pilot plant experiments were considered in releasing varieties C.P. 44-154 and N.Co. 310 for commercial sugar production, after their productivity and agronomic qualities had been shown to be satisfactory by field testing. The processing data also contributed to the decision to discontinue further field testing of variety C.P. 45-184.

Summary

The clarification of six new varieties and of the widely grown commercial variety used as standard has been studied on a pilot plant scale to obtain information on the suitability of the new canes for commercial use. The results were considered, together with agronomic and other qualities, in releasing two new varieties for large scale planting and in discontinuing further field tests of a variety that yields juice that cannot be clarified efficiently.

Although the scale of operation is only $^1/_{200}$ that of an average Louisiana factory, effective clarification can be carried out continuously under conditions duplicating those of the large scale operation. Accurate control of operating conditions makes it possible to duplicate results on cane of the same variety and quality with reasonable accuracy. Sufficient numbers of individual experiments were carried out with each variety to yield average results that are significant in determining the important differences to be anticipated in the commercial clarification of juices from these canes.

The most important variable studied was the total quantity of clarifier discharge, which ranged from about 130 to over 190 pounds per ton for the best and the poorest cane varieties tested, respectively. A general relationship has been observed between the clarities of the juices and quantities of precipitate; better clarities are obtained in processing the varieties that yield larger quantities of more voluminous clarifier discharge. Increased quantities of precipitate are compensated to some extent by higher filtration rates as determined by laboratory filtration tests.

Methods developed in this research are applicable to the evaluation of new varieties in any areas in which the composition of the sugar-cane crop is being altered continually by the breeding and introduction of improved canes, and will be extended to the study of other sugar-cane processing operations.

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FISH PROCESSING

Expression of Oil from Dried Fish Meal

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Expression of oil from fatty fish has been a process of commercial importance for more than a century. The most common process, generally referred to as wet reduction (*2, 4, 24*), employs the wet press which separates the cooked fish into two fractions, press cake and press liquor. The press cake is dried and marketed as fish meal, whereas the press liquor is separated into two fractions, oil and stickwater. The fish oil is used for various industrial purposes. The stickwater is usually discarded, although in some instances in the United States it is concentrated and marketed as condensed fish solubles.

The wet-press method is well suited for large scale continuous operation and the production of fish oil, but there are disadvantages inherent in this process. The loss of water-soluble solids to the stickwater may amount to 20% of the dry weight of the fish (*13, 22*). Stickwater, when concentrated to 50% solids, is used as a vitamin supplement in animal and poultry feeding and is an excellent source of B vitamins and minerals. Its nutritive quality has been thoroughly investigated by Lassen and associates (*17, 18*), Deas and Tarr (*10, 11*), workers of the U. S. Fish and Wildlife Service (*7–9*), and those of Herring Oil and Herring Meal Industry's Research Institute in Bergen, Norway. Bakken (*3*) has demonstrated that stickwater contains 40 to 60% of the vitamins of the fish.

Fish meal and fish solubles are used extensively in the feeding of domestic animals and have been found especially valuable as a supplement in poultry feed. Discovery of vitamin B_{12} and other recent growth factors has been of special interest to fish meal manufacturers, as fish meal and fish solubles are good sources.

Realization of the high nutritive value of the stickwater as well as lowered demand for marine oils during recent years has enhanced the interest in recovering the stickwater solids. Concentration of stickwater is practiced to some extent, mostly using the Sharples Lassen process (*24*). However, feeders prefer to obtain stickwater nutrient included in the meal, and in some Norwegian plants the stickwater is returned to the press cake after wet-pressing of the fish to produce what is known as "whole meal." Einarsson (*6, 13*) has developed a method involving evaporation of water from the whole fish and subsequent solvent extraction of the oil. Levin and Lerman (*19*) and Smith (*23*) report a solvent extraction process known as the VioBin process.

Dry rendering is commonly used for the reduction of nonfatty fish. The wet press is eliminated and there is no stickwater; hence essentially all the constituents of the fish occur in the meal, with the exception of water. Anderson, Harrison, and Pottinger (*1*) investigated this method in 1935. The percentage of oil in the meal is approximately four times that of the original fish. Thus, in the case of oily or medium oily fish it becomes essential to lower the oil content of the

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This work was done to investigate a process of removing oil from fatty fish meal which would not cause gross loss of stickwater soluble nutrients, as the wet-press method does, and would not involve costs of evaporation. The process consists of drying to 5 to 9% moisture, followed by pressing out the oil to about 6% oil content. The work was done on a laboratory scale with several varieties of fish. The efficiency of oil removal was found to be a function of several variables: temperature; dwell time; pressure, providing the piston is large enough to minimize wall effects; age of the dried meal; original oil content; and final moisture content. Empirical equations, principally based upon measurements on turbot (*Atheresthes stomias*) meal, permit the prediction of press efficiency in removing oil. The mathematical relationships in these experiments may be compared with those published for vegetable oil pressing. Oil expressed from dried fish had a lower free fatty acid content than that remaining in the press cake.

meal by solvent extraction or by expression.

Expression as a unit operation is a special case of filtration, but is used for mixtures which are too thick to flow readily and is accomplished by compression under conditions that permit the liquid to escape while the solid is retained between the compressing surfaces (*21*). The general equilibrium conditions have been studied by Gurnham and Mason (*14*).

Most actual cases in the vegetable and fish-oil industries do not involve equilibrium conditions, and most experimental work has been with particular material without general application. Koo (*16*) has developed an empirical formula for the expression of vegetable oils.

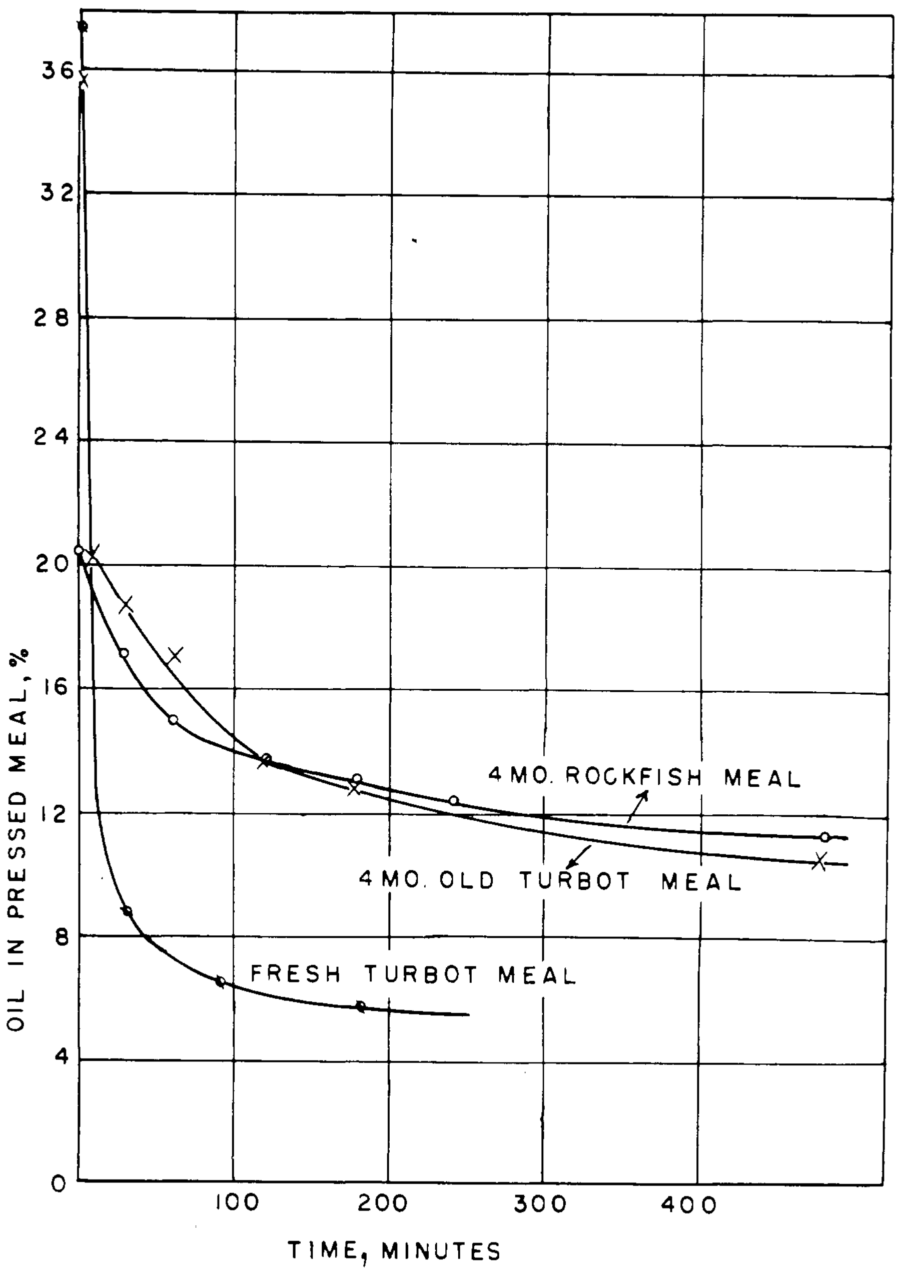
The object of this work (*12*) was to investigate oil removal from fish meal by expression in a hydraulic press, and to study some of the variables which govern the efficiency of oil removal.

Experimental Work

A Carver laboratory press (*5*) was employed for pressing the dried fish meals. The press was capable of producing a hydraulic pressure of 16,000 pounds per square inch, obtained by a hand-operated oil pump. The pressing surface was 6 × 6 inches. Electric hot plates, 6 × 6 inches, were provided for heating, and were equipped with thermostatic temperature controls. Thermometers were located in holes in the hot plates. Standard press cylinders from the Fred S. Carver Co. (*5*) were used for confining the meal samples. A 2.25 inch cylinder was used for the major part of the trials, but a few experiments were carried out in $1^1/_8$-inch and 3.5-inch cylinders.

Preparation Of Samples Various types of fish meals were pressed, some produced in the laboratory in pilot plant equipment, and others

Figure 1. Effect of pressure dwell-time upon per cent of oil remaining in dried fish meal



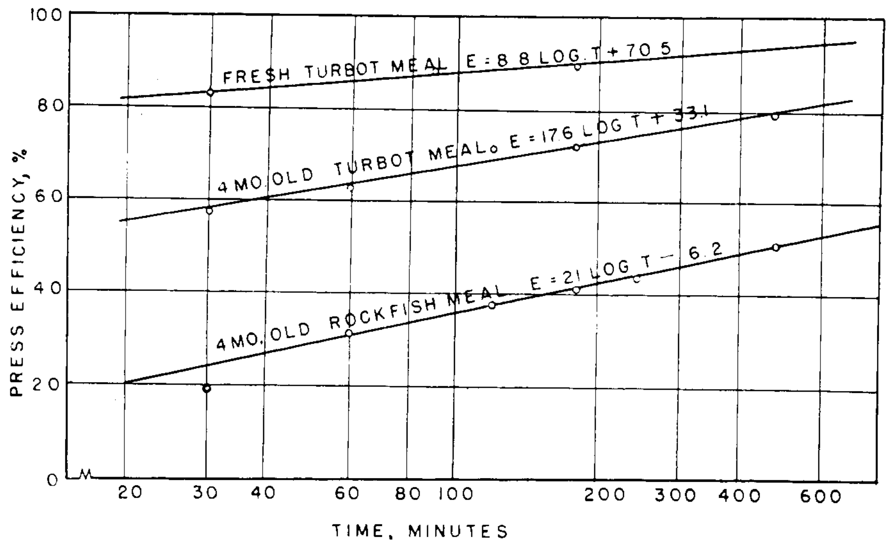


Figure 2. Effect of pressure dwell time upon per cent press efficiency

Semilog graph. Obtained from the same primary data as Figure 1.

obtained from commercial fish meal plants. Most of the fish meals used were dried in the laboratory using a pilot plant double-drum dryer. The drums were heated on the inside with steam at a pressure of 80 pounds per square inch (*12*).

Detailed runs were made with meal from whole turbot (*Atheresthes stomias*). The fish was finely ground and then dried on the double-drum dryer. The dry meal (referred to below as fresh turbot meal), which came off the dryer in flakes, was run through a disintegrator, put into cans, vacuum sealed, and stored at 0° C. until pressed. A few expression runs were made using meal that had been stored at room temperature for 4 months (referred to below as 4-months-old meal). Among other fish meals used for the experiment were meals from rockfish (*Sebastodes* sp.) and dover sole (*Microstomus pacificus*), which were both dried on the double-drum dryer; shad (*Alosa sapidissima*), dried on a small rotary vacuum dryer; and commercially manufactured meals, including scrap meal from tuna and bottom fish, shad and bottom fish, and sucker (*Mytocheilus caurinus*).

Expression The effects of the various conditions were tested by varying one factor at a time. For most of the work 50 grams of meal were pressed in the 2.25-inch cylinder. In a few special cases, different sample sizes and cylinders were used as indicated below.

The pressed meal was analyzed for oil using a slightly modified method of the Vitamin Oil Producers Institute (*25*), the difference being that after three extractions with 30 ml. in a mortar, the residue was transferred to a Waring Blendor and the extractions were continued with 30 ml. of the petroleum ether (Skellysolve F).

All moisture determinations were made by the vacuum oven method, the weight loss being taken as water.

Free fatty acids (FFA) were determined and computed as oleic acid, using a modified method of the American Oil Chemists' Society (*20*). Since the quantity of oil available in each case was much smaller than suggested in the above method, a 5-ml. microburet was used for

Table I. Effect of Temperature on Efficiency of Oil Expression from Turbot Meal

Temp., ° C.	*Pressed Meal, % Oil*	*Efficiency of Oil Removal, %*	*Viscosity of Oil, Centipoises*
30	9.76	84.1	30.5
35	8.00	85.6	25.2
56	6.61	88.3	11.8
79	5.92	89.5	6.0
102	5.46	90.3	3.9
124	5.24	90.0	2.9

Initial oil 37.5%; pressed 3 hours; pressure 1500 lb./sq. inch; 4-square-inch press cylinder.

Table II. Effect of Meal Age on Efficiency of Oil Expression from Turbot Meal

Run	*Age of Meal, Days at 0° C.*	*Pressed Meal, % Oil*	*Efficiency of Oil Removal, %*
I[a]	4	5.41	90.4
	13	5.92	89.5
	27	6.45	88.4
II[b]	4 months at room temp.	12.9	72.4

Pressure 1500 lb./sq. inch; sample 50 grams; 4-square-inch press cylinder; temperature 78° C.; pressed 3 hours.

[a] Oil 37.5%; water 8.6%. [b] Oil 35.7%; water 8.3%.

Table III. Expression of Oil from Various Types of Fish Meals

Pressure, Lb./Sq. Inch	*Dryer*	*Type of Meal*	*Original Moisture, %*	*Oil, % Original meal*	*Oil, % Pressed meal*	*Efficiency of Oil Removal, %*
3000	Double drum	Turbot fresh	8.6	37.5	6.36	88.6
		Rockfish 4 mo. old	7.9	20.4	13.1	40.7
		Dover sole fresh	9.1	24.6	6.92	77.2
	Vacuum	Vacuum-dried shad	5.3	20.6	5.27	78.5
3000	Double drum	Turbot fresh	8.6	37.5	5.41	90.4
		Turbot 4 mo. old	8.3	35.7	12.9	72.4
		Rockfish 4 mo. old	7.9	20.4	12.9	42.3
1500	Commercial	Tuna and bottom fish *a*	6.74	8.03	4.70	43.4
		Tuna and bottom fish *b*	6.57	8.27	4.58	46.8
		Shad and bottom fish	5.79	12.54	5.67	58.1
		Sucker	7.56	13.6	12.72	7.24

Pressing time 3 hours; temperature 78° C.; 4-sq.-inch press cylinder.

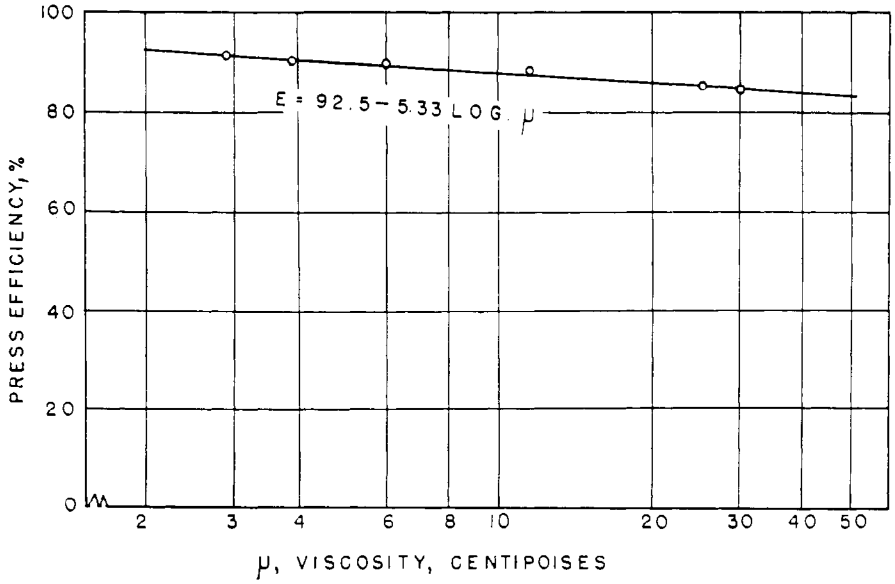


Figure 3. Effect of viscosity of constituent fish oil (function of temperature) upon per cent press efficiency

See Table I.

titration to minimize the error. Thymolphthalein was used as indicator as it was impossible to see the color of phenolphthalein in the reddish fish oil. All titrations were carried out in an atmosphere of nitrogen.

The viscosity of the fish oil was determined by a Stormer viscometer. A 60% sucrose solution was used as a standard. Viscosity data for the sucrose solution were obtained from the "Handbook of Chemistry and Physics" (*15*).

Press Efficiency

The term "press efficiency" or "efficiency of oil removal" is defined as the per cent of the original oil which is removed by the press:

$$E = \frac{\frac{F_0}{100 - F_0} - \frac{F_1}{100 - F_1}}{\frac{F_0}{100 - F_0}} \times 100 \qquad (1)$$

where E is per cent press efficiency, F_0 is per cent oil in the meal prior to pressing, and F_1 is per cent oil in the meal after pressing.

Typical Data

Indicating the effect of various factors on the efficiency of oil removal, typical data are shown in accompanying tables and figures.

Figure 1 shows the effect of dwell time in terms of oil remaining in the pressed meal, while Figure 2 shows the same data in terms of press efficiency.

The effect of dwell time (time of applied pressure) appears to follow an equation of the following kind:

$$E = a_1 \log T + b_1 \qquad (2)$$

where E is the per cent press efficiency, T is the dwell time, and a_1 and b_1 are constants depending on the type of meal and its condition.

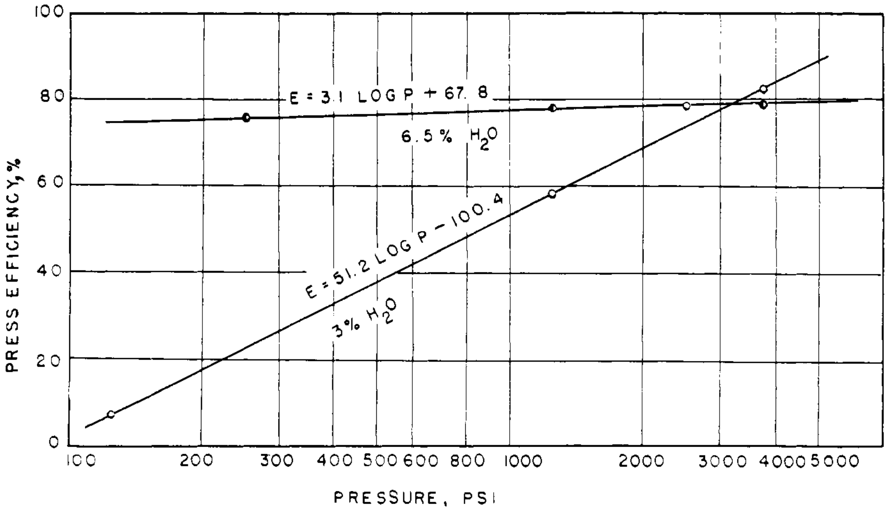
The effect of temperature on the press efficiency was more conveniently expressed in terms of oil viscosity and appears to follow an equation as follows (Figure 3 and Table I):

$$E = b_2 - a_2 \log \mu \qquad (3)$$

where μ is the absolute oil viscosity.

In experiments with pressure, it appeared at first that increased pressure did not result in increased press efficiency. A hypothesis that the high pressure was applied too quickly, thus building up a dense presscake at an earlier stage and restricting the flow of oil, was tested and rejected. The factor seemed not to be the critical one.

Figure 4. Effect of magnitude of pressure upon per cent press efficiencies, at two moisture levels



The possibility was considered that the narrow (2.25 inches in diameter) and solid press cylinder restricted the flow of oil out of the meal. Such a wall effect was mentioned by Gurnham and Mason (*14*). When the larger press cylinder 3.5 inches in diameter, was used to test this hypothesis, higher pressure did result in increased press efficiency. The cylinder size was definitely found to be a factor for these laboratory scale experiments.

Moisture content of the meal is a factor in efficiency of oil removal, particularly at low moisture content and low pressure, as is well illustrated in Figures 4 and 5. Figure 4 also shows that the effect of pressure on efficiency can be empirically expressed as

$$E = a_3 \log P + b_3 \qquad (4)$$

where P is pressure in pounds per square inch gage.

Equations 2 to 4 are empirical equations applying for only a rather narrow experimental range. Thus 100% efficiency is never reached and when any of the above variables (time, pressure, etc.) is zero, the efficiency is zero and not that indicated by Equations 2 to 4.

As the meal aged, it became considerably more difficult to express the oil from it, even when stored under vacuum in a sealed container at 0° C. (Table II). This was even more obvious in the case of meal stored at room temperature with access to air.

The results of pressing various types of fish meals are summarized in Table III. Most of the laboratory-prepared meals as well as the commercial meals yielded good results when the meal was fresh. The lowest value obtained was 4.6% oil in the residual meal in the case of commercial meal from tuna and bottom fish.

Free Fatty Acids

The residual oil in the meal was higher in free fatty acid content than the expelled oil, as shown in Table IV. The expelled oil had a mean value of 4.99% free fatty acids as oleic and the residual oil 5.85%,

Table IV. Free Fatty Acid Content of Turbot Oil[a]

FFA in Expelled Oil, %	FFA of Oil Left in Meal, %
...	5.33
5.26	6.39
4.89	6.39
4.31	5.90
5.43	5.27
4.95	5.97
4.75	5.96
5.37	5.59
Mean[b] 4.99	5.85

[a] From freshly dried meal, pressed at 78° C. for 2 hours in 9.6-sq.-inch cylinder. Oil in original meal, 32.4%. FFA of oil, 5.35%.
[b] Significant difference at 1% level.

the difference being statistically significant at the 1% level. Thus, the expressed oil was well below the 6% limit for good grade industrial oil (*16, 21*). There was no measureable increase in free fatty acids during pressing for 3 hours at 78° C.

Conclusions

Oil may be expressed from freshly dried fish meal prepared from fatty fish to yield a fish meal that has an oil content of less than 6%.

A definite relationship exists between the time of applied pressure and the efficiency of oil removal.

Increased temperature results in greater yields of oil.

Increased pressure results in increased oil yield if the press cylinder is large enough to minimize wall effects.

For good results fish meal should not be pressed when the water content is below 5%.

The older the meal, the less the efficiency of oil removal.

Oil expressed from meal is lower in free fatty acids than the residual oil.

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Figure 5. Relationship between original moisture content of turbot meal and resultant per cent of oil remaining in press cakes

This shows an optimum moisture content of not less than about 5% for maximum press efficiency.