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Critical Unit Operations of the Aqueous Processing of Fresh Coconuts[1]

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ABSTRACT

An aqueous process was investigated for the recovery of oil and food grade protein from fresh coconuts. Efficient recovery of oil, which is very important for economical reasons, was related to three critical unit operations: separation of oil from the fiber, destabilization of an oil-in-water emulsion, and recovery of a protein product that is low in oil content. The material balance is reported for a laboratory process that satisfactorily separates oil and breaks the emulsion, and data are shown which has led to a process for recovery of a protein with low oil content.

INTRODUCTION

In the Food Protein Research and Development Center at Texas A&M University, work is in progress on the recovery of oil and food grade protein concentrate from the coconut. We are considering two general approaches to the problem. The first is a conventional processing similar to that currently used for soybeans: the coconut meats are dried and the oil extracted with hexane. The hexane is subsequently distilled from the oil. Protein is separated from the defatted coconut meal by the normal protein isolation procedure: extraction at high pH, followed by precipitation at low pH (1).

Another approach, with which this work is concerned, is the aqueous processing of the coconut. The characteristic feature of aqueous processing is that the coconuts are not subjected to preliminary drying. The fresh coconut meats are ground while still wet, with optional addition of water to facilitate grinding, and the oil and protein are recovered from the resulting emulsion. Various schemes for the aqueous processing of coconuts have been proposed (2). The flow diagram presented in Figure 1 is general enough to incorporate most variations for the aqueous processing of fresh coconuts.

The first step in the process is the grinding of the coconut meats, which results in a slurry of fibrous particles in a milky emulsion. Upon subsequent filtration to remove the suspended solids, the oil and protein are observed to stay in the liquid phase, even though only 30% of the protein is dissolved. The undissolved protein stays with the liquid phase because it is acting as an emulsifying agent for the oil globules, which are small enough to pass through the openings in the filter.

The oil-in-water emulsion, commonly called coconut milk, is centrifuged next, with three phases resulting: the light and heavy liquid phases, and the solids. The composition of the light liquid phase depends on the intensity of centrifugation. Under the very intense centrifugation, as is used by Timmins (unpublished results, 1970) the light phase may be clear oil. Under the conditions of most aqueous processing methods, the light phase is a "cream," which contains a high concentration of protein-emulsified oil globules. The cream-like phase must be demulsified to make possible the separation of clear oil from a solids phase containing the protein. The heavy liquid phase consists of water and water-soluble material, and comprises ca. 90% of the total volume of the system. The third phase consists of undissolved solids that are more dense than the aqueous phase. These solids consist of the fiber that survived the filtration operation, together with precipitates formed after the filtration. It should be pointed out that insofar as the centrifugation demulsifies, it forms precipitate, because the protein removed from the oil globules is not dissolved.

A study of the literature has led to the recognition of two elusive goals in the development of an aqueous processing of coconuts. They are: first, the control of conditions so that the protein survives the processing without becoming irreversibly denatured, and so that the oil is recovered in good condition; and secondly, the recovery of at least 95% of the oil. In order to achieve these goals the critical operations seem to be extraction of oil from the fibrous residue, demulsification, and recovery of a protein that does not bind an excessive amount of oil.

Reported processes for the aqueous processing of coconuts apparently fail to achieve these goals. For example in the Krauss-Maffeti process (2,3) the demulsification was accomplished by heating, which irreversibly denatured the

[1]Presented at the 162nd National Meeting of the American Chemical Society.

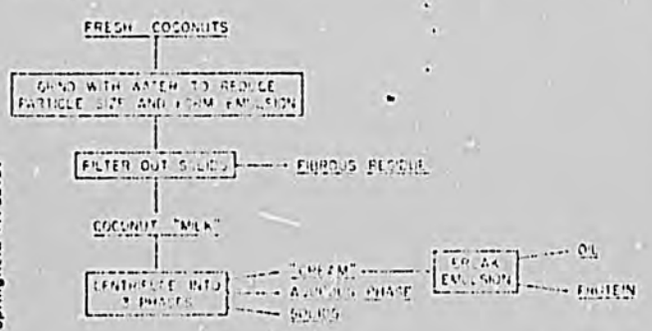

FIG. 1. General procedure for the aqueous processing of fresh coconuts.

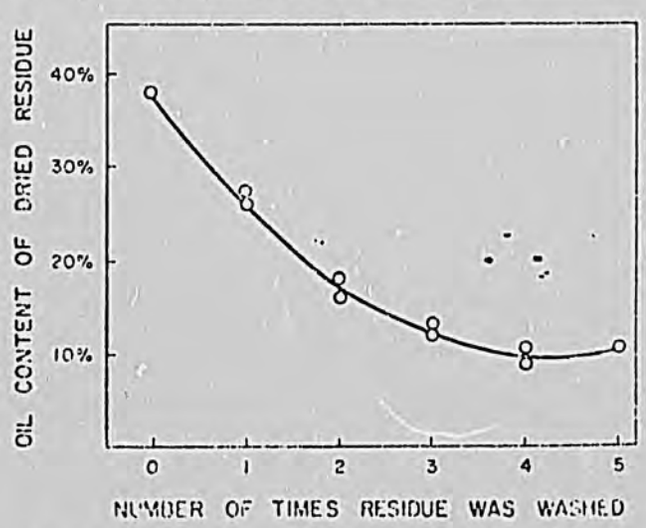

FIG. 2. Removal of oil from residue by repeated washing with water.

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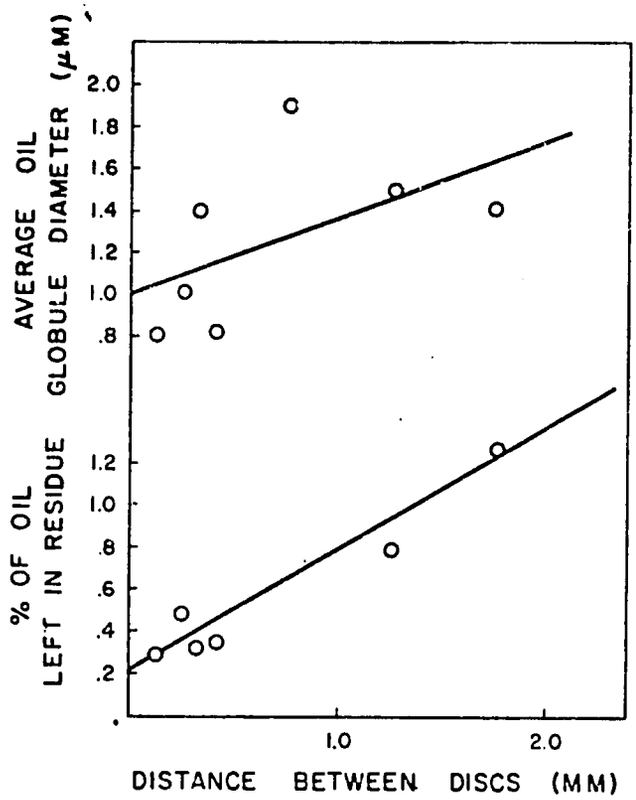

FIG. 3. Effect of disc spacing in Bauer Mill on oil globule size and oil retention of residue.

protein. Furthermore ca. 14% of the oil remained with the residue and ca. 7% with the protein.

Other works on wet processing of coconuts is currently in progress at the Tropical Products Institute in London. The data reported by Timmins (unpublished), indicate that their residue holds ca. 8% of the oil, and that 5-10% of the oil remains with the protein.

METHODS AND EQUIPMENT

Batch centrifugation was performed in the laboratory with a Sorvall Model RC2-B Centrifuge, with a swinging bucket rotor. Centrifugation was at 9000 x g at 30 C, for 10 min. Continuous centrifugation was accomplished with a Westfalia disc type centrifuge (Model SA7-06-476), at 55 C, at a flow rate of approximately 100 gal/hr. Wet coconut was ground with a cutting mill (Urschel Laboratories, Comitrol 3600) with cutting spaces of 0.25 mm, followed by milling with water in a disc attrition mill (The Bauer Bros. Co.), normally with a disc spacing of 0.3 mm.

Filtration was accomplished in the laboratory by hand squeezing the ground coconut with water through three layers of cheesecloth. Standard methods were used for the determination of oil, moisture and protein (as nitrogen).

Oil globules were photographed at 440 magnification, and the globule diameter measured in the resulting photographs. Average globule sizes were calculated exactly as one calculates a weight-average molecular weight.

GRINDING

The first critical step in the processing is the wet milling of the coconut. The primary purpose of the grinding is the breakdown of the fibrous meat of the coconut, in order to increase the efficiency of extraction of the oil and protein. However the grinding also has the very important effect of forming a protein stabilized oil-in-water emulsion. Excessive grinding favors cell rupture and removal of oil from the fiber; however it also produces smaller oil globules which

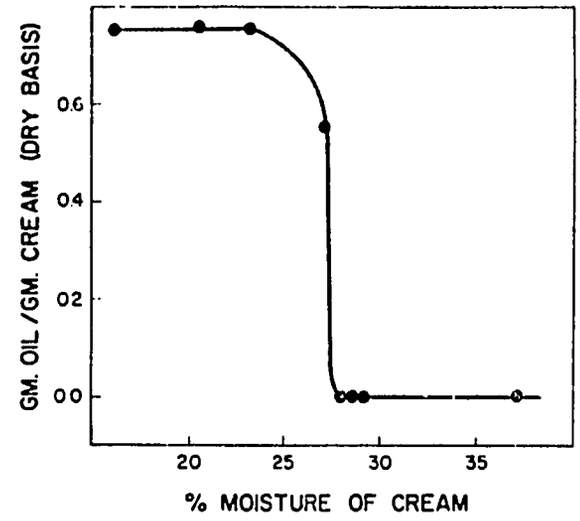

FIG. 4. Effect of moisture content of cream on its inversion by shear, at pH 4.0.

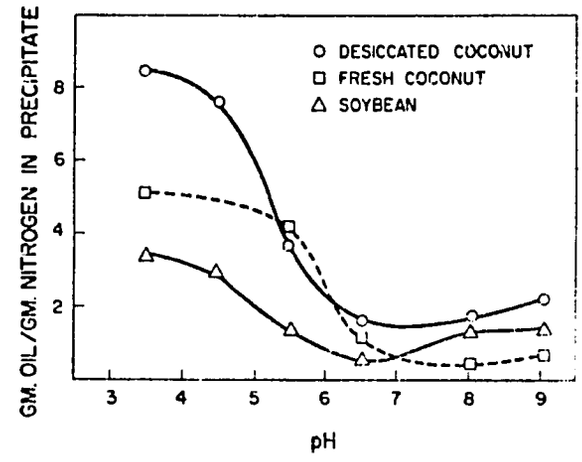

FIG. 5. Effect of pH on ratio of oil and nitrogen in solids obtained when milk is centrifuged.

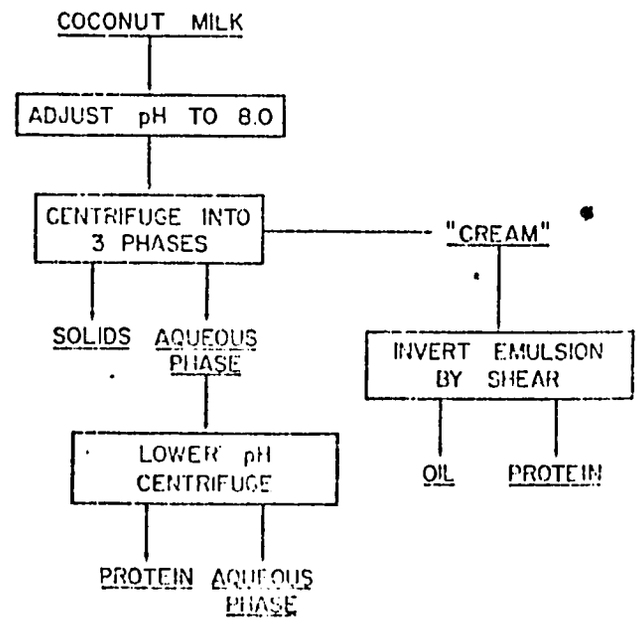

FIG. 6 Modified aqueous processing for recovery of less oil protein from fresh coconuts.

TABLE I

Laboratory Scale Material Balance for the Aqueous Processing of Coconuts at pH 4.0

Material	Dry weight, g	Weight oil, g	Weight protein, g (N x 5.3)
Fibrous residue (washed 3 times)	75	15	1.6
Aqueous phase	45	2	2.1
Solids	7	2.9	2.6
Cream	370	339	21
Oil from cream	306	306	0
Protein from cream	60	30	21
Starting material (1000 kg fresh coconut meats)	550	385	32

makes demulsification more difficult. Insufficient grinding, on the other hand, results in intolerable losses of oil in the residue.

In order to evaluate methods of grinding the coconut, a very simple experiment was conducted. The ground coconut was squeezed through cheesecloth; then the residue was gently mixed with water and squeezed again, and the washing repeated. The idea was that this washing would not break any more cells than were broken in the grinding operation, and therefore allow us to determine the amount of oil present in unbroken cells. Fresh coconut meat was ground in a blender for the experiment reported in Figure 2. The results show that the oil is gradually washed out with successive washes, with two washes being adequate to remove almost all the oil not in unbroken cells. These data, combined with microscopic examination of the wet residue, indicate that oil globules cling to the coconut residue and that washing is an effective method for recovering them. Incomplete removal of these oil globules may be partly responsible for the failure of other workers to efficiently extract oil from the residue.

In order to investigate optimum grinding, coconut-water mixtures were ground in the Bauer mill with varying distances between the grinding surfaces. Fibrous solids were filtered out with cheesecloth and washed three times with water. The resulting average oil globule size was determined for each grinder setting. The results are shown in Figure 3. The disc spacing was varied from 0.1-1.8 mm. The lines were drawn by least squares analysis of the data, and indicate that as the disc spacing increases the globule size increases, and more oil is left in the residue.

It was considered necessary that somewhat less than 5% of the oil remain with the fibrous residue. The data in Figure 3 show that grinding, which conditions the coconut so that less than 5% of the oil remains with the residue, forms oil globules about 10 μm in diameter. An emulsion with oil globules of this size should be expected to be quite stable. To use another protein-stabilized emulsion for comparison, we note that the average globule size of fresh cow's milk is about 10 μm (4). These experiments suggest that a relatively stable emulsion is the price one must pay for efficient wet-extraction of oil from the fresh coconut.

CENTRIFUGATION OF THE COCONUT MILK

Fresh coconut was ground in the Urschel Mill, then in the Bauer Mill with 0.3 mm disc spacing. These grinding conditions leave 4% of the oil in the residue, as evaluated by washing and squeezing through the cheesecloth. It was decided to adjust the coconut milk to pH 4.0 (from its unadjusted value of 6.5), because at this pH the emulsion is reported to be less stable (5). The coconut milk was batch centrifuged, resulting in three phases: solids, aqueous phase and cream. The compositions of these phases are reported in Table I, where each result is the average of at least two experiments.

Note that most of the oil and protein were centrifuged into the cream phase, which contains 66% of the protein and 88% of the oil. The appearance of so much protein in the cream phase results from the fact that the centrifugation step did not efficiently demulsify the milk. The data also show that the aqueous phase at pH 4.0 is very low in both protein and oil. Also only a small amount solid phase was obtained, which was about 42% oil.

A similar experiment was carried out on a large scale with a disc type continuous centrifuge. Here however the results were quite different, with only 14% of the protein appearing in the cream phase instead of the 66% reported for the batch centrifugation. With the disc centrifuge there was much more protein in the solids, indicating that the disc centrifuge was a more effective demulsifier. However in both types of centrifuge the oil content of the solids was rather high, about 40%, which suggests that centrifugation of the coconut milk under these conditions necessarily results in an oily protein precipitate.

EMULSION BREAKAGE

A method was needed for separating the emulsion into clear oil, aqueous phase and solids phase. A criterion for the method is that it avoid irreversibly denaturing the protein, and as always the method must be economically feasible.

The method investigated most thoroughly was the inversion of the emulsion by shear, first suggested by Sugarman (6). The idea is to first concentrate the oil globules of the emulsion into a cream by centrifugation, and then to convert the cream into a water-in-oil emulsion by agitation violent enough to break the globules. Subsequent centrifugation separates the continuous phase, which is the oil, from the wet protein precipitate.

The data in Figure 4 show that the use of shear is effective in inverting the coconut emulsion if the water content is below about 28% at pH 4.0. Normally when coconut milk was adjusted to pH 4.0 and centrifuged, the resulting cream layer was about 30% moisture, and agitation of the cream did not invert the emulsion. Therefore it was necessary to reduce further the moisture content of the cream. This reduction in moisture content was accomplished by adding coconut oil to the system before agitating. After agitating and inverting the emulsion, the added oil was recovered together with the original oil that was in the emulsion. Table I indicates the amount of oil and protein recovered from emulsion inversion on the laboratory scale aqueous processing.

One of the problems with the procedure is that the protein precipitate is quite oily. The oil content could only be reduced to 40% with quite severe agitation (3 min agitation at 50 C with a high speed on a blender). An advantage of the method is that the protein recovered was not irreversibly denatured, as judged from the fact that 70% was dissolved at pH 8.0.

There are two products of the pH 4.0 aqueous processing that are high enough in protein content to warrant consideration as food protein. They are the solids obtained when the milk is centrifuged and the solids obtained when the demulsified cream phase is centrifuged; both were 40-45% oil. Although the relative amounts of the two products were different for batch and continuous centrifugation, in both cases about 9% of the oil was retained with the protein solids. That 9% of the total oil represents a loss of marketable oil, which is the principal product of coconut processing from the consideration of economics. Therefore other processing methods were considered.

PROCESSING AT pH 8.0

Oil binding of coconut protein was investigated in an attempt to produce a protein with low oil content. Milk

was prepared by blending coconut or soybean with water and filtering through cheesecloth to remove the solids. The pH values were adjusted, the milky emulsions centrifuged, and the nitrogen and oil contents of the precipitates measured. Figure 5 shows the results. Note that coconut protein binds oil considerably better in the isoelectric pH range, i.e., at pH near 4.0. Soybean protein, shown for comparison, has a similar property. It is not known how the residual oil is bound to the protein; however part of the oil can be removed by rinsing with water, which suggests that part of the oil is bound to the protein as oil globules.

Based on our knowledge of the pH dependence of oil binding, we modified our processing scheme to that shown in Figure 6. The centrifugation of coconut milk is now done at pH 8.0 instead of pH 4.0. This modification was designed to reduce the oil content of the precipitated protein. We expected the protein obtained upon centrifugation of the milk to be low in oil because, as Figure 5 showed, the protein binds less oil at pH 8.0. We further anticipated that the protein precipitated from the aqueous phase would be low in oil, because there is little oil available in the aqueous phase to bind to the protein. As anticipated the results indicate that the protein obtained when the milk is centrifuged at pH 8.0, and that precipitate formed when the aqueous phase is adjusted to low pH, only have about 20% oil. An unexpected result was that the cream phase only contained about 3% of the total protein (for pilot plant centrifugation), as contrasted to 14% observed for identical centrifugation at pH 4.0.

It was decided to determine a material balance for the processing at pH 8.0 on a pilot plant scale, rather than a laboratory scale. We went to the larger scale because on that scale we could use a desludging, continuous-feed centrifuge. As indicated in this report, a continuous centrifuge results in considerably less protein in the cream phase. Consequently a significant effect on the material balance was observed.

The design of the pilot plant equipment, the material balance for processing at pH 8.0 on that scale, and an analysis of the products are under active investigation and will be reported on at a later date.

ACKNOWLEDGMENT

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