Cooking Indices to Predict Screw-Press Performance for Crambe Seed

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ABSTRACT: Screw presses offer one means for extracting oil from crambe seed. Crambe seed was steam-cooked at 80 to 112°C for 5 to 20 min, dried to 6% (wet basis), and screw-pressed. Meal residual oil decreased with increased cooking time and temperature to a minimum at 10 to 15 min and 100°C (8.5 to 8.9% oil vs. 11 to 12% in uncooked or lightly cooked seed). More intense cooking increased residual oil to a high of 16% at 20 min and 112°C. The degree of cooking was quantified using indices based on light absorbance at 280 nm (A280 index, a measure of soluble protein) and myrosinase activity for aqueous seed extracts. Regression analysis showed that oil recovery, meal residual oil, and the A280 index were significantly correlated with cooking time and temperature. A plot of residual oil vs. the A280 index showed that this index helps discriminate between under-, over-, and optimally cooked seed. The myrosinase index helped identify undercooked samples but was unable to identify overcooked samples. The optimal A280 index values from this bench-scale study may not be the same in full-scale processes, but this approach can be adapted for tuning such processes.

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KEY WORDS: Cooking, cooking index, crambe seed, screw press.

There is a resurgence of interest in the use of continuous, mechanical screw presses to recover oil from oilseeds. Compared to solvent extraction, screw presses place much lower safety and environmental burdens on the processor (1), require lower initial capital investment, and can be more rapidly switched to handle different feed streams. Screw presses appear to be particularly well-suited for processing niche oilseed crops (2). Niche crops, specialty, or identity-preserved crops are those produced in relatively low quantities but for which customers are willing to pay more because of some desired attribute. Important examples of these crops are new oilseed crops, such as crambe, and oilseeds that are "organically" grown and processed; the use of solvent is not permitted in the latter case. Screw-pressed oil often is higher in quality compared to solvent-extracted oil, as determined by such attributes as higher oxidative stability and lower nonhydratable phospholipids (3).

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Screw presses will not extensively replace solvent extraction in the processing of commodity oilseeds, because screw presses recover a lower proportion of the oil. However, screw presses are finding niches in the oilseed industry, just as the types of oilseeds processed in this way are themselves finding niches. New screw-press-based operations of up to 1000 m t/d have been reported in North America (1).

Screw-press performance with a given oilseed depends upon the preparation of the raw material as well as upon the mechanical design of the worm and barrel of the screw press. Preparation may consist of a number of unit operations, such as cleaning, conditioning, decorticating, cracking, flaking, cooking, extruding, and drying. Although some oils are cold-pressed, meaning there is no thermal treatment before or during pressing, cooking before pressing generally improves oil yield and process capacity. Cooking may also improve pressed oil and/or meal quality by preventing undesirable enzymatic reactions, such as those catalyzed by lipase and myrosinase. On the other hand, excessive cooking seriously reduces the yield of screw-pressed oil (4) and oil quality (5). Thus, there is an optimal range of cooking, a range which probably varies with seed and screw-press design.

Relatively little has been reported on the quantification of cooking-induced changes in oilseeds. Cooking is known to inactivate enzymes and coagulate other proteins, facilitate coalescence of oil droplets, increase plasticity, and cause other changes in oilseeds (6,7). Cooking-induced changes in the amount of water-soluble protein and products of Maillard browning were quantified in soybeans (8). It is likely that a number of changes take place during cooking that are related to cooking time and temperature in accordance with basic kinetic models; those changes that are easily and reproducibly measured might be useful to processors. The main objective of this study was to determine whether certain measures of change are correlated to screw-press performance. If true, they may help processors tune the cooking conditions for optimal screw-press performance. Seed from crambe (*Crambe abyssinica*) 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 (2).

EXPERIMENTAL PROCEDURES

Source of materials. Crambe seed (*C. abyssinica* cv. Meyer) was grown during 1998 at a station (Casselton, ND) of the North

Dakota Agricultural Experimental Station. Seed was stored at 4°C with a moisture content of 9% wet basis (w.b.) and then brought to room temperature (24°C) before use.

Overview of process. The process was performed using whole (not dehulled) seed and involved cooking, drying, and pressing. Duplicate samples were cooked, and each cooked duplicate was divided into duplicate portions that were pressed separately; thus, pressing was replicated four times for each combination of cooking time and temperature.

Description of 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) was modified as follows: A tube (1.6-cm inside diameter) for steam injection was passed through the cooker lid 7 cm from the center of the lid and steam flow was directed away from the seed bed and toward the inside face of the cooker wall. A gate valve on the steam line 0.8 m from the lid was used to turn steam flow on and off. A branch line immediately upstream from this valve permitted steam flow through the line to purge the line of condensate and preheat the line just before cooker operation.

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 3-mm layer of silicon 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 cooker operation. The data logger was connected to a laptop computer (Compaq, Houston, TX; 486DX25 Processor, 8 MB ram and 200 MB hard drive) 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 600 mL water was first preheated by a hot plate (1060 W, maximum) to a gentle boil. Crambe seed (550 to 600 g, total) was spread uniformly to a depth of 2 cm on three wire-mesh trays (18 cm diameter). Trays were stacked at 5-cm intervals 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 in duplicate at 80, 90, 100, 105, and 112°C for 5, 10, 15, and 20 min. The seed was cooled as quickly as possible at the end of cooking by quickly opening the pressure-relief valve of the cooker and then removing the seed and spreading it on trays exposed to room-temperature air. The seed was stored in polyethylene zipper bags at 4°C for analysis and further processing.

Seed drying. Cooked seed initially having 11 to 13% (w.b.) moisture was dried to 5.9 to 6.2% (w.b.) in a gravity convection oven for 1.5 to 3.5 h at 60°C. Seed was spread on aluminum trays to a depth of 1.5 cm and stirred two or three times in the course of drying. Seed moisture was monitored during drying with an infrared moisture analyzer.

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 20 rpm screw speed (9). 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 for 4 to 4.5 min to achieve a steady flow of oil and meal before processing cooked samples. Upon achieving steady operation, duplicate 450-g samples were immediately pressed. The crude oil obtained was analyzed for percentage solids content, and the cake for residual oil content.

Samples were stored less than 10 h between cooking and drying, and 1 to 2 d between drying and pressing, except for the following series of control tests, in which seed was dried and pressed immediately after cooking, to determine whether there was a storage-time effect. This series was performed with the following additional modifications to the above procedure: (i) seeds were cooked only at 5, 10, and 15 min and at 90 and 100°C; (ii) cooked samples were not analyzed for cooking indices; (iii) drying was for 1.5 h at 85°C; and (iv) duplicates were not performed at the cooking step (but were performed at the screw-press step).

Moisture content. The seed moisture content before and after cooking was determined in duplicate on a w.b. by oven drying at 135°C for 2 h (10).

Oil content. The crude oil content was determined in duplicate on a w.b. by using AACC method 30-25 (10) with three modifications: (i) the samples were milled in a coffee mill (model CG – 1; Melitta, Inc., Cherry Hill, NJ) for 1.5 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.

Solids content of oil. Screw-pressed oil was vacuum filtered in duplicate over a Buchner funnel using Whatman no. 4 filter paper. The filtered solids were rinsed with 150 mL of *n*-hexane, dried and weighed. The suspended solids content was defined as dry solids weight per weight of unfiltered oil.

Extract preparation for cooking indicators. Aqueous extracts were prepared from samples of cooked crambe seed for each temperature–time combination, and from uncooked seed, for analysis of cooking indices using a modification of the procedure described by Hsu and Satter (8). Water (150 mL) was blended with 10 g of milled seed sample in a 250-mL beaker for 2 min using a homogenizer (IKA WERK; Janke & Kunkel KG, Staufen, Germany). The solution was held for 5 min at room temperature (24°C), and then 15 mL

was immediately (in less than 15 s) filtered through Whatman no. 4 filter paper for determining myrosinase activity.

The remaining suspension was centrifuged at 13,900 × *g* for 20 min. The supernatant was then filtered through Whatman no. 4 filter paper. The extract was used within 30 min to measure absorbance at 280 nm. These analyses used an HP 8452 A Diode-Array spectrophotometer (Hewlett-Packard Company, Scientific Instruments Division, Palo Alto, CA) with a range of 195–900 nm, and disposable cuvettes having a 1-cm pathlength. Absorbance data were logged on a desktop computer using HP 89532K UV–Visible Kinetics software.

Absorbance value at 280 nm. The extract was diluted 1:25 (vol/vol, extract/water) to measure absorbance at 280 nm (A280). This wavelength is indicative of soluble protein content (11).

Myrosinase activity. Glucose concentration was measured colorimetrically using the Surestep Blood Glucose Monitoring System (Life Scan, Inc., Milpitas, CA) at room temperature, to provide a semiquantitative indication of crambe seed myrosinase activity. Myrosinase releases glucose by hydrolysis of glucosinolates. Two drops of fresh, filtered extract were applied to the test strip, which contained glucose oxidase, peroxidase, naphthalene sulfonic acid salt, and 3-methyl-2-benzothiazolinone hydrazone. The test strip was then inserted into a meter that displayed the glucose concentration in mg/dL within 30 to 45 s. The range of this meter was 0–500 mg/dL. The total time from the onset of blending to obtaining a reading was 8 min.

Calculations. Oil recovery 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, oil recovery (OR) was calculated from:

$$\mathrm{OR} = \frac{x_0(x_f - x_m)}{x_f(x_o - x_m)} \qquad [1]$$

where *x* denotes oil content and subscripts *m*, *f*, and *o* denote meal, screw-press feed, and product oil, respectively. Equation 1 was derived from balance equations on total weight and on oil weight. Oil recovery was readily and reproducibly determined using this equation together with product cake and oil samples collected at steady-state conditions.

Cooking indices were calculated by normalizing indicator values with respect to uncooked seed:

$$\text{cooking index} = \frac{\text{value of indicator for cooked seed}}{\text{value of indicator for uncooked seed}} \qquad [2]$$

Data analysis. Regression and calculation of sample standard deviation were performed using Microsoft Excel 97.

RESULTS AND DISCUSSION

Expression of oil from cooked, whole seed. Cooking reduced the residual oil in screw-pressed meal and increased oil recovery at 90 and 100°C (Table 1 and Fig. 1). The best performance in terms of low residual oil in meal was achieved at 10 and 15 min and 100°C; oil loss to the meal was reduced by nearly one-fourth compared with uncooked seed. Long cooking times and high temperatures (15 to 20 min at 105°C, and 10 to 15 min at 112°C) adversely affected residual oil and recovery and increased sediment in the oil; this poor result may have resulted from reduced plasticity of the seed. The most intense cooking (20 min at 112°C) resulted in the poorest screw-press performance.

TABLE 1
Characteristics of Screw-Pressed Oil and Meal from Cooked Crambe Seed

Temperature (°C)	Time (min)	Residual oil (%)[a,b]	Solids (%)[a]
Not cooked	0	11.0 ± 0.3	2.9 ± 0.09
80	5	12.2 ± 0.6	2.5 ± 0.14
	10	11.4 ± 0.8	2.0 ± 0.10
	15	11.9 ± 2.2	2.4 ± 0.11
	20	12.3 ± 0.2	3.2 ± 0.11
90	5	10.8 ± 0.3	2.3 ± 0.15
	10	10.0 ± 0.4	2.8 ± 0.06
	15	9.6 ± 0.1	2.4 ± 0.09
	20	10.7 ± 0.2	2.8 ± 0.08
100	5	9.2 ± 0.4	2.5 ± 0.07
	10	8.5 ± 0.2	2.7 ± 0.09
	15	8.9 ± 0.1	2.6 ± 0.05
	20	9.6 ± 0.1	2.8 ± 0.06
105	5	10.3 ± 0.2	2.9 ± 0.17
	10	10.2 ± 1.1	3.1 ± 0.05
	15	13.0 ± 0.4	3.5 ± 0.09
	20	14.0 ± 0.2	3.8 ± 0.04
112	5	11.7 ± 0.6	3.3 ± 0.07
	10	13.3 ± 0.4	3.7 ± 0.09
	15	14.6 ± 0.9	5.1 ± 0.04
	20	16.0 ± 0.0	5.6 ± 0.07

[a]Mean values ± standard deviation.
[b]Residual oil is reported on a wet basis.

Oil recovery was a nonlinear function of both *t* (cooking time in min) and *T* (temperature in °C). Thus, oil recoveries (OR in %) were fitted to the following equation:

$$\mathrm{OR} = a + bt(T - 80°\mathrm{C}) + ct(T - 80°\mathrm{C})^2 + dt^2(T - 80°\mathrm{C}) \qquad [3]$$

where *a*, *b*, *c*, and *d* are constants. The values of *a*, *b*, *c*, and *d* were determined by regression to be 72.3, 0.0892, –0.00242, and –0.00175, respectively, and were used to calculate the model values in Figure 1. Respective *P*-values of 3×10^{-22}, 6×10^{-5}, 6×10^{-6}, and 0.006 show a good fit of data to Equation 3. Residual oil contents were fitted to an equation of the same form, resulting in values of 11.6, 9.1×10^{-4}, 6.5×10^{-4}, and –0.033 for *a*, *b*, *c*, and *d,* respectively, and respective *P*-values of 6×10^{-16}, 8×10^{-6}, 0.008, and 8×10^{-5}.

The extraction process used in this study differed from industry practice in several important respects: (i) the cooked seed was not dried and pressed immediately but was stored 1

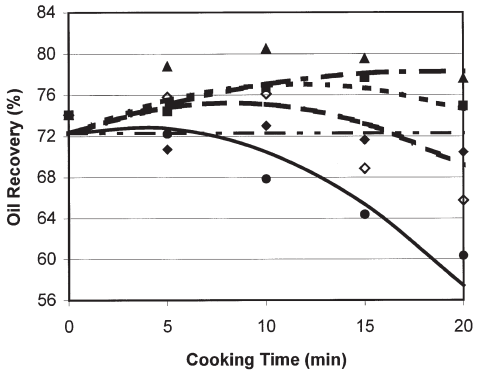

FIG. 1. Mean experimental (points) and model (lines) values (Eq. 3) of oil recovery for crambe seed that was steam-cooked at 80°C (◆, alternating long and two short dashes), 90°C (■, alternating long and short dashes), 100°C (▲, short dashes), 105°C (◇, long dashes), and 112°C (●, solid line) before pressing.

to 2 d; (ii) the seed was neither dehulled nor flaked; and (iii) the screw press was only a bench-scale unit and its design differed from full-size screw presses. A comparison of no storage between cooking and drying–pressing vs. storage for 1 to 2 d between cooking and drying–pressing showed no significant difference (Table 2). Flaking was omitted in this study, because the feed rate of intact crambe seed into the screw press could be made much more uniform. This in turn contributed to the good reproducibility of results that allowed comparison of effects of altering other process conditions.

The small scale on which this study was performed limits the extension of the results to industrial scale. Nevertheless, the bench-scale process provides a suitable opportunity for evaluating the use of cooking indices for crambe seed. Cooking indices are tools for monitoring the degree of cook in preparation for pressing, and thus may be useful for tuning cooker–press processes at both bench and industry scale. This study used only two of many possible indices, namely, the A280 index (as an indication of water-soluble protein) and an index based on myrosinase activity.

The potential usefulness of a cooking index is shown in plots of residual oil vs. the corresponding A280 index value (Fig. 2). "Uncooked seed has, by definition, a cooking index of 1," thus would appear on the right side of Figure 2. The A280 index and residual oil both initially decreased with increased cooking. Further cooking continued to reduce the index value, but as noted, residual oil reached a minimum and then began to rise. Figure 2 shows that values of A280 index in the range of 0.65 to 0.85 corresponded to the best residual oil for the process used in this study, although not all residual oils within this index range were low. Trends in Figure 2 suggest that the pressing of cooked samples having index values above or below this range will always have high residual oil in this process, indicating undercooked and overcooked seeds, respectively. The optimal range would likely change with changes in screw-press operating conditions and may be different in industrial processes.

TABLE 2
Comparison of Residual Oils in Meals Obtained by Pressing Crambe Seed Immediately After Cooking and Drying vs. Seed Stored 1 to 2 d After Cooking

Temperature (°C)	Time (min)	Residual oil (%)[a] no storage	Residual oil (%) 1–2 d storage
90	5	11.1	10.8*[b]
	10	9.0	10.0*
	15	9.8	8.6*
100	5	8.7	9.2*
	10	8.6	8.5*
	15	9.0	8.9*

[a]Residual oil is reported on a wet basis.
[b]Asterisk (*) denotes no significant difference from no storage at 99% level of confidence.

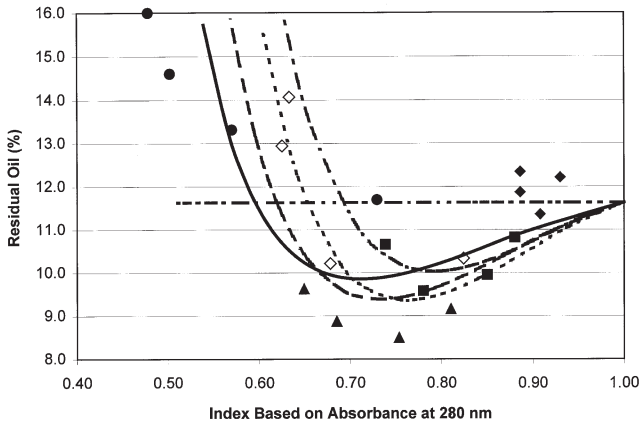

FIG. 2. Relationship between residual oil in screw-pressed meal and A280 index (dimensionless) for crambe seed cooked at 80°C (◆, alternating long and two short dashes), 90°C (■, alternating long and short dashes), 100°C (▲, short dashes), 105°C (◇, long dashes) and 112°C (●, solid line). Points and lines denote mean experimental values and model values (Eq. 4), respectively. SD values for A280 index typically ranged from 0.005 to 0.03. Uncooked seed by definition has an A280 index of 1.

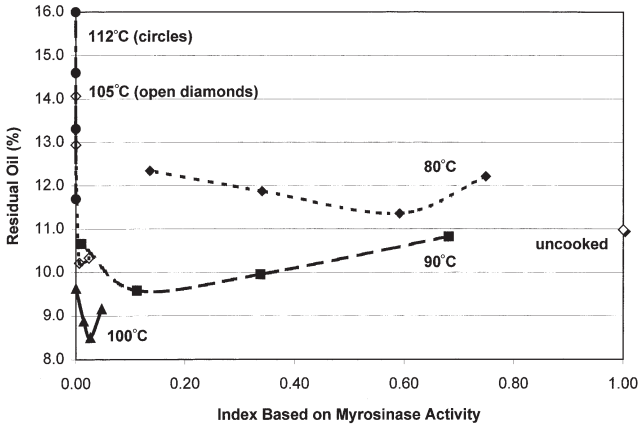

FIG. 3. Relationship between mean residual oil in screw-pressed meal and mean myrosinase index (dimensionless) for crambe seed cooked at different time–temperature combinations. S.D. values for myrosinase index ranged from 0 to 0.05. Smooth trend lines connect data obtained at the same cooking temperature.

A cursory look at the experimental values in Figure 2 suggests considerable scatter at a given index value. However, models show this is not purely random variation, as follows: The model for residual oil was that described earlier. The relationship of the A280 index (I) with cooking time (t) and temperature (T) can be described using a modified first-order kinetic model, similar to models used in thermal processing (12):

$$\log_{10}\left(\frac{I-I_f}{1-I_f}\right) = -(t/D_0)^c \times 10\left[(T-T_o)/z\right] \quad [4]$$

where I_f denotes a limiting A280 index value of 0.40 reached upon extensive cooking; D and z denote the decimal reduction time and thermal resistance constant, respectively; c represents a dimensionless empirical constant; and subscript 0 denotes the standard reference temperature of 121°C used in thermal processing. The values of D_0, z, and c were determined by regression to be 9.6 min, 38.6°C, and 0.90, respectively, with respective P-values of 4×10^{-14}, 6×10^{-12}, and 2×10^{-24}. The curves in Figure 2 are based on these models of the relationships of residual oil and A280 index with time and temperature and show distinct patterns that reflect the same trends as the experimental data.

It was hoped *a priori* that all points in Figure 2 would fall on the same smooth curve with one minimum corresponding to the best time–temperature combination(s). Thus, the minimum at each cooking temperature would occur at the same index value, if this idealized trend held true. But there was actually a different minimum with each temperature, and this observation is consistent with the model. This deviation from the ideal trend does not likely indicate insufficient control of cooking or inaccurate measurement of cooking indices; otherwise, it would not be possible to achieve a good fit of the A280 index data with the kinetic model. Nor does it indicate poor control of the screw-press, because reproducibility of screw press results was generally good (Table 1). Most likely, mechanical characteristics of the seed that influence screw-press performance, such as plasticity, do not change with cooking time and temperature in the same way as the solubility of the protein (the basis of the A280 index).

An alternative cooking index was based on the seed enzyme myrosinase. Active myrosinase can be readily detected by the formation of glucose upon addition of water to ground seed, hence its use in the thermal processing of grains that contain this enzyme (13). The assay used here was semi-quantitative and was intended to be a very simple and rapid but sensitive method. The observed pattern for the myrosinase index was quite different from the A280 index (Fig. 3). All myrosinase index values were zero or low (<0.1), except for seed cooked at 80 and 90°C. The myrosinase index differentiated samples that were undercooked to varying degrees, but was unable to indicate whether any samples were overcooked. Myrosinase was selected among a variety of enzymes that could potentially be used for the purpose of a cooking index. It may be worthwhile to assess the use of other native enzymes as alternative cooking indices. An enzyme that is more heat-stable than myrosinase might allow distinctions to be made between properly cooked and overcooked seed.

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