempered corn was ≈5%, and the total variation was <3% points. Tempering period had no statistically significant effect on the production of –6 M grits, with the exception that the yield for 60 min of tempering was significantly different than that for tempering periods between 10 and 30 min, and for 180 min or longer.

Through-Stock Fraction

The total through-stock yield for untempered corn was <23%, and was statistically similar to yields resulting from milling the kernels tempered for 120 min or longer (Table III). However, the percent through stock was significantly lower for 180 and 240 min of tempering when compared to that of 120 min. The percent of through stock was statistically similar for tempering durations

TABLE II
Variation in Throughput and Tail-Stock Fractions of the Dry-Milled Corn with Tempering Period[a]

		Tail-Stock Fraction[b] (%)						
Tempering Period, min	Throughput (kg/hr)	Total	Flaking Grits (–3.5+6 M)	+3.5 M	–3.5+4 M	–4+5 M	–5+6 M	–6 M
0	994.0c	77.3ab	20.7de	51.5b	5.5b	11.9d	3.3b	5.4a
5	967.6d	48.6c	34.8ab	10.1de	7.0ab	24.6a	3.2b	3.6bc
10	970.0d	46.5cd	35.6a	7.4de	6.9ab	25.6a	3.1bc	3.4c
15	967.6d	42.6cd	34.6ab	4.8de	6.2ab	25.2a	3.2bc	3.2c
30	851.7f	36.1d	30.3c	2.8e	5.2b	21.7b	3.4b	2.9c
45	865.0f	45.3cd	31.3bc	9.9de	6.7ab	20.3bc	4.3a	4.0a–c
60	887.7f	45.9cd	28.4c	12.3d	5.8ab	17.9c	4.7a	5.3ab
120	927.6e	71.1b	23.6d	43.0c	7.8a	12.6d	3.2bc	4.5a–c
180	1027.9b	82.2a	17.3ef	61.9a	6.5ab	8.4e	2.4cd	3.0c
240	1086.4a	85.4a	16.5f	65.9a	6.3ab	8.1e	2.1d	3.0c

[a] Values in the same column with different lowercase letters are statistically different at the 5% level.

[b] –M indicates that a fraction passed through sized mesh screen; +M indicates that a fraction was retained over a sized mesh screen.

between 5 and 60 min, except for 5 and 30 min of tempering which were significantly different from each other.

+6 M Grits. The yield of +6 M grits increased with an increase in the tempering period up to 30 min. Further increasing the tempering period decreased the yield (Table III). The change in the yield of +6 M grits with tempering period can be divided into two groups. Group 1 had tempering periods between 5 and 60 min and group 2 had untempered corn and a tempering period of 120 min or longer. Within these groups, the yields were statistically similar, but yields were significantly different between the groups with the yield of group 1 being significantly higher than group 2.

–6+10 M Grits. The yield upon degerminating the untempered corn was ≈7%. Increasing the tempering period increased the yield, and the highest yield was observed for 30 min of tempering. Further increasing the tempering period resulted in a decrease in yield and, finally, the yield leveled off at 180 min of tempering.

–10+22 M Grits. The yield was approximately 3% for untempered corn, and was statistically similar to the ones observed for 180 and 240 min of tempering. Tempering periods varying between 5 and 60 min had no significant effect on the yield, but the yields were significantly higher than that observed for the untempered corn.

Fines (–22 M). The yield of fines produced upon degerminating the untempered corn was ≈7%. Statistically similar yields of fines were produced upon degerminating corn tempered for tempering periods between 5 and 45 min, but the yields of fines were significantly higher than that observed for the untempered corn. Further increasing the tempering period (beyond 45 min) resulted in a reduction in the yield of fines.

According to MacMasters (1961) and Tran et al (1981), what happens during tempering is usually described as the toughening of the pericarp and mellowing of the endosperm. The untempered corn kernel is very hard; the addition of water followed by a tempering period mellows the corn kernel. Most of the product yields were statistically similar for tempering periods up to 45 min, and were significantly higher than those observed for the untempered corn. This significant increase in the yields can be attributed to the increased milling action due to the tempering of the corn. However, longer tempering periods cause the kernels to lose their friability and they become more plastic, resulting in a reduction in the milling action and increased throughput. Also, the moisture gradients are sharply defined during the initial tempering periods, and these gradients induce swelling zones (White 1966). These zones help in rupturing the corn kernel and facilitate the detachment of the germ from the endosperm. The significant decrease in almost all of the yields for tempering periods longer than 60 min could be due to the increased plasticity and reduction in the swelling stresses.

Pericarp Recovery

The pericarp yield increased with an increase in tempering period and the highest yield was observed for 30 min of tempering. Further increasing the tempering periods beyond 30 min resulted in a decrease in the pericarp yield (Table III). These pericarp yield trends are in disagreement with Brekke (1965), who had reported a peak pericarp separation at 60 min of tempering. The pericarp yield at 180 and 240 min of tempering was statistically similar to the one observed for the untempered corn.

The variation in the pericarp yield can be explained on the basis of the corn kernel structure. The spongy thin-walled cross and tube cells with only a small area of contact between them constitutes a line of weakness along which the pericarp is readily separated from the seed.

Separation along this line is favored by absorption of water as the branched, filamentous cells enlarge and walls become swollen, thus serving to lubricate the surface during milling (Wolf et al 1952a). Therefore, the pericarp yield increased with increase in the temper period up to 30 min. Beneficial effects of this rapid initial swelling are lost during longer tempering periods as the moisture begins to redistribute into the endosperm and, therefore, the decrease in the pericarp yield for tempering periods longer than 30 min was observed.

Germ Yield

Germ yield was closely related to the pericarp yield trend. The highest recovery of germ was observed for 30 min of tempering. Increasing the tempering period from untempered to 30 min resulted in a significant increase in the germ yield, except for 10 min for which the recovery was significantly higher than 15 min. Further increase, beyond 30 min, significantly decreased the germ yield (Table III). The trend observed in this study is contrary to the increase in germ recovery with tempering period and eventual stabilization at 150 min of tempering period as observed by Brekke (1965). Surprisingly, the recovery was significantly higher for untempered corn as compared to 180 and 240 min.

According to Wolf et al (1952b), the junction between the germ and endosperm is a critical zone in both dry- and wet-milling. Despite a sharp change from endosperm to embryo tissue in this region, no preexisting separation of endosperm is observed. The separation is further complicated due to the presence of a thin cementing layer of amorphous material between the endosperm and the germ (Wolf et al 1958). Absorption of water helps in two ways: it loosens the cementing layer (Wolf et al 1952b) and the faster rate of moisture absorption and swelling of the germ in relation to the endosperm establishes a differential swelling stress at the endosperm-germ interface. During the initial period of water absorption, the swelling stresses per unit thickness of the germ is higher than that of the endosperm (White 1966). Therefore, the germ yield increased with an increase in tempering period, achieving a peak yield at 30 min of tempering. With a further increase in the tempering period, moisture begins to redistribute uniformly inside the kernel and therefore the decrease in the germ yield was observed. Highest recovery of germ observed

TABLE III

Variation in the Through-Stock Fraction of the Dry-Milled Corn, and the Yield of Pericarp and Germ with Changes in the Tempering Period[a]

Tempering Period (min)	Through-Stock Fraction[b] (%)					Pericarp Yield (%)	Germ Yield (%)
	Total	+6 M	–6+10 M	–10+22 M	–22 M		
0	22.7cd	6.7c	6.7ef	3.1c	7.2d	1.2f	3.8g
5	51.4b	17.8b	10.3cd	6.5a	16.7a	6.2c	5.6e
10	53.5ab	19.2b	10.9bc	6.8a	16.5a	7.2b	8.7b
15	57.4ab	21.1ab	11.7bc	7.4a	17.2a	6.4c	8.3c
30	63.1a	25.3a	13.9ab	7.7a	17.0a	7.6a	10.0a
45	54.7ab	18.3b	13.6ab	7.5a	15.4ab	5.4d	8.1d
60	54.1ab	17.8b	15.0a	7.0a	14.2b	5.7d	8.3c
120	28.9c	8.2c	7.6de	4.4b	8.7c	2.4e	4.2f
180	17.8d	4.6c	4.9ef	2.8c	5.4de	1.3f	1.9h
240	14.6d	3.7c	4.0f	2.4c	4.5e	0.9f	1.3i

[a] Values in the same column with different lowercase letters are statistically different at the 5% level.

[b] –M indicates that a fraction passed through a sized mesh screen; +M indicates that a fraction was retained over a sized mesh screen.

for 30 min of tempering could possibly be attributed to optimum swelling stresses and the weakening of the cementing layer.

Degerminator Throughput

The degerminator throughput for untempered corn was 994 kg/hr. The influence of tempering period on throughput was divided into three groups. Significant differences were observed between these groups, compared to untempered corn: a significant decrease for the group 1 (tempering period of 5–15 min) and continued significant decrease for group 2 (30–60 min of tempering), followed by an increasing trend for tempering periods of 120 min or longer in group 3. This trend of decrease followed by an increase in throughput with tempering period is closely related to that of the +3.5 M fraction, which was significantly lower for tempering periods of 5–60 min when compared to the untempered corn and tempering of 120 min and higher. The increase in throughput observed for group 3 is explained by the fact that the +3.5 M fraction is generally composed of whole kernels subjected to little or no milling action and is recycled back to the mill. Brekke (1965) reported an increasing trend up to a tempering period of 2 hr followed by a decreasing trend after 4 hr of tempering. The minimum tempering period for his study was 20 min, and the decreasing trend observed in the present study was for tempering periods of 0–30 min. However, the increasing trend observed for tempering periods longer than 120 min appear to be contrary to his observations.

Role of Moisture Distribution

The only variable in this study was the tempering period. No significant change in either tempering moisture or moisture absorbed was observed with tempering period (Table I). However, the difference between through- and tail-stock moistures could be divided into two significantly different groups. Group 1 had tempering periods of 5–60 min, and group 2 consisted of untempered corn and tempering periods of 120 min and longer. The tails are generally recovered from the hard endosperm portion of the corn, while the through stock is composed of tip cap, pericarp, germ, and soft endosperm portions of the corn. The moisture reaches these regions before it reaches the hard endosperm region. Therefore, the difference between the tail- and through-stock moistures provides an estimate of the moisture distribution in the corn kernel. The milling action, as indicated by the yield of product on the 3.5 M screen, follows a close relationship to the difference between through- and tail-stock moistures because the group for which the differences were significantly higher, had increased milling action compared to the group for which the differences were nonsignificant with respect to the untempered corn. This implies that the moisture distribution inside the corn kernel plays a vital role with regard to milling action.

Mehra (1996) conducted an intensive study on the factors influencing the Beall degermination of corn for dry-milling. In this study, the mechanism of tempering and pilot-scale comparison of single-stage and multiple-stage procedures has been made. The effect of variables such as temperature, moisture, and Beall parameters on the throughput and product yields has also been studied.

CONCLUSIONS

Based on these experiments, a tempering period of 10 min seems to be optimum, which agrees with the commercial practice of tempering corn. The recovery of flaking grits is highest at 10 min of tempering, but is not significantly different than that observed for either 5 or 15 min of tempering. If the objective of milling is to increase pericarp and germ yield, then a tempering period of 30 min might be more suitable. The study also verified the hypothesis that corn subjected to single-stage short-duration tempering can be successfully milled.

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