Effect of Mill Plate Setting and Number of Dynamic Steeping Stages for an Intermittent Milling and Dynamic Steeping (IMDS) Process for Corn

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ABSTRACT

Effect of corn degermination mill parameters (clearance between mill plates and rpm) were assessed on the broken germ and number of whole kernels in mash so as to optimize the cracking procedure for the intermittent milling and dynamic steeping (IMDS) process. The dynamic steep time and number of intermittent milling stages for the IMDS process were also optimized for maximum starch recovery. A comparison was made between the IMDS and the conventional steeping process for fraction yields. A clearance of 0.45–0.48 cm between the plates gave the most optimum processing conditions (minimum broken germ and least amount of whole kernels in mash after cracking). Effect of rpm on germ damage and kernel cracking was not significant when optimum clearance between the degermination plates was maintained. Two stages of intermittent milling with a dynamic steep time of 30 min or higher was recommended because it produced the highest yield of starch and germ. Comparison of the IMDS process with the conventional wet-milling process showed that starch and gluten yield increased by 1.6 and 4.26%, respectively, in the IMDS process. Germ recovered from the IMDS process was 0.54% lower than that from the conventional steeping process.

Conventional corn wet-milling is a capital- and energy-intensive process. The first and foremost operation in corn wet-milling is the steeping process. Steeping involves soaking corn kernels countercurrently in warm sulfurous water. The purpose of steeping is to soften the corn kernel and break the disulfide bonds within the protein matrix. Of all of the corn wet-milling unit operations, steeping is the most time-consuming and is very energy- and capital-intensive. Reducing steep time will decrease the energy cost, increase plant capacity, and reduce the capital cost involved in the construction of new wet-milling plants.

One alternative to conventional wet-milling is the intermittent milling and dynamic steeping (IMDS) (Lopes Filho et al 1997). In the IMDS process, diffusional barriers that inhibit the penetration of steep chemicals are reduced by decreasing particle size. The whole kernels are soaked in water for 1–3 hr to soften the kernels' germ. The partially soaked corn is cracked open to increase the diffusional flux of sulfur dioxide into the corn kernel. Cracking of kernels is done using a degermination mill (Bauer mill). The resulting mash is steeped for 0.5–1 hr and again milled (at a tighter setting) to loosen the germ and reduce the particle size. This intermittent milling and dynamic steeping is repeated two more times and followed by germ recovery and conventional milling. Compared with the conventional wet-milling process, in the IMDS process there is an increase in starch yield of ≈1–2% and an increase in gluten yield of ≈4–5% with only 3–5 hr of total steep time (Lopes Filho et al 1997). Because the soak time is short, one drawback of the IMDS process is that the percentage of oil in germ is ≈5% lower, and there is slight (5–10%) germ damage compared with the germ obtained from the conventional wet-milling process.

Lopes Filho et al (1997) evaluated three different kernel cracking methods (roller mill, Waring blender, and degermination mill) to determine which one opened up the kernels with a minimum of germ damage. They found that the degermination mill performed the best and gave maximum germ recovery with minimum germ damage when compared with other cracking methods. However, the germ damage in the IMDS process, even with degermination mills, was higher when compared with that of the conventional wet-milled germ.

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Degermination mills are equipped with one fixed and one rotating Devil's tooth plate, which mesh closely and are designed specifically for corn (Blanchard 1992). Mill plates can be adjusted for gap settings. Plate gap setting and the rpm of the mill controls the impact and shearing force on the kernels and, therefore, affects the quality of germ recovered. Lopes Filho et al (1997) did not evaluate the plate gap setting and the rpm of the degermination mill for optimum germ recovery (maximum germ recovery with minimum germ damage). In this study, the effect of plate gap setting and the rpm of the degermination mill on germ damage and kernel cracking was determined for the IMDS process.

Lopes Filho et al (1997) used three dynamic steeping stages of 1 hr each with two intermittent milling stages for the IMDS process. However, they did not study the number and the duration of dynamic steeping stages for maximum starch recovery. In this study, the number and duration of dynamic steeping stages needed after kernel cracking for maximum starch recovery were also determined.

MATERIALS AND METHODS

A yellow dent corn hybrid FR600 × Mo17, grown during the 1995 season at the University of Illinois at Urbana-Champaign, was used for the study. Samples were hand-cleaned to remove the broken corn and foreign material (BCFM) and packaged in plastic bags until tested. The whole kernel moisture content of the samples was measured using the 103°C convection oven method (AACC 1995). Corn samples were steeped using the IMDS procedure as proposed by Lopes Filho et al (1997). After IMDS, the samples were wet-milled using the 1-kg laboratory wet-milling procedure outlined by Eckhoff et al (1993).

Two factorial experiments were done to optimize the intermittent milling and dynamic steeping process for maximum starch recovery. In the first experiment, four plate gap settings (clearance between the plates) of 0.35, 0.43, 0.51, and 0.59 cm and four rpm of the degermination mill were used to determine the effect on germ damage and kernel cracking. Only one measurement was taken for each combination of plate gap and rpm setting. For the first experiment, uncracked kernels (whole kernels) were manually separated from the mash (after the cracking of the kernels), and the germ was skimmed from the slurry using a 1.1156 specific gravity (15 Bé) sodium nitrate solution. The separated germ was dried and divided into broken and unbroken germ by visual observation. Any germ that was even slightly chipped was classified as broken germ. Germ yield and whole kernels were expressed as a percentage of initial dry solids and broken germ was expressed as a percentage of the germ yield.

In the second experiment, three different numbers of dynamic steeping stages (2, 3, and 4) after kernel cracking and three different durations (30, 45, and 60 min) for each dynamic steeping stage were tested for maximum starch recovery. Duplicate measurements were taken for each combination of steeping stage and steep durations. The optimum conditions of the degermination mill (plate gap setting and the rpm) obtained from the first set of experiments were used for this experiment

Based on the first two experiments, the optimum conditions of plate gap setting (clearance between the plates), rpm, number, and duration of dynamic steeping stages were identified and a third experiment was done with single measurement in which fraction yields from the IMDS process and the conventional corn wet-milling process were compared for the same corn hybrid. This experiment was done to verify the results (comparison of the IMDS and the conventional wet-milling process for fraction yields) from the previous study by Lopes-Filho et al (1997).

Analysis of variance (ANOVA) and Duncan's multiple range test were used (SAS Institute, Cary, NC) for data analysis. The level selected to show statistical significance was 5% ($P < 0.05$).

RESULTS AND DISCUSSION

The effects of the clearance between the plates and the rpm (of the degermination mill) on the germ yield were significant (Fig. 1). As the clearance between the two "Devil's tooth" plates of the degermination mill increased from 0.35 to 0.59 cm, the average germ yield decreased by 4.21–7.24%, depending on the rpm of the mill. As the clearance between the plates increases in a degermination mill, the impact on the corn kernels is reduced, resulting in a lower germ yield and greater number of whole kernels in the mash. An increase in the rpm of the mill from 1,000 to 1,750 increased the germ yield by 0.6–3.9%, depending on the clearance between the plates. As the rpm of the mill increased, the shearing force on the corn kernels increased, resulting in more germ and fewer whole kernels in the mash.

With an increase in the clearance between the plates of the mill an opposing trend was observed for the percentage of broken germ and the percentage of whole kernels after cracking for each of the rpm speeds tested (Figs. 2–5). The percentage of the broken germ decreased with an increase in the clearance between the two plates; however, the percentage of whole kernels in the mash increased. The rate of decrease of broken germ and the rate of increase of whole kernels in the mash with clearance was nonlinear. Intersection of the two lines, one for percent broken germ versus clearance and the other for percent whole kernels versus clearance, gives the optimum processing conditions for the degermination mill. For all of the four rpm speeds of the degermination mill, the intersecting point of the two lines were approximately the same (0.45–0.48 cm). Therefore, a clearance of 0.45–0.48 cm between the mill plates gave the optimum processing conditions (minimum broken germ and least amount of whole kernels in the mash after kernel cracking) for all of the rpm speeds tested (1,000–1,750).

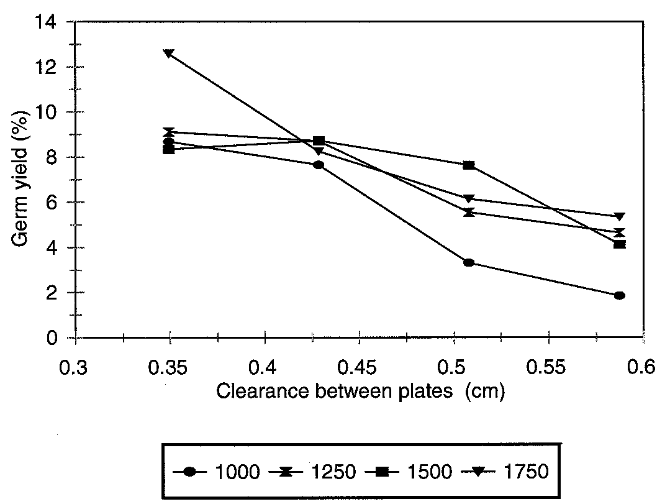

Fig. 1. Corn germ yields at different degermination mill settings (clearance between plates and rpm) in an intermittent milling and dynamic steeping (IMDS) process.

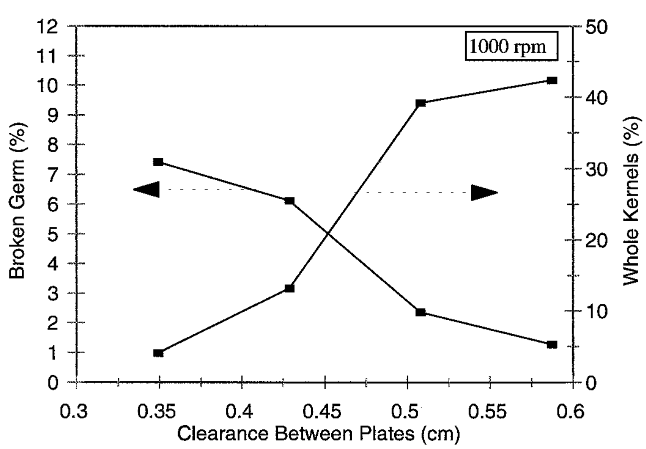

Fig. 2. Effect of 1,000 rpm and clearance between plates of a degermination mill on corn germ damage and kernel cracking.

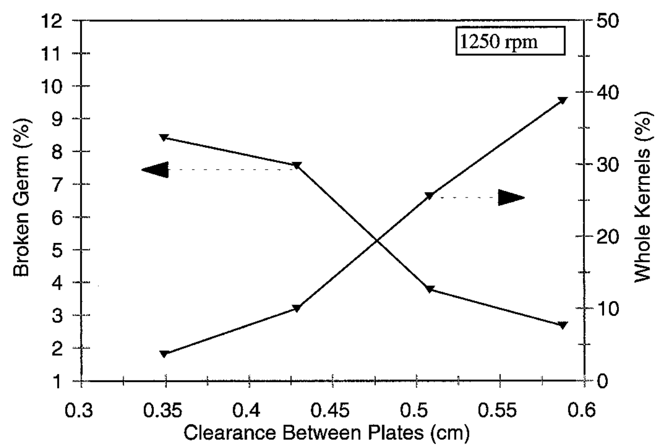

Fig. 3. Effect of 1,250 rpm and clearance between plates of a degermination mill on corn germ damage and kernel cracking.

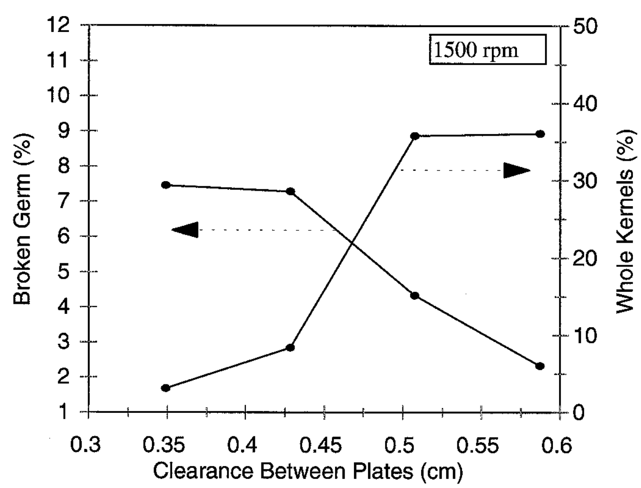

Fig. 4. Effect of 1,500 rpm and clearance between plates of a degermination mill on corn germ damage and kernel cracking.

Three (1,250, 1,500, and 1,750) of the four rpm speeds of the degermination mill produced a similar amount of broken germ when the clearance between the plates was set at 0.42–0.5 cm (Fig. 6). These results suggest that the rpm of the degermination mill does not have a significant effect on the optimum processing conditions as compared with the effect of the clearance between the plates. An rpm of 1,250 was selected for use in the other parts of the study.

In the second study, neither steep time nor the number of intermittent milling stages had a significant effect on the starch yield (Table I). No significant effect of steep time and number of intermittent milling stages was observed on other fractions (germ, fiber, and gluten). This might be due to the fact that ≈90% of the soaked kernels get cracked (or opened up) during the degermination mill operation. During the subsequent dynamic steeping stages, these cracks reduce the diffusion pathways and allow the steeping chemicals to quickly diffuse into the corn kernels and react with the protein matrix surrounding the starch particles. Rapid diffusion of chemicals and the dynamic nature of steeping considerably reduces the reaction time of chemicals with the protein matrix. This could be the reason why increasing the dynamic steep time to >30 min and the number of steeping stages to >2 did not help in increasing the starch yield. Therefore, two or three stages of intermittent milling with a dynamic steep time of ≥30 min is the recommended combination for the IMDS process.

Comparison of IMDS and Conventional Laboratory Wet-Milling Procedure

The fraction yields for starch and gluten from the IMDS process were 1.6 and 4.3% higher, respectively, compared with the starch and gluten yields from the conventional wet-milling procedure (Table II). These results were in agreement with the previous study by Lopes-Filho et al (1997). The lower yields from the conventional process were due to the fact that ≈4.5% solids were extracted in steepwater in the conventional steeping process. However, in the IMDS process, the soakwater (or the steepwater) was utilized as process water, and the solids in the soakwater were eventually recovered in the gluten fraction. The germ yield obtained from the IMDS process was 0.5% lower than that from the conventional corn wet-milling process. The germ recovered from the IMDS process was also slightly (2–4%) broken. The fiber fraction from the IMDS process was also higher by 1.0% compared with that of the conventional process. The fiber fraction from the IMDS process was higher because the broken germ was not recovered and ended up in the fiber fraction.

TABLE I
Effect of the Number and Duration of Dynamic Steeping Stages on Starch Yield in an Intermittent Milling and Dynamic Steeping (IMDS) Process

	Steeping		Fractions (%)[a]				
Run	Time[b]	Stages	Germ	Fiber	Starch[c]	Gluten	SW Solids[d]
1	30	2	6.2	11.7	69.0a	12.2	0.2
2	30	3	6.0	11.0	69.8a	12.6	0.3
3	30	4	6.3	11.1	69.1a	12.9	0.2
4	45	2	6.1	11.4	69.7a	13.3	0.2
5	45	3	6.4	11.8	68.8a	12.1	0.2
6	45	4	6.3	11.1	69.1a	12.9	0.4
7	60	2	6.0	10.9	69.7a	13.8	0.2
8	60	3	6.2	12.2	68.2a	11.4	0.2
9	60	4	5.8	11.2	68.1a	13.7	0.1

[a] All yields are % of dry solids and the mean of two observations.
[b] For each step (min).
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).
[d] SW = soakwater.

TABLE II
Comparison of Fraction Yields[a] from the Intermittent Milling and Dynamic Steeping (IMDS) Process and the Conventional Corn Wet-Milling Processes

Fraction	IMDS Process[b]	Conventional Process
Starch	69.9	68.3
Gluten	13.3	9.0
Germ	6.1	6.6
Fiber	11.4	10.4
Soakwater solids	0.2	···
Steepwater solids	···	4.6

[a] All yields are % of dry solids.
[b] Yields from the IMDS process were obtained using two stages of intermittent milling and 45 min of dynamic steeping for each stage.

CONCLUSIONS

The clearance between the mill plates and the rpm of the degermination mill both have a significant effect on germ damage and kernel cracking during the IMDS process. However, the effect of plate clearance is more pronounced when compared with the effect of the rpm of the degermination mill. With an increase in clearance between the plates, an opposing trend was observed for germ damage and kernel cracking (percentage of whole kernels in the mash). A clearance of 0.45–0.48 cm between the plates gave the optimum processing conditions (minimum broken germ and least amount of whole kernels in the mash after kernel cracking). The effect of rpm on germ damage and kernel cracking was not significant when the optimum clearance between the degermination plates was maintained. Both the dynamic steep time and the number of intermittent milling stages showed little effect on the fraction yields. Two stages of intermittent milling with a dynamic steep time of

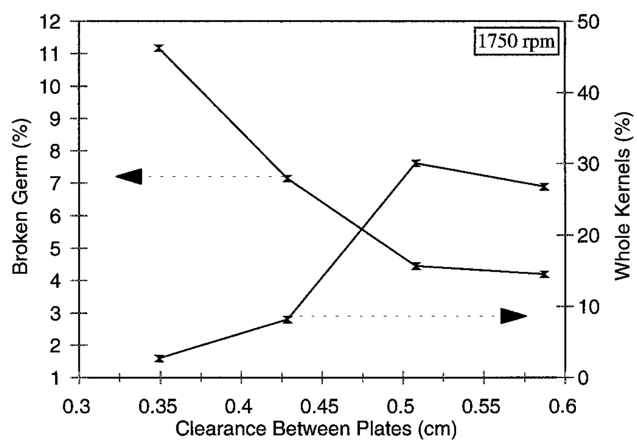

Fig. 5. Effect of 1,750 rpm and clearance between plates of a degermination mill on corn germ damage and kernel cracking.

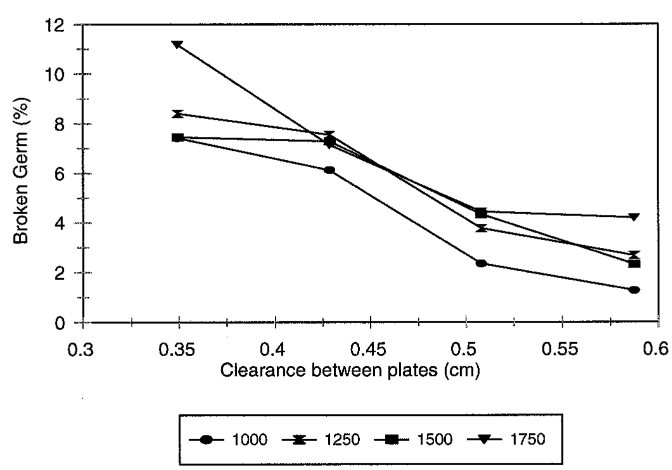

Fig. 6. Percentage of broken corn germ vs. clearance between plates of a degermination mill at four different rpm settings.

≥30 min was recommended because it produced the highest yield of starch and germ. Comparison of the IMDS process with the conventional wet-milling process showed that starch and gluten yield increased by 1.6 and 4.3%, respectively, in the IMDS process. The germ yield obtained from the IMDS process was 0.5% lower than that from the conventional process. The germ recovered with the IMDS process was also slightly (2–4%) broken.

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