Continuous Extrusion Cooking of Cottonseed Kernels and of Partially Defatted Meal[1]

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Abstract

Continuous extrusion cooking produces a short time pressure cooking of the material in process. The Wenger extruder-cooker has been successfully applied by others to soybeans for manufacture of full fat flour. This is a report of an investigation of the extruder-cooker applied to glanded cottonseed kernels and to partially defatted cottonseed meal. The purpose was production of cottonseed flour for human food. The principal objective in extruder processing was lowering of free gossypol to 0.12% of protein. On full fat kernels the extruder system was effective in lowering free gossypol. Most of the binding occurred in the preconditioner, and the extruder itself was relatively ineffective in binding gossypol. However the contribution of the extruder was necessary to allow free gossypol levels of 0.12% of protein to be reached. Flaked kernels cooked in this manner and then dried were successfully screwpressed. The extruder system was effective also in binding gossypol in ground, screened (through 30 mesh) meal but not in ground, unscreened meal.

Introduction

Continuous extrusion cooking of full fat soybeans and of mixtures of kernels and oilseed products has been reported by Mustakas et al. (1) and by de Muelenaere and Buzzard (2). A large Wenger extruder, Model No. 50, was used in the former while the latter study employed the smaller Wenger Model X-25 (Wenger Mixer Manufacturing, Sabetha, Kansas).

UNICEF (The United Nations Childrens Fund) was a collaborator in work which led to the successful application of the Wenger extruder to the manufacture of full fat soy flour directly from soybeans (1). This success was the stimulus for experiments with cottonseed to explore the possibility of producing full fat cottonseed flour. UNICEF provided a Wenger extruder X-25 which was installed in the Oilseed Products Research Center.

Reduction of free gossypol in cooked kernels was one of the principal objectives of the cooking experiments. Free gossypol has undesirable physiological effects in nonruminant animals. The United Nations Tentative Quality and Processing Guide for Cottonseed Flour for Human Consumption specifies free gossypol not greater than 0.06% in 50% protein flour (3). This is equivalent to 0.12% of protein which is the way gossypol values are expressed in this report.

Gribbins developed the following equation relating free gossypol reduction to time and temperature effects during cooking of cottonseed kernels (4).

$$1/X - 1/Xo = MT\,10^{(B\theta + A)}$$

In which X equals free gossypol in cooked meats, %; Xo, free gossypol in uncooked meats, %; M, moisture content of kernels during cooking, %; T, time of cooking, minutes; θ, temperature of kernels during cooking, F; and B and A are constants.

Presumably this equation applies to extrusion cooking although the present work did not generate all of the data needed to allow the equation to be evaluated for extrusion cooking. However, it is useful for explanations of some of the results.

Description of Extruder-Cooker

Figure 1 is a schematic diagram which illustrates the features of the X-25 extruder-cooker. It was comprised by a 19½ in. diameter vertical holding bin and preconditioner, a variable speed screw feeder feeding into a 5 in. diameter paddle type mixing conveyor conveying to a horizontal extruder screw which forced the material being processed through holes in a die at the end of the screw.

The vertical holding bin and preconditioner, and the variable speed screw feeder and mixing conveyor were constructed of stainless steel. The extruder was constructed of carbon steel.

The extruder screw was about 5 in. in diameter and 26 in. long from the forward edge of the downspout to the die. The screw housing was steam jacketed. The volume per turn of the extruder screw decreased as it progressed toward the die to give a compression ratio of about 2½ to one.

Live steam could be admitted to the preconditioner at four levels. Live steam and water could be admitted to the mixer. Live steam was metered only by turns on control valves while water was metered with a variable area flowmeter.

Thermocouples for temperature measurement were provided at six locations. These were at three levels in the preconditioner, at two locations in the extruder wall, and in the extruder die for part of the runs. The thermocouples were connected to a 6 point Leeds & Northrup continuous chart recorder.

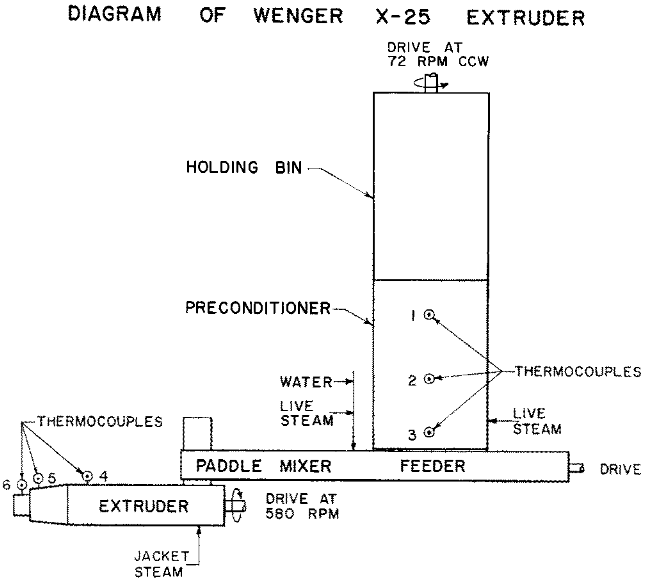

FIG. 1. Schematic diagram illustrating features of the Wenger X-25 extruder-cooker.

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[1] Presented at the AOCS Meeting, San Francisco, April 1969.

Inspection openings ¾ in. in diameter were located in the walls of the preconditioner and holding bin at levels of 13, 26, 33, 46 and 58 in. above the bottom of the preconditioner. These were employed to observe the approximate levels of material inside.

Figure 2 is a photograph of the installation showing the temperature recorder in the foreground, the interior of the holding bin and preconditioner, the mixer downspout and extruder, and the back of the electrical switch panel.

The cooking process in the Wenger extruder-cooker actually occurs in three locations. Live steam is injected into material in the preconditioner to raise the temperature. This also increases the moisture content. Temperature remains about constant in the mixer but moisture may be considerably increased with the addition of live steam and water. Moisture then remains constant in the extruder but temperature is increased.

Considerable pressure, generated by the rotation of the extruder screw, is required to force the material through the die at rapid rates. The work put into the material to force it through the die raises the temperature and pressure just ahead of the die to levels considerably above the temperature at the feed end of the screw. This elevation of temperature and pressure performs the pressure cooking which occurs in the extruder. The temperature is a function of area of die opening, die thickness, space between die and end of screw, oil content and moisture in feed material, through-put rate and perhaps other variables. Temperature can be raised also by using steam pressure in the jackets of the extruder screw. However jacket steam was not used in this work except for preheating before operation was started.

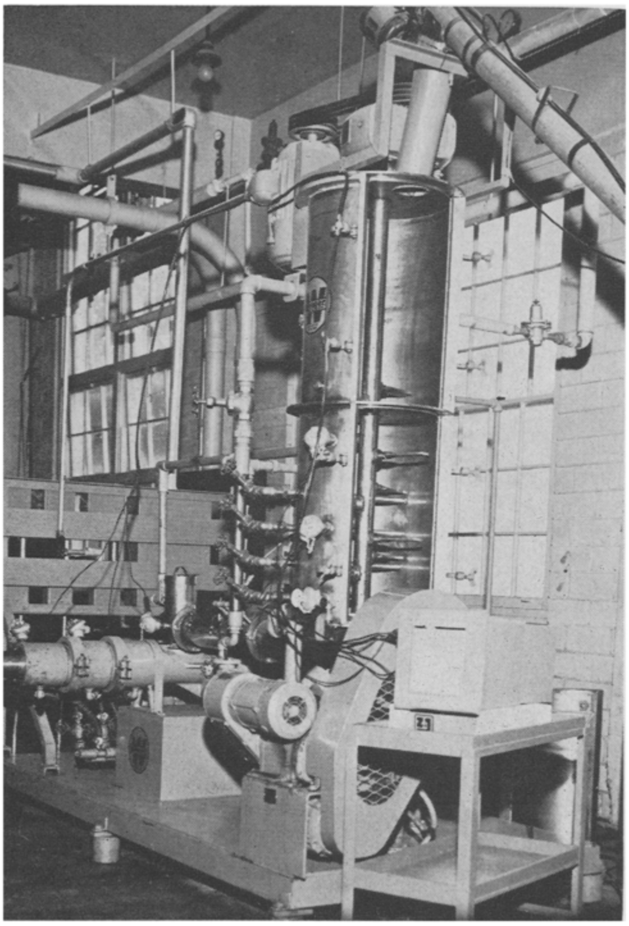


FIG. 2. Installation photograph of extruder.

Experimental Procedures

Materials

Cottonseed kernels from gin-run glanded seed were prepared for cooking by rolling with five high crushing rolls or with flaking rolls to flake thicknesses of about 0.01 in. Moisture in kernels was adjusted 9% to 10%, sufficient for production of good flakes, by water addition to kernels just before rolling or to delinted seed 48 hr before hulling. The kernels after dehulling were low in hulls, but were not hull free.

Total gossypol levels in kernels used in this work ranged from 1.54% to 3.94% of protein and for the runs shown in Table I the range was 2.1% to 2.88%. Free gossypol in kernels to the preconditioner was 96% to 100% of the total.

Partially defatted meal products processed in the Wenger extruder-cooker were commercial hydraulic pressed cottonseed meal, meal from commercial prepress cake and meal from laboratory prepress cake.

Some of these lots of meal were ground and were extruder processed without screening. Others were screened after grinding and only the fractions through a 30 mesh screen were extruder processed. Table II shows the meals used covered a range in oil content from 6% to 25% and free gossypol from 0.20% to 0.88% of protein. Soluble nitrogen was above 69% in all cases.

Analytical Methods

Moisture, oil, free fatty acid and protein were determined by the standard methods of the American Oil Chemists Society (5). Soluble nitrogen (abbreviated as Sol. N.) was determined by Lyman's method (6). Free and total gossypol were assayed by a modification of the AOCS method described by Deacon (7).

Extrusion Cooking

Procedures were generally the same for processing either flaked cottonseed kernels or partially defatted meal.

The vertical holding bin and preconditioner were filled by an inclined screw elevator which received material from a variable speed, hoppered feeder. Before operation of the extruder the preconditioner and bin were filled to a level above the inspection opening at 46 in. During operation the rate of feed of fresh material was adjusted to maintain the level between the 33 and 46 in. openings.

Steam was turned into the extruder jackets for preheating until the extruder was started, at which time the jacket steam was turned off.

With the preconditioner mixer operating, live steam was admitted to the preconditioner at the lowest level. When the temperature at thermocouple 3 reached about 5 F below the desired operating temperature (or usually 215 F) the extruder was started. Live steam or water additions to the mixer or both were then started.

Usually 15 to 30 min of operation were required for adjustments to be made and for equilibrium to be attained before samples were taken.

Results and Discussion

Processing Flaked Kernels

When trial runs were started, we were immediately confronted with two operating problems. The first was a strong tendency for the sticky, wet, flaked kernels to bridge over in the downspout between the mixer and the extruder screw. This was solved by the periodic use of jets of compressed air directed downward which broke the buildup of material and allowed it to fall into the screw.

The second problem was free oil in the extruder discharge which caused the discharge to be fluid, foamy and sloppy. Oil often ran out of piles of extruded pellets and collected in pools in the bottom of pellet containers or on the floor. This condition was difficult to handle experimentally and it would be intolerable in manufacture of a food product.

The possible causes of this condition were considered to be point of water addition to seed or kernels before rolling, type of rolls used, seed lot including free fatty acid level in kernels, amounts of live steam and water added in the extruder mixer. As experimentation proceeded none of these was found to have an apparent effect on foaming except amount of water added in the mixer. Water addition was found to curb foam in most but not all runs where it was used. Often the degree of foaming as well as the incidence could be controlled by merely changing the rate of water addition. Foaming usually did not occur if moisture in kernels entering the extruder was 12% or higher. If moistures were less than 12%, foaming usually occurred.

This problem was never completely eliminated and possibly never could be with the high oil content of about 32% to 35% in most cottonseed kernels. Pellets from runs in which foaming and free oil were not operating problems were still extremely oily, and oil could often be squeezed from them between thumb and fingers until they had cooled and dried.

Mustakas (1) described free oil being expelled during extrusion cooking of full fat soybeans, however the lower oil content of about 18% to 20% in soybeans was completely reabsorbed into the product.

Moistures of materials leaving the preconditioner were not measured. In any future work this should be done and the foamy conditions may be found to be controllable by control of moisture and temperature conditions in the preconditioner.

Figure 3 shows estimated cooking times vs. temperatures in the preconditioner and in the extruder for typical runs. Two conditions are shown for a feed rate of about 700 lb./hr. In one, live steam injection was slow and temperature at TC2 (13 in. above the bottom of the preconditioner) was only about 130 F. In the other, live steam injection was more rapid and temperature at TC2 was about 190 F. Temperatures at the remaining thermocouples were the same for both. These were 220 F at TC3, 3 in. above the preconditioner bottom, 210 F at TC4 in the extruder 11 in. from the die, 240 F at TC5, 1½ in. from the die. Temperature changes were extremely rapid between TC4 and TC6, the latter located in the die itself. The temperature at TC5 was presumably the highest reached during the process. Maximum temperature might be expected to occur in the die, however this was not found to be the case.

The estimated residence times at TC5 and in the die itself were 1 sec and 2×10^{-3} sec.

The curves show very rapid cooling of material occurred in extruded material after it left the die. Cooling was largely by evaporation of moisture which caused concomitant drying.

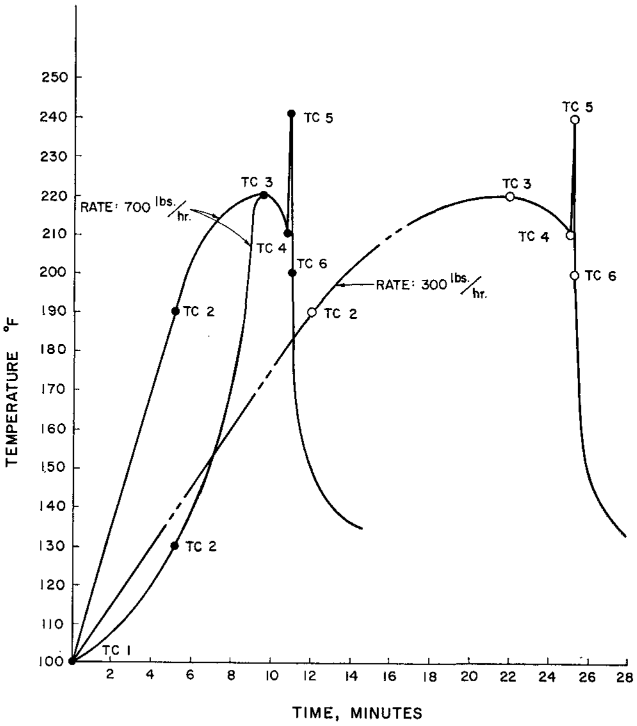
The figure also shows estimated cooking time vs. temperatures for a feed rate of about 300 lb./hr. Cooking time in the preconditioner at this feed rate was considerably longer than for the higher feed rate. Similar curves to those shown were used to estimate cooking times in the preconditioner which are given in Table I. Nearly all runs were made with preconditioner temperatures at TC3 between 215 and 225 F.

The data in Table I are arranged in order of increasing residence time of flaked kernels in the preconditioner with 190 F used arbitrarily as time for beginning of cooking. The data are also arranged in order of increasing moisture in material leaving the mixer. Data for cooking times of 3.6 to 6.6 min were collected at approximate feed rates to the extruder of 700 lb./hr. The remaining data were at feed rates of about 300 lb./hr. All of the data but those on lines 1, 11 and 15 were from a continuous run on one batch of flaked kernels.

The only process variable which could be correlated with decreasing free gossypol in processed kernels was cooking time above 190 F in the preconditioner. The data in Table I show decreasing free gossypol in material from both mixer and extruder.

The data on free gossypol in material from the mixer are too few for a moisture effect to be demonstrated although the data on lines 1–3 and 7 do show some tendency for lowered gossypol at higher moistures.

For free gossypol from the extruder comparison of data on lines 1–4 with lines 5–7 shows a tendency toward decreased gossypol at higher moistures. However comparison of lines 5–7 with lines 8–10 does not show this tendency. Likewise the data on lines 11–14 do not show this tendency although free gossy-



TEMPERATURE VS. TIME IN PRECONDITIONER AND EXTRUDER FOR TYPICAL RUNS AT TWO FEED RATES

FIG. 3. Temperature vs. time in preconditioner and extruder for two feed rates.

TABLE I

Processing Conditions and Analyses of Extruded Kernels

Line No.	Cooking time in precond., min	Moisture leaving mixer, %	Temp. at TC5 F	Free gossypol from mixer, P[a] %	Free gossypol from extruder, P[a] %	Total gossypol P[a] %	Sol. N. from extruder, %
1	3.6	12.9	240	0.49	0.34	2.88	78.0
2	4.3	13.1	250	0.26	0.23	2.64	68.5
3	4.3	15.4	240	0.24	0.24	2.64	60.0
4	4.3	15.7	240	......	0.23	2.64	61.6
5	4.3	20.8	237	......	0.18	2.64	37.8
6	4.3	22.1	238	......	0.14	2.64	40.5
7	4.3	22.1	238	0.22	0.19	2.64	39.5
8	5.3	13.2	247	......	0.17	2.64	70.6
9	5.6	14.6	244	0.24	0.17	2.64	71.3
10	6.6	13.3	250	......	0.14	2.64	70.2
11	12.5	14.7	253	......	0.16	2.84	67.0
12	13.0	17.2	230	0.14	0.11	2.64	61.0
13	17.7	19.3	230	......	0.11	2.64	62.0
14	19.0	15.5	250	0.13	0.10	2.64	67.8
15	22.5	21.0	235	......	0.10	2.10	66.7

[a] Gossypol as per cent of protein.

pol levels here have become so low that not much further improvement is achievable.

Possibly increasing moisture in the preconditioner tends to decrease free gossypol, but increased moisture in the mixer alone may not have the same effect, i.e., when there is not enough retention time for much gossypol binding to occur. Data were collected on mixer moisture when what was needed was preconditioner moisture. Samples were not procured from the preconditioner. In any future work this should be done so that moisture and free gossypol in material leaving the preconditioner can be known, and the gossypol binding occurring in preconditioner, mixer and extruder can be separated.

The table shows that nearly all of the gossypol binding occurred before the extruder was reached. And if a low gossypol was not achieved by the time the extruder was reached, the extruder was unable to lower it much further. Observe that free gossypol from the mixer ranged from 0.49% to 0.13%. However the spread in free gossypol between the mixer and the extruder was about the same throughout the range at an average value of 0.05%. If the extruder were effective in binding gossypol, the spread would have been much greater at the higher free gossypol levels.

The contribution of the extruder to binding, although it was small, nevertheless was necessary to allow the UN guideline level of free gossypol to be reached in extruded material. This level is 0.12% of protein.

Temperatures at TC5 for the data in Table I ranged from 230 to 253 F. They were maintained in this relatively low range in attempts to minimize damage to protein. Perhaps higher temperatures in the preconditioner and extruder should have been tried because, according to Gribbins' equation, free gossypol varies exponentially with temperature. Temperature effects were indeterminate in this work.

Table I shows that at short cooking times in the preconditioner, high moisture in the extruder appeared to result in low soluble nitrogen. However, at longer preconditioner cooking times soluble nitrogen was about the same in all samples even though moisture in the extruder ranged between 14.7% and 21.0%.

The tentative conclusions from processing flaked kernels in the Wenger extruder-cooker are that most of the gossypol binding occurs in the preconditioner, and the extruder itself is relatively ineffective in binding gossypol. However the contribution of the extruder is necessary to allow free gossypol levels of 0.12% of protein be reached. This investigation was terminated before all questions were answered. For future work, experiments should be carefully designed to separate the effects of moisture, time and temperature in the preconditioner, the mixer and the extruder. Statistically designed experiments would be desirable which would provide estimations of experimental error and statistical significance.

Screw Pressing Extruded Meats

Pellets from one Wenger extruder run were allowed to cool and were stored in a bin for a week. Then they were warmed in a stack cooker to about 160 F before they were fed to an Anderson No. 1 screw press. The press operated very well on this material although the meats were more oily than from other extruder runs. Oil content of cake averaged 6.7%. This demonstrated the Wenger machine could be used to cook meats for screw pressing.

For continuous operation, equipment should be provided to dry and reheat pellets or else to maintain temperature while drying extruded pellets before they were fed to the screw press.

No advantage is seen for extrusion cooking over conventional cooking for screw pressing, however unusual circumstances might sometimes make extrusion cooking desirable at some location.

Processing Partially Defatted Meal

All processing was conducted with cooking periods of 15 min or more in the preconditioner. Every run was conducted over ranges of moistures and temperatures in the extruder because these were the variables which were considered to be important.

Variations in moisture and temperature had no apparent effect. As shown in the summary in Table II, free gossypol was high in all samples from a given run when meal was not screened and it was low in all samples when meal was screened. Screening was the only variable showing a definite effect on free gossypol.

An interpretation of this result is that residual gossypol in meal is not difficult to bind if particles are small enough for moisture to penetrate to their interiors.

This finding is in agreement with Olcott (8) who stated that moist heat is more effective in binding free gossypol in cottonseed meal if the meal particles are small.

Not enough data were secured on free gossypol content of materials leaving the mixer or preconditioner to allow determination to be made of whether gossypol binding occurred principally in the preconditioner, mixer or extruder. In future work sam-

TABLE II

Analyses of Partially Defatted Meal and Extruded Products

Feed to preconditioner					Products			
		Gossypol			Free gossypol		Soluble N	
Screened through 30 mesh	Oil %	Free P[a] %	Total P[a] %	Sol. N. %	Mixer P[a] %	Extruder P[a] %	Mixer %	Extruder %
No	6.0	0.26	3.19	69.0	0.20	0.16	58	34
No	20.1	0.20	1.91	80.1	......	0.13	....	71
No	20.1	0.40	1.80	80.4	......	0.14	....	69
Yes	9.5	0.66	1.72	74.1	......	0.05	....	37
Yes	8.7	0.20	1.81	73.0	0.17	0.09	71	39
Yes	16.1	0.88	1.75	90.1	......	0.08	....	59
Yes	25.0	0.60	1.96	94.7	0.09	0.07	77	72

[a] Gossypol values expressed as per cent of protein.

ples should be taken after passage through each of these three cooking zones to evaluate the effectiveness of each.

When operating the extruder on kernels, samples could be obtained from the preconditioner by collecting material from the mixer while water and steam to the mixer were shut off. On meal, this procedure would probably cause the extruder die to become plugged unless provision were made to feed some high oil content material to the extruder while the preconditioner or mixer was being sampled.

Soluble nitrogen in extruded material increased approximately linearly with increase in oil content. No other variable had any apparent effect. Thus soluble nitrogen apparently was influenced only by oil content.

The only difficulty in processing meal was fluctuating temperatures at thermocouple 5 when oil content of meal was below 16%. On flaked kernels, or on high oil content meal, the recorder usually printed a nearly straight line for TC5. On lower oil contents the temperature continually fluctuated about 5 to 10 F.

ACKNOWLEDGMENTS

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