Dehulling Crambe Seed for Improved Oil Extraction and Meal Quality

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ABSTRACT: Crambe seed had low bulk density (328 kg/m^3) due to thick hulls (0.23 mm), which made up 21.2% of the seed weight. The mean seed diameter was 2.7 mm (SD ± 0.2 mm); the thousand-grain-weight was 6.2 g. Dehulling improves oil extraction efficiency and facilitates the marketing of high-protein meal (>40% protein). The effectiveness of roller milling/aspirating and the effectiveness of impact milling/aspirating on dehulling crambe seed were studied and compared by analyzing the meat and hull fractions for oil and protein contents and calculating material balances. Roller milling was more effective than impact milling. The optimal roller mill gap was 7/64 in. (0.28 cm), and the optimal impact mill speed was 2,400 rpm generating 44.7 m/s tangential speed. The optimal aspiration airflow was 1,970 ft^3/min (55.7 m^3/min). Roller milling/aspirating was projected to produce 46% protein meal at 12% moisture and 1% residual oil (typical of solvent extraction) or 42% protein meal at 12% moisture and 6% residual oil (typical of screw pressing most other oilseeds). Hand-dissected hulls contained 10.4% moisture, and 1.2% oil and 8.8% protein on a dry basis, whereas the meats contained 8.8% moisture, and 47.6% oil and 31.6% protein on a dry basis. Optimal roller milling/aspirating produced hulls with 8.1% oil and 11.4% protein and meats with 42.6% oil and 30.5% protein on a dry basis.

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KEY WORDS: Crambe, decorticating, dehulling, hulls, impact milling, meal, meats, roller milling.

Crambe seed has been commercially grown in eastern North Dakota since 1990 for industrial oil (1,2). Crambe belongs to the *Brassica* genus and, as such, is similar to rapeseed, with fatty acid compositions of the oil being high in erucic acid (about 60%) and seed contents being high in glucosinolates [about 2.7% dry basis (db)]. Crambe oil can be used in pharmaceuticals, lubricants, heat transfer fluids, dielectric fluids, and waxes. The erucic acid can be derivatized to amides and amines and used for plasticizers, slip agents, surfactants, antistats, flotation agents, and corrosion inhibitors or cleaved to produce pelargonic and brassylic acids, the latter useful in the plastics, resins, and nylon industries (1). The high level of glucosinolates poses limitations on the use of the meal for feeding livestock; however, water-washing crisped meal is effective in extracting the glucosinolates (3).

The bulk density of whole crambe seed is low compared with other oilseeds, and shipping costs are quite high per unit weight. This is due to the high proportion of seed weight that is low-density hull material; the hull constitutes about 23% of the seed weight (4). Also, there appears to be an air space between the hull and much of the meat, which would contribute to the low bulk density. Dehulling increases extraction efficiency, reduces energy required to desolventize the meal, facilitates marketing of a high-protein meal, and eliminates unwanted materials in the hulls that may be extracted with the oil. The livestock feeding industry prefers oilseed meals high in protein and low in fiber contents, and pays premium prices for such materials. Some have also proposed dehulling crambe prior to transporting to regional crushing facilities to achieve more economical shipping, provided oil deterioration can be avoided.

An effective dehulling process must meet several conditions: there must be near-complete cleavage of the hull from the meat (decortication); the loss of oil from the meat and subsequent adsorption by the hull must be minimized; and the production of fines, which may cause solids to be present in the oil, fouling of evaporation equipment, and reduced drainage of solvent from the bed of flakes, must be avoided. Dehulling oilseeds includes two steps: decortication (freeing the hulls from the meats) and separation of the hulls from the meats. Commonly used decortication methods include roller milling, impact milling, bar milling, disc milling, and hammer milling (5). The free oil-lean hulls are then removed from the oil-rich meats with aspirators, shaker screens, or gravity tables.

Crambe differs from rapeseed in that the seed is larger than rapeseed, and crambe seed hulls are less tenaciously bound to the meats. Several approaches to dehulling rapeseed have been attempted (6) but are rarely practiced. One approach is to use an impact mill, where the seed is impacted against a solid surface to shatter the seed coat. The higher the rotational speed of the impact mill, the faster and more forcefully the grain is flung outward to impact the outer wall of the mill. The optimal velocity allows effective dehulling without excessively damaging the meats so that little oil is absorbed by the hulls to decrease oil yield. After air classification, the separated rapeseed hulls contain only 3% meats (6). Impact mills are also often used in dehulling sunflower seed. Another dehulling system employs a roller mill in which the spiral-corrugated rolls turn in counter directions at a small differential. Each type of seed has an optimal gap setting and type of corrugation (7). Roller mills are often used to crack soybeans in dehulling operations.

The objective of the present work was to compare the effectiveness of impact milling/aspirating and the effectiveness of roller milling/aspirating in dehulling crambe seed and to predict the maximal protein levels achievable in crambe meal when processing by solvent extraction and screw pressing.

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MATERIALS AND METHODS

Seed. About 230 kg of crambe seed, Meyer variety, was grown at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa. The seed had 7.5% moisture content (mc) at the time of processing. We measured the diameter of 1,000 seeds by using a micrometer and determined the weight of 1,000 seeds. We also measured the hull thickness of 100 hand-dissected seeds by using a micrometer. About 35 g of crambe seeds were carefully hand-dissected to provide a benchmark for pure hulls and pure meats for comparisons.

Decortication. An Entoleter impact mill (model 141 FDG; Division of Safety Railway Service Corp., New Haven, CT) was evaluated at three different disc speeds: 1,750, 2,100, and 2,400 rpm. The tangential speeds of the crambe seed spun by the 14-in. (35.6-cm) disc were 32.6, 39.1, and 44.7 m/s, respectively. These speeds correspond to centripetal forces of 4.0×10^{-2}, 5.7×10^{-2}, and 7.45×10^{-2} N, respectively. The Entoleter was fed by means of a vibratory feeder.

A Blount/Ferrell-Ross roller mill (Oklahoma City, OK) with 30.5-cm-diameter rolls having a 0.5-mm/cm spiral and 2 mm spacing between corrugations was used. The roller mill was evaluated at three different gap settings: 5/64 in. (0.20 cm), 6/64 in. (0.24 cm), and 7/64 in. (0.28 cm). The roller mill was fed by means of a vibratory feeder.

All decortication and aspiration trials were replicated three times each. About 4.25 kg of seed was used for each replication of each trial.

Aspiration. All decorticated samples were aspirated by a cascade-type multiaspirator (model 6F6; Kice Industries, Inc., Wichita, KS). Each sample was aspirated at three different airflow rates using the following butterfly settings: high air, 2,470 ft^3/min (70.0 m^3/min); medium air, 1,970 ft^3/min (55.7 m^3/min); and low air, 1,500 ft^3/min (42.4 m^3/min). All aspiration trials were replicated three times.

Analyses. A one-stage ground grain method was used to determine moisture content. Samples were finely ground using a laboratory flour mill. Samples (3.0 g) were placed into weighed metal pans with lids and heated at 130°C for 1 h. The metal pans were weighed after cooling in a dessicator to determine moisture loss. Protein contents in 1.0-g samples were determined by using the macro-Kjeldahl method, AOAC 2.056 (8), and a Tecator Kjeltec System (Boulder, CO). Crude free fat was determined in 2.0 g samples by extracting for 5 h with petroleum ether on a Goldfisch extraction apparatus and using AOAC method 14.089 (8). Fiber content was determined at Woodson-Tenet Laboratories, Inc. (Des Moines, IA) using AOCS method Ba 6-84 (9). Triplicate samples of hand-dissected hulls and meats were analyzed for moisture, oil, protein, and fiber contents.

Material balances. After milling/aspirating, both hulls and meats fractions were analyzed for oil, protein, and moisture contents. The percentages of hulls in the meat fractions and meats in the hulls fractions were calculated based on the protein balance in the samples and using comparable values for the same fractions from hand-dissected seeds. Masses of meats and hulls incorporated in the meal to achieve specified protein levels were also calculated by mass balance. The following equations were used:

% Hulls in meats @ 0% moisture = 100 · (meats' protein content @ 0% moisture – protein content of pure dissected meats @ 0% moisture)/ (protein content of pure dissected hulls @ 0% moisture – protein content of pure dissected meats @ 0% moisture) [1]

% Meats in hulls @ 0% moisture = 100 · (hulls' protein content @ 0% moisture – protein content of pure dissected hulls @ 0% moisture)/ (protein content of pure dissected meats @ 0% moisture – protein content of pure dissected hulls @ 0% moisture) [2]

Mass of hulls added to meats for a specific meal protein level @ 12% moisture = target meal protein content · mass of meats fraction · [(1.01 – oil content of meats fraction) – 0.88 · (mass of meats fraction · protein content of meats fraction)]/0.88 · [(protein in hulls fraction – targeted protein level) · (1.01 – oil content of hulls fraction)] [3]

Optimal settings were identified where the amount of hulls in the meats and the amount of meats in the hulls were the least, thus achieving the greatest practical meal protein content and the greatest yields of oil and meal protein. Separate calculations were made for screw pressing and solvent extracting using residual oil contents of 6.0 and 1.0%, respectively, which are typically found in screw-pressed and solvent-extracted meals of other oilseeds. Recent experience indicates that 6% residual oil in crambe screw press cake is difficult to achieve, but we believe that once the optimal screw press configuration is identified and the art of screw pressing crambe seed is perfected such levels are practical (they are common levels for soybeans and cottonseed). The level of residual oil may also be impacted by the amount of hulls present in the material fed to the screw press. All calculations were based on meeting a maximal level of 12.0% moisture in the meal.

RESULTS AND DISCUSSION

Seed characteristics. The thousand-grain-weight was 6.4 g, and the bulk density was 328 kg/m^3 compared to 50–350 g (10) and 770 kg/m^3 (11) for soybeans, respectively. The mean seed diameter of our seed lot was 2.7 mm (1 SD = 0.2 mm) compared to 1.8–2.0 mm diameter for rapeseed. Based upon hand-dissecting the seed, our crambe comprised 21.2% hulls and 78.8% meats (db), which translates to 212 kg of hulls and 788 kg of meats per metric ton of seed (Table 1). The moisture content of the hulls was 10.4%, and the moisture content of the meats was 8.8%. The thickness of the seed coat ranged from 0.18 to 0.28 mm.

Compositions of hulls and meats. On a dry basis, whole crambe seed contained 33.9% oil, 25.2% protein, and 12.3% crude fiber. Crambe meats were high in oil (47.6%) and protein (31.6%) and low in crude fiber (5.0%). Crambe hulls were low in oil (1.2%) and protein (8.8%) and high in crude fiber (42.6%) (Table 1). By comparison, rapeseed hulls con-

TABLE 1
Yields of Crambe Meats and Hulls for Various Dehulling Strategies at Their Optimal Settings

	Meats	Hulls
Hand dissected		
Moisture, %	8.8	10.4
Protein, % (mfb)	31.6	8.8
Oil, % (mfb)	47.6	1.2
Weight, kg/mt (mfb)	788.4	211.6
Optimal roller milling/aspirating		
Protein, % (mfb)	30.5	11.4
Oil, % (mfb)	42.6[a]	8.1[a]
Weight, kg/mt (mfb)	746.1[a]	254.0[a]
Optimal impact milling/aspirating		
Protein, % (mfb)	30.3	13.8[a]
Oil, % (mfb)	43.5[a]	14.2[b]
Weight, kg/mt (mfb)	670.6[b]	329.6[b]

[a] Significant ($P < 0.05$) from hand dissecting.
[b] Significant ($P < 0.05$) from hand dissecting and roller milling/aspirating. Abbreviations: mfb, moisture-free basis; mt, metric ton.

tain 12 to 14% oil, 16 to 18% protein, and 24 to 26% crude fiber (12). Therefore, dehulling seed is more advantageous in crambe seed processing than in rapeseed processing.

Mass balances. Figures 1–4 show oil yields at different meal protein levels (at 12.0% moisture content) for the different dehulling strategies and settings and for solvent extracting and screw pressing. Roller milling/aspirating was more effective than impact milling/aspirating for dehulling crambe seed because of greater oil yield when using roller milling/aspirating. We attribute this to more oil absorption by the hulls due to bruising of the meats (so that oil absorption by hulls is greater) and to producing more fine meats when using impact milling/aspirating.

Small gap settings in roller milling cause more fine meats to be produced, which are carried over with the hulls as resulting in lower projected oil yields. Some of these fine meats might be recovered by screening the hulls. At high aspiration airflow rates, more meats were lost to the hulls fraction with both mills, causing lower oil yields. At low aspiration airflow rates, greater meal protein levels could not be achieved due to greater proportions of hulls remaining in the meats fraction. The optimal gap setting for the roller mill was 7/64 in. (0.28 cm), and the optimal aspiration airflow rate was 1,970 ft^3/min (55.7 m^3/min).

The optimal rotational speed for the impact mill was 2,400 rpm, which generated 44.7 m/s tangential speed. Faster speeds increased oil absorption and amounts of fine meats, whereas slower speeds did not achieve sufficient decortication. The optimal aspiration airflow rate for impact-decorticated crambe seed was also 1,970 ft^3/min (55.7 m^3/min)—the same as for roller milling/aspirating.

At the optimal settings for roller milling/aspirating, the meats fraction was almost devoid of hulls without losing meats to the hulls fraction (Table 1). The oil and protein contents of the meats when using optimal roller milling/aspirating were 42.6 and 30.5%, respectively, vs. 47.6 and 31.6%, respectively, for hand dissection. The hulls fraction from impact milling/aspirating contained over 1.5 times more oil than it did with roller milling/aspirating (14.2 vs. 8.1%, respectively). In addition, the net hulls fraction was significantly larger for optimal impact milling/aspirating than for optimal roller milling/aspirating, 330 vs. 254 kg/mt.

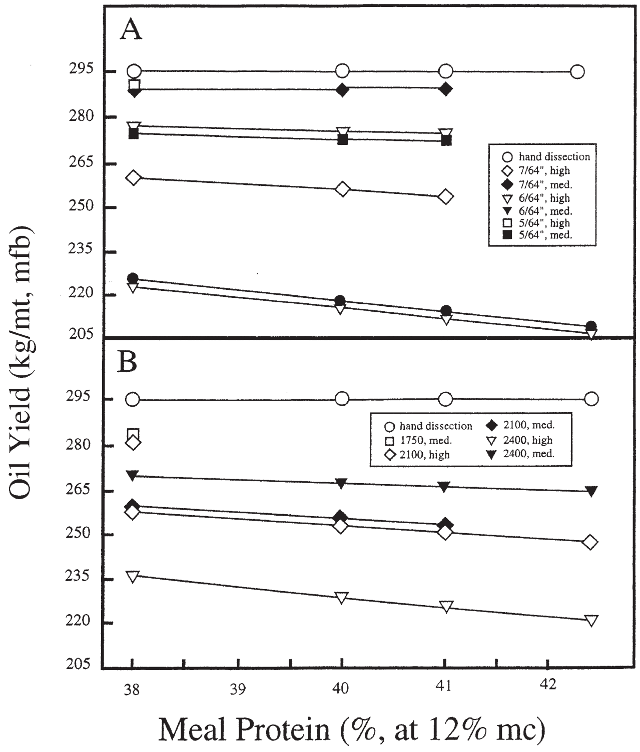

FIG. 1. Effects of roller milling/aspirating at different gap settings (A, $LSD_{0.05}$ = 13.1) and impact milling/aspirating at different disc speeds (rpm) (B, $LSD_{0.05}$ = 10.9) on oil yield when processing crambe seed by screw pressing. Moisture free basis, mfb; moisture content, mc; $LSD_{0.05}$, least significant difference when P = 005.

Figures 1–4 show that oil and meal yields with respect to meal protein levels (at 12.0% moisture content) are much greater when using optimal roller milling than when using optimal impact milling/aspirating for both solvent extraction and screw pressing. In addition, oil losses and the amount of net hulls fractions were lower using optimal roller milling/aspirating as opposed to optimal impact milling/aspirating.

It was possible to make a 44 to 46% protein meal when using solvent extraction where the residual oil content was <1% and moisture content was about 12%. By using screw pressing, where the residual oil content was about 6% and the moisture content about 12%, 42.5% was the highest obtainable meal protein content. For optimal roller milling/aspirating to produce 46% protein meal by solvent extraction, about 224 kg of hulls, 315 kg of oil, and 461 kg of meal would be recovered per ton of seed processed. By comparison, about 282 kg of hulls, 288 kg of oil, and 430 kg of meal would be recovered when employing optimal impact milling/aspirating. For screw pressing to produce 42.5% protein meal, about 220 kg of hulls, 286 kg of oil, and 502 kg of meal would be recovered when using optimal roller milling/aspirating and about 284 kg of hulls, 264 kg of oil, and 461 kg of meal per ton of seed when using optimal impact milling/aspirating.

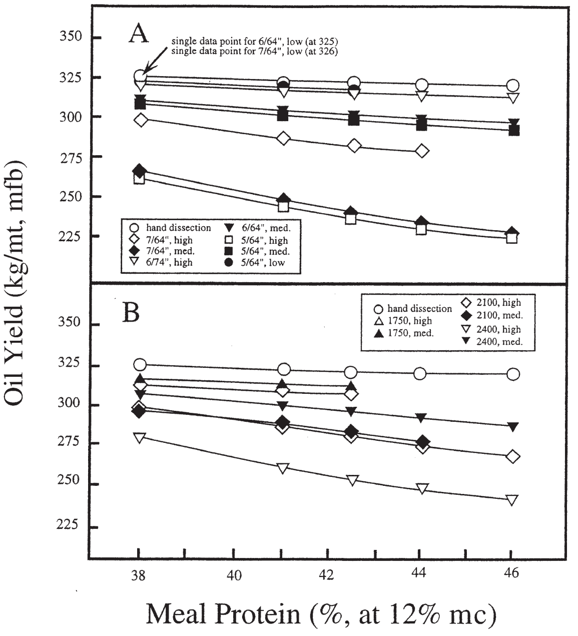

FIG. 2. Effects of roller milling/aspirating (A, $LSD_{0.05}$ = 13.1) and impact milling/aspirating variables (B, $LSD_{0.05}$ = 10.9) on oil yield when processing crambe seed by solvent extraction. See Figure 1 for abbreviations.

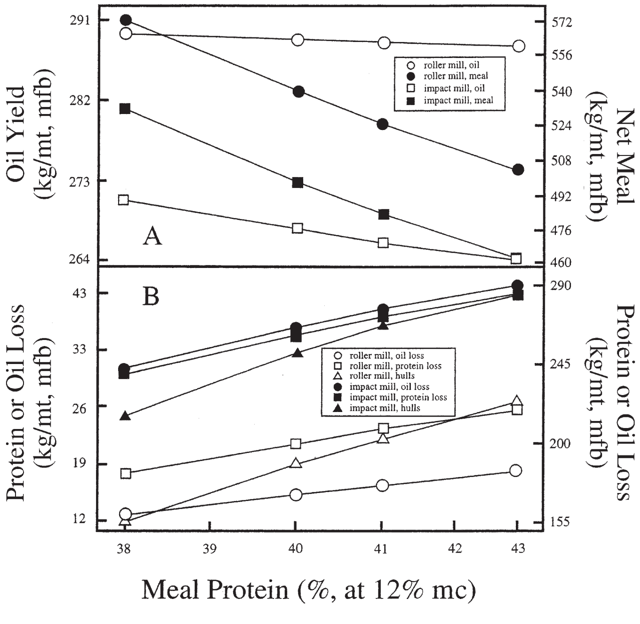

FIG. 3. Oil and meal yields (A, $LSD_{0.05}$ = 8.4 and 25.4, respectively) and net hull yields and oil and protein losses (B, $LSD_{0.05}$ = 7.6, 8.0, and 31.5, respectively) when preparing crambe meal with different protein contents by screw pressing. See Figure 1 for abbreviations.

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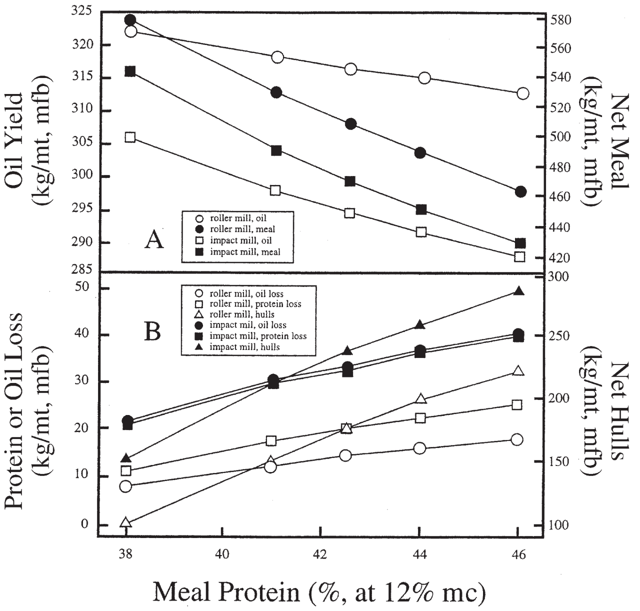

FIG. 4. Oil and meal yields (A, $LSD_{0.05}$ = 8.4 and 25.4, respectively) and net hull yields and oil and protein losses (B, $LSD_{0.05}$ = 7.6, 8.0, and 31.5, respectively) when preparing crambe meal with different protein contents by solvent extraction. See Figure 1 for abbreviations.

REFERENCES

1. Van Dyne, D.L., M.G. Blasé, and K.D. Carlson, *Industrial Feedstocks and Products from High Erucic Acid Oil: Crambe and Industrial Rapeseed*, University of Missouri-Columbia, Columbia, 1990.
2. Watkins, C., Crambe—Ready to Be a Success, *INFORM 10*:828–834, 836 (1999).
3. Baker, E.C., G.C. Mustakas, and V.E. Sohns, Crambe Processing: Glucosinolate Removal by Water Washing on a Continuous Filter, *J. Am. Oil Chem. Soc. 54*:387–388 (1977).
4. Kirk, L.D., G.C. Mustakas, and E.L. Griffin, Jr., Crambe Seed Processing: Filtration–Extraction on a Bench Scale, *Ibid. 43*:334–336 (1966).
5. Galloway, J.P., Cleaning, Cracking, Dehulling, Decorticating and Flaking of Oil-Bearing Materials, *Ibid. 53*:271–274 (1976).
6. Baudet, M., Le Depelliculage des Graines de Colza, *Bull. CETIOM 79*:162, 165 (1981).
7. Haque, E., Application of Size Reduction Theory to Roller Mill Design and Operation, *Cereal Foods World 36*:368–375 (1991).
8. *Official Methods of Analysis of the Association of Official Analytical Chemists*, 13th edn., edited by W. Horwitz, AOAC, Arlington (1984).
9. *Official and Tentative Methods of the American Oil Chemists' Society*, 3rd edn., edited by R.O. Walker, American Oil Chemists' Society, Champaign, 1980.
10. Bockish, M., *Fats and Oils Handbook*, AOCS Press, Champaign, 1993, p. 223.
11. Perkins, E.G., Physical Properties of Soybeans, in *Practical Handbook of Soybean Processing and Utilization*, edited by D.R. Erickson, AOCS Press, Champaign, 1995, p. 37.
12. Evrard, J., and P. Burghart, Dehulling of Rapeseed: The French Experience, presented at the 83rd Annual Meeting of the American Oil Chemists Society, Toronto, Canada, *INFORM 3*:518 (1992).

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