

Influence of Temper Duration and Weight Distance on System Output in the Corn Dry-Milling Process

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ABSTRACT

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Initial uniform distribution of moisture in the corn kernel is transformed into nonuniform distribution through tempering to facilitate easy fractionation of corn components. Proper temper duration is essential for effectiveness of the tempering process: a short temper time is insufficient to cause necessary nonuniformity; a long temper duration may allow moisture to redistribute uniformly. Untempered corn suffers from lack of beneficial swelling stress and therefore produces lower yields of flaking grits, coarse grits, and germ. For tempered corn, the system throughput exponentially decreases with temper duration and then stabilizes; the period of stabilization is dependent on weight distance. Throughput values are lower

at longer weight distances. At a temper duration of 0.066 m, throughput was ≈ 33 –50% at 0.053 m weight distance. Tail stock fraction rapidly and nonlinearly decreases with increase in temper duration; the rate of decrease is higher at longer weight distance. The peak values of flaking grits can exceed 50% at some combinations of weight distance and temper duration. Coarse grit yields were 9–19% and 16–24% for the shorter and longer weight distances, respectively. Germ recovery improved due to tempering, and differed only by $\approx 0.5\%$ at the two weight distances. Tempering lowered the oil content of flaking grit, but the temper duration did not have much influence on moisture content of various fractions.

Tempering of corn is an important step in dry milling as it helps in easy fractionation of the corn kernel and facilitates recovery of germ, endosperm, and pericarp with purity because these components are quite distinct and their tissues are not continuous within each other (Wolf et al 1952a). Wetting the pericarp reduces brittleness and enables the miller to remove it in large pieces. Similarly, endosperm mellowing on wetting facilitates milling and generation of large pieces of endosperm grits (MacMasters 1961; Tran et al 1981). Absorption of water helps in separation of germ by reducing the influence of the cementing layer of amorphous material between the endosperm and germ (Wolf et al 1952d). Faster rate of moisture sorption by the germ than by the endosperm creates a differential swelling stress at the endosperm-germ interface (Wolf et al 1952d). The differential swelling results in different interfaces and is responsible for weakening bonds at the joints of various fractions. Initially, the corn kernel has nearly uniform moisture which is transformed into nonuniform distribution through tempering. The outer surface of the corn kernel contains considerable moisture-impermeable cutin and little moisture is absorbed into the pericarp through the epidermal cells. The moisture mainly enters the kernel through the tip cap (Wolf et al 1952a–d; MacMasters 1961, 1962; Eckhoff and Okos 1989; Ruan et al 1992) and moves to the crown under the action of capillary forces. The moisture diffuses through the seed coat and the outer aleurone layer and moves through the germ and the endosperm. Eckhoff and Okos (1989) discovered a pathway of movement of moisture through the germ and endosperm, which was confirmed by Ruan et al (1992). As the movement of moisture through the kernel requires time, too short a temper duration may be inadequate to achieve the desired level of moisture nonuniformity, whereas, too long a temper duration may allow the moisture to redistribute uniformly, thereby defeating the purpose of tempering. Therefore, proper duration of temper is essential for tempering process effectiveness. Besides proper temper duration, addition of precise quantity of moisture is also very important for the success of the operation; stress crack formation is sensitive to temper moisture as well as duration. Increase in temper moisture or duration promotes stress crack formation. The importance of proper tempering in achieving good degerminator performance is well recognized. This article presents an analysis of the effect of temper duration in a single-stage tempering procedure on degerminator performance.

MATERIALS AND METHODS

A single hybrid supplied by a commercial seed company was used for the study. Corn (30 kg/run) was tempered by adding the required amount of water at 293 K in a spiral ribbon blender (40-kg capacity) in a single step to bring corn moisture to 22% (wb). The corn in the blender was agitated for 15 min and then removed for tempering into a plastic container with a tightly secured lid. Eleven levels of temper duration beyond blending were taken as 0, 5, 10, 15, 20, 30, 40, 50, 60, 90, and 120 min. Corn moisture measurements were made using Approved Method 44-15A (AACC 2000). The corn was then fed to a degerminator (model 0, Beall Degerminator Co., Decatur, IL). The feed rate of the corn was regulated to maintain input current to the degerminator system between 35 and 40 amperes to prevent system overloading and to maintain the same level of power consumption for all experimental runs. The degerminator was fitted with three 0.0056 m (14/64") round perforated screens and one section was blocked with blunt spikes. The rotor was operated at 50% closed position at 840 rpm by an 11.19 kW (15 hp) electric motor. A weighted tailgate installed above the rotor shaft was used for tail stock discharge. Two weight distances of 0.053 and 0.066 m were used. Moisture content of both tail and through stocks was determined, and the net weight of the stocks was obtained by subtracting the weight of moisture from the gross weight. Tail stock was expressed as percent of total product yield (tail + through stock) on a dry basis. Representative samples (3 kg) of each stock were dried at 323 K overnight, and the moisture content was determined using Approved Method 44-19 (AACC 2000).

Representative samples (500 g each) of both tail stock and through stock were sifted separately (model 130-11, Great Western Laboratory Sifter, J. W. Hance Mfg. Co., Westerville, OH) over 3.5, 5, 10, and 24 mesh (5.613, 3.962, 1.651, and 0.701 mm) screens. The fraction retained on 3.5 mesh (M) sieve was designated as recycle fraction, the fraction between 3.5 and 5 M as flaking grit, the fraction between 5 and 10 M as coarse grit, the fraction between 10 and 24 M as coarse meal, and the fraction passing through 24 M as fines. An aspirator (model 6DT4, Kice Metal Products Co., Wichita, KS) was used to separate pericarp from all sifted fractions except fines (pericarp yield from the fine fraction contained a large proportion of fines) and tail stocks (contained negligible pericarp). As the degerminator could achieve steady-state operation in < 2 min, no measurements were made for the initial 2 min of operation. All observations were taken for 1.5 min after the degerminator had achieved steady-state. Sodium nitrate solution of 1.3 specific gravity was used to separate the germ from 100-g samples of flaking grits

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from through stocks, and coarse grits from both through and tail stocks. Percent germ yield was obtained as a ratio of dry weights (Approved Method 44-19, AACC 2000) of germ and grits (Mehra 1996). The oil content of the flaking grits was determined by a Midwest corn dry-milling company using a near-infrared (NIR) instrument based on a proprietary calibration.

RESULTS AND DISCUSSION

Throughput

The throughput of the system was influenced by both the temper duration and the weight distance. At a weight distance of 0.053 m, the throughput of the system exponentially decreased from 29 kg/min for untempered corn to 13 kg/min for corn tempered for 60 min (Fig. 1), indicating an average throughput decrease of 0.27 kg/min/min of temper duration. The rate of decrease in throughput during the first 15 min of temper duration was 0.76 kg/min/min of temper duration which decreased to 0.17 kg/min/min in the next 15 min of tempering and further to only ≈ 0.10 kg/min/min during the 30–50 min of tempering. The rate of decrease in throughput later approached 0 because the throughput remained practically constant after a temper duration of 50 min. At a weight distance of 0.066 m, the throughput was 13 kg/min/min for untempered corn which decreased to 3.94 kg/min/min for a 60-min temper duration, representing an overall average rate of throughput decrease of 0.15 kg/min/min, which is $\approx 75\%$ of the average rate of decrease at 0.053 m weight distance. In fact, the throughput-temper time behavior for both weight distances was similar (Fig. 1), but the longer weight distance had much lower throughput, 0.5 to 0.33 of the throughput at the shorter weight distance. The pattern of the throughput-temper duration relationship did not support the findings of Brekke (1965), who reported an increase in throughput with increase in temper time. The discrepancy could have resulted from Brekke's methodology wherein the weight distances were adjusted to maintain the recycle fraction level at 5%.

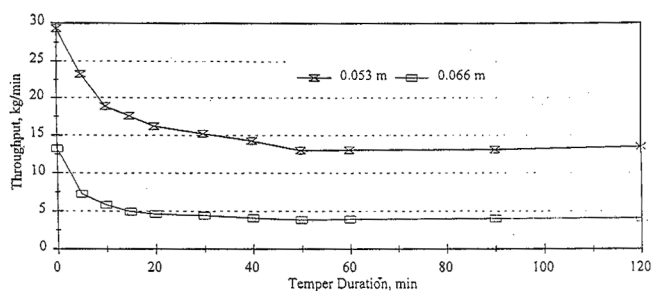


Fig. 1. Variation in degerminator throughput with change in temper duration.

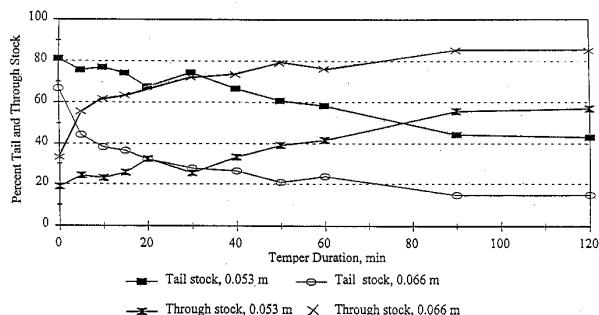


Fig. 2. Variation in tail and through stock fraction yields with change in temper duration.

Tail and Through Stock Fractions

Untempered corn yielded the highest tail stock and the lowest through stock for both weight distances. Tempering caused a decrease in the tail stock fraction. The nature of decrease was an exponentially decaying function. At a weight distance of 0.053 m, the tail stock fraction decreased from 80 to 43% when temper duration increased from 0 to 120 min, $\approx 50\%$ decrease (Fig. 2). This represents an overall average rate of 0.32%/min of temper duration. The tail stock fraction had almost stabilized at $\approx 44\%$ after a temper duration of 90 min. At 0.066 m weight distance, a 5-min tempering yielded 44% tail stock and 56% through stock compared to 64 and 36%, respectively, for the untempered corn. The tail stock decreased continuously with temper duration up to a temper duration of 50 min, and thereafter the change was small. Tail stock is more sensitive to temper duration variations than throughput as it took more time to stabilize than throughput.

Recycle Fraction

The recycle fraction contains unbroken or partially broken corn kernels subjected to little or no milling action. Also, this fraction generally had the germ still intact and attached to the endosperm. The recycle fraction yield was affected by both the temper duration and the weight distance (Fig. 3). It decreased rapidly with increase in temper duration and was consistently lower at a weight distance of 0.066 m than at 0.053 m. At a weight distance of 0.053 m, the recycle fraction yield was 53% for untempered corn, which decreased to 32% when temper duration was only 5 min, and to $\approx 2\%$

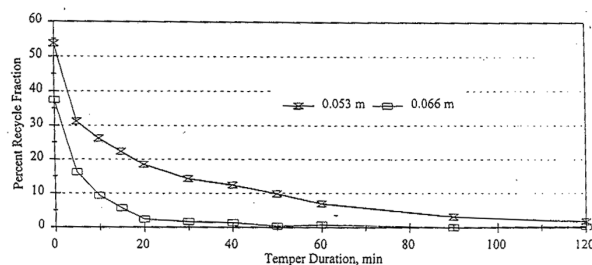


Fig. 3. Variation in recycle fraction yield with change in temper duration.

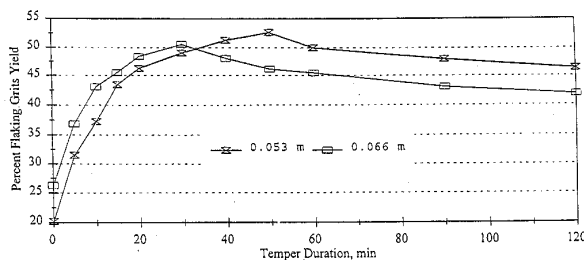


Fig. 4. Variation in flaking grit yield with change in temper duration.

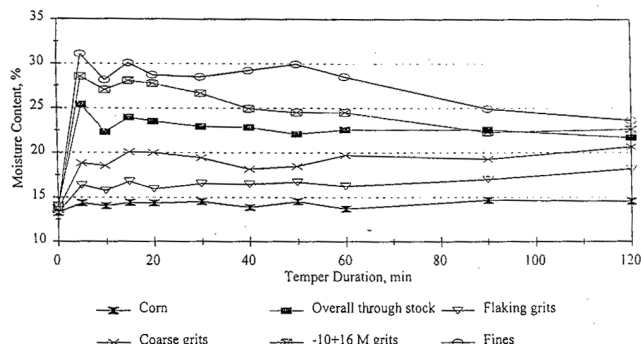


Fig. 5. Variation in moisture content of through stock fractions with change in temper duration.

as the temper duration increased to 120 min. Even at midrange temper duration (60 min), there was a drastic reduction ($\approx 85\%$) in the recycle fraction. The rate of decline in recycle fraction yield was lower for longer temper duration. This rate of decrease at a weight distance of 0.053 m was $\approx 23\%$ for an initial 5-min change in temper duration, 1% in the next 5 min, and negligible in the last 5 min (Fig. 3). At the longer weight distance (0.066 m), the effect of temper duration was similar to that at the lower weight distance, but the values of the recycle fraction were much smaller. For untempered corn, the recycle fraction at this weight distance was 37%, which decreased to ≈ 1 and 0% when temper duration increased to 60 and 80 min, respectively.

Flaking Grits

Flaking grits are the most important products for a dry corn miller. Although, the flaking grit yields were influenced by both the weight distance and the temper duration, the pattern of dependence was different from that for throughput, tail yield, or recycle fraction (Fig. 4). For both weight distances, the flaking grit yields initially increased sharply with increase in temper duration, attained a peak value, and then decreased at a slow rate. For a weight distance of 0.053 m, the flaking grits yield for the untempered corn was 20%, which increased to 32% at a temper duration of 5 min, and further increased with temper duration at a decreasing rate, achieving a peak yield of 53% at a temper duration of 50 min. Further increase in temper duration resulted in a decrease in the flaking grits yield, although at a slower rate. The average rate of decrease in flaking grits yield was sevenfold slower than the average rate of increase. The flaking grits yield increased from 20 to 53% for a 50-min increase in the temper duration, and decreased to just 47% in the next 70-min increase in the temper duration.

Increasing weight distance to 0.066 m resulted in slightly higher flaking grits yield (2–6%) up to a temper duration of 30 min. However, for temper durations >30 min, the flaking grit yields were lower than those corresponding to 0.053 m weight distance by 3–7%. Therefore, for flaking grit yields, greater weight distance is more effective at shorter temper durations, but peak recovery of flaking grits was lower by $\approx 2\%$ at the longer weight distance. The flaking grits yield was equal for both weight distances at a temper duration of 33 min, and thereafter the yields were higher at the shorter weight distance.

The total flaking grit yields consist of through stock and tail stock components. The tail stock flaking grit yield is preferred by industry because it contains negligible pericarp and germ and requires fewer further processing steps. For a weight distance of 0.053 m, the flaking grit yield of the untempered corn from the tail stock was 18%, which increased with increase in the temper duration to a maximum of 46%, of a temper duration of 30 min, and then decreased to 33% at a temper duration of 120 min. The through stock flaking grit yields were $<5\%$ for temper durations <30 min and increased at a slow rate to 12% when temper duration increased to 90 min, and remained constant thereafter.

Increasing the weight distance to 0.066 m, except for the first 5 min of temper duration, resulted in a decrease in tail stock flaking grit yields from 28 to 12% when temper duration increased to 90 min, and then the yield became constant. The flaking grit yield from the through stock was 5% for untempered corn, which increased to 30% when temper duration increased to 30 min. However, at longer temper duration, the flaking grits yield from the through stock fluctuated at 28–30%. These results indicate that greater weight distance reduces the flaking grit yield from the tail stock in addition to reducing throughput.

Coarse Grits

The coarse grit yields varied from 9–19% and 16–24% for 0.053 and 0.066 m weight distances, respectively. The coarse grits yield was $\approx 9\%$ for untempered corn and fluctuated at 9–11% for the first 50 min of temper duration at a weight distance of 0.053 m.

Thereafter, it increased to 19% as the temper duration increased to 120 min. However, at a weight distance of 0.066 m, a somewhat different pattern was observed. Two distinct periods of sharp increase in coarse grits yield occurred at 0–5 min and 60–90 min.

At a weight distance of 0.053 m, coarse grit yields from the tail and through stocks were nearly equal at $\approx 5\%$, up to a temper duration of 40 min. Thereafter, the through stock yields increased to 13% for a temper duration of 120 min compared to a near constant value of 5% for the tail stock coarse grits yield. For the 0.066 m weight distance, the coarse grit yields from the through stocks were distinctly higher (13–22%) than from the tail stock (2–8%), the difference being as large as 20% at the maximum temper duration of 120 min.

–3.5 +10 M Grits

The yield of –3.5 +10 M grits depended on both the temper duration and the weight distance. This yield range was 30–65% for 0.053 m weight distance and 42–70% for 0.066 m weight distance. There was a distinct difference in the pattern of variation of the grits yield with temper duration for the two weight distances. At a weight distance of 0.053 m, the yield consistently, though at a decreasing rate, increased with temper duration, whereas at a weight distance of 0.066 m, it attained a peak value of 70% at a temper duration of 30 min and then slowly decreased.

Fines

The yield of fines range was 7–12% and 8.5–15% for weight distances of 0.053 and 0.066 m, respectively. At the shorter weight distance, the yield increased rapidly up to a temper duration of 15 min and then the rate of increase slowed down, becoming almost 0 at 50–120 min temper duration. For 0.066 m weight distance, a distinct peak yield of 15% was attained at a temper duration of 40 min, and then the yield decreased to $\approx 13\%$ at a 90-min temper duration, thereafter it stabilized. These results do not support the observations of Brekke (1965), who reported a decrease in fines with increase in temper duration up to 3 hr. However, the results of Brekke (1965) were based on an adjusted recycle fraction approach.

Pericarp

Pericarp yield at a weight distance of 0.053 m was $\approx 1\%$ for the untempered corn, which increased to as high as 7% for a temper duration of 120 min. The corresponding values of pericarp yield at a weight distance of 0.066 m were 2 and 6.5%. Although the pattern of variation of pericarp yield with the temper duration was similar, the longer weight distance resulted in higher pericarp yield up to a temper duration of 60 min and then the trend reversed. The maximum difference in pericarp yields at the two weight distances was 1.25% at a temper duration of 15 min. Brekke (1965) observed an increase in pericarp yield with increase in temper duration up to 3.5 hr.

Germ

The germ yield for untempered corn was 4.5 and 4% at the shorter and longer weight distances, respectively. Tempering improved the recovery of germ at both weight distances to $\approx 8.5\%$ for shorter distance at a temper duration of 90 min and to 8% at longer distance for a temper duration of 40 min. The longer weight distance had generally higher germ yield up to a temper duration of 50 min; thereafter the trend reversed.

Oil Content of Flaking Grits

The untempered corn produced flaking grits of the highest oil content (0.8–1.0%). The oil content of flaking grits was consistently higher for the shorter weight distance. But for both weight distances, the oil content of flaking grits from tempered corn rapidly decreased as the temper duration increased and then attained a constant value. At 0.053 m weight distance, the grit oil content decreased at a decreasing rate from a peak value of 1.02 to 0.3% when temper duration increased to 50 min, and then stabilized.

However, at a weight distance of 0.066 m, the oil content quickly decreased from 0.8 to 0.3% in only the first 10 min of tempering and then nearly stabilized, varying only between 0.3 and 0.2%. As greater weight distance results in longer retention time, there is more abrasion and polishing of the grits and, thus, lower oil content.

Moisture Content

The variation in moisture content among the corn samples was <1.5%, whereas the difference between moisture content of tail stock and corn samples was 0.25–1.7% compared to 7.5–10% between through stock and corn samples. The moisture content of the recycle fraction, flaking grits, and coarse grits was almost constant for temper durations of 15–60 min but increased for longer temper durations. The moisture content of –10 +16 M grits displayed a distinct pattern. At temper duration of 0 min, moisture content was the same as that of the untempered corn but increased rapidly as the temper duration increased. It became higher than any other fractions at a temper duration of 15 min, attained a peak value of 18% at temper duration of 30 min, and then rapidly decreased to a value almost lower than any other fraction at a temper duration of 120 min (Fig. 5).

CONCLUSIONS

In a corn dry-milling system, temper duration and weight distance affect throughput and product yield considerably. Throughput exponentially decreased with increase in temper duration at both 0.053 and 0.066 m weight distances, but throughput values were 2–3 times higher at shorter weight distance. Recycle fraction was higher in untempered corn than tempered corn. Flaking grit yields had numerically almost same peak values for both weight distances, though these occurred at different temper durations. But the coarse grit yields were consistently higher at the longer weight distance. At both weight distances, the yields of –3.5 +10 M grits, fines, and pericarp nearly exponentially increased, whereas oil content of flaking grits decreased with temper duration. Germ yield was somewhat

greater at a weight distance of 0.066 m than at 0.053 m up to a temper duration of 50 min. Moisture content variation was <1.5% among corn samples and between corn samples and tail stock but it was 5–6 times greater between through stock and corn samples.

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