Effect of Maize Tempering on Throughput and Product Yields

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ABSTRACT

Scientifically researched 2- and 3-stage tempering procedures and the commercially practiced 1-stage procedure were compared for throughput and corn dry-milling product yields at pilot-scale (30-kg lots) operation. The throughput and product yields were influenced by the temper procedure and the tailgate weight distance. For most corn dry-milling products, yields corresponding to 2- or 3-stage tempering procedures could be equaled or surpassed using the 1-stage tempering procedure at specific temper durations. In general, yields from the 2-stage and 3-stage procedures were comparable to the yields from the 1-stage procedure at temper durations of 30–40 and 50–60 min, respectively. An increase in the tailgate weight distance improved the product yields for temper durations <30 min but reduced the yields for longer temper durations. An increase in temper duration ≤50 min resulted in a reduction in throughput but an improvement in flaking grit yield. The temper duration and tailgate weight distance could be suitably adjusted for obtaining the desired output.

Dry corn milling technology has advanced considerably from the age old mortar and pestle nondegerminating technology (Mehra 1996) to the curent large-scale tempering and degerminating technology (Eckhoff and Paulsen 1996). The tempering-degerminating technology has a distinct superiority over the old technology because it combines physical and mechanical treatments to facilitate recovery of germ, endosperm, and pericarp with purity (Brekke 1970). Tempering for dry milling involves controlled addition of cold or hot water or steam in a single stage or in multiple stages (Brekke 1970; Eckhoff and Paulsen 1996). The addition of moisture toughens the bran and mellows the endosperm (MacMaster 1961; Tran et al 1981). It also increases the volume of the kernels, which results in differential swelling (White 1966) that facilitates separation of the structurally distinct germ, pericarp, and endosperm (Wolf et al 1952a–c). The efficiency of the tempering-degerminating process is largely governed by the tempering procedure, degerminator characteristics, and operational settings. Tempering for too short a time is inadequate to realize the advantages of differential swelling, and tempering for too long can result in uniform redistribution of moisture, losing the effectiveness of differential swelling. Most of the scientific literature on tempering-degerminating reports a 3-stage tempering procedure (Brekke 1970; Brekke et al 1971, 1973; Manoharkumar et al 1978; Peplinski et al 1983, 1992; Kirleis and Stroshine 1990; Mistry and Eckhoff 1992; Yuan and Flores 1995, 1996; Pan et al 1996; Verma 1996). Some work on 2-stage procedure has also been done (Brekke 1967; Hill et al 1991; Wehling et al 1996). Whereas Brekke (1967) found the 2-stage procedure comparable to the 3-stage procedure, others did not present a comparison between the two procedures. Discussions with industry revealed that using a 1-stage tempering procedure to raise corn moisture by 6–8% points is common; multiple stage procedures are not common in the industry. Peplinski et al (1984) compared the three procedures using a horizontal drum degerminator, but Mehra (1996) observed that the horizontal drum degerminator was not efficient in separating the pericarp from the grits. The importance of proper tempering procedure in achieving good degerminator performance has been adequately highlighted by most of the researchers. This article presents a comparison of 1-, 2- and 3-stage tempering procedures using a degerminator and also analyzes the effect of duration on degerminator performance in the 1-stage tempering procedure.

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MATERIALS AND METHODS

A single corn hybrid donated by a major seed company was used in the study. The physical properties and proximate analysis of the hybrid are given in Tables I and II. The pilot plant dry-milling procedure used in this study involved tempering, degermination, drying, sifting, aspiration, and germ separation (Fig. 1). Corn (30 kg) was tempered for each run by adding the required quantity of water at 293 K in a spiral ribbon binder (40-kg capacity). All moisture measurements were made using the Approved Method 44-15A (AACC 2000). The tempered corn was then fed to a degerminator (Beall Degerminator Co., Decatur, IL) using a spiral conveyor auger (model 4C8S, Howes Co., Silver Creek, NY). The feed rate of the corn to the degerminator system was regulated to maintain input current 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 5.6-mm (14/64") round perforated screens, and one of section was blocked with blunt spikes. The rotor was operated in the 50% closed position at 840 rpm by an 11.19 kW (15 hp) electric motor. Tail stock was discharged through a weighted tailgate installed above the rotor shaft. Two tailgate weight positions (distance between tailgate and the tail weight) of 0.053 and 0.066 m were used. As the degerminator achieved steady state in <2 min, all weight observations were taken for 1.5 min after 2 min of initial degerminator operation to ensure the steady-state of operation. Moisture content of both through and tail stocks was determined, and the wet weight was converted to the dry weight by subtracting the weight of moisture. Tail stock was expressed as % total product yield (tail stock + through stock) on dry basis. For drying of tail and through stocks, six samples of 500 g each were collected from different locations in the well-mixed lots of each stock; these samples were then well mixed to obtain representative samples (3 kg). The representative samples of tail and through stock were dried separately in an oven at 323 K overnight. Moisture content was determined using Approved Method 44-19 (AACC 2000). Representative samples (500 g each) of both tail and through stock were sifted separately over a set of screens (Fig. 2) (sifter model 130-11, Great Western Mfg. Co., Leavenworth, KS). An aspirator (model 6DT4, Kice Metal Products Co.,Wichita, KS) was used to separate pericarp from all sifted fractions except fines (because pericarp yield from the fines contained a large proportion of fines) and tail stock (because tail stock contained negligible pericarp). Before germ separation, samples containing both germ and grits were kept at 277 K for one week to achieve an equilibrium between the grits and the germ. Sodium nitrate solution of 1.3 specific gravity was used to separate the germ from 100-g samples of flaking grits (through stocks) and coarse grits (through and tail stocks). Percent of germ yield was obtained from the ratio of dry weights of germ and grits dried after separation (Approved Method 44-19).

In the 1-stage tempering procedure, the required quantity of water to bring corn moisture to 22% (wb) was added in a single step in the spiral binder. The corn in the blender was agitated for 15 min and then placed in a plastic container with a tightly secured lid for tempering. Six levels of temper duration (15, 20, 30, 40, 50, and 60 min) were used. For a temper duration of 15 min, the corn was removed from the blender after 12 min of mixing and milled immediately. For the other temper durations, the corn was removed from the blender, held in the plastic container, and milled on completion of temper duration. The 2-stage tempering procedure involved a pretemper to elevate corn moisture to 16%, followed by a rest period of 10 hr and then a dehulling temper to raise the moisture content to 20%, followed by a rest period of 20 min before degermination (Brekke 1967). In the 3-stage tempering procedure, corn moisture was raised to 16% and left overnight (18 hr), then subjected to a first temper to raise the moisture content to 21%, followed by a rest period of 1.75 hr, followed by a second temper to raise the moisture to 24% for 15 min before degermination (Mehra 1996).

RESULTS AND DISCUSSION

Throughput

The throughput of the system varied considerably depending on the tempering procedure and the weight distance (Tables III and IV).

TABLE I
Physical Properties of Corn Hybrid

Property	Value
Test weight, kg/hL	81.50
Thins, %	18.20
Horny endosperm, %	90.00
True density, g/cm^3	1.34
100-kernel weight, g	38.80
Kernel size, cm^3	0.29
Stress crack, %	10.00
Stress crack index, %	19.00

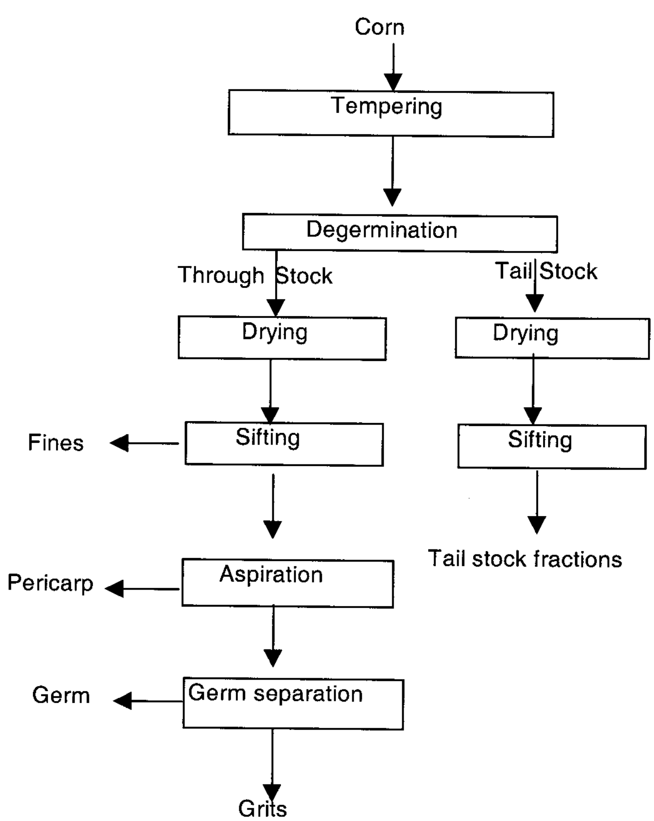

Fig. 1. Flow diagram for dry milling procedure.

The values of throughput at a weight distance of 0.053 m were 13.0–17.59, 17.95, and 14.99 kg/min for the 1-, 2-, and 3-stage tempering procedures, respectively. However, as the weight distance was increased to 0.066 m, throughput reduced to 3.85-4.95, 4.25, and 2.40 kg/min, respectively. This was a reduction of ≈70%, indicating dominance of weight position in controlling throughput.

The throughput value of 17.95 kg/min for the 2-stage procedure at a weight distance of 0.053 m was nearly equal to the value of 17.59 kg/min in the 1- stage procedure at 15- min temper duration. These values were not statistically different from the throughput for 3-stage tempering or for 1-stage tempering at temper durations of 20 and 30 min. Therefore, the 3-stage procedure did not improve throughput of the system. Similarly, even in the 1-stage tempering procedure, a temper duration of 15 min appeared adequate; longer temper durations, particularly >40 min, had an adverse effect on throughput. The lowest values of throughput observed in the 1-stage procedure at a temper duration of 40–60 min was not statistically different from the throughput in the 3-stage procedure or in the 1-stage procedure at temper durations of 20–60 min. Brekke (1966) had also observed nearly similar throughput for the 2-stage tempering procedure and for a 20-min temper duration in the 1-stage procedure. Although Brekke (1966) obtained higher throughput for the 3-stage tempering procedure, his study had a limitation that only a single temper duration was used in the 1-stage procedure. Even for a weight distance of 0.066 m, maximum throughput was attained at a temper duration of 15 min in the 1-stage procedure, not statistically different from throughput in the 2-stage procedure. This observation supports the pattern for the lower weight distance. On the basis of the system throughput, the 1-stage tempering procedure with a 15-min temper duration appeared to be a good option.

TABLE II
Proximate Analysis of Corn Hybrid

Constituent	NIR Transmission	NIR Reflectance
Protein, %	10.75	10.35
Oil, %	3.77	4.24
Starch, %	71.30	72.47
Fiber, %	2.14	2.27

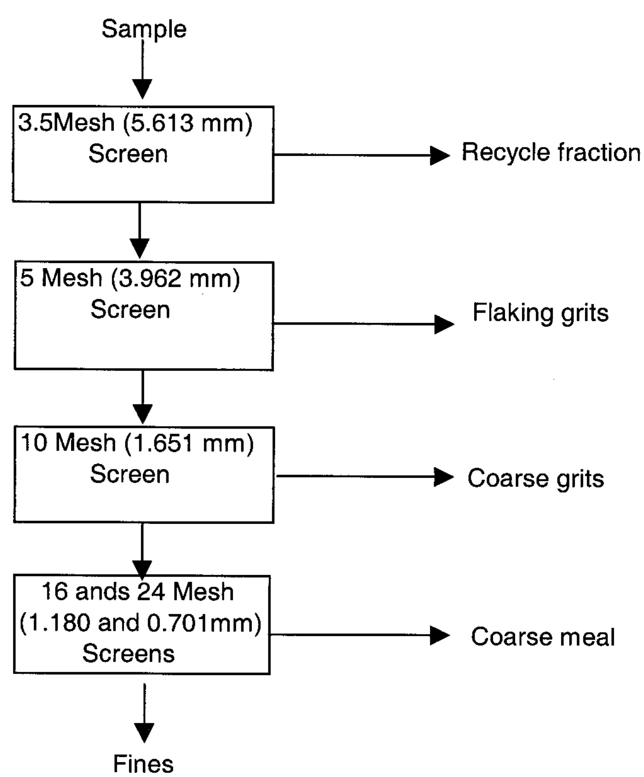

Fig. 2. Flow diagram for sifting operation.

Tail Stock

Tail stock yield is an important parameter in a dry-milling operation because it is the major source of flaking grits, a fraction most preferred by millers. Comparison of tail stock yields from various tempering procedures was not made earlier by Brekke (1966) or Peplinski (1984). For a weight distance of 0.053 m, the tail stock varied considerably at 58.25–74.42% for the 1-stage tempering procedure and was 69.89 for the 2-stage procedure and 57.31% for the 3-stage procedures. The highest value of tail stock (74.42%) was observed in the 1-stage procedure at a 30 min temper duration (Table III). This yield (74.42%) was not significantly different from the yields observed at 15- and 20-min temper durations in the 1-stage procedure nor in the 2-stage procedure. The percent yield for the 3-stage procedure was numerically the lowest and statistically different from yields at all temper durations except at 50 and 60-min temper durations in the 1-stage procedure (Table III).

Increasing the weight distance to 0.066 m resulted in a sharp decline in tail stock yields (Table IV). The highest tail stock yield (36.60%) was observed at 15-min temper duration in the 1-stage procedure. The tail stock yields in the 2-stage procedure (35.91%) was statistically not different from the yields at 20-min temper durations in the 1-stage procedure. In the 1-stage procedure, statistically no difference was observed in the tail stock yields at 20-, 30-, and 40-min temper durations. Also, the difference in the tail stock values between 40- and 60-min temper durations in the 1-stage procedure was nonsignificant. At a weight distance of 0.053 m, the tail stock fractions in the 2- and 3-stage procedures were comparable to those at 15–40 min and 50–60 min temper durations in 1-stage procedure but at a weight distance of 0.066 m, tail stock yields in 2- and 3-stage procedures were comparable to tail stock fractions at 20- and 50-min temper durations in 1-stage procedure.

Recycle Fraction

The recycle fraction represents mainly the corn subjected to no or very little milling action and therefore is an undesirable fraction. At a weight distance of 0.053 m, the least amount of recycle fraction (4.93%) was produced in the 3-stage procedure, which was comparable to that produced using 60-min temper duration in the 1-stage procedure (Table III). The yield from the 2-stage procedure corresponded to those from 15- and 20-min temper durations in the 1-stage procedure. Similarly, in the 1-stage procedure, recycle fraction yields were statistically not different for temper durations of 15 and 20 min; 30 and 40 min; 40 and 50 min; and 50 and 60 min. Increasing the weight distance to 0.066 m resulted in a sharp decrease in the recycle fraction. The 3-stage procedure still produced the least amount of recycle fraction (0.38%). This yield (0.38%) was numerically lower but statistically not different from the yields in 1-stage procedure at temper durations of 30–60 min.

In contrast to the results for a weight distance of 0.053 m, the yield for the 2-stage procedure at a weight distance of 0.066 m was significantly lower than that at 15-min temper duration in the 1-stage procedure.

On the basis of similar recycle fraction yields, the 1-stage procedure temper durations could be put together into two groups, 20–30 and 30–60 min. For both weight distances, 2- and 3-stage procedures produced significantly different tail stock yields.

The yields from the 2-stage procedure (18.51 and 3.42%) were similar to those obtained from 20-min temper duration in the 1-stage procedure (18.49 and 2.44%), whereas yields from the 3-stage procedure (4.93 and 0.38%) corresponded to yields from 60 min (6.95 and 0.79%) temper duration in the 1-stage procedure.

TABLE III
Comparison of Tempering Procedures for Throughputs (kg/min) and Product Yields (w/w) at Weight Distance of 0.053 m

	Temper Durations in 1-Stage Procedure						2-Stage	3-Stage
Variable	15 min	20 min	30 min	40 min	50 min	60 min	Procedure	Procedure
Throughput	17.59b[a]	16.22ab	15.26ab	14.27a	13.00a	13.06a	17.95b	14.99ab
Tail stock	74.27d	67.47b–d	66.59bc	60.72ab	58.25a	69.85cd	23.76bc	57.31a
Recycle	22.32e	18.49e	14.28d	12.38cd	9.87bc	6.95ab	18.51e	4.93a
Flaking grit	43.43a	46.25ab	49.06bc	51.51cd	52.68cd	50.0bcd	47.26ab	53.37d
Tail stock	40.47a	42.34a–c	46.59bc	46.85c	45.65bc	42.07ab	43.51a–c	45.34bc
Trough stock	2.97a	3.91a	2.47a	4.45a	7.03b	7.93b	3.74a	8.04b
Coarse grits	10.59ab	10.54ab	9.17ab	10.61ab	10.59ab	11.97b	7.62a	9.86ab
–10+ 16 M	2.15ab	2.59ab	2.34ab	3.23b	2.86ab	2.38ab	1.89a	3.07a
–16+ 24 M	2.11ab	1.68a	2.45b	2.58b	2.30ab	2.09ab	1.88ab	2.53b
Fines	10.53a	10.52a	11.13a–c	11.54a–c	12.00bc	12.16c	10.15a	10.72ab
Pericarp	4.30a	4.95ab	5.19a–d	5.70b–d	5.98cd	6.20d	4.99a–c	5.66b–d
Germ	6.54a	7.66a	5.85a	6.63a	6.63a	7.74a	7.68a	9.84a

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE IV
Comparison of Tempering Procedures for Through puts and Product Yields at a Weight Distance of 0.066 m

	Temper Durations in 1-Stage Procedure						2-Stage	3-Stage
Variable	15 min	20 min	30 min	40 min	50 min	60 min	Procedure	Procedure
Throughput	4.95c[a]	4.62bc	4.42bc	4.11bc	3.85b	3.94b	4.25bc	2.40a
Tail stock	36.60c	32.33de	27.87cd	26.52b–d	20.90ab	23.76bc	35.91e	16.20a
Recycle	5.74d	2.44bc	1.64ab	1.38ab	0.44a	0.79a	3.42c	0.38a
Flaking grit	45.50b	48.41cd	50.58d	48.09b–d	46.16bc	45.48b	41.96a	41.21a
Tail stock	26.22c	25.37c	22.53bc	21.99bc	17.73ab	19.88b	26.84c	13.42a
Trough stock	19.27ab	23.03bc	28.05c	26.09bc	28.43c	25.59bc	15.12a	27.79c
Coarse grits	19.81a	19.44a	20.19a	20.57a	20.83a	21.20a	22.69ab	26.00b
–10+ 16 M	2.95b	3.62b	3.39b	2.18a	3.02b	3.11b	3.45b	3.50b
–16+ 24 M	2.18ab	2.28b	2.40b	1.48a	1.83ab	2.23ab	1.82ab	1.78ab
Fines	13.53a	14.33a	15.00a	15.29a	14.65a	13.86a	14.72a	15.52a
Pericarp	5.56ab	5.93a–c	5.86a–c	6.06bc	6.21b–d	6.10bc	5.31a	6.76d
Germ	7.21a	7.55a	7.79a	8.01a	7.69a	7.71a	6.59a	4.83a

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

Flaking Grits

Flaking grit yields varied between 43–53% and 41–51% for weight distances of 0.053 and 0.066 m respectively (Tables III and IV). For a weight distance of 0.053 m, the flaking grit yield in the 2-stage procedure was significantly lower than that in the 3-stage procedure. The 2-stage procedure produced 47.26% flaking grit yield which was not statistically different from those observed for 15-, 20-, and 30-min temper durations in the 1-stage procedure. The flaking grit yield in the 3-stage procedure (53.37%) was similar to the yields in the 1-stage procedure at 40–60 min temper durations. For a weight distance of 0.066 m, the 2- and 3-stage procedures resulted in similar flaking grit yields that were significantly lower than the flaking grit yields observed for all temper durations in the 1-stage procedure. Although Brekke (1966, 1967) had reported contradicting results on differences in yield of -4+6 M grits from the 1-, 2-, and 3-stage procedures, Peplinski et al (1984) reported that the results from the 2- and 3-stage procedures were comparable to those from the 1-stage procedure corresponding to a temper duration of 15 min. In the present study, the flaking grit yields from the tail stock decreased drastically (from 40–47% to 13–26%) when the weight distance increased from 0.053 to 0.066 m. In dry milling, the general interest is to obtain the maximum total quantity of flaking grits, which depends on both the throughput and the percent flaking grit yield. The conditions of high throughput, even at a slightly lower flaking grit yield, could result in greater total quantity of flaking grits. The total flaking grits obtained as a product of throughput and the flaking grit yield were 6.53–8.48 kg/min and 0.99–2.36 kg/min at weight distances of 0.053 and 0.066 m respectively. The total quantity of flaking grits were much lower at a weight distance of 0.066 compared with the weight distance of 0.053 m, mainly due to lower throughputs (Tables III and IV). At the weight distance of 0.053 m, the maximum flaking grits (8.48 kg/min) were obtained in 2-stage procedure, followed by 3-stage procedure (8.00 kg/min) and 15-min temper duration in 1-stage procedure (7.64 kg/min). The total flaking grits decreased with increase in temper duration in 1-stage procedure at a weight distance of 0.053 m. At a weight distance of 0.066 m, the maximum total quantity of flaking grits (2.36 kg/min) was obtained at a 30-min temper duration in 1-stage procedure and the lowest total yield in 3-stage procedure (0.99 kg/min) followed by 2-stage procedure (1.78 kg/min).

Coarse Grits

Coarse grit yields were 7.62–11.97% and 19.44–26.00% for weight distances of 0.053 and 0.066 m, respectively, indicating a definite increase in coarse grit yield at longer weight distance. At the weight distance of 0.053 m, the 2-stage procedure produced 7.62% coarse grits that were significantly lower than that (11.97%) at 60-min temper duration in the 1-stage procedure. The yield from the 3-stage procedure did not differ statistically from the yields at any temper duration in the 1-stage procedure or from the 2-stage procedure. In fact, the coarse grit yields did not depend on the temper duration in the 1-stage procedure (Table III). Similarly, at a weight distance of 0.066 m, the yield from the 3-stage procedure was similar only to the yield from the 2-stage procedure and was higher than the 1-stage procedure at all temper durations (Table IV). The yield from the 2-stage procedure did not statistically differ from the yield in the 1-stage procedure. The independence of coarse grit yield on temper duration in the 1-stage procedure for weight distance of 0.066 m also supports this pattern for the lower weight distance.

Coarse Meal

The material retained on the 16 and 24 mesh sieves was considered as coarse meal. At a weight distance of 0.053 m, coarse meal yields for –10+16 mesh were 2.15–3.23%, 1.89%, and 3.07% for the 1-, 2-, and 3-stage procedures, respectively. These yields were not statistically different except that the yield at 40-min temper duration in the 1-stage procedure was higher (Table III). For –16+24 mesh meal, the yields from all procedures were similar but the yield corresponding to 20-min temper duration in the 1-stage procedure was lower. At a weight distance of 0.066 m, a similar pattern was observed that yields from all tempering procedures were similar except for lower yields at 40-min temper duration in the 1-stage procedure (Table IV).

Fines

The fines varied from 10–12% and 13–15% for weight distances of 0.053 and 0.066 m, respectively. For 0.053 m weight distance, the 3-stage procedure produced nearly 11% fines yield which was statistically similar to the yield from the 2-stage procedure and also from the 1-stage procedure up to a temper duration of 50 min (Table III). The fines produced in the 2-stage procedure were significantly lower than those produced from 50–60 min tempering in the 1-stage procedure. At 0.066 m weight distance (Table IV), the fine grit yields were independent of not only the tempering procedure but also of the temper duration in the 1-stage procedure. This result supports the observation of Brakke (1966), who also observed that the fines yields were similar for all tempering procedures.

Pericarp

Pericarp yield was 4.30– 6.20% at 0.053 m weight distance (Table III). In the 3-stage procedure, pericarp yield of 5.66% was similar to the yields from all other tempering procedures except the 15-min temper duration run in the 1-stage procedure. Similarly, pericarp yield in the 2-stage procedure was 4.99% which was similar to pericarp yields in all other runs except for 60-min temper duration in the 1-stage procedure. An increase in the weight distance resulted in somewhat higher (5.31–6.76%) pericarp recovery (Table IV). The highest yield (6.76%) was observed for the 3-stage procedure, which was comparable only to the yield in the 1-stage procedure with-50 min temper duration. The lowest yield (5.31 %) was observed for the 2-stage procedure, which was significantly lower than those observed the 3-stage procedure, as well as the 1-stage procedure corresponding to 40–60 min temper durations.

Germ

The germ yield primarily depended on the weight distance and was independent of tempering procedure. The germ yields varied at 5.85–9.84% and 4.83–8.01% for weight distances of 0.053 and 0.066 m, respectively (Tables III and IV).

CONCLUSIONS

The throughput and product yields in a corn dry milling system are influenced by the tempering procedure and the tail gate weight distance. No definite improvement in terms of all system parameters were achieved from the 2 and 3-stage-tempering procedures over the 1-stage procedure. In most cases the performance levels of the multiple stage tempering procedures could be achieved or in some cases even surpassed by appropriate adjustment of weight distance and temper duration in the 1-stage procedure.

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