Composition and Economic Comparison of Germ Fractions from Modified Corn Processing Technologies

David B. Johnston[a,*], Andrew J. McAloon[a], Robert A. Moreau[a], Kevin B. Hicks[a], and Vijay Singh[b]

[a]USDA, ARS, ERRC, Wyndmoor, Pennsylvania 19038, and [b]Department of Agricultural Engineering, University of Illinois, Urbana, Illinois 61801

ABSTRACT: Several new processes for milling corn have been developed recently specifically to isolate germ as a value-added co-product and improve the profitability of dry-grind ethanol production. The present work used modified and conventional corn milling technologies to recover germ fractions from corn kernels using either wet or dry separation processes. This study determined the quality, composition, and yield differences among the corn germ produced and compared these properties with those of the conventional wet- and dry-milled germ. A method for calculating the estimated market value for germ produced by the alternative processing methods is given. There were significant differences in the oil, protein, starch, and ash compositions and in the estimated market values among germ fractions produced by the alternative milling processes. The different germ fractions produced (including the traditional wet- and dry-milled) were found to contain 18–41% oil, 13–21% protein, and 6–21% starch, depending on the milling process used. The estimated value of germ from these processes varied from as low as $0.058/lb ($0.128/kg) to a maximum of $0.114/lb ($0.251/kg), showing that the specific process used to produce the germ will have the major impact on the overall economics of the ethanol process.

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KEY WORDS: Co-product, corn, ethanol process economics, germ, germ quality, maize, milling, oil, process, value.

Corn is processed commercially using one of three main processes: wet milling, dry milling, or dry grind for ethanol production. These three processes currently consume approximately 26% of the entire annual U.S. corn crop. Corn production in the United States during the 2003 crop year was 257 million metric tons (10.1 billion bushels) (1). Of the corn processed, approximately 34.4 million metric tons (1.35 billion bushels) of corn was processed by the corn refining industry (wet milling), 28.5 million metric tons (1.12 billion bushels) was used for fuel ethanol production (dry-grind ethanol production), and approximately 3.0 million metric tons (188 million bushels) was processed by dry milling for cereal production or other food and industrial uses. The remaining corn grown was used as feed, exported, or stored for future use.

*To whom correspondence should be addressed at USDA, ARS, ERRC, 600 East Mermaid Lane, Wyndmoor, PA 19038.

E-mail: djohnston@arserrc.gov

Wet milling is a process involving separation of the corn kernel into germ, fiber, gluten meal, and starch. In the wet milling process, the corn is first steeped in a dilute sulfur dioxide solution for 24–36 h followed by grinding and physical separations in water to produce the five components (2). Currently, only three of the companies belonging to the Corn Refiners Association process germ to recover oil (3). The remaining member companies sell the germ they produce to other member companies for extracting and refining.

Dry milling is primarily used for processing corn for food purposes; it uses one of two general procedures (or variations): the water-tempering and degermination process (producing grits, meals, and flours) (4), or the stone-grinding process without degermination (primarily used to produce hominy grits or corn meal) (4). The alkali cooking process (used primarily for masa production for tortillas) is sometimes also included as a dry milling process (4). In the water-tempering method, the pericarp/germ stream is dried, cooled, and aspirated to separate the pericarp from the germ. The germ oil (~20%) can be expelled or extracted to recover the oil; however, this is not done on a large scale.

The dry-grind process for fuel ethanol production is the second-largest corn processing industry, next to wet milling. In the dry-grind process, whole corn kernels are ground and mixed in water before heating and converting the starch enzymatically into glucose. The glucose is then fermented into ethanol and recovered by distillation. The remaining liquid and solids are dried to produce distillers dried grains with solubles, or DDGS.

Over the past few years a number of new processes for milling corn have been proposed, although none has yet reached large-scale commercial production. These proposed processes involve the removal of corn components (i.e., germ) as new co-products. Several of these processes use aspects of the three general milling methods just described; however, others use completely new processing technology (e.g., enzymatic milling) (5). In the enzymatic milling process (E-Milling), corn is treated with enzymes rather than sulfur dioxide to prepare the kernels for fractionation. In this process, the kernels are soaked, coarsely ground, and then incubated with protease prior to fractionation into germ, fiber, gluten meal, and starch using conventional wet-milling separation techniques. Many of these proposed processes have been developed to include the isolation of germ as a value-added co-product to improve the overall profitability of dry-grind ethanol production.

Because the corn germ currently used to make corn oil is almost exclusively derived from the traditional wet-milling process, the need exists to compare the quality, composition, yields, and benefits from new processes to determine acceptance by corn oil extraction facilities and the potential market value.

The successful implementation of these new processes is highly dependent on having an adequate market for the germ produced. The acceptance and purchase price of germ (determined by owners of extraction facilities) from newly developed processes will depend on the quality and composition of the germ derived from these processes. The economic benefits from the new germ recovery processes will ultimately be determined by the composition, quality, and yields of the germ and any other benefits derived from the specific process. The goals of the work presented here were to determine and compare the composition of corn germ derived from modified processing technologies and to evaluate a proposed method for calculating the estimated market value for germ derived from these processes.

MATERIALS AND METHODS

Materials. A single hybrid of yellow dent corn (Pioneer 33A14) was used in all laboratory experiments. The corn was grown at the University of Illinois experimental station during the 2002 season, field-dried, and combine-harvested. The corn was hand-cleaned to remove broken kernels and foreign materials, weighed into polyethylene bags (1-kg wet weight, with approximately 14% moisture content), and stored at 4°C until use. Kernel moisture content was determined at 103°C in a convection oven according to American Association of Cereal Chemists' (AACC) Method 44-15A (6). Commercial germ samples from wet-milling and dry-milling facilities were from unknown hybrids, but were #2 or better yellow dent corn.

The proteases used were bromelain, which was purchased from Sigma-Aldrich (St. Louis, MO), and GC106, which was donated by Genencor International (Rochester, NY). Test kits purchased from Megazyme International (Wicklow, Ireland) were used to perform starch determinations in duplicate according to AACC Method 76-13 (6). All other chemicals were at least reagent grade.

Analyses. For protein content analysis, samples were ground with a coffee mill for approximately 30 s with dry ice to 20-mesh or smaller to produce uniform sample preparations and analyzed as triplicate 50–250 mg samples. Nitrogen determinations were done according to the Dumas combustion method using a Thermo Finnegan nitrogen analyzer (CE Elantra, Lakewood, NJ). Protein content was calculated as $\%N \times 6.25$ and expressed as dry weight basis (db).

Oil content was determined using an Accelerated Solvent Extractor (ASE 200; Dionex Corporation, Sunnyvale, CA) with hexane as the extraction solvent. Approximately 1 g of sample was extracted with three cycles of hexane at 1000 psi (6.8 N/mm^2) and 100°C, with a holding time of 10 min between cycles. Hexane volumes varied between 18 and 22 mL. Sample weight and moisture were determined prior to extraction, and the dry mass of the extracted lipid (dried under a stream of nitrogen) was measured to determine the percent lipid content (7). All samples were extracted in duplicate.

Milling procedures: (i) Conventional wet milling. Conventional wet-milled germ samples were graciously donated by two commercial corn wet-milling facilities and were both germ samples from kernels that had been steeped countercurrently for a minimum of 24 h at the mill prior to processing. Additional details of the specific plant process (time, temperature, and SO_2 concentrations) were not available. Laboratory-scale conventional corn wet milling was done according to the procedure developed by Eckhoff *et al*. (8).

(ii) Modified milling processes. In the first instance, quick germ was produced according to Singh and Eckhoff (9). Samples of approximately 1 kg were soaked for 12 h in water and then ground coarsely to release the germ. The germ was then recovered by flotation, with the remaining material available for use in fermentation. In the second instance, modified dry milling was done by using samples of approximately 1 kg and tempering for 18 min after the addition of 8.5% (by weight) water to the corn. The tempered corn was then passed through a horizontal drum degerminator, which resulted in partial separation of the germ and fiber from the endosperm pieces. The product (a mixture of germ, fiber, and endosperm) was dried for 1 h at 49°C (120°F) to approximately 15% moisture. A 10–15 g subsample was removed and used to determine moisture content by drying at 130°C for 2 h. The remaining material was sieved using a laboratory box sifter. The largest-sized fractions (+5) were roller-milled and aspirated at 0.4–0.5 in. of water vacuum to remove the pericarp fraction. The "heavy" material was sifted on a 10-mesh screen to remove the "flattened" germ particles. The remaining endosperm fraction was weighed and identified as "large (flaking) grit." The –5 portion was also rolled, aspirated, and sifted. The "lifts" from the aspirator were added to the pericarp fraction. The "heavies" were sifted on a 10-mesh sieve. The +10 germ particles were added to the germ fraction and the –10 endosperm portion was sifted on a 24-mesh sieve. The +24 particles were identified as "small grit" and the –24 as "fines." Data were reported on a dry basis percentage of the original sample dry weight. In the third instance, E-Milling was done according to Johnston and Singh's method (5,10) using two different proteases (bromelain and GC106). Corn was soaked in water for 4 h and, after coarse grinding and pH adjustment, enzyme was added at 2 g/kg for bromelain and 5 mL/kg for GC106. In the fourth instance, alkali milling was done according to Du *et al*. (11).

Statistical analyses. ANOVA and Duncan's multiple range test (SAS Institute, Cary, NC) were used to compare oil, protein, starch, ash, and germ yields. The level selected to show statistical significance was 5% ($P < 0.05$).

RESULTS AND DISCUSSION

Germ yields. Germ yield from the conventional laboratory wet mill process was almost identical to published yields of commercial corn wet milling (Table 1); however, germ yields from the conventional process were 10–30% greater than those obtained from the other alternative milling processes tested (Table 1). These observations were consistent with yields reported by Eckhoff *et al.* (8).

Germ yields for both the 12-h steeping process and the Quick Germ process were the highest among alternative milling methods, but still lower than those of conventional milling (Table 1). The yield, however, for the 12-h steep was slightly higher than that of the Quick Germ process, and this was likely due to the added benefits of the SO_2 and lactic acid in solubilizing components from the germ. It may also be attributed to a slight difference in water usage affecting the floating and recovery of the individual germ. The yields for these two processes were also found to be consistent with those published by Singh and Eckhoff (9) and Blanchard (12).

Germ yields for both E-Milling processes were 20% lower than those of conventional wet milling and 10% less than those of Quick Germ and the 12-h steeping processes. The differences, however, were not statistically significant among the Quick Germ, the 12-h steeping, and the E-Milling processes. Germ yields from the two E-Milling processes (bromelain vs. GC106) were not statistically different. Yield from the GC106 process appeared to be markedly higher than that of the 4-h water soaking process, which was the lowest among procedures tested. Additional experiments in our laboratory have shown that the E-Milling germ yields can be improved considerably by altering the water balance to increase the specific gravity (Baumé) of the slurry during germ flotation (results not shown).

Laboratory dry milling generated the highest germ yields among all the processes tested because separation of the germ from endosperm in the dry milling process is not clean and a significant amount of fiber and endosperm is attached to the germ fraction (clearly visible upon examination). In addition, the soluble components from the germ fraction are not removed, unlike in processes involving soaking or steeping. Earle *et al.* (13) published data indicating that the weight percentage of the kernel making up the germ was approximately 11%. When this is considered, at least 9–26% non-germ components would be included in this fraction if all the germ were recovered here. If any portion of the germ is lost in any other fraction, the non-germ content in the dry-milling germ fraction will increase proportionately. This loss is believed to be responsible for the lipid content of approximately 2.5% in corn flour.

Germ oil contents. The oil content of the germ is likely the most critical component for evaluation, as it ties directly to the value the germ will have from any given process (14). The oil contents of the germ samples tested (Table 1) ranged from 18 to 41 wt% (db). There was a surprisingly large difference in the oil contents of the two commercial wet milling samples (40.89 and 36.39 wt%, Table 1). Visually, the qualities of the germ appeared to be equivalent (size and amount intact vs. broken); however, wet mill B appeared to have a slightly increased amount of fiber relative to the other, which correlated to its lower oil content. The increased fiber could be the cause for the difference in oil. Oil differences could also be from oil lost from the germ due to differences in processing conditions. Oil content of the germ from laboratory conventional wet milling was precisely in the middle between the two commercial wet-milled germ samples, indicating that the laboratory milling process used was an acceptable method for preparing germ for evaluation of compositional properties.

TABLE 1
Compositional Comparison of Germ Derived from Different Milling Processes[a,b]

Milling process	Oil wt%	Protein wt%	Starch wt%	Ash wt%	Yield % corn (dry wt)	Germ value $/lb
Conventional wet mill A[c]	40.89 ± 0.13^{A}	14.03 ± 0.15^{E}	8.00 ± 1.70^{E,F}	2.20 ± 0.13^{B,C}	7.50^{d,D}	0.112
Conventional wet mill B[c]	36.39 ± 0.17^{B}	13.09 ± 0.61^{E}	6.90 ± 0.19^{F}	1.43 ± 0.04^{D}	7.50^{d,D}	0.099
Conventional wet mill kg lab	38.77 ± 0.07^{A,B}	18.38 ± 0.93^{C}	11.60 ± 0.09^{C,D}	2.30 ± 0.01^{B}	7.51 ± 0.22^{D}	0.113
12 h SO_2 steep	36.32 ± 1.21^{B}	18.12 ± 0.87^{C}	7.40 ± 0.04^{F}	ND	6.88 ± 0.41^{D,E}	0.106
Quick Germ (12-h water soak)	36.43 ± 0.46^{B}	21.36 ± 0.69^{A,B}	6.20 ± 0.16^{F}	ND	6.50 ± 0.18^{e,E,F}	0.111
Enzymatic milling bromelain	38.28 ± 0.13^{A,B}	17.57 ± 1.68^{C}	9.70 ± 1.33^{D,E}	3.22 ± 0.37^{A}	5.92 ± 0.86^{F,G}	0.111
Enzymatic milling GC106	39.33 ± 1.61^{A}	18.16 ± 0.32^{C}	12.10 ± 1.51^{C}	3.15 ± 0.00^{A}	6.17 ± 0.25^{E,F}	0.114
4-h water soak (no enzyme)	33.36 ± 3.22^{C}	20.93 ± 0.13^{B}	7.85 ± 0.25^{E,F}	ND	5.18 ± 0.26^{G}	0.103
Commercial dry milled[c]	23.00 ± 0.24^{D}	15.35 ± 0.37^{D}	19.81 ± 0.47^{B}	ND	12.00^{B}	0.068
Laboratory dry milled kg lab	18.06 ± 1.86^{E}	17.46 ± 0.50^{C}	21.20 ± 0.79^{B}	ND	13.86 ± 0.70^{A}	0.058
Boiled corn (15 min)	32.24 ± 1.27^{C}	22.17 ± 0.63^{A}	11.40 ± 0.09^{C,D}	ND	6.34 ± 0.57^{E,F}	
Alkali milled	24.99 ± 0.23^{D}	ND	ND	ND	8.78^{f,C}	
Ground corn	3.98 ± 0.17^{F}	8.08 ± 0.21^{F}	69.48 ± 0.78^{A}	1.55 ± 0.59^{C,D}		

[a]All values (except germ value) are expressed on a dry wt basis and are means of duplicate analysis ± 1 SD.
[b]Values in each column with different uppercase letters are significantly different ($P < 0.05$). ND, not determined.
[c]Unknown corn hybrid.
[d]Based on published yields (12).
[e]Based on published yields (9).
[f]Single milling run was done.

The oil contents of the commercial germ samples (wet mill A and B) were found to be significantly different; however, there was no significant difference between oil contents of the laboratory wet-milled samples and the commercial samples. No significant difference was found between the laboratory conventional wet-milled germ and the Quick Germ or the enzymatic-milled germ. The dry-milled samples (laboratory and commercial) had much lower oil contents than all of the other processes tested. The commercial dry-milled germ had only about 60% of the oil content of the commercial wet-milled samples. Commercial dry-milled samples had 27% more oil (calculated as [(higher value minus lower value)/lower value] × 100) than the laboratory dry-milled germ. The latter had a higher fiber and endosperm content based on visual evaluation, which is the likely reason for the reduced oil content of the laboratory-milled sample relative to the commercial sample.

The low oil content of the dry-milling process relative to the wet-milling processes was not unexpected since the germ still contains many of the soluble components that would be removed in water and therefore dilute the oil content. These data also clearly indicate that two times the weight of the dry-milled germ would need to be extracted to get the same amount of oil from a given weight of wet-milled germ. In addition, using germ from the Quick Germ process, the E-Milling process, or a short (12-h) steeping process would give essentially equivalent oil yields compared with using conventionally wet-milled germ (Table 1).

The oil in germ is approximately twice as valuable as the protein on a unit weight basis. As a result, there is a strong correlation between the market value of germ and its extractable oil content and a much lower correlation between the germ's protein content and its value in the marketplace. However, oil content alone does not always determine germ value, as can be seen in Table 1. The germ from the 4-h water soak process had a lower oil content than the germ from Conventional Wet Mill B but actually had a greater estimated economic value owing to its much higher protein level.

Germ protein contents. The protein content is the second-most important factor after the oil content when evaluating the value of the germ, because the extracted germ will most likely be used in animal feed and the value of the spent material will be closely related to its protein content (15). Although the extracted material was not evaluated directly for protein, the protein content of the intact germ can be used to estimate the final protein content after oil removal. The protein contents (Table 1) ranged from 13 to –21 wt% (db). The estimated protein content of the extracted corn germ meal would correspond to 20–33 wt% (db) assuming a residual of 1.5 wt% of the original oil remaining and no loss of other components.

Quick Germ and the 4-h soak processes showed notably higher protein contents than the other processes tested. This is likely due to the increased removal of protein caused by sulfur dioxide or protease addition. In the absence of these added components, as in the case of Quick Germ and the 4-h soak, more protein remains in the germ.

Conventional laboratory wet milling and the 12-h steeping procedures were not significantly different in protein content compared with the E-Milling processes but were significantly lower in protein than the Quick Germ and 4-h soak. All laboratory and dry-milling processes gave higher protein contents than the two commercial wet-milling samples. The notable difference in protein content between the laboratory and the commercial conventional wet-milled samples was surprising, as the data for oil and yield correlated extremely well. It is speculated that the growth of lactic acid bacteria that occurs during steeping of the commercially processed samples somehow decreases the protein content further than could be simulated by directly adding lactic acid, as is done in the laboratory process (8).

The commercial dry-milled sample had the second-lowest protein content among the process samples evaluated. The laboratory dry-milled sample also had a lower protein content than the Quick Germ and the 4-h soaking samples, but its value was still greater than that of commercial wet- and dry-milled samples.

Germ starch contents. Germ starch values ranged from 6 to 21 wt% (db) (Table 1). Starch values were highest for the dry-milled germ owing to the endosperm carryover in this fraction. The laboratory dry-milled germ had a slightly higher starch value than did the commercial dry-milled germ, but both were much greater than those in germs from the other processes by at least 64%. Among the modified processes, the starch contents of the germs did not vary as widely as those observed between the conventional wet and dry milling. Despite the smaller variation, the differences were still significant. Among non-dry-milled germ samples, those from enzymatic milling and conventional laboratory wet milling had the highest starch values. The remaining processes gave starch values that were close to those of commercial wet milling. The substantial loss of starch with the dry-milling process is a contributing factor in the low oil content for germ from this process. Whereas even the best processing technologies cannot remove starch from within the intact germ, this internal starch should only account for about 8–10% of the germ composition.

Determining the value of corn germ. The corn germ market is relatively small, and corn germ prices are not readily available; however, because corn germ is the source of corn oil and also is used in animal feed, its market value can be estimated based on the price of these two products. The overall profitability for corn germ from any one process will depend on a number of additional factors not evaluated in this work, including specific processing efficiency, overall yield, additional capital and operating costs, and co-product credits.

Crude corn oil prices have fluctuated over the last several years, with a low value of <$0.15/lb (<$0.31/kg) to a high of >$0.30/lb ($0.66/kg) (14). The current price is approximately $0.26/lb ($0.57/kg) (15). It is not economically efficient to extract all of the oil from corn germ, and 1–2% of the oil normally remains in the germ meal after extraction (12).

Corn germ meal, the residue remaining after the oil has

been extracted from corn, is typically blended with corn fiber and sold as corn gluten feed (an animal feed). Corn gluten feed has a crude protein content of 21% and is sold as a protein feed, currently at about $60.00/ton (12), or $0.14/lb ($0.45/kg) of protein in the feed. Corn gluten feed also has 1–2% fat and about 10% starch that contribute to its value, but their impact is small when compared with the impact of the protein and will not be considered in this analysis.

The cost of separating corn germ into crude corn oil and germ meal with hexane extraction is estimated at $0.01/lb ($0.02/kg) of corn germ regardless of its oil content (Stroup, R., personal communication). We found credible values in the range of $0.0075 to $0.0175/lb ($0.0165 to$ 0.0386/kg) and decided to use a more conservative value. Using the higher cost would increase the differences in germ values; however, this difference would be small relative to the differences due to oil and protein contents.

Based on the immediately preceding information, we have developed an equation to estimate the commercial value for corn germ derived from any given process:

$$\text{estimated value} = \%\ \text{of commercially extractable oil in germ} \times \text{value of crude corn oil}) + (\%\ \text{germ protein content} \times \text{value of protein in corn gluten feed}) - \text{cost of separating germ into oil and germ meal} \quad [1]$$

By using this formula, the estimated market values for a range of corn germ protein and oil contents were calculated. Figure 1 shows the estimated values for protein contents from 0 to 25% and oil contents from 0 to 50%. In this figure it is clear that the oil content has a significantly higher impact on the germ value relative to protein. The negative values shown at the lower oil and protein concentrations are from separation costs that exceed product revenue. Using this same relationship, we calculated the estimated market values for each of the germ samples prepared in the laboratory and for the commercially prepared samples (Table 1).

The calculated market values show that there are major differences among the processes tested. Notably, the germs from the dry-milling processes have a value of less than one-half of the germs from the other milling processes. The reason for this is the significantly lower oil content relative to the other processes and the fixed cost per pound to process the germ. Although we were unable to evaluate the comparative processing costs, we believe that the loss of starch with co-products streams derived from germ separated using dry milling will further reduce the overall profitability of an ethanol plant through decreased ethanol production per unit of corn.

By using this method to estimate germ value, an interesting conclusion arises. Each of the methods being examined in Table 1 as potential alternatives to the traditional dry grind ethanol process (Quick Germ and E-Milling), as well as the experimental 12-h sulfite steep and 4-h water soak, produces germ with projected values that are within the range shown for the two commercial wet-mill germ samples and all are far more valuable than the germ from the traditional dry-milling process. These results are encouraging to researchers trying

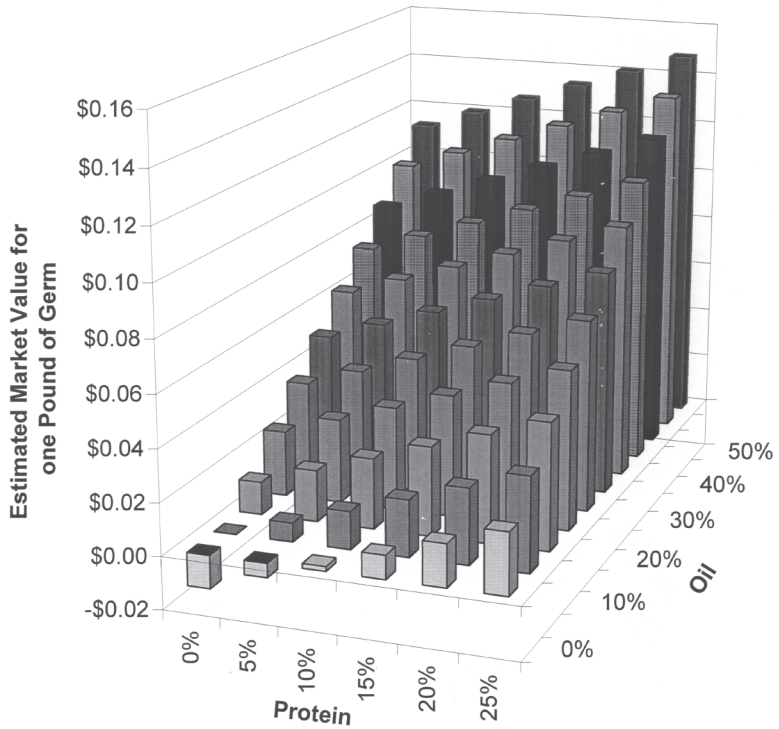

FIG. 1. Estimated market values calculated for corn germ based on extraction costs and protein and oil content.

to use these and similar methods to recover high-quality germ as a valuable co-product from future corn-to-ethanol plants.

The highest oil concentrations are reached when milling is done using either conventional SO_2 milling or E-Milling. The Quick Germ process did reach oil yields close to those from conventional SO_2 milling but not as high as the E-Milling process. Achieving oil concentrations equivalent to conventional wet-milled germ is possible by a number of different chemical and enzymatic processes tested; however, dry milling was unable to produce germ with high oil concentrations. Although it is not possible to make any definitive statements about the overall profitability for the various processes, knowing the approximate value for germ having a specific composition should be of great value in determining whether a new process could be cost effective. The yield of germ produced, the loss of starch into the co-products, and the effects of lost nutrients (particularly with dry milling) on fermentation rate must also be considered in the overall economic analysis.

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