Influence of Moisture Content and Cooking on Screw Pressing of Crambe Seed

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ABSTRACT: The cooking and drying conditions for oilseeds preparatory to screw pressing are some of the most important factors that influence screw-press performance. Screw-press oil recovery, residual oil, pressing rate, and oil sediment content were measured for uncooked crambe seed and crambe seed cooked at 100°C for 10 min, pressed at six moisture contents ranging from 9.2 to 3.6% dry basis. Oil recovery significantly increased ($P \leq 0.01$) from 69 to 80.9% and 67.7 to 78.9% for cooked and uncooked seeds, respectively, as moisture content decreased. Residual oil significantly decreased ($P \leq 0.01$) from 16.3 to 11.1% and 16.9 to 11.9%, respectively, as moisture content decreased. The reduced oil loss due to only drying the seed from 9.2 to 3.6% was 32% for cooked seed, whereas cooking contributed only 3.6 to 7% reduced oil loss. Pressing rate decreased from 5.81 to 5.17 kg/h and 6.09 to 5.19 kg/h for cooked and uncooked seeds, respectively, whereas sediment content increased from 0.9 to 7.8% and 1.1 to 5.4%, respectively, as moisture content decreased. The effects of moisture content on pressing rate and sediment content were significant at $P \leq 0.05$. All relationships of screw-press performance to moisture content were fitted to a second-order polynomial.

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KEY WORDS: Cooking, crambe seed, moisture content, screw press.

Screw pressing is experiencing renewed interest as an alternative process to solvent extraction, especially for specialty oils (1). The "organic" segment of the edible-oils industry forbids the use of certain process technologies, especially oil extraction by using petroleum solvents; this effectively leaves screw pressing as the one alternative that is both commercially viable and acceptable to that segment. In the case of new specialty industrial oils, such as oil from the seed of crambe (*Crambe abyssinica*), screw pressing provides a simple means of processing small batches of seed. This aids the commercial establishment of these new oilseed crops.

Screw-press performance with a given oilseed depends on the method of preparing the raw material, which may consist of a number of unit operations, such as cleaning, conditioning, decorticating, cracking, flaking, cooking, extruding, and drying to optimal moisture content. Although some oils are cold-pressed, meaning there is no thermal treatment before or during pressing, cooking before pressing generally improves oil yield. The heating/cooking of oilseeds increases oil yield as a result of the breakdown of oil cells, coagulation of protein, adjustment of moisture content to the optimal value for pressing, and decreased oil viscosity, which allows the oil to flow more readily (2). The heating of flaked, whole crambe seed (6% moisture content) or flaked, dehulled crambe meats (7% moisture content) to 108°C over 11 min, followed by pressing in a lab-scale screw press, resulted in 9 to 10% residual oil in the presscake. Further, in both whole and dehulled seed, prolonged cooking to 122°C did not enhance oil recovery over values obtained by cooking to 108°C (3). In a separate study of bench-scale screw pressing of crambe seed in which cooking time and temperature were precisely controlled, the best performance in terms of low residual oil in the cake was achieved at 10 and 15 min and 100°C; oil loss with the cake was reduced by nearly one-fourth compared with uncooked seed (4). Not all studies showed beneficial effects of cooking or heating; for example, dry preheating had little effect on oil recovery in screw pressing of sunflower seed (5). However, the method of cooking or heating, temperature, time, and seed moisture content are important factors.

The seed moisture content at the time of pressing is another key process variable, as reported by various research workers who used either hydraulic or screw presses with various oilseeds (6–10). The moisture content was reported to be the most important factor affecting cake residual oil content, and 6% moisture was reported to be optimal in hydraulic pressing of sunflower seed (11). Screw pressing of uncooked crambe seed showed that the residual oil content decreased as seed moisture content decreased; low moisture content (5.9%) was particularly important, but further reduction in moisture content (4.1%) was not beneficial and resulted in more sediment in the oil (12). In screw pressing soaked and sun-dried flaxseed, oil recovery increased from 78 to 88% as moisture content increased from 5 to 7%, and thereafter it decreased to 76% at 9% moisture content. One explanation for this trend was that higher moisture content increased plasticity and thereby reduced the level of compression and contributed to poor oil recovery (13). Another explanation was that moisture acted as a lubricant in the barrel; therefore, higher moisture content resulted in insufficient friction during pressing (3). The aforementioned studies typically reported effects of moisture on either cake residual oil or oil recovery, but not on pressing rate and rarely on sediment content of oil.

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Considering the importance of seed cooking and seed moisture content at the time of pressing, a systematic study was deemed necessary to determine the effects of these parameters on pressing characteristics of crambe seed. This information may help processors select the seed moisture level and cooking treatment for optimal screw performance. Seed from crambe was used in this study because of recent efforts by a growers cooperative in the Northern Plains to process this new crop using screw presses (14).

EXPERIMENTAL PROCEDURES

Source of materials. Crambe seed (*C. abyssinica* cv. Meyer) was grown during 1999 at a farming station (North Central Research/Extension Center, ND) of the North Dakota Agricultural Experimental Station. Seed was stored at 4°C with a moisture content of about 9.9% moisture content dry basis (d.b.) and then was brought to room temperature (24°C) before use.

Overview of the process. The process was performed using whole (not dehulled) seed and involved cooking, drying, and pressing. Duplicate samples were cooked, dried, and pressed separately, whereas uncooked samples were directly dried in duplicate to the desired moisture contents.

Description of the cooker system. An aluminum pressure cooker (Model 01570; National Presto Industries, Inc., Eau Claire, WI) having a rated capacity of 16.5 L and equipped with a pressure-relief valve and Bourdon-tube pressure gauge (0 to 140 kPa, gauge) and described previously (4) was modified as follows. A tube (1.6 cm i.d.) for steam injection was passed through the cooker lid at 9.1 cm from the center of the lid; steam flow was directed away from the seed bed and toward the inside face of the cooker wall. A ball valve (1.8 cm diameter) was mounted on the cooker lid at 10.5 cm from the center for quick release of the steam pressure to rapidly cool the seed. A gate valve on the steam line at 1.7 m from the lid was used to turn steam flow on and off. A branch line immediately before this valve permitted steam flow through the line to purge the line of condensate.

Three sieves (ASTM No. 20), each measuring 20 cm in diameter and 5 cm in height, were used as trays to support seed during cooking. The bottom and middle trays were modified to facilitate proper steam flow as follows. Eight 38-mm diameter holes were bored into the side walls of the trays to allow lateral flow of steam into the trays, and the holes were covered with wire mesh. The center-to-center spacing between holes was 70 mm. A portion (15 cm length) of the wall facing the steam inlet was left solid to shield the seed from drops of condensate.

Three type-T thermocouple wires were passed through the lid of the cooker, and the passage point was sealed with silica gel. The thermocouple junctions were coated with a shrink-wrap sealant and positioned to measure the temperature at the center of the seed bed on each tray. Thermocouple voltages were converted to temperature values and logged by a CR10X data logger (Campbell Scientific, Inc., Logan, UT) at 30-s intervals during the cooker operation. The data logger was connected to a personal computer for a real-time display of the temperatures. This aided manual control of the cooker temperature and documented the temperature–time profile inside the cooker.

Operation of cooker. The cooker, containing 500-mL water, was first preheated by using a hot plate (1060 W, maximum) to a gentle boil. Crambe seed (500 g, total) was spread uniformly to a depth of 1.5 cm on the three trays. The trays were stacked atop each other inside the cooker, and the cooker was sealed. Steam was injected into the cooker at the onset of cooking to rapidly boost the temperature to the desired level. Once the cooking temperature was achieved, the steam valve was closed, and the temperature was controlled manually within ± 1°C of the desired cooking temperature using the hot plate, intermittent steam injection, and the cooker pressure-relief valve.

Crambe seed batches were cooked at 100°C for 10 min as suggested in earlier studies on crambe seed (4). The seed was cooled as quickly as possible at the end of cooking by opening the pressure-relief valve of the cooker, removing the cooker lid, and spreading the seed on trays cooled by a fan using ambient air. The seed was stored in polyethylene zipper bags at 4°C for analysis and further processing.

Seed drying. Cooked seed (having 12.4 to 15% d.b. moisture after cooking) and uncooked seed (about 9.9% d.b. moisture) were dried in duplicate to the desired moisture content (3.6, 4.7, 5.4, 6.3, and 7.5% d.b.) in a gravity convection oven (Model 18 EG; Precision Scientific, Inc., Chicago, IL) for 1.5 to 3.5 h at 60°C. The seed was spread on aluminum trays to a depth of 1.5 cm and stirred at 30-min intervals during the course of drying. The final seed weight was calculated from the initial moisture content and weight of seed, and from the desired final moisture content. Thus, seed weight was used as a rapid method for estimating moisture content time-to-time to completion of drying. Samples of final, dried seed were collected for accurate moisture content analysis. These were stored in polyethylene zipper bags at 4°C. In commercial operation, the cooked, dried seed is immediately pressed. However, we cooked and dried all samples first and pressed later, because this was expected to result in better reproducibility and more efficient use of personnel. Results obtained by pressing stored, cooked seed were not significantly different from results obtained by pressing freshly cooked seed (4).

Oil expression. Oil was expressed from seeds with a Komet screw press (Model S 87G; IBG Monforts GmbH 7 CO., Monchengladbach, Germany) with compression screw R8, an 8-mm restriction die, and a screw speed of 20 rpm (4). The screw press was first run for 20 min without seed but with heating *via* an electrical resistance-heating ring attached around the press head, to raise the screw-press barrel temperature to 120°C. A digital thermometer with a type-T thermocouple measured the temperature between the heating ring and the press head. Temperature was thereafter manually controlled at 120 ± 3°C by an on/off switch. Whole, uncooked seed (300 g) was then pressed over a period of 4 to 4.5 min to achieve a steady flow of oil and cake before processing the actual samples. Upon achieving steady operation, duplicate 500-g samples were immediately introduced into the press inlet. Collection of the crude oil and cake was initiated 1 min after sample introduction and stopped when the inlet was empty of the seed. Experience showed that this procedure resulted in good reproducibility between duplicate samples. Sample collection time was determined with a stopwatch. The crude oil and cake were weighed, and the pressing rate was calculated using

$$\text{rate} = (\text{crude oil weight} + \text{cake weight})/\text{time} \qquad [1]$$

The crude oil obtained was analyzed for percentage solids content, and the cake for residual oil content.

Moisture content. The seed moisture content before and after cooking was determined in duplicate on a dry basis by oven drying at 135°C for 2 h (9).

Oil content. The crude oil content was determined on a wet basis by using AACC Method 30-25 (9) with three modifications: (i) the samples were milled in a coffee mill (model CG–1; Melitta, Inc., Cherry Hill, NJ) for 0.5 min prior to the oil extraction, (ii) hexane was used instead of petroleum ether, and (iii) the hexane was removed from the crude oil with a rotary evaporator.

Sediment content of oil. Screw-pressed oil was vacuum filtered over a Buchner funnel using Whatman no. 4 filter paper. The filtered solids were rinsed with 150 mL of hexane and allowed to dry under vacuum. The filter paper was weighed before and after filtering and drying; the dry-solids weight was calculated by the difference. The suspended-solids content was defined as dry-solids weight per weight of unfiltered oil.

Calculations. Oil recovery (OR) was defined as the ratio of oil weight in the product oil to original oil weight in the seed that was pressed. The product oil weights showed poor reproducibility because determining the transition point between successive samples of product oil is subjective. Thus, OR was calculated from Equation 2,

$$\mathrm{OR} = \frac{x_o(x_f - x_m)}{x_f(x_o - x_m)} \qquad [2]$$

where x_m, x_f, and x_o denote oil content of cake, screw press feed, and product oil, respectively (4). Equation 2 was derived from balance equations on total weight and on oil weight. OR was determined readily and reproducibly using this equation together with product cake and oil samples collected at steady-state conditions.

Data analysis. The ANOVA was carried out to test the effect of moisture content on dependent variables. A paired *t*-test was carried out to test the significant difference between cooked and uncooked seed. The data were fitted to a polynomial model to obtain best-fit regression equations. The ANOVA, *t*-test, regression, and calculation of sample standard deviation were performed using Microsoft Excel 97.

RESULTS AND DISCUSSION

OR and cake residual oil. Decreasing moisture content from 9.2 to 3.6% d.b. increased oil recovery from 69.0 to 80.9% and 67.7 to 78.9% for cooked and uncooked seeds, respectively (Fig. 1). The relationships between moisture content and OR may be represented by second-order polynomial equations as given in Table 1.

The relationships were statistically significant ($P \leq 0.01$) for both cooked and uncooked seeds (Table 2). A similar trend was reported for flaked and cooked soybean (in the moisture content range of 8.1 to 13.6% d.b.) (7) and uncooked canola seed (in the moisture content range of 6 to 10% d.b.) (6). However, other reports showed a peak in OR at 7.5% (d.b.) for uncooked flaxseed (in the moisture content range of 5.3 to 12.4% d.b.) (13) and at 11.1% (d.b.) for uncooked rapeseed (in the moisture content range of 5.3 to 12.4% d.b.) (10); recovery decreased with further decrease in moisture content

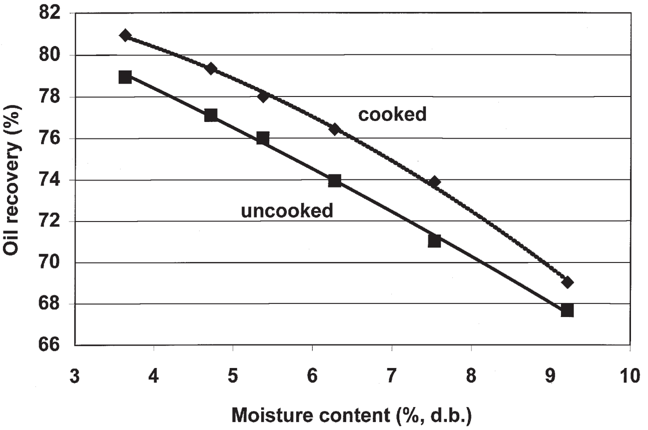

FIG. 1. Relationship between moisture content and oil recovery in screw pressing of cooked and uncooked crambe seed. d.b., dry basis.

TABLE 1
Regression Equations for Oil Recovery (OR), Cake Residual Oil (X_m), Pressing Rate (PR), and Sediment Content (SC) as Functions of Moisture Content (M)

Variables	Equations	Correlation coefficient
Oil recovery		
Cooked	$\mathrm{OR} = 83.46 - 0.1648\,\mathrm{M} - 0.1513\,M^2$	($r^2 = 0.99$)
Uncooked	$\mathrm{OR} = 85.13 - 1.511\,\mathrm{M} - 0.0434\,M^2$	($r^2 = 0.99$)
Cake residual oil		
Cooked	$X_m = 9.936 + 0.092\,M + 0.065\,M^2$	($r^2 = 0.99$)
Uncooked	$X_m = 9.111 - 0.704\,M - 0.0164\,M^2$	($r^2 = 0.99$)
Pressing rate		
Cooked	$\mathrm{PR} = 5.701 - 0.245\,M + 0.0275\,M^2$	($r^2 = 0.97$)
Uncooked	$\mathrm{PR} = 6.154 - 0.402\,M + 0.0425\,M^2$	($r^2 = 0.95$)
Sediment content		
Cooked	$\mathrm{SC} = 16.27 - 2.713\,M - 0.115\,M^2$	($r^2 = 0.96$)
Uncooked	$\mathrm{SC} = 11.82 - 2.259\,M - 0.121\,M^2$	($r^2 = 0.95$)

TABLE 2
Analysis of Variance of Oil Recovery, Cake Residual Oil, Pressing Rate, and Sediment Content[a]

Source	d.f.	Mean square	*F* ratio
Oil recovery			
Cooked	5	37.1	619.2*
Uncooked	5	34.9	603.1*
Cake residual oil			
Cooked	5	7.1	611.6*
Uncooked	5	6.8	615.5*
Pressing rate			
Cooked	5	0.12	16.1*
Uncooked	5	0.23	76.2*
Sediment content			
Cooked	5	13.1	145.2*
Uncooked	5	4.5	13.0*
Error	11	—	—

[a],*Significant at $P < 0.01$, Table value of $F_{5,11,\,0.99} = 5.32$.

in those studies. In the present study, the pressing could not be carried out successfully below a moisture content of 3.6% (d.b.) due to plugging of the screw press; however, the trend suggests that an even higher OR could be achieved at lower moisture content.

Cooking increased OR by 3.6 to 7% relative to uncooked seed, and the difference was significant at $P \leq 0.01$ (Table 3). Although this may appear to be no more than a slight improvement, it represents up to a 10% reduction in the oil that remained in press cake. However, this was a lower benefit than the 6.4% increase in recovery reported previously at 6.3 to 6.6 % d.b. moisture content (4). The difference may be due to improvements in our methods that resulted in more accurate and uniform control of moisture content in the present study, and use of crambe seed from different growing locations and years.

Drying was much more beneficial than cooking in terms of OR for the range of conditions in this study. The design of the screw press also should play an important role in determining the effects of seed moisture content and cooking treatment on pressing characteristics. In the case of crambe seed, cooking is required to inactivate the enzyme myrosinase, thereby resulting in a press cake that is suitable for livestock feed; the improved OR is a secondary benefit.

Increased OR implies decreased cake residual oil, as is seen by comparing Figures 1 and 2. Thus, the residual oil decreased from 16.9 to 11.9% and 16.3 to 11.1% for uncooked and cooked seeds, respectively, as moisture content decreased from 9.2 to 3.6% d.b. (Fig. 2). The relationships between moisture content and residual oil content may be represented by second-order polynomial equations as given in Table 1. The decrease in residual oil with decreased moisture content was significant ($P \leq 0.01$) for cooked and uncooked seeds (Table 2).

TABLE 3
Calculated *t*-Values for Cooked and Uncooked Seeds[a]

Source	d.f.	*t*-value
Oil recovery	5	10.38*
Cake residual oil	5	10.22*
Pressing rate	5	2.44**
Sediment content	5	3.09**

[a]Table value of $t_{5,0.05} = 2.015$ and $t_{5,0.01} = 3.365$. *Significant at $P < 0.01$. **Significant at $P < 0.05$.

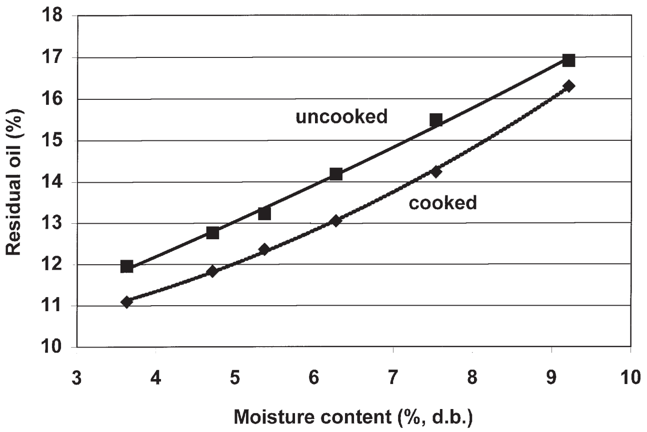

FIG. 2. Relationship between moisture content and cake residual oil in screw pressing of cooked and uncooked crambe seed. See Figure 1 for abbreviation.

Singh *et al.* (11) also observed a trend of decreasing residual oil with decreased moisture content from 14 to 6% in hydraulic pressing of uncooked sunflower seed. This trend might be due to higher frictional resistance offered by low-moisture seed in the barrel during pressing. Hoffmann (15) and Reuber (3) also suggested that lower moisture content of seed increases friction, whereas higher moisture acts as a lubricant during pressing.

The residual oil in cooked seed was 0.9 to 1.3% lower than that of uncooked seed, and this difference was statistically significant ($P \leq 0.01$). This is the expected response, given the results for OR presented earlier and the expected negative correlation between OR and residual oil.

Pressing rate. The pressing rate decreased from 5.81 to 5.17 kg seed/h and 6.09 to 5.19 kg seed/h for cooked and uncooked seeds, respectively, as moisture content decreased from 9.2 to 3.6% d.b. (Fig. 3). These rates were achieved at the lowest available screw-speed setting. There was an initial, steep decrease in pressing rate with decrease in moisture content from 9.21 to 7.53% d.b.; thereafter, the pressing rate was nearly constant with further reduction in moisture content. Bargale and Singh (10) also reported decreased pressing rate with decrease in moisture content (in the range of 5.3 to 12.4% d.b.) in screw pressing of moisture-conditioned rapeseed but observed a peak at 10.1% d.b. in the screw pressing of hot-water-soaked and sun-dried rapeseed in the above-mentioned moisture-content range. However, Blake (6) reported pressing rate increased from 15 to 25 kg/h when moisture content decreased from 10 to 6%. From the above

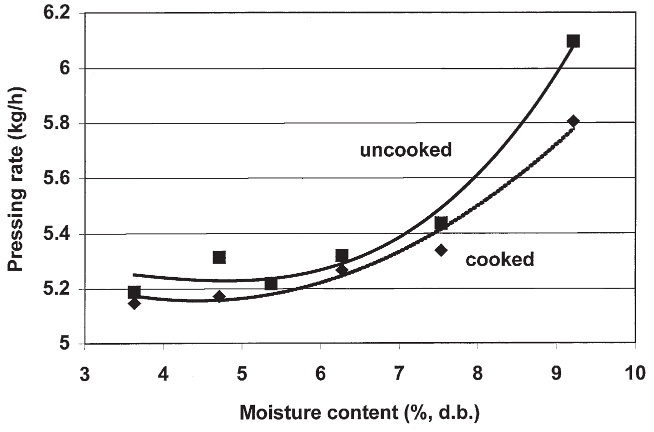

FIG. 3. Relationship between moisture content and pressing rate in screw pressing of cooked and uncooked crambe seed. See Figure 1 for abbreviation.

studies, it seems that the relationship between moisture content and pressing rate varies with method of seed preparation and type of screw press.

The relationships between moisture content and pressing rate were statistically significant at $P \leq 0.05$ in both cases, and may be represented by second-order polynomial equations (Table 1). Moisture apparently behaved like a lubricant that reduced resistance during pressing, resulting in higher pressing rate. The higher pressing rate achieved with the higher-moisture seed implied lower presscake residence time in the barrel, which probably contributed to the reduced OR associated with this moisture content. The pressing rate of uncooked seed was slightly higher than that of cooked seed, and the difference was significant at $P \leq 0.05$ (Table 3). The reason for this difference could be that denatured protein in cooked seed caused higher frictional resistance in the barrel during pressing.

Sediment content. The sediment content dramatically increased from 0.9 to 7.8% and 1.1 to 5.4% for cooked and uncooked seeds, respectively, with a decrease in moisture content from 9.2 to 3.6% d.b. (Fig. 4). The trend is similar to Vargas-Lopez *et al.* (12), who observed increasing sediment content from 2.9 to 4.4% when decreasing moisture content from 12.1 to 4.3% (d.b.) in a study on screw pressing of uncooked crambe seed. These followed polynomial second-order relationships as presented in Table 1.

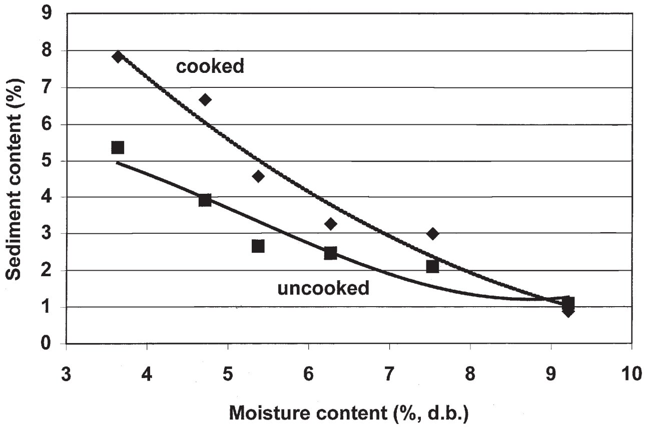

FIG. 4. Relationship between moisture content and sediment content in screw pressing of cooked and uncooked crambe seed. See Figure 1 for abbreviation.

The effect of moisture content on sediment content was significant at $P \leq 0.05$. The sediment content in cooked seed was slightly higher than that of uncooked seed, which depended upon the moisture content. The difference was significant at $P \leq 0.05$ (Table 3). The trends can again be partially explained through frictional resistance; the increased frictional resistance from protein denaturation and decreased moisture results in higher back-pressure (3). High back-pressure apparently diverts more solids to the barrel openings. The visible discharge of presscake through the barrel openings often foretells plugging of the press.

Figures 1 to 3 suggest that lower moisture contents than those used in this study are desirable because the trends point toward higher OR, lower residual oil in the cake, and constant pressing rate at moisture contents less than 3.6% d.b. One might conclude that all that is needed is to apply greater torque to the screw to overcome the plugging that occurred with lower-moisture seed in this study. However, the trend in Figure 4 argues against lower moisture content. Although the sediment can be removed from the oil *via* filtration and recycled to the press to recover the associated oil, this will become impractical at some moisture level, given the trend in Figure 4.

Alternative screw-press designs or seed preparation methods are needed to further improve OR. Commercial processors frequently decorticate seeds before pressing, which increases protein content of the meal, increases oil production rate, and decreases equipment wear. However, the reduced fiber content can reduce the efficiency of oil extraction; thus, decortication should be evaluated in combination with cooking and drying. Also, although oil quality was not a concern with the crambe seed oil in this study, quality is a very important consideration with heat-sensitive edible oils. Increased friction results in mechanical heating of the oil; thus, either oil quality will suffer or the press should be cooled.

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