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FINAL REPORT

on

THE DEVELOPMENT AND TESTING OF A COCONUT CHEESE PRODUCTION TECHNOLOGY

UNIDO Contract No. 91/105/VK
UNIDO Project No. US/RAS/90/132
UNIDO Activity Code: J13106
(TEES Project No. 32534-30720 FP)

Submitted by

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to

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September 1995

EXECUTIVE SUMMARY

1. Background

Coconut protein is of relatively good nutritional quality but its use as food has been limited due mainly to its extremely small amount in the nut and the difficulty of extracting and recovering it. This study was therefore undertaken to determine if the extraction and recovery of coconut protein can be improved and if new food products can be developed utilizing the recovered coconut protein as one of the main ingredients.

Successful development of new coconut protein extraction and recovery techniques and new coconut protein-based food products will bring substantial economic benefits to the coconut-growing countries by enabling them to produce not only one but two basic types of valuable products from coconuts for food uses -- the traditional product, coconut oil, and the new product, coconut protein. Traditionally, the majority of coconut protein has been consumed in the form of coconut milk, both full fat and defatted (or skimmed). While coconut milk has enjoyed wide acceptance among the people in coconut-producing countries, it has not been practical to use coconut milk as a commercial food product or ingredient because of the severe limitations inherent to all dilute liquid-type products, i.e., extremely large volume to handle, relatively low protein concentration, and poor shelf stability and palatability. Nevertheless, there have been some indications in published reports that coconut protein could be used, along with coconut fat, to prepare highly acceptable and relatively inexpensive new types of dairy-like foods.

2. Objectives

The overall objective of this study was to develop technologies that can be used to produce cheese-like products from coconuts. To accomplish this objective, a series of specific tasks were to be carried out in two phases.

The first phase consisted of a detailed literature review to assess the current status of the technology, laboratory testing of a selected number of published methods to determine if any of the methods would merit for further evaluation, and to define new production technologies for preparing various types of dairy-like products. The second phase dealt with pilot plant operations, identification of process equipment and market acceptance tests.

3. Literature Review

A comprehensive literature search has been conducted on cheese-like products made from coconut milk utilizing global computer database systems which included Knowledge Index (Agribusiness, Agricola, Cab Abstracts, Food Science and Technology Abstracts and Biotechnology Abstracts) and BRS (Patent Data. Agricultural, Biological and Environmental Sciences, Engineering Technology and Applied Sciences).

Most of the published articles and patents dealt with the use of coconut oil as a substitute for butterfat in the manufacture of various types of cheese-like products, such as "Cadtri", "Kesong Puti", "Queso de Ajo", blue cheese and a few different types of soft cheeses. Some of these products were quite acceptable and coconut oil was the major source of fat. However, in all cases, skim milk powder (mostly in the form of reconstituted skim milk) was the major source of protein, and information regarding the use of coconut milk and/or dry coconut protein as the major source of protein for preparation of cheese-like products was not available.

4. Experimental

In order to utilize coconut protein as the major source of protein in preparing coconut-based cheese-like products, the investigation has been focused on two areas: extraction and recovery of coconut protein and product development. Maximum extraction and recovery of protein was considered the single most important critical task facing the project because of the extremely low protein content of coconuts as opposed to the very high oil content.

A wide spectrum of known techniques was therefore examined to maximize protein extraction and recovery. As a first step, various process conditions, such as type of salt, salt concentration, pH, temperature, extraction time and method, were optimized to increase the extractability of the protein from grated fresh coconut meats. These extraction studies were then followed by the development of methods for maximum recovery of the extracted protein. It is well known that a considerable amount of the extracted protein cannot be recovered as products by conventional protein recovery techniques. Also, a series of experiments were conducted to optimize conditions for separation of coconut oil so that both protein and oil can be separated and recovered simultaneously.

The product development part of the investigation concentrated on two distinctively different types of products -- tofu-type and cheese-like products. In both cases, coconut protein was the major source of protein. As necessary, soy and milk proteins were also used to learn the tofu and cheese making techniques and to compare the quality of the resulting products.

Finally, a selected number of final products were evaluated through a limited consumer acceptance test to determine the response of general public toward the new types of coconut protein food products.

5. Results

The optimum extraction of coconut protein was achieved by using 0.5-1.0 M NaCl solution at pH 7-8 and 35-55°C. Acceptable tofu-type products were produced from coconut milk with a maximum yield of about 50% without adding other proteins. Textural properties of the final products differed considerably depending on the manner the starting coconut milk was prepared and the method of protein coagulation. Tofu-type products were produced from various types of coconut milks, but the products from defatted (skimmed) coconut milk were firmer than those from full-fat coconut milk. Calcium sulfate produced firmer products than other coagulants tested.

Cheese-like products can be produced from coconut protein concentrate, as reported in Interim report II, but it is rather expensive to produce. Therefore, in order to reduce the amount of coconut protein concentrate, fresh coconut milk or UF concentrated coconut milk was used as a partial source of protein and oil along with coconut protein concentrate. Products were also made by replacing a portion of coconut protein concentrate with various amounts of Na-caseinate or non-fat dry milk. Cheese-like products made entirely from coconut milk had a cream cheese texture. Cheese-like products prepared from formulas consisting of more than 60% coconut protein concentrate had a hardness similar to sharp Cheddar. All analog cheeses displayed unique characteristics, i.e., high adhesiveness, no fracturability and no melting properties.

Toward the end of the project, another alternative method of producing cheese-like products was tested based on the suggestions made by the consultant. This involved the use of wet coconut protein curd (tofu-like product) prepared from fresh defatted or concentrated coconut milk along with hydrocolloid such as guar gum. Cheese-like products containing 6-7% guar gum had a texture similar to sharp Cheddar. All guar gum containing products displayed certain unique characteristics, i.e., stickiness, no adhesiveness, no fracturability and high springiness.

A selected number of tofu-type and cheese-like products were produced at the Department of Food Science and Technology, Kasetsart University, Bangkok, Thailand for a limited consumer response test. A few minor modifications were made to the formulations and processes as needed to accommodate the local capability.

The preliminary test received mixed reactions -- flavor and texture were acceptable but the products were too salty. Once the protein extraction procedure was modified to reduce the saltiness of the products, the response became favorable. Cheeese-like products received an overall acceptance rating of 5.1-5.6 (hedonic scale of 1-9). Tofu-type products received an overall acceptance rating of 4.1, with such comments as "too bland" or "tasteless".

6. Conclusions and Recommendations

Technologically sound processes have been developed and optimized to produce acceptable cheese-like and tofu-type products with a wide range of protein and fat contents and texture. However, economic merit of these processes has to be addressed more carefully due mainly to the extremely low protein content in comparison to the extremely high fat content of coconut meats. Even under the best conditions, only about one half of the protein present in the coconut meat can be recovered as usable products and a very large volume of process water has to be dealt with. Because of these reasons, economics of producing cheese-like and/or tofu-type products does not seem favorable if these products were to be considered the major products from coconuts. If, however, these products were to be considered byproducts (coconut fat being the major product), then the economic merit of the newly developed processes and products becomes brighter.

It is therefore recommended to consider adding the tofu-type and cheese-like product lines as a part of the existing coconut oil extraction plant rather than a free-standing facility. This approach will eliminate large sums of initial capital investment on equipment that can be shared with the oil extraction process.

FORWARD

This contract research was officially signed by United Nations Industrial Development Organization and Texas Engineering Experiment Station on July 16, 1991; however, the actual research began in October due to difficulties in securing a local merchant who could supply fresh coconuts on a regular schedule.

At one time or another, the following individuals were involved in various aspects of the research and development work.

Dr. K. C. Rhee, Principal Investigator

Dr. S. H. Kim, Research Associate

Dr. C. H. Kim, Research Associate

Ms. S. Hall, Technician II

Mr. D. H. Bae, Graduate Research Assistant

Mr. K. S. Kwon, Graduate Research Assistant

Mr. L. R. Watkins, Research Engineer

Mr. C. Vavra, Research Engineer

Student Workers

In addition, Mr. J. L. Middleton, Vice President, Olympia Cheese Company has served as a resource person (or consultant) at no cost to the project.

Also, Dr. S. Sringam, Associate Professor of Food Science and Technology, Kasetsart University, Bangkok, Thailand has served as a subcontractor for the Consumer Response Testing portion of the project, with the assistance of her colleagues and graduate students. Dr. Sringam also served as a National Expert on the project.

ABSTRACT

This project was undertaken with the aim of developing new technologies needed for producing food products, specifically cheese-like products, utilizing coconut protein as well as oil. Efficient extraction and recovery of coconut protein was considered the single most important factor which will determine the outcome of this new endeavor due to the fact that the mature coconuts contain only about 4% protein. Therefore, new procedures have been developed and optimized to maximize the extraction and recovery of the protein. This was followed by the development of procedures to prepare new food products using the recovered coconut protein as the major ingredient for protein. As a result, a series of acceptable tofu-type and cheese-like products were formulated as judged by the texture analysis and the limited consumer response tests. However, even under the best conditions, only about one half of the protein present in the coconut meat can be recovered as usable products and a very large volume of process water has to be dealt with. Because of these reasons, economics of producing cheese-like and/or tofu-type products does not seem favorable if the protein were to be considered the major product from coconuts. However, if the protein were to be considered a byproduct (coconut fat being the major product), then the economic merit of the newly developed processes and products becomes brighter.

It is therefore recommended to consider adding the tofu-type and cheese-like product lines as a part of the existing coconut oil extraction plant rather than a free-standing facility. This approach will eliminate large sums of initial capital investment on equipment that can be shared with the oil extraction process.

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I. INTRODUCTION

Coconut production and processing have been the predominant economic activities in rural communities in many tropical regions of Southeast Asia and the South Pacific. Traditionally, production of coconut oil from copra (dehydrated coconut meat) has been the largest economic sector of the coconut industry. Although copra contains proteins of reasonably good nutritional quality, its use as food has been limited for various reasons -- lipid oxidation and microbial contamination due to the high temperature and unsanitary conditions during drying and storage. High crude fiber content and poor protein recovery as a result of the low protein content of the nut and poor protein extractability are the other limiting factors. Although many coconut-producing countries are in dire need of additional food proteins, most of the potentially valuable coconut proteins have thus far been wasted because of these problems.

This study was undertaken to determine if the recovery of coconut protein can be improved and if new food products can be developed using the recovered protein for the purpose of expanding their uses, minimizing waste of the potentially valuable indigenous protein source and reducing importation of other protein ingredients into the coconut-producing countries. In most coconut-producing countries, the current capacity for local production of cow's milk is very small and the majority of milk and other dairy products are manufactured from imported milk. Over the years, the importation of extremely large quantities of milk to satisfy the consumer demands for milk and other dairy products has been the source of genuine concern for the governments, processors and consumers alike because the imported milk is expensive and it drains large sums of foreign exchange reserves. It is therefore regarded urgent and timely to develop dairy-type products from less expensive alternative sources of indigenous raw materials, such as coconuts, to extend the locally produced milk and to develop new dairy foods with minimum use of the imported dairy ingredients.

Among other products, the modern coconut industry is capable of producing two basic types of valuable products from coconuts for food uses: the traditional coconut oil and the newer coconut protein. Traditionally, the majority of coconut protein is recovered and used in the form of coconut milk, both full fat and defatted (or skimmed). While coconut milk has enjoyed wide acceptance among the people in coconut-producing countries, it has not been practical to use coconut milk as a commercial food product or an ingredient because of the severe limitations inherent to all dilute liquid-type products, i.e., extremely large volume to handle, extremely low protein concentration, poor shelf stability, and palatability. However, there have been some indications in published reports that coconut protein could be used, along with coconut fat, to prepare highly acceptable and relatively inexpensive new types of dairy-like foods such as custard-like products, various types of cheeses (soft, Cheddar and Blue cheeses), yogurt and drinks.

II. OBJECTIVES

The ultimate goal of this contract research was to study the feasibility of developing new technologies that can be used to produce food products (cheese-like) from coconuts. To accomplish this goal, the following activities were outlined in the contract:

Phase One: Literature review, raw materials studies and laboratory tests and experiments

a. The conduction of a comprehensive literature review worldwide using inter-connected computer systems;

b. The evaluation of the literature review combined with laboratory tests and process verifications;

c. The outline of the work to be carried out with the aim to develop and define a suitable coconut "cheese" production technology;

d. The conduction of the required laboratory experimentation and testing work;

e. The biochemical and microbiological definition of the final products, their quality criteria and the methods to be used for quality control activities;

f. The definition of the production technology for practical application in the pilot plant production and testing phase to follow;

Phase Two: Pilot plant operations, equipment specifications and market acceptance tests

g. Based on research report No. 1 the required experimental technical pilot equipment is to be arranged;

h. The experimental technical pilot operations are to be carried out and the coconut "cheese" production technology as outlined in research report No. 2 will either be confirmed or suitably amended and improved. As a result of this work, the following activities will be performed;

I. Definition of the final coconut "cheese" production technology;

j. Develop process specifications for possible industrial scale operations;

k. Production of adequate quantities of coconut "cheese" for market and consumer acceptance tests;

l. Conduction of market and consumer acceptance tests in selected countries/areas.

III. SCOPE OF WORK

The scope of this contract work was limited to the activities outlined in the "Objectives" above. Also, this contract work was not intended to obtain detailed information necessary for designing a production plant. Although much of the information generated from this project can be used for such purposes, additional information will be needed to ensure proper design and operation of an economically viable full-scale production plant.

IV. LITERATURE REVIEW

A comprehensive literature search has been conducted on cheese-like products made from coconut milk utilizing global computer database systems which included Knowledge Index (Agribusiness, Agricola, Cab Abstracts, Food Science and Technology Abstracts and Biotechnology Abstracts) and BRS (Patent Data, Agricultural, Biological and Environmental Sciences, Engineering Technology and Applied Sciences).

There are a number of published articles and patents on the use of coconut oil as a substitute for butterfat in the manufacture of various types of cheese-like products; however, information regarding the use of coconut protein as one of the major raw materials for preparation of dairy-like products is very scarce.

IV.1 Utilization of Coconut Milk in the Manufacture of "Soft Cheese"

The demand for dairy products, particularly cheese varieties, is increasing rapidly in coconut-producing countries; however, not enough fresh milk is available for processing into these products. Skimmilk powder and coconut milk, on the other hand, are more readily available than fresh milk.

The potential of water-extracted coconut milk as a less expensive substitute for butterfat in the manufacture of fresh soft cheese manufacture was investigated (Davide et al., 1987). Also, Davide et al. (1986, 1988) developed a fresh soft cheese spiced with garlic (Queso de Ajo), with starter and blue-type cheese, from a blend of skimmilk powder and coconut milk. The coconut cheeses were then compared with control cheeses similarly prepared from fresh cow's milk.

IV.1.1 Fresh Soft Cheese (Cadtri Cheese)

A low-fat soft cheese named "Cadtri" (from the acronym for College of Agriculture Dairy Training and Research Institute, University of Phillippines at Los Banos) and a skimmilk cheese (control) were prepared (Davide et al., 1987).

IV.1.2 Coconut Milk and Filled Cheese Milk

Coconut milk is low in protein but very rich in fat and emulsifiers (**Table 1**) and it is a natural oil-in-water emulsion just like a cow's milk, hence, both can mix readily. As a carrier of vegetable fat to substitute butterfat, water-extracted coconut milk would be less expensive and much easier to blend with skim milk than coconut oil.

Table 1. Gross composition of coconut milk extract (CCM) and Cadtri cheese milk

Composition	Coconut milk[a]	Cheesemilk[b]
Total solids, %	16.4	10.4
Fat, %	12.5	1.5
Total protein, %	1.5	3.8
Total ash, %	9.6	0.8
Titratable acidity, %	9.1	0.2
pH	6.0	6.4

[a]Extracted with 388 ml water per nut.
[b]RCM-CCM blend. Blended from 13% CCM and 8.7% skim milk powder.

The coconut milk was prepared by initially extracting the grated meat with 230 ml water per nut. The resulting coconut meal was then re-extracted with 158 ml water. The two extracts were combined and strained through a nylon cloth before mixing with reconstituted skimmilk. The cheesemilk was formulated by blending 13 parts of the coconut milk and 87 parts of a 10% reconstituted skimmilk (Davide et al., 1987).

IV.1.2.1 Characteristics of Cadtri Cheese

Gross composition. Cadtri cheese is relatively low in fat content (7.3%), but rich in protein (13.2%) and salt (1.7%), and the pH (6.20) did not differ greatly from those soft cheeses that simulate the traditional "Kesong Puti" of the Filipinos (**Table 2**).

Table 2. Gross composition, yield and sensory scores of Cadtri and fresh soft cheese from skimmilk and cow's milk[a,b]

Attribute	Cadtri	Skim milk	Cow's milk
Moisture, %	72.8b	77.2b	63.8b
Fat, %	7.3b	0.0c	19.1a
Total protein, %	13.2b	15.8a	12.5c
Salts, %	1.7a	1.6a	1.8a
pH	6.2b	6.2b	6.4a
Yield, %	21.9b	25.4a	21.9b
Flavor and aroma	7.2a	5.9b	7.5a
Body and texture	7.5a	6.2b	7.1a
Color	7.9a	7.1b	6.8b

[a]Values on the same row with different letter are significantly different at 5% level.
[b]Score of 5 means neither like nor dislike, 6 like slightly and 7 like moderately.

Sensory evaluation and consumer acceptance. Sensory evaluation and consumer acceptance data indicated a higher preference for Cadtri cheese (**Tables 1-2**). About 79% of the consumers liked Cadtri cheese slightly to extremely, although a small percentage of consumers neither liked nor disliked it, and still others disliked it slightly. Evidently, the addition of coconut milk gave it the desired firm body, smooth texture, and mild coconut flavor in contrast to the skimmilk cheese which had a tougher but brittle body, coarse texture, and astringent "skimmilk powder flavor".

Shelf life. When refrigerated, Cadtri cheese had a shelf-life of 6-7 days. With slow drainage of the whey during storage, the cheese became slightly firmer in body, yet, no objectionable changes in sensory qualities were observed.

IV.1.2.2 Low-Fat "Queso de Ajo" and Fresh Soft Cheese with Starter

A fresh soft cheese spiced with garlic to overcome the coconut flavor problem (Queso de Ajo) and another cheese with lactic starter, S54 (*Streptococcus cremoris* and *S. lactis*), were developed from a less expensive blend of skimmilk powder and coconut milk (Davide et al., 1988). Using a 2% fat standardized-cheese milk formulated from a coconut milk and a 10% reconstituted skimmilk, soft cheeses were prepared and analyzed in comparison with control cheeses prepared from fresh cow's milk .

The 2%-fat experimental cheesemilk formulated from a coconut milk and a reconstituted skimmilk was noted to be nutritionally comparable to a similarly standardized cow's milk. The values for total solid (11.0%), fat (2.1%), total protein (3.4%), ash (0.7%), titratable acidity (0.2%) and pH (6.2) of the 2%-fat experimental cheesemilk were not significantly different from those of the standardized cow's milk, and yet its cost was about 21% lower.

Gross composition. Both cheese varieties were found to be very nutritious and acceptable. They were lower in fat contents (9.2-10.0%) than the traditional white soft cheese or Kesong Puti (16-33%), and contained 69.6-71.1% moisture, 11.7-13.0% total protein, and 1.6-1.% salt, which are comparable with those of the control cheese. The blend was regarded as having a high potential as a cheesemilk for the local soft cheese industry.

IV.1.2.3 Use of Coconut in Blue-Type Cheese Production

Davide et al. (1986) developed a blue cheese production technology from coconut milk-skimmilk powder blends.

The coconut milk was blended with 12% or 15% reconstituted skimmilk to obtain a filled cheese milk containing about 3% fat. Cheese milks were heated to 55°C, homogenized at 2,000 psi and then pasteurized. The cheesemilk was mixed with 0.5% lactic or 0.003% or 0.005% blue mold cheese starter (Lactic starter S54 and *Penicillium roqueforti* spores), and 0.02% $CaCl_2$ before it was set for 1.5 hours.

The filled Blue cheese had somewhat lower fat content (24.2%) than the control cow's milk Blue cheese (27.7%). The filled Blue cheese retained more moisture than did the cow's milk cheese. The filled Blue cheese made from a 15% reconstituted skimmilk-coconut milk blend contained a significantly higher moisture (49.9%), total protein (23.5%) and yield (13.5%) but lower fat (19.8%) contents than those of cow's milk.

Apparently, the addition of more skimmilk powder to the blend caused the cheese to retain more moisture and significantly increased its protein content. The higher pH observed in the six-week-old control and 15% reconstituted skimmilk-coconut milk experimental cheese, as compared to that of the cheese obtained from the 12% reconstituted skimmilk-coconut milk blend and control cheese of the same age, could be due to more proteolysis and lipolysis resulting from the higher level of fungal spores (0.005%) added to the cheese milk.

Based on the scores, the cow's milk Blue cheese was liked moderately (7.15) for flavor and aroma, while the filled blue cheese was slightly to moderately liked (6.52). The difference could have been due to the stronger rancid-like flavor and smell of the filled Blue cheese.

The Blue cheese from 15% reconstituted skimmilk-coconut milk blend had flavor and aroma as well as color that were liked slightly to moderately. Its body and texture did not differ significantly from those of the control, and was liked moderately (7.11). Increasing the skimmilk powder from 12% to 15% in the cheesemilk and adding 0.005% instead of 0.003% fungal spores improved the sensory qualities of the filled Blue cheese.

Results showed that coconut milk is highly suitable for blending with skimmilk powder in making a modified Blue cheese which is a potential substitute for the extremely expensive Roquefort and other blue-type cheeses.

IV.1.2.4 Formulations of Coconut and Skim Milks in White Soft Cheese Production

Davide and Foley (1981) reported that filled cheese like Cheddar made from milk fat/coconut oil blends did not give any desirable flavor of its own nor develop the flavor and physical attributes of Cheddar cheese. The cheese was brittle, crumbly and appeared very coarse. Its loose moisture increased proportionately with the concentration of coconut oil substituted. On the other hand, coconut milk-blended soft cheese is comparable to the product made of 100% fresh cow's milk in body, texture and general acceptability.

Sanchez and Rasco (1983a,b) conducted study to utilize coconut milk as a cow's milk extender in processing white soft cheese using formulations of various combinations of coconut milk and skim milk.

Also, the effects of the amounts of rennet on the coagulation time of cheesemilks consisting of coconut milk plus reconstituted skim milk at different concentrations were studied.

Coagulation Studies. Using rennet and a starter consisting of *Streptococcus lactis* and *S. diacetilactis*, the coagulation studies of cheesemilks consisting of various combinations of coconut milk and skim milk with added salt (3%), rennet (3%), starter (10%) and 0.1% aqueous solution of 25% calcium chloride showed that as the amount of coconut milk increased with corresponding decrease in skim milk, the time required for curd formation increased. The maximum amount of coconut milk in combination with skim milk that formed a curd which could be cut was 60%.

Based on the analysis, formulations having higher amounts of skim milk (10% coconut milk + 90% reconstituted skimmilk to 40% coconut milk + 60% reconstituted skimmilk) produced hard curds while those with lower amounts of skim milk (70% coconut milk + 30% reconstituted skimmilk to 90% coconut milk + 10% reconstituted skimmilk) produced curds that were too soft to cut.

The acceptable texture of white soft cheese was obtained from treatments with 50% coconut milk + 50% reconstituted skimmilk and 60% coconut milk + 40% reconstituted skimmilk. Further tests indicated that soft cheeses made from these two formulations were comparable to the soft cheeses made from 100% cow's milk in flavor, aroma, texture and general acceptability.

IV.1.2.5 Low-Fat Yogurt and Fermented Beverage from Coconut Milk

Davide (1988) reported that a low-fat yogurt can also be prepared from coconut milk and skimmilk blends by first homogenizing and pasteurizing it, followed by adding sugar and cultures of *S. thermophilus* and *L. bulgaricus*.

Apart from being 98% fat-free with the pleasant blending of sweetness and acidity, the low-fat yogurt (Niyogurt) had a smooth texture with bits of pineapple, thick consistency, and desirable flavor and aroma which the commercial brand and control yogurt made from cow's milk exhibited.

The high fat content of coconut milk made it unsuitable for fermented beverage processing; instead, coconut skim milk was used (Sanchez et al., 1984). Various combinations of coconut skim milk and non-fat dry milk were used in preparing fermented beverages. Based on sensory evaluation, a coconut skim milk to non-fat dry milk ratio of 1:1 was found to be the most acceptable formulation in terms of the sensory attributes tested and chemical compositions when compared to the control.

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V. DEVELOPMENT OF CHEESE-LIKE PRODUCTS

V.1 Materials and Methods

V1.1 Raw Materials

All fresh coconuts used in this development work were purchased locally on as needed and stored in a refrigerator for a short period of time until used. A commercial partially defatted shredded coconut was used to prepare coconut protein concentrate. A commercial desiccated coconut meal was purchased to prepare defatted coconut flour. Coconut meal was extracted with solvent and then desolventized at low temperature by either the conventional semi-pilot-scale hexane extraction method or the chloroform-methanol method. The defatted meal was then dried in a fume hood and ground in a coffee grinder to pass a 40-mesh screen. The shredded coconut, coconut meal and defatted flour were stored at -20°C in air-tight plastic containers until used.

V.1.2 Profiles of Different Solubility Fractions of Coconut Proteins

Five different solvents, deionized distilled water, 0.5M NaCl, 70% 2-propanol, 60% glacial acetic acid, and 0.1 M NaOH (hereafter referred to as H_2O, NaCl, IPA, HAc, and NaOH, respectively), were used in sequence to extract virtually all protein components in the coconut flour. The protocol for this sequential extraction is outlined in **Figure 1**. The flour was extracted for 14-16 hr at 4°C and centrifuged at 20,000 x g for 30 min. Extraction with each solvent was repeated three times.

All supernatants with the same solvents were combined to obtain a pool representing each solubility fraction and assayed for protein according to the method of Bradford (1976) using bovine serum albumin (BSA) as the protein standard. All fractions were then dialyzed against their own solvents followed by deionized water, respectively. Dialysates were freeze-dried and the resulting protein powders were stored in a freezer at about -20°C.

V.1.3 Proximate Compositions

Protein contents (total nitrogen x 6.25) were determined by the semi-micro Kjeldahl method while moisture was determined by the AOAC Official Methods (AOAC, 1984). Fat contents were determined according to the method of Folch et al. (1957).

V.1.4 Preparation of Defatted Coconut Milk (Extraction of Coconut Protein)

Coconut milk is the term used for the liquid obtained by mechanical expression of grated coconut meat with added water, and is the first product in coconut processing. This process consists of the steps of cracking, grating, blending, squeezing and defatting (**Figure 2**).

Extractabilities of coconut proteins were compared for two coconut meat-to-water ratios, 1:1 and 1:2 (w/v). Effects of sodium chloride on the extraction of coconut protein were studied at concentrations of 0, 0.2, 0.4, 0.6, 0.8 and 1M in water.

Effects of temperature on extraction of coconut protein were studied by blending grated coconut meats with 0.5 M sodium chloride (1:2, w/v) at temperatures of 25, 35, 45, 55 and 65°C. The percent protein extracted was calculated as follows:

$$\% \text{ Protein Extracted} = \frac{\% \text{ Protein in Meat x Weight of Meat Used}}{\% \text{ Protein in Milk x Weight of Milk}}$$

To reduce the fat content of coconut milk, the efficiency of three defatting methods was compared: chilling, centrifugation and solvent extraction. In the chilling method, the coconut milk was cooled at 5°C overnight. The white solidified fat layer was then separated and the protein content determined. In the centrifugation method, coconut milk was centrifuged at 7,000 rpm, 60°C using a Westfalia separator (Model SA7-06). The protein content of the fat layer was determined. In the solvent extraction method, the desiccated coconut meat was defatted by soaking in hexane at 59°C for 30 minutes. This procedure was repeated two additional times at 29°C for 20 minutes to remove most of the fat. After solvent extraction, the defatted coconut meat was desolventized and dried by blowing cold air through it.

V.1.5 Production of Coconut Protein Concentrate

The defatted coconut milk was concentrated by an ultrafiltration process using a 10,000 or 5,000 molecular weight cut-off (MWCO) membranes (Romicon Types PM 10 and 5). After ultrafiltration, the amount of salt and sugar in the coconut milk was then reduced to approximately 30% by a diafiltration process. The concentrated coconut milk was spray-dried to produce a coconut protein concentrate containing approximately less than 5% moisture. The schematic diagram for the process is shown in **Figure 3.**

V.1.6 Production of "Tofu-type" Product by Salt-coagulation

The traditional method of cheese making uses rennet to coagulate casein in cow's milk. However, preliminary experiments conducted in this laboratory concluded that enzymatic coagulation of coconut proteins using rennet is not feasible due to the totally different characteristics of coconut protein from cow's milk protein in structure and physiological properties. Therefore, new procedures were developed to precipitate or coagulate coconut proteins into semi-solid cheese-like texture.

First of all, a series of basic studies were carried out to better understand coconut proteins in terms of their precipitation characteristics. For this study, a dry powdered coconut protein was prepared by partially removing coconut oil from coconut milk using chilling and centrifugation methods followed by freeze drying the defatted CM to minimize the effect of oil and thermal denaturation of proteins on protein coagulation/precipitation. Protein precipitation studies were carried out using 1% coconut protein solution. The volume of the protein solution was brought to 40 ml after the final pH adjustment and salt addition. The suspension was centrifuged at 4,300 x g (Sorvall RC2-B Refrigerated Centrifuge) for 20 minutes and filtered through Whatman Filter Paper No. 1 to remove flocculent materials. The supernatant was taken for protein analysis using the Bio-Rad method (Bradford, 1976).

Two different calcium salts (calcium chloride and calcium sulfate) were tested for their effects on coconut protein precipitation at various concentrations ranging from 0.1 to 1.0 M. Based on the results of these precipitation tests, a kind of tofu-type product was produced in the laboratory from coconut milk (whole or partially defatted using the chilling method) by adjusting the pH to 3.5 and adding 1.0 M calcium chloride in the presence of 0.5 M sodium chloride. The experimental scheme for the process is shown in **Figure 4.**

V.1.7 Production of "Tofu-type" Product by Heat-coagulation

Considering the possibly high cost of calcium chloride and operational difficulties of adjusting pH, tofu-type products were also produced by heating according to the procedure outlined in **Figure 5.** Coconut milk (whole, partially defatted or completely defatted) was stirred continuously and heated to 98°C. After boiling for 10 min without stirring, the heated coconut milk was removed from the heat and allowed to cool to room temperature. After the curd was formed, the custard-like mass was drained by squeezing through cheese cloth. The curd was pressed with slight pressure and stored at 4°C.

V.1.8 Effects of Fat Content of Coconut Milk on Texture and Melting Property of "Tofu-type" Products

"Tofu-type" product is produced by heating coconut milk that is an emulsion between coconut protein and coconut fat. When denatured protein molecules aggregate to form an ordered protein network, the process is referred to as coagulation. Although the protein plays the major role in the coagulation, fat has important effects on texture and yields of tofu-type product, because fat is trapped within the protein network formed by protein denaturation that can also alter the emulsion capacity (Food Chemistry, 1985). Moreover, coconut milk contains so much fat that it is necessary to control the fat content properly before heat treatment to enhance the textural integrity and handling of the resulting products.

Nine types of reconstituted coconut milks were prepared by mixing the separated cream and the defatted coconut milk at cream:defatted coconut milk ratios of 1.8:8.2 (i.e., full-fat coconut milk), 1.35:8.65, 0.9:9.1, 0.45:9.55, 0.144:9.856, 0.108:9.892, 0.072:9.928, 0.036:9.964 and 0:10 (i.e., defatted coconut milk), and they were named as coconut milk types 1 through 9, respectively. The proximate compositions of these reconstituted coconut milk types are shown in **Table 3**. From these nine types of reconstituted coconut milks, nine different tofu-type products were produced as discussed previously and coconut milk were named as coconut curd type 1 through 9, respectively.

V.1.9 Effects of pH, NaCl and $CaSO_4$ on Formation and Hardness of "Tofu-type" Products

Aliquots (500 ml) of defatted coconut milk in citric acid buffer (pH 5) were heated until boiling. After boiling for 3 min., aliquots were removed and cooled down. After draining the whey through cheese cloth, aliquots (2 ml) of the coagulated soft curd were transferred to syringes (inside diameter, 8 mm) which were sealed at one end with cheese cloth, and then centrifuged at the speed of 1,000 rpm for 5 min. to remove the extra whey. The curds in the syringes were kept at 4°C for 20 hr under 500 g/cm pressure to ensure complete coagulation. Where specified, 0.01-0.05 M of $CaSO_4$ or 0.05 M of NaCl were added to defatted coconut milk prior to heat treatment. Also, pHs of defatted coconut milk were adjusted to 3-10 by adding HCl or NaOH to determine the optimum pH for coagulation.

Table 3. Composition of several reconstituted coconut milk type

Milk Type	Moisture (%)	Protein (%)	Fat (%)
1	87.63	1.04	9.47
2	90.41	1.06	4.52
3	92.29	0.96	3.21
4	94.16	0.85	1.88
5	95.43	0.79	0.99
6	95.58	0.78	0.89
7	95.83	0.77	0.78
8	95.88	0.76	0.68
9	96.03	0.75	0.57

V.1.10 Preparation of Cheese-like Products from Coconut Protein Concentrate

Experimental-cheese like products (cheese analogs) were prepared using the basic formula in **Table 4** according to the modified procedure of Chen et al. (1979) who made cheese analogs from peanut protein and oil. In order to develop suitable formulations for cheese analogs, various combinations of ingredients were investigated based on the textural and melting properties of the resulting products. Two experiments were conducted to test the protein sources and to adjust the levels of protein ingredients.

In formulating and producing coconut protein-based cheese-like products, both the formulation and processing steps used to manufacture commercial cheese analogs have been modified based on the results obtained from the preliminary experiments. The procedure used to make the cheese analogs is shown in **Figure 6**. Disodium phosphate (0.8%), sodium citrate (0.8%), citric acid (0.6%), and potassium sorbate (0.1%) were dissolved in coconut milk, and the milk was preheated to 60°C in a water bath. A Kitchen-Aid mixer (Model K5-A) with a water bath was used for mixing. The coconut protein concentrate was mixed at medium slow speed within one half of the salt solution. Mixing time was equipment dependent, but hydration was complete after an elastic and tacky character of a homogeneous blend was noted. The rest of the salt solution was then added while mixing. Mixing was continued until the oil and water were thoroughly emulsified in the mixture and a smooth, homogeneous, molten processed cheese-like product was formed. The resulting cheese-like products were poured into a cheese mold, allowed to cool, and then refrigerated 24 hours prior to evaluation.

Table 4. Cheese analog preparation formula

Ingredients	Content (%)
Coconut protein concentrate	47.7
Concentrated coconut milk	50.0
Sodium citrate	0.8
Disodium phosphate	0.8
Citric acid	0.6
Potassium sorbate	0.1

V.1.11 Electrophoresis

Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) was conducted using the method of Laemmli (1970). Running gels containing 12% acrylamide were prepared. Electrophoresis was performed in a 7x8x0.75 cm mini PROTEAN™ II dual slab cell (Bio-Rad, Richmond, CA) at a constant voltage of 200 V. Each gel was fixed and stained with Coomassie Blue R-250 for 3 hours in 25% methanol and 10% acetic acid solution and then destained in the same 25% methanol and 10% acetic acid solution overnight. A high molecular weight standard mixture (Bio-Rad) containing myosin (200,000 daltons), ß-galactosidase (116,250 daltons), phosphorylase b (97,400 daltons), bovine serum albumin (66,220 daltons), and albumin (45,000 daltons) was used as a molecular weight marker. For electrophoretic profiles of coconut protein fractions, protein powders were solubilized to a final concentration of 10 mg/mL in a sample buffer containing 2% SDS, 10% glycerol, and 0.05% bromophenol blue in Tris-HCl, pH 6.8, and then heated at 95°C for 3 min prior to loading to gel. Also, 2-mercaptoethanol was added to the sample buffer to a final concentration of 5% when analyzing reduced proteins. Ten micrograms of protein were loaded to each sample well. Protein bands were then compared in relation to the mobilities of the following marker proteins to estimate the molecular weights: phosphorylase b (97.4 kD), BSA (66.2 kD), ovalbumin (45.0 kD), carbonic anhydrase (31.0 kD), trypsin inhibitor (21.5 kD), and lysozyme (14.4 kD).

V.1.12 Textural Property Analyses

Textural properties of experimental tofu-type products, commercial dairy cheeses and cheese-like products were objectively determined using an Universal Instron Testing Machine Model 1011 (Bourne, 1978). All samples were cut into cubes (about 1.3 cm), and subjected to a double-compression test with a 50 kg reversible load cell after equilibrating in an air-tight container at room temperature for 1 hour. The samples were compressed to 75% of their original height. The full-scale load of 5 or 10 kg was used. The cross head speed was 20 mm/min with a chart speed of 50 mm/min. From the force-time curve (TPA curve) of Instron data, five textural parameters were obtained: hardness, cohesiveness, adhesive force, springiness and fracturability.

V.1.13 Melting Property Analyses

Melting properties of tofu-type products, commercial cheeses and cheese-like products were determined by the method of Chang et al. (1976). Cheese plugs (0.6 cm thick and 1.9 cm in diameter) were heated at 232°C for 3 min and subsequently assessed for melt as percent increase in diameter.

V.1.14 pH-Solubility Profiles of Coconut Proteins

pH-solubility profiles of coconut proteins were determined by a modified method of Sathe and Salunkhe (1981) on coconut meal and coconut protein concentrate. Levels of soluble nitrogen at pH values ranging from 1.0-12.0 were determined on 2.0% protein solutions of coconut meal and coconut protein concentrate dispersed in distilled water. Solutions after pH adjustment, were stirred for 1 hour at 23°C, centrifuged at 15,000 x G for 30 min, and the protein contents of the supernatants were determined by the method of Bradford (1976) with bovine serum albumin as standard. The solubility was expressed as percentage of total protein concentration.

V.1.15 Emulsion Stability of Coconut Protein Concentrate

Emulsion stability was measured according to the method of Acton and Saffle (1970). A 0.2% protein solution was put into a vessel with solvent extracted coconut oil at a ratio of 35:65 (v/v), to a total volume of 100 ml in order to provide a constant stirring. The samples were emulsified by homogenization using a propeller-type mixer (Mixer Model V-7, Mixing Equipment Co.) at 16,000 rpm for 1 minute. Ten grams of the emulsion were immediately placed into a 15 X 150 mm test tube. After standing for 30 minutes at room temperature, 5 g of the emulsion were removed from the bottom and the moisture content determined. The emulsion stability was calculated as follows:

$$\text{Emulsion stability} = \frac{100 - M_{test}}{100 - M_{original}} \times 100$$

where M_{test} = % moisture after 30 minutes and $M_{original}$ = % moisture of the original emulsion.

V.2 Results and Discussion

V.2.1 Protein Contents of Various Solubility Fractions

Results indicate that after defatting the protein content of coconut meal prepared from coconut meat (endosperm) used in this study was 17.16% (w/w). The sum total of protein in five different solubility fractions amounted to 84.6% of coconut meal. This suggests that sequential extraction with five solvents did not completely release all of the protein in the coconut meal. The contribution of individual solubility fractions to the total protein is given in **Table 5**. Water- and NaCl- soluble fractions accounted for almost 70% of the total protein.

Table 5. The contribution of different solubility fractions to the total protein

Fractions	% of total protein
Water	22.70
NaCl	46.10
Isopropyl alcohol	2.06
Glacial acetic acid	12.53
NaOH	1.20
Residue	13.41

V.2.2 Electrophoresis

Electrophoretic analysis, using SDS-PAGE without ß-ME, is shown in **Figure 7**. Four major polypeptides with estimated molecular weights (MW) ranging between 21-55 kD (**Figure 7, lane 1**) dominated the total protein composition. When β-ME was added, the reduced proteins were resolved into six major bands and four or more minor bands ranging between 18.0 kD and 55.0 kD (**Figure 8, lane 1**). It appears from this data, that the major protein in coconut is made up of at least three types of polypeptides (MW range 21.5-55.0 kD) linked via disulfide bond(s).

Water-, NaCl-, and IPA-soluble fractions contained two major coconut protein components.

HAc-soluble fraction was separated into at least two major bands with molecular weights greater than 100 kD and 55 kD; on reduction, it dissociated into more than seven peptides with molecular weights of 20.0-55.0 kD.

V.2.3 Extraction of Coconut Protein

As shown in **Table 6**, the protein content of coconut meat is only about 4.4% (as compared to about 33% oil). Recovering this minor component into coconut milk is therefore the key yield-determining factor. Therefore, effects of coconut meat to water ratio, concentrations of salts and extraction temperature on the extractability of coconut proteins were studied.

Table 6. Yield and composition of coconut meat, coconut water and coconut fiber

	Coconut meat	Coconut water	Coconut fiber
Yield (g)	45.5	16.6	11.0
Protein (%)	4.4	0.2	0.1
Fat (%)	32.9	0.2	19.5
Moisture (%)	48.3	95.1	33.4

As shown in **Table 7**, protein extraction was enhanced by 10% by increasing the coconut meat-to-water ratio to 1:2 (2.2% protein) from 1:1 (2.0% protein).

Table 7. Effects of coconut meat:water ratio and salt on extractability

Composition	Coconut meat:water (1:1, w/v)	Coconut meat:water (1:2, w/v)	Coconut meat:0.5 M salt soln. (1:2, w/v)
Protein (%)	2.0	1.1	1.2
Fat (%)	12.0	8.5	9.3
Moisture (%)	83.1	88.6	87.6

Protein recovery was further improved by adding sodium chloride to solubilize the salt-soluble proteins in coconut meat. As the sodium chloride concentration increased up to 1 M, the amount of protein in coconut milk also increased (**Figure 9**). However, the sodium chloride concentration of 0.5 M was chosen for use in subsequent experiments because higher concentrations of salt significantly increased the saltiness of the milk with only a small increase in protein extraction. Combining the effects of using higher meat to water ratio and 0.5 M salt, the extraction of coconut protein increased by more than 20%.

The amount of extracted coconut proteins increased sharply by increasing the extraction temperature from 25 to 35°C, but the value remained relatively unchanged at extraction temperatures higher than 35°C (**Figure 10**). Therefore, 35°C was chosen as the extraction temperature to produce coconut milks for all subsequent studies. Also, this temperature can easily be maintained and denaturation of coconut proteins will be minimum at this temperature.

V.2.4 Removal of Fat from Coconut Milk

Protein contents of coconut oils recovered by various defatting methods are summarized in **Table 8**. As expected, the solvent extraction method was the most efficient defatting method with less than 0.1% protein in the oil as compared to 2.4% protein in the chill-separated oil and 0.7% protein in the centrifuge-separated oil.

Table 8. Removal of fat from coconut meat and milk by various defatting methods

Defatting methods	Amount of fat removed (%)	Protein content of fat (%)
Chilling	90.0	2.4
Centrifugation	71.7	0.7
Solvent extraction	91.0	<oil

According to the electrophoretic pattern shown in **Figure 11**, the molecular weights of the extracted coconut proteins range from 13,000 to 57,000 daltons as previously reported (Chakraotry, 1985). Also, the pattern demonstrated the effectiveness of the centrifugal defatting method as exhibited by the extremely dark coconut protein bands in the defatted milk (**lane 3** in **Figure 11**).

V.2.5 Production of Coconut Protein Concentrate

It has already been demonstrated that certain milk-derived proteins such as nonfat dry milk and caseinate can be used in cheese-making. However, no information is available if concentrated or isolated coconut proteins would perform similar functions in cheese-making as milk proteins do. Therefore, production of a coconut protein concentrate (CPC) was attempted.

The data in **Table 9** show that approximately 22% of the protein in coconut milk was lost to UF permeate when a10,000 MWCO membrane was used. Also, in earlier trials, approximately 40% of the protein in coconut milk was lost to permeate and fat when the 10,000 MWCO membrane and chilling methods were used. However, these losses were reduced substantially by using a tighter membrane (such as 5,000 MWCO) and a cream separator.

Table 9. Composition of defatted coconut milk, UF retentate, UF permeate and coconut protein concentrate prepared by ultrafiltration method

Composition	Defatted coconut milk	UF permeate	UF retentate	Coconut protein concentrate
Protein (%)	0.8	0.2	5.2	64.2
Fat (%)	0.6	0.5	1.3	14.0
Moisture (%)	96.0	96.7	91.2	2.0

The full-fat milk was separated by a cream separator (Westfalia centrifuges, Westfalia Separators Ltd.) into coconut fat and defatted milk. The fat content of this defatted milk was 0.4%, compared to 6.0% for the chill-separated milk. The defatted coconut milk was then concentrated by an ultrafiltration process using a 5,000 MWCO membrane (Romicon Type PM 5) instead of 10,000 MWCO. The concentrated coconut milk was spray-dried to produce a coconut protein concentrate. Although the protein content of CPC decreased by approximately 10%, the protein yield increased from 20% to 41%, more than twice as much (**Table 10**).

Table 10. Compositions and yield of coconut protein concentrate prepared by different defatting and ultrafiltration methods

Composition and Yield	Chilling & UF[a] (10,000 MWCO[b])	Cream Separator & UF (5,000 MWCO)
Protein (%)	57.8	52.1
Fat (%)	14.0	13.7
Moisture (%)	2.0	5.0
Protein Yield (%)	20.0	41.0

[a]Ultrafiltration.
[b]Molecular weight cut-off.

V.2.6 Protein Extractability Profiles of Defatted Coconut Flour and Coconut Meat

The nitrogen solubility profiles of defatted coconut flour and coconut meat in water and 0.1M NaCl solution at pHs from 1 to 12 are shown **Figures 12** and **13**. As indicated in **Figure 12**, nitrogen solubility of coconut meal in water is slightly different from that in 0.5M NaCl solution. Although nitrogen solubility increased with increasing acidity or alkalinity, the solubility on the acid side was rather low (with a minimum solubility at pH 1.0). The solubility increased rapidly to over 70% at pH 7.0 or higher. The highest nitrogen solubility in water was attained at pH 11.0 and the lowest at pH 4.0-6.0

Coconut meat showed lower protein solubilities than defatted coconut flour in both water and sodium chloride solution, but the solubility curves showed similar trends (**Figure 13**).

The yield of coconut protein from coconut meat as starting material is presented in **Table 11.** The yield of UF concentrate was 10.5% of the total solids with 8.6% protein content, accounting for 39.7% of the nitrogen in the starting meat. The large loss of solids was due mainly to the high fiber content of coconut meat. Total nitrogen loss was 56.6% -- 36.6% in the residue, 9.5%

in the fat and 4.5% in the permeate. The meat residual consisted mainly of fiber. It contained 2.5% protein accounting for 36.6% of the nitrogen in the starting meat.

Table 11. Distribution and yields of coconut meat solids and protein in pilot plant extractions

	Composition (%)		Yield (as % of starting meal)	
	Protein	Solid	Protein	Solid
Starting Meat	3.8	59.1	100.0	100.0
Meat residue	2.5	39.1	36.6	36.8
Fat (Cream)	0.9	48.6	9.5	36.3
UF permeate	0.1	3.0	4.5	8.6
UF conc.	8.6	10.5	39.7	3.1
Loss	---	---	9.7	15.5

V.2.7 Emulsion Stability of Coconut Protein Concentrate (CPC)

Stability of protein emulsion is one of the important properties for process cheese making. The emulsion stability is dependent on pH, heating temperature and the presence of emulsifiers. During process cheese making, often emulsification of CPC and coconut oil did not work, or the emulsion formed broke easily. Therefore, a series of studies on the emulsion stability of CPC were conducted.

V.2.8 Effects of pH on Emulsion Stability of CPC

Emulsions were prepared from solutions of coconut protein concentrate at various pH values. **Figure 14** shows the effect of pH on the stability of the coconut protein concentrate emulsions. The emulsion stability was the lowest at its isoelectric point region and increased at pH's above and below this region. The emulsion stability of Na-caseinate at pH 6 was markedly higher than that of CPC.

V.2.9 Effects of Emulsifying Salts

Effects of two emulsifying salts, sodium phosphate and disodium phosphate (anhydrous) which are used widely in cheese industry, and control (no emulsifier) were compared (**Figure 15**). Tests were conducted in triplicates at pH 5.0 at 30°C. Addition of disodium phosphate showed the highest stability.

V.2.10 Effects of Heat Treatment

The emulsion properties of soy protein generally tend to decrease if the protein solution was heated previously (Aoki and Nagano, 1975). **Figure 16** shows the effect of heat treatment on the stability of the CPC emulsions. The protein solution was heated for 5 min at selected temperatures between 30 and 95°C. The emulsion stability decreased as the treatment temperature increased, with the lowest value at 85°C. The highest stability was observed at 50°C (mild heat).

V.2.11 Tofu-type Products Directly from Coconut Milk

Effects of pH and added salt on coconut protein precipitation are are shown in **Figures 17** and **18**. As evident in **Figure 17**, the isoelectric point of coconut proteins is around pH 4, which agrees well with the reported value of pH 3.9 (Peters, 1960).

As shown in **Figure 18**, a maximum of only about 20% of coconut proteins were precipitated by either one of these salts. However, in the presence of 0.5 M sodium chloride, addition of 1 M calcium chloride markedly increased the protein precipitation, more than 80% at pH 4 or below (**Figure 19**).

Based on these results, two kinds of tofu-type products were produced in the laboratory from coconut milk (whole or partially defatted using the chilling method), one product by adding 1.0M calcium chloride in the presence of 0.5 M sodium chloride at the pH of 3.5 and the other by heating the coconut milk.

V.2.12 Comparison of Salt-coagulated and Heat-coagulated Tofu-type Products

The yields and proximate contents of two kinds of Tofu-type products (salt-coagulated and heat-coagulated) were compared in **Table 12.**

Table 12. The yields and proximate composition of two kinds of Tofu-type products

	Salt-coagulated product (defatted)	Heat-coagulated product (defatted)	Heat-coagulated product (full-fat)
Yield[a], %	0.6	4.3	49.7
Protein, %	8.0	16.4	5.0
Fat, %	2.1	5.0	49.5
Moisture, %	46.4	72.0	39.9

[a]Yield= (weight of product/weight of coconut meat used) x 100.

All attempts to produce salt-coagulated tofu-type product from whole coconut milk were not successful because the protein did not coagulate. On the other hand, the salt coagulated product from defatted coconut milk had very low yield, strong salt taste and very weak texture. Therefore heat-coagulation method was chosen to produce tofu-type products. Heat-coagulated tofu-type products prepared from whole coconut milk had higher yield and retained more flavor (sweetness and coconut-like aroma) but were much more oily than the product from the defatted coconut milks.

V.2.13 Effect of Fat Content of Coconut Milk on Texture and Melting Property of Tofu-type Products

The proximate composition of each tofu-type product, made from the reconstituted coconut milk types 1 through 9 as discussed previously (see **Table 3**), is summarized in **Table 13**. There was no significant difference in fat contents between curd types 1 and 5 although the fat contents of the corresponding reconstituted coconut milks were decreased from 9.47% (milk type 1) to

0.99% (milk type 5). However, there was a significant difference in fat contents between curd types 5 and 9, although the difference in fat contents between coconut milk types 5 and 9 was not significant. These unusual phenomena were caused by the fact that the full-fat coconut milk has too much fat to produce a tofu-type product.

Table 13. Composition of tofu-type products made from several reconstituted coconut milks

Curd type	Moisture (%)	Protein (%)	Fat (%)
1	39.86	3.61	49.50
2	29.75	5.00	55.43
3	31.68	5.76	53.91
4	35.73	5.09	48.00
5	44.81	5.30	43.47
6	56.99	7.70	30.87
7	56.93	10.45	30.17
8	61.24	10.70	21.81
9	72.02	16.38	5.00

The effect of fat content of the reconstituted coconut milk on the yield of each tofu-type product is shown in **Figure 20**. The yields were calculated as follows:

$$\text{Yield (\%)} = \frac{\text{Weight of Curd (g)}}{\text{Weight of Coconut Meat Used (g)}} \times 100$$

The yield of tofu-type product increased proportionally to the increase in fat content of coconut milk. The yield of type 1 was 49.70%, which means 2 kg coconut meat were needed to produce 1 kg type 1 product, while for 1 kg type 9 product, 24 kg coconut meat were needed (yield = 4.26%).

V.2.14 Effects of pH, $CaSO_4$ and NaCl on Hardness of Coconut-tofu

Coconut protein was coagulated at pH 4, 5 and 6. The cur was hardest and the whey clearest at pH 5 (**Figure 21**). At pHs near the pI (pH 4), protein molecules show minimal interactions with water and net charges are sufficiently small to allow polypeptide chains to approach each other.

There was no significant change in tofu hardness until the $CaSO_4$ concentration reached 0.03M. The hardness increased rapidly at the concentration of 0.04M $CaSO_4$ and decreased until the hardness became the same as control at 0.06M $CaSO_4$ (**Figure 22**) Overall, as $CaSO_4$ concentration increased, the curd became harder and coarser and had the appearance of precipitates rather than coagulates. This effect could be due to the increased syneresis and loss of whey from the curd as more bonding occurred thus making the protein matrix denser and more compacted.

In the presence of 0.05M NaCl, a soft and nonelastic curd was formed, but the curd was hardly formed at concentrations above 0.1M (**Figure 23**). Therefore, the effects of NaCl on coagulation and hardness of tofu at low concentration are attributed to charge neutralization effects; the contribution of electrostatic interactions to the formation of coconut-tofu is apparently high). This effect relates to the "salting out": the ions, especially Cl^-, react with the charges of proteins and decrease the electrostatic attraction between opposite charges of neighboring molecules.

V.2.15 Evaluation of Textural Properties

Five tofu-type products (curd types 1, 2, 3, 4 and 9), from coconut milk types 1 (cream:defatted milk=1.8:8.2), 2 (1.35:8.65), 3 (0.9:9.1), 4 (0.45:9.55) and 9 (0:10), were used for texture evaluation. As shown in **Figures 24** through **28**, the product type 9 (product made from defatted coconut milk) had the highest values of almost all textural attributes, except for adhesiveness, among all tofu-type products. The other tofu-type products have similar properties to each other, because they have similar compositions. It was difficult to evaluate the textural properties of curd types 1 through 4, because they melted during compression on an Instron texture measuring machine. These products looked just like butter rather than tofu due to very high fat contents in relation to protein contents. Curd type 9 was as hard as sharp cheddar cheese in texture, but it was closer to hard tofu rather than cheese, due to its lack of adhesiveness. As fat content of coconut milk decreased, the cohesiveness increased.

Based on the results of these studies, it was concluded that the tofu-type product made from defatted coconut milk was the most acceptable among all tofu-type products.

V.2.16 Evaluation of Melting Properties

While most types of commercial cheeses, except for cream cheese, melted in round shapes, most tofu-type products, except for curd types 8 and 9, had transparent coconut oil separated out, but did not shrink or melt during the tests. In fact, oil was separated from curd types 1 through 7 products even at body temperature, but curd types 8 and 9, like cream cheese and tofu, retained the same size without melting. These results indicated that the coconut protein network, denatured by heat treatment, may not be able to hold oil more than twice its weight. Adding an emulsifier (disodium phosphate) did not improve the emulsion capacity of the heat-denatured coconut protein either.

Overall, curd types 8 and 9 had the highest acceptability and handling properties, although the product yields were relatively low. Especially, curd type 8 product was highly recommendable for a commercial tofu-type product because of its higher yield and four times more fat content than curd type 9. Moreover, curd type 8 had better texture and did not separate oil when held in hands. To produce curd type 8, it is necessary to control the protein:fat ratio of the coconut milk to approximately 53:47 (52.78:47.22) by defatting and reconstituting with enough added water.

V.2.17 Formulations and Textural Properties for Cheese-like Products

In order to develop suitable formulations for cheese-like products, various combinations of ingredients were investigated based on textural and melting properties.

As reported earlier in Interim Report II, cheese-like products can be produced by using coconut protein concentrate as the major ingredient, but it rather expensive to produce CPC. Therefore, production of cheese-like products was attempted by utilizing fresh coconut milk or UF concentrated coconut milk and CPC as protein and fat sources without adding any additional fat and water. In spite of the limited flexibility in preparing formulas, this production method was to minimize the use of CPC. In experiment 1, cheese analogs were formulated to have about 28% protein, 20% fat, and 36% moisture in finished products. Five formulations were prepared by mixing appropriate amounts of concentrated coconut milk and coconut protein concentrate, or partially replacing the total protein in CPC with 0, 10, 20, 30% Na-caseinate or 15% non-fat dry milk (NFDM).

In experiment 2, five formulations were prepared adjusting the levels of CPC and CCM. The amounts of ingredients used for each formulation and their compositions are shown in **Table 14.**

V.2.18 Textural Properties of Cheese-analogs

In experiment 1, five processed cheese analogs were produced from concentrated coconut milk and CPC or 0, 10, 20 and 30% of Na-caseinate or 15% of non-fat dry milk (formulations 1, 2, 3, 4 and 5, respectively). These cheese analogs were subjected to Texture Profile Analysis to compare their textural properties with those of commercial dairy cheeses. The commercial cheeses were Cream, Processed (American cheese) and sharp Cheddar which represented the creamy-, soft- and hard-type cheeses, respectively. Surprisingly, no pronounced difference was observed in hardness and adhesiveness between processed and sharp Cheddar cheeses ($P < 0.05$).

Table 14. Amount of protein ingredients used in the preparation of five formulations of coconut-based cheese analogs and their composition

	Cheese Analog Formulas				
	6	7	8	9	10
Ingredients (%)					
Protein Concentrate	37.6	47.6	57.6	62.0	67.0
Coconut Milk	60.0	50.0	40.0	35.6	30.6
Product (%)					
Protein	21.4(1.0)*	26.3(1.1)	30.9(0.7)	33.1(1.3)	35.9(1.0)
Fat	26.2(1.0)	23.6(0.8)	21.9(0.5)	21.5(0.9)	20.7(0.5)
Moisture	36.0(1.5)	31.4(0.7)	25.9(1.3)	23.5(1.5)	21.6(0.3)

*Numbers in parentheses are standard deviations.

Figure 29 shows that protein ingredients have significant effects on cheese analog characteristics. The cheese analogs had higher hardness and adhesiveness and lower cohesiveness with increasing Na-caseinate levels. The observed increases in adhesiveness were not anticipated because an earlier report showed that increasing the amount of Na-caseinate markedly decreased adhesiveness when working with peanut proteins (Chen et al., 1979). The strongest rubbery texture (higher compress force) was noted at the 70:30 (coconut protein:Na-caseinate) replacement level. With decreasing Na-caseinate, cheese-like products become softer and less rubbery. No pronounced difference was observed in springiness except the product made with 15% NFDM. As shown in **Figures 29-31**, coconut cheese analogs with 0, 10 and 20% levels of Na-caseinate replacement showed TPA curves similar to that of cream cheese in hardness and the 30% replacement product showed characteristics similar to those of processed and sharp Cheddar cheeses. Since 0% replacement product (containing 100% coconut protein) exhibited desirable cream cheese characteristics, i.e., the smooth and spreadable properties, the effects of adjusted levels of coconut protein on textural properties were further investigated to determine if medium or hard type cheese analogs, i.e., processed or sharp Cheddar cheese, can be produced.

Five formulations (6, 7, 8, 9 and 10) were prepared with increasing levels of CPC (decreasing levels of CCM). As shown in **Table 14**, these adjustments in CPC and CCM levels resulted in the increased protein content and reduced fat and moisture contents of the resulting cheese analogs. As shown in **Figures 29-31**, different levels of CPC and CCM also altered textural properties of cheese analogs containing 100% coconut protein. The obvious differences were observed in hardness and adhesiveness. Increasing the CPC content (higher protein, lower moisture and oil) increased hardness and adhesiveness but decreased cohesiveness of cheese analogs. Springiness was not significantly affected by the these changes in CPC levels (**Figure 32**). Formulations 9 and 10 brought about increased hardness (25-35 newtons), which fell within the hardness range observed for sharp Cheddar (hard type cheese) but they also brought about strong adhesiveness. However, one of the desirable characteristics of dairy cheeses is their low adhesiveness.

All analogs displayed unique characteristics, higher adhesiveness, no fracturability and no melting properties. All commercial cheeses melted in round shapes but none of the coconut cheese analogs melt well. These differences in textural properties are due largely to the differences in molecular structure, size and composition between coconut and milk proteins, because such protein molecular properties would influence the characteristics of the resulting gels or curds.

V.2.19 Preparation of Cheese-like Products from Wet Coconut Curd and Guar Gum

The cheese-like products discussed thus far were produced by using coconut protein concentrate as the major protein source, but the cost of preparing coconut protein concentrate is rather expensive. Therefore, an alternative method of producing cheese-like products was examined by utilizing wet coconut protein curd prepared from fresh or concentrated coconut milk and hydrocolloid (guar gum).

Based on the results obtained from preliminary experiments, both the formula and process used to prepare commercial cheese analogs were modified in formulating and producing coconut curd and guar gum-based cheese-like products. The procedure used to make cheese-like products is shown in **Figure 33.**

Defatted coconut milk was obtained according to the process discussed earlier except a coconut meat to extraction solvent ratio of 1:1 (w/v) was used. The separated coconut fat was stored under refrigeration until used. The partially defatted coconut milk was heat at 95°C for 15 minutes while stirring slowly and then allowed to cool to room temperature. The wet curd formed was recovered by filtering the milk through cheese cloth. The wet curd and guar gum mixed vigorously at 60-70°C for 3 minutes in a Kitchen Aid Mixer with a water bath. Coconut fat, emulsifier and other additives were added and mixed thoroughly until oil and water were completely emulsified and a smooth, homogeneous, molten cheese-like product was formed. The cheese analog was then poured into a cheese mold and refrigerated before evaluation.

All experimental products were produced according to the basic formula shown in **Table 15.** Five different levels of guar gum were investigated based on the textural properties of the resulting products.

Five processed cheese-like products were produced from wet coconut curd and five levels of guar gum, 3.0, 4.0, 5.0, 6.0 and 7.0% (formulations 1, 2, 3, 4 and 5, respectively). The addition of 6% gum resulted in a product with hardness of 25-30 newtons, which is comparable to that of commercial sharp Cheddar (**Figure 34**). With increasing levels of guar gum, cohesiveness of products decreased, and formulations 4 and 5 (6 and 7% gums, respectively) exhibited cohesiveness almost identical to commercial processed type and sharp Cheddar cheeses (**Figure 35**). Springiness of products decreased with increasing levels of gum (**Figure 36**).

Table 15. Cheese-like product preparation formula from wet coconut curd and guar gum

Ingredient	Content (%)
Coconut curd	87.0
Guar gum	3.0-7.0
Coconut fat	8.0
Phosphate	0.7
Sodium citrate	0.8
Potassium sorbate	0.1

All coconut curd and guar gum-based products displayed certain unique characteristics, such as stickiness, no adhesiveness, no fracturability and high springiness. Based on the textural property data, the formulation with 6 or 7% guar gum can be used to produce products with better texture, less stickiness and more rubbery.

V.3 References

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VI. CONSUMER RESPONSE TESTING

The consumer response testing was subcontracted to the Department of Food Science and Technology, Kasetsart University, Bangkok, Thailand between June 1 and September 30, 1993. The project leader of the test was Dr. S. Sringam, Associate Professor, and she was assisted by her colleagues and graduate students in the department. The test was carried out on both tofu-type and cheese-like products. The test site was visited by Dr. K. C. Rhee, the principal investigator, in early June for a period of one week to train Dr. Sringam and her crew on how to prepare coconut protein ingredients using the ultrafiltration membrane system and the test products. The following is the report from Dr. Sringam on the preparation of coconut milk, coconut protein concentrate and tofu-type and cheese-like products as well as the consumer acceptance test results.

VI.1 Coconut Milk Extraction

The coconut milk extraction procedure, which was developed for the project, was slightly modified according to the facilities available at the test site (**Table 16**). Preliminary testings showed that the original extraction method yielded too low solid content in the UF retentate to spray drying and the resulting coconut protein concentrate was judged too salty by the local panelists.

A two-step extraction was used with reduced salt concentration from 2% to 1%. For 25 kg shredded coconut meat, 50 kg of water and 500 g of salt were used. Percent extractable protein increased from 77% to 80%, and the oil from 71% to 76%. The yields were still low, and they were believed to be caused by the absence of the grinding step of coconut meats with salt solution, resulting in too large coconut meat particles for efficient extraction.

Table 16. Comparison of two procedures of coconut milk extraction

	Coconut meat	Original[a]	Modified[b]
Amount/Residue (kg)	25.00	7.74	7.00
Moisture (%)	54.24	47.80	45.06
Protein (%)	3.16	2.37	2.29
Oil (%)	27.23	25.44	23.32
Extractable protein (%)	---	76.78	79.75
Extractable oil (%)	---	71.08	76.02

(a) Original procedure: Shredded coconut meat (25 kg) was mixed for 10 min with 2% NaCl solution (50 kg) 45°C before pressing.
(b) Modified procedure: Shredded coconut meat (25 kg) was pressed with water (2.5 kg), the residue was mixed for 10 min with 1% NaCl solution (35 kg), 45°C before pressing.

VI.2 Coconut Protein Concentrate Preparation

The coconut protein concentrate (CPC) from 1% salt solution extraction was still too salty (8.5% salt). Therefore, CPC was prepared without salt. Coconut protein was then precipitated with acid at pH 4.5. The coconut milk was prepared by pressing 25 kg of shredded coconut meat with 2.5 kg of water, and made up to 30 liters before defatting (**Figure 37**). The defatted milk was adjusted to pH 4.5 with HCl and kept overnight at 5°C. Supernatant was removed, water added, pH adjusted to 6.0 with NaOH and the final volume adjusted to 6.5 liters. The yield of the acid precipitated CPC was about 80% of the UF processed CPC. This new CPC contained about 3% salt (**Table 17**).

Table 17. Chemical composition of raw materials

	CPC I	CPC II	CCM I	CCM II	CMP
Moisture (%)	4.22	4.36	57.53	76.61	4.16
Protein (%)	48.22	45.29	3.40	1.69	3.41
Oil (%)	25.62	30.35	34.27	17.21	34.35
Sodium chloride (%)	8.45	2.69	---	---	---

CPC I: Coconut protein concentrate prepared by ultrafiltration method.
CPC II: Coconut protein concentrate prepared by acid precipitation method.
CCM I: Concentrated coconut cream prepared by pressing shredded coconut milk without water added.
CCM II: Concentrated coconut cream as UHT homogenized coconut milk.
CMP: Coconut milk powder (contains about 51% dextrin).

VI.3 Production of Cheese-like Products

The two CPC's were mixed 1:1 for the first sensory test (**Tables 18** and **19**). The concentrated coconut milk was replaced with coconut milk pressed without added water because the amount needed was too small to use the ultrafiltration method. The preparation procedure was followed except that manual mixing was done over hot water bath. The hedonic scale of 1-9 was used. The scores for the 3 products were low (3.96, 3.71 and 4.1, respectively) due mainly to the saltiness of the products.

For the second test, the acid precipitated CPC was then used. The liquid portion of the formula was reduced to 85% to improve the consistency and texture. Also, UHT homogenized coconut milk was used in place of the concentrated coconut milk to improve oily appearance and strong coconut oil smell. The scores were improved to 4.21 and 4.45 (for products 1 and 3, respectively) (**Table 20**).

For the third sensory test, sugar was added to the formula based on the suggestions from a large number of panelists. Coconut milk powder was added to adjust the solid content of the concentrated coconut milk. The texture of the cheese-like product 3 became too soft to cut at room temperature. However, the scores improved to 5.06 and 5.61 (**Table 21**).

VI.4 Production of Tofu-type Products

Tofu-type product was prepared by heat precipitation of defatted coconut milk at pH 5.0 (**Figure 38**). Sodium chloride was added just before removing from the heat. The adjustment of salt from 1.7 to 1.9% (based on the defatted milk) in the first and second tests did not significantly change the score. The first was too milky and the second one was too salty. Salt content of 1.8% was then used in the third test. The score improved a little to 4.10, showing that the salty taste was not the major factor (**Table 22**).

Based on the panelists' suggestions (**Table 23**), an additional test was conducted. Tofu-type product was cut in dices and served with syrup and ice. The dices were soft, but the score improved to 4.6. The test results on four typical sensory attributes of cheese-like and tofu-type products are summarized in **Table 24**.

VII. PROPOSED PROCESSES AND PRODUCTS

Based on the experimental results thus far obtained, it is proposed that the following options are to be considered to commercially produce both tofu-type and cheese-like products using several different types of coconut milk and other additives.

1. Cheese-like products from defatted coconut milk or concentrated coconut milk prepared by ultrafiltration (**Figure 39**). The wet curds prepared by heat or salt precipitation become tofu-like products when the liquid is drained and put in a mold.
2. Aged cheese-like products from partially defatted coconut milk or concentrated coconut milk by ultrafiltration using the combined heat and salt coagulation method to increase the product yield (**Figure 40**).

3. Modified cheese-like products from partially defatted coconut milk using a processed cheese making procedure (**Figure 41**).

According to the equipment manufacturers as well as our consultant, process equipment are readily available for a wide range of production capacities for both tofu and cheese type products from soybeans (tofu-type) and cow's milk (cheese-like), respectively, none of them were able or willing to make a recommendation for processing of coconut milk into either one of the products because their equipment has not been tested for such purposes. They were however confident to come up with a production plant if they can make a few trial runs using their equipment to learn the mass and rheological characteristics of coconut milk and the it.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Technologically sound processes have been developed and optimized to produce acceptable cheese-like and tofu-type products with a wide range of protein and fat contents and texture. However, economic merit of these processes has to be addressed more carefully due mainly to the extremely low protein content in comparison to the extremely high fat content of coconut meats. Even under the best conditions, only about one half of the protein present in the coconut meat can be recovered as usable products and a very large volume of process water has to be dealt with. Because of these reasons, economics of producing cheese-like and/or tofu-type products does not seem favorable if these products were to be considered the major products from coconuts. If, however, these products were to be considered byproducts (coconut fat being the major product), then the economic merit of the newly developed processes and products becomes brighter.

It is therefore recommended to consider adding the tofu-type and cheese-like product lines as a part of the existing coconut oil extraction plant rather than a free-standing facility. This approach will eliminate large sums of initial capital investment on equipment that can be shared with the oil extraction process.

Also, it is strongly recommended that the new processes be tested with the existing commercial tofu and cheese making equipment as suggested by the equipment manufacturers to obtain the information needed for proper identification or fabrication of process equipment.

Table 18. Formulation for cheese-like product 1 for sensory testing

	Test 1	Test 2	Test 3*
Coconut protein concentrate I	24.33	---	--
Coconut protein concentrate II	24.33	53.05	47.93
Concentrated coconut milk I	49.00	---	---
Concentrated coconut milk II	---	45.42	36.68
Coconut milk powder	---	---	11.96
Citric acid	0.60	---	---
Disodium phosphate	0.85	0.78	0.78
Sodium citrate	0.80	0.74	0.74
Sugar	---	---	1.83
Flavor	(0.30)	(0.30)	(0.30)

Note: When not all liquid portions in the original formula were used, each percentage was recalculated.

*Composition (by calculation): Moisture 30.69%, protein 22.73%, oil 24.97%.

Table 19. Formulation for cheese-like product for sensory testing

	Test 1	Test 2	Test 3*
Coconut protein concentrate I	30.83	---	--
Coconut protein concentrate II	30.83	65.83	58.32
Concentrated coconut milk I	36.00	---	---
Concentrated coconut milk II	---	32.67	23.65
Coconut milk powder	---	---	14.56
Citric acid	0.60	---	---
Disodium phosphate	0.85	0.78	0.57
Sodium citrate	0.80	0.74	0.53
Sugar	---	---	2.36
Flavor	(0.30)	(0.30)	(0.30)

Note: When not all liquid portions in the original formula were used, each percentage was recalculated.

*Composition (by calculation): Moisture 21.27%, protein 27.25%, oil 26.77%.

Table 20. Result of sensory test of cheese-like product 1

	Test 1	Test 2	Test 3
Number of panelist	49	66	80
Hedonic scale	3.98	4.21	5.06
Sensory attribute	Number of Judgements for given score (%)*		
Odor			
Strong	7 (14.28)	2 (3.03)	6 (7.50)
Rancid	6 (12.24)	7 (10.61)	3 (3.75)
Strange	1 (2.04)	---	---
None - little	2 (4.08)	4 (6.06)	3 (3.75)
Fair	2 (4.08)	---	5 (6.25)
Pleasant	1 (2.04)	2 (3.03)	20 (25.00)
Flavor			
Very salty	29 (59.18)	25 (37.88)	28 (32.50)
Slightly salty	4 (8.16)	15 (22.73)	13 (16.25)
Flavorless	---	---	1 (1.25)
Not sweet	---	2 (3.03)	2 (2.50)
Sour	1 (2.04)	1 (1.51)	1 (1.25)
Too rich	5 (10.20)	1 (1.51)	2 (2.50)
Strange	---	2 (3.03)	3 (3.75)
Poor	---	2 (3.03)	---
Fair	1 (2.04)	1 (1.51)	4 (5.00)
Good	2 (4.08)	4 (6.06)	4 (5.00)
Texture			
Soft, mushy	3 (6.12)	4 (6.06)	8 (10.00)
Hard, dry	---	---	---
Sticky	2 (4.08)	---	9 (11.25)
Poor	---	---	1 (1.25)
Good	3 (6.12)	3 (3.03)	6 (7.50)

*Percentage based on total number of panelists.

Table 21. Result of sensory test of cheese-like product 2

	Test 1	Test 2	Test 3
Number of panelist	49	66	80
Hedonic scale	4.10	4.45	5.61
Sensory attribute	Number of Judgements for given score (%)*		
Odor			
Strong	10 (20.41)	1 (1.51)	4 (5.00)
Rancid	2 (4.08)	1 (1.51)	2 (3.03)
Strange	---	4 (8.06)	---
None - little	---	1 (1.51)	4 (5.00)
Fair	---	---	5 (6.25)
Pleasant	2 (4.08)	2 (3.03)	13 (16.25)
Flavor			
Very salty	30 (61.22)	26 (17.16)	13 (16.25)
Slightly salty	5 (10.20)	14 (21.21)	15 (18.75)
Flavorless	---	---	2 (2.50)
Not sweet	2 (4.08)	4 (6.06)	2 (2.50)
Sour	2 (4.08)	3 (4.54)	1 (1.25)
Too rich	3 (6.12)	6 (9.09)	3 (3.75)
Strange	1 (2.04)	3 (4.54)	2 (2.50)
Poor	---	3 (4.54)	---
Fair	1 (2.04)	6 (9.09)	12 (15.00)
Good	2 (4.08)	1 (1.51)	10 (12.50)
Texture			
Soft, mushy	3 (6.12)	---	1 (1.25)
Hard, dry	2 (4.08)	---	---
Sticky	4 (8.16)	16 (24.24)	14 (17.50)
Poor	---	1 (1.51)	3 (3.75)
Good	3 (6.12)	1 (1.51)	6 (7.50)

*Percentage based on total number of panelists.

Table 22. Result of sensory test of tofu-type product

	Test 1	Test 2	Test 3	Test 4
Number of panelist	49	66	80	30
Hedonic score	3.71	3.79	4.10	4.60
Sensory attribute	Number of Judgements for given score (%)*			
Odor				
Strong	2 (4.08)	---	---	---
Rancid	---	1 (1.51)	---	---
Strange	---	---	---	---
None - little	---	2 (3.03)	22 (27.50)	2 (6.08)
Fair	1 (2.04)	---	---	1 (3.33)
Pleasant	2 (4.08)	---	4 (5.00)	3 (10.00)
Flavor				
Very salty	1 (2.04)	18 (27.27)	8 (10.00)	2 (6.67)
Slightly salty	8 (16.33)	7 (10.61)	6 (7.50)	8 (26.67)
Flavorless	18 (36.73)	15 (22.73)	34 (42.50)	---
Not sweet	3 (6.12)	1 (1.51)	2 (2.50)	---
Sour	1 (2.04)	2 (4.08)	---	1 (3.33)
Too rich	1 (2.04)	8 (12.12)	1 (1.25)	5 (16.67)
Not rich	---	---	---	2 (6.67)
Poor	---	5 (7.57)	4 (5.00)	3 (10.00)
Good	5 (10.20)	3 (4.54)	3 (3.75)	1 (3.33)
Texture				
Soft, mushy	11 (22.45)	6 (9.09)	6 (10.00)	7 (23.33)
Hard, dry	---	1 (1.51)	3 (3.75)	1 (3.33)
Course, friable	5 (10.20)	15 (22.73)	33 (41.25)	24 (80.00)
Poor	---	7 (10.61)	2 (2.50)	---
Good	1 (2.04)	---	1 (1.25)	---

*Percentage based on total number of panelists.

Table 23. Serving suggestions by panelists of test 1 and test 2

Serving	Number of Suggestion (%)*		
	Cheese-like 1	Cheese-like 3	Tofu-type
Alone	3 (2.73)	12(10.34)	13 (12.74)
With bread	44 (40.00)	37 (31.90)	15 (14.71)
With cracker	45 (40.91)	49 (42.24)	20 (19.61)
With fruit	2 (1.82)	5 (4.31)	7 (6.86)
As food ingredient	16 (14.54)	13 (11.21)	47 (46.08)
Total	110 (100)	116 (100)	102 (100)

* Percentage based on total suggestions of each product.

Table 24. Results of sensory test on four attributes of products in test 3

Attribute	Hedonic score		
	Cheese-like 1	Cheese-like 3	Tofu-type
Odor	6.21	6.16	4.45
Flavor	4.56	5.05	3.85
Texture	5.61	5.80	3.93
Overall acceptance	5.06	5.61	4.10

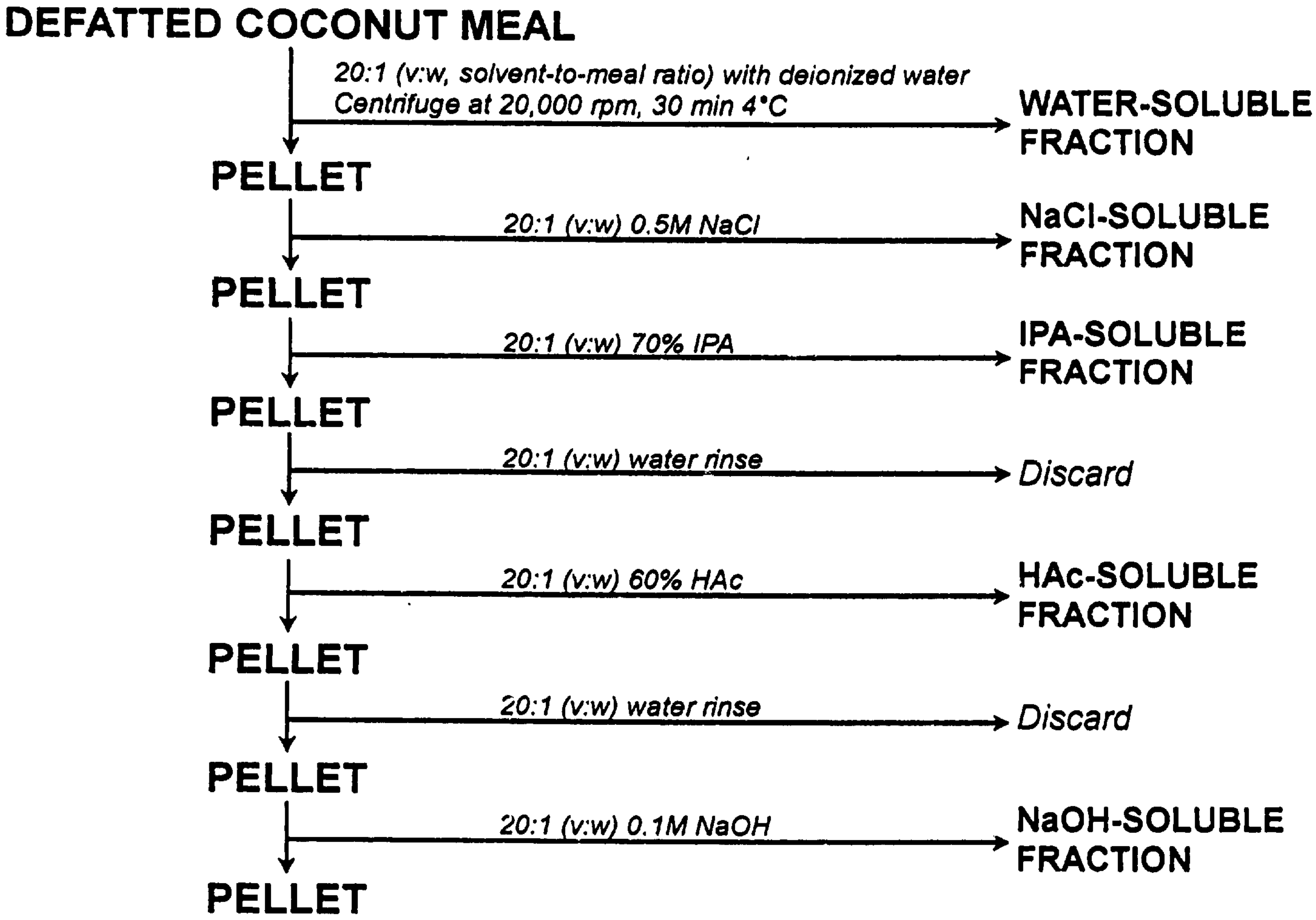

Figure 1. Flow diagram showing the protocol used for fractionation of coconut proteins by solubility in different solvents.

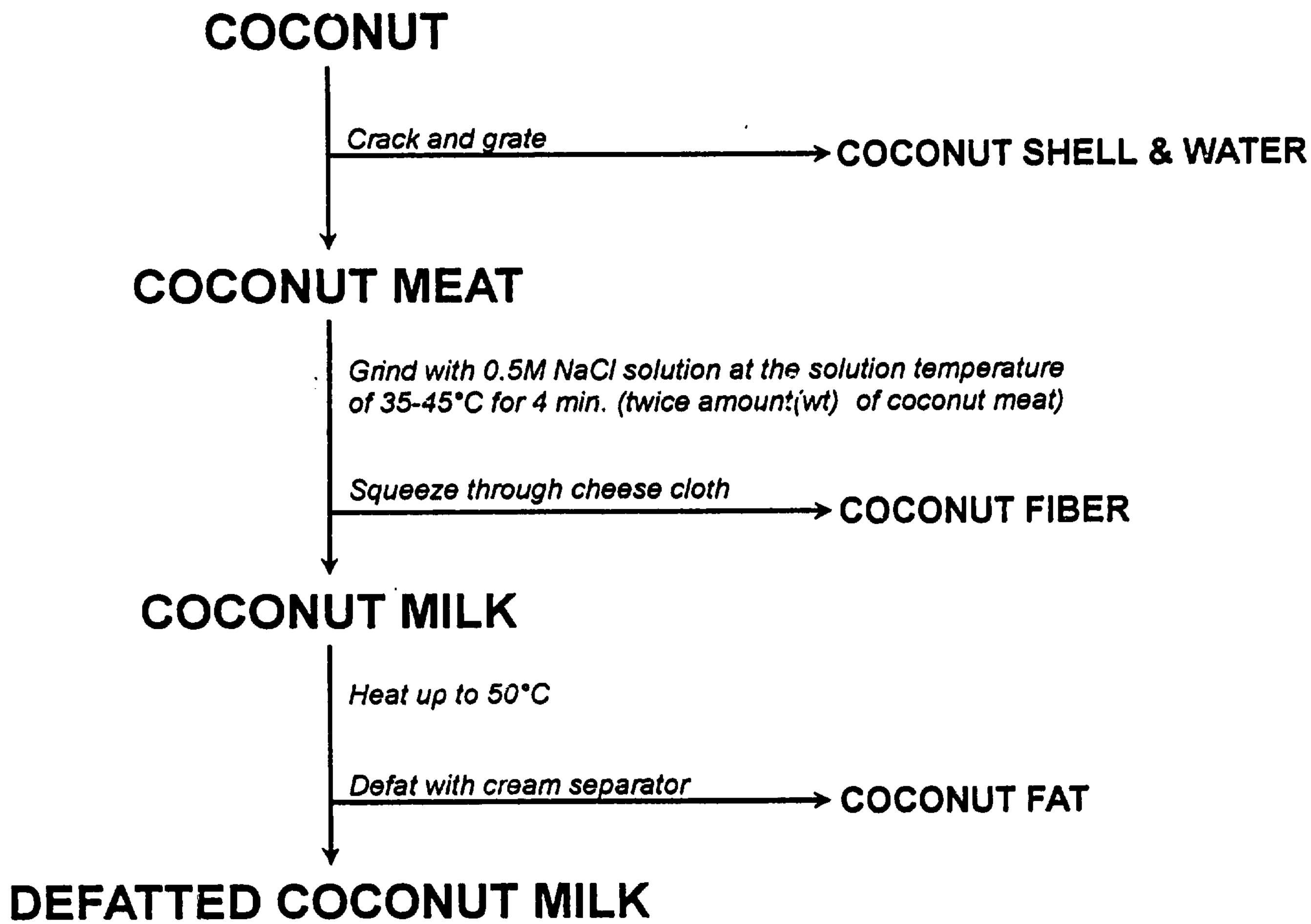

Figure 2. Shematic diagram for producing defatted coconut milk.

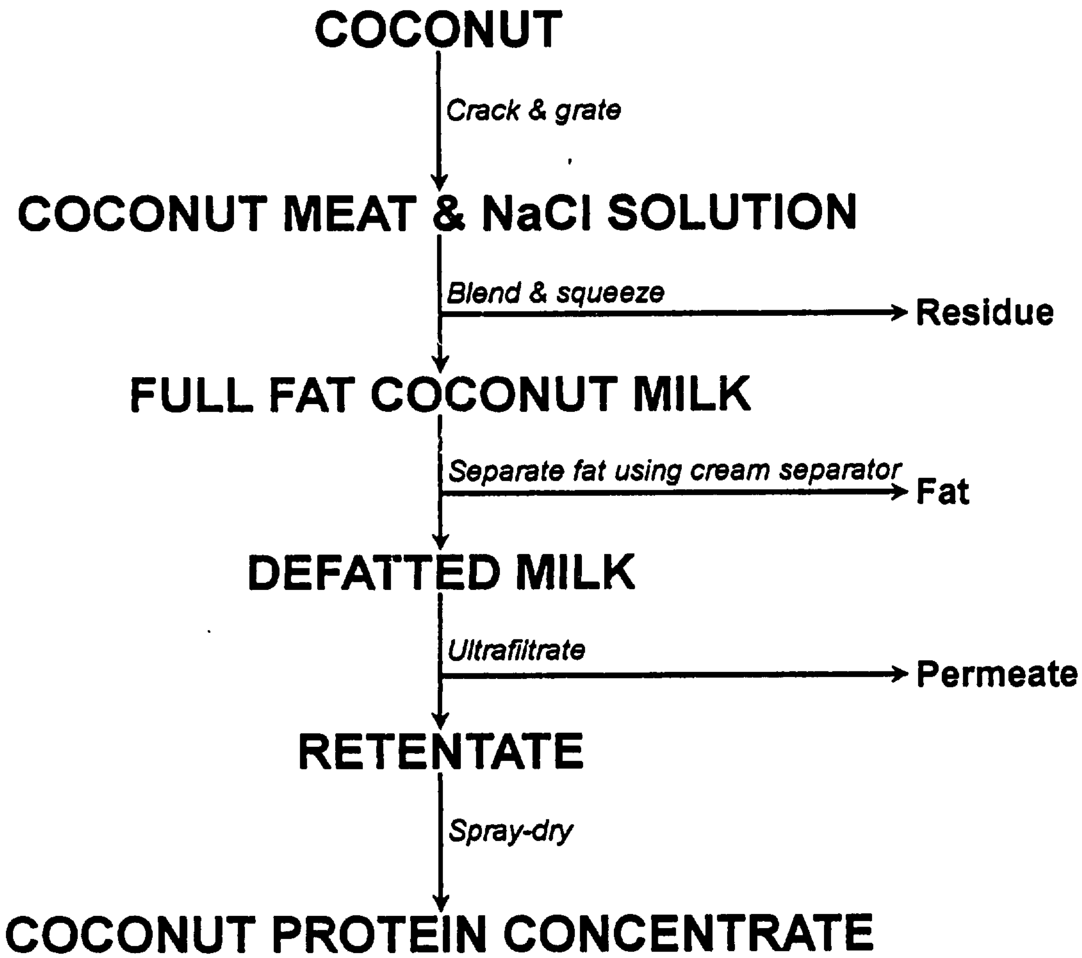

Figure 3. Production of coconut protein concentrate utilized for producing cheese-like products

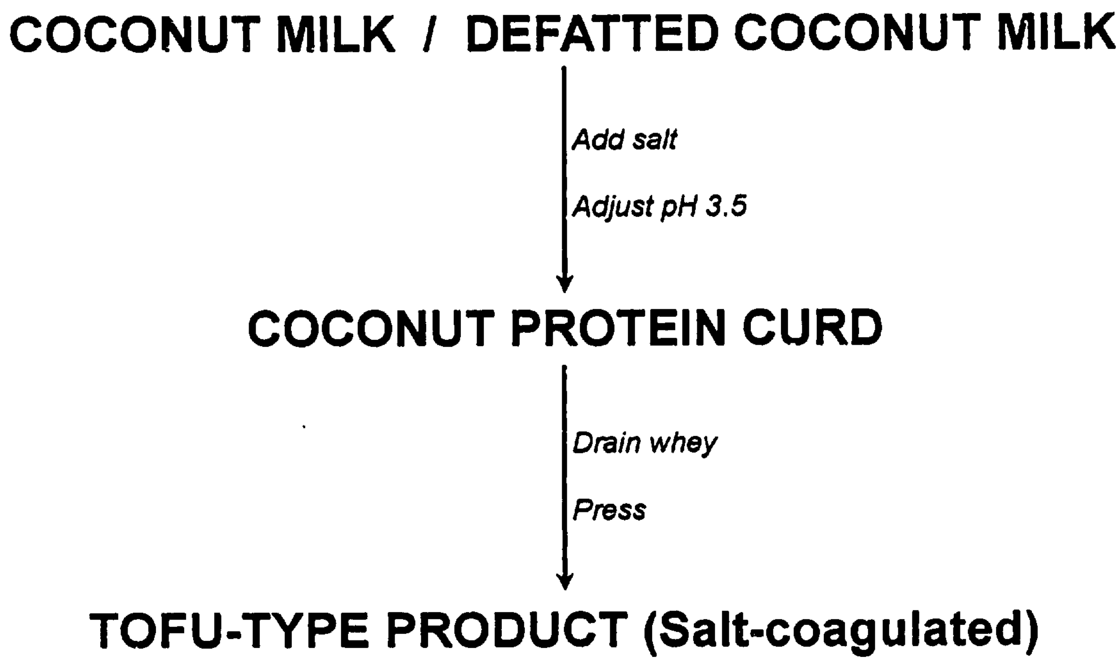

Figure 4. Schematic diagram for producing salt-coagulated tofu-typeproducts from whole or defatted coconut milk.

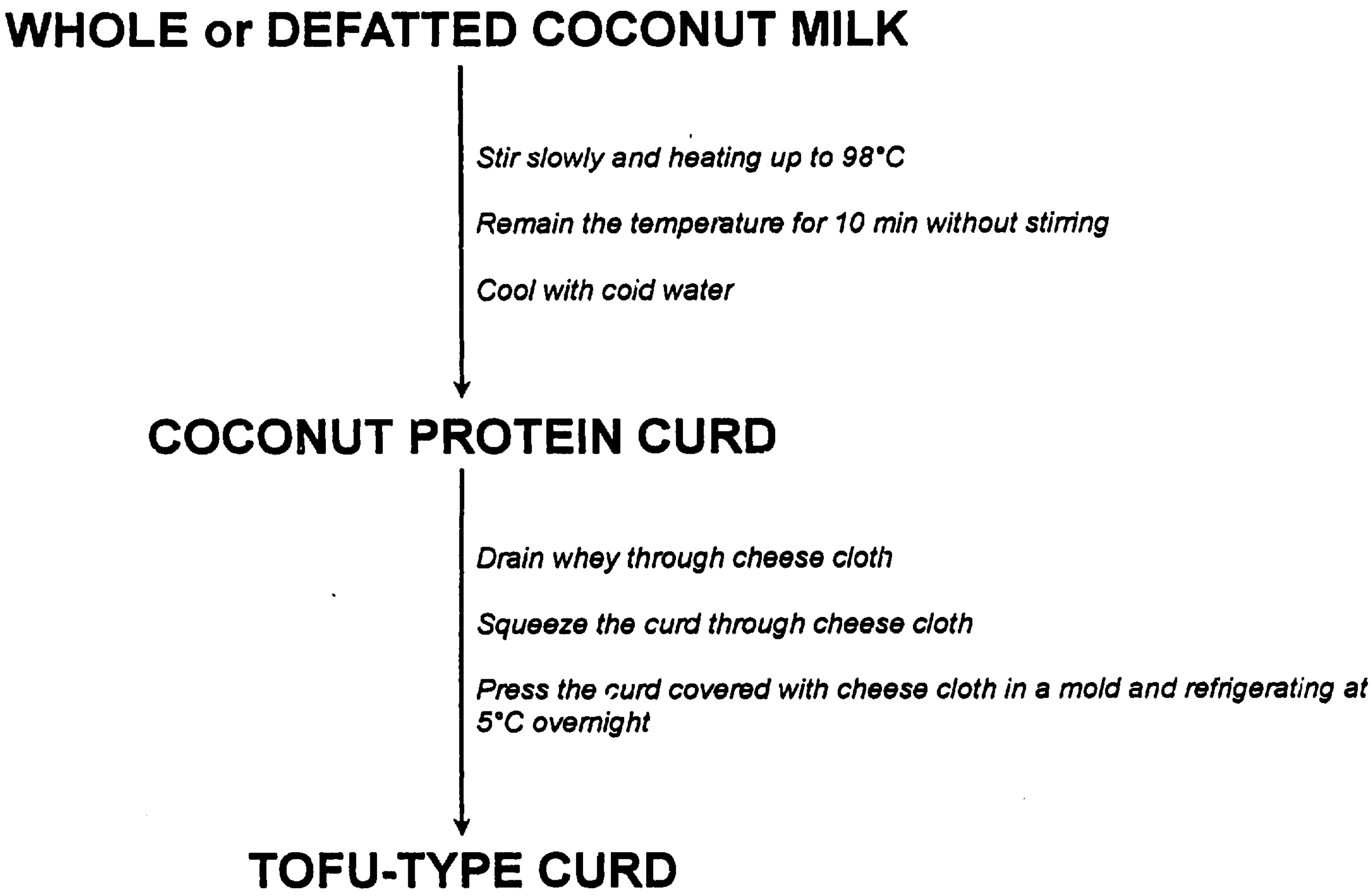

Figure 5. Schematic diagram for producing heat-coagulated tofu-type products from whole or defatted coconut milk.

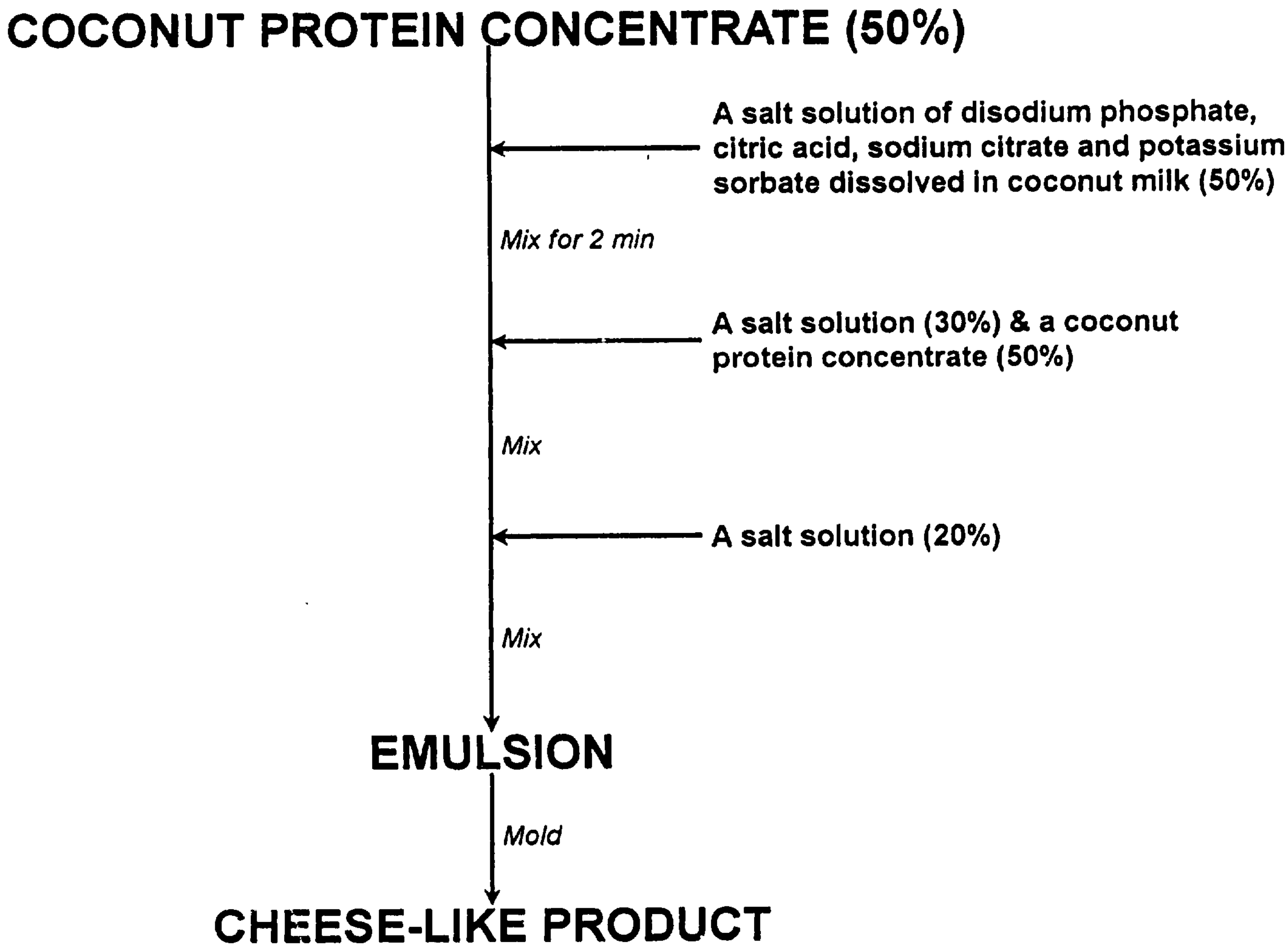

Figure 6. Production of cheese-like products from coconut protein concentrate and coconut milk.

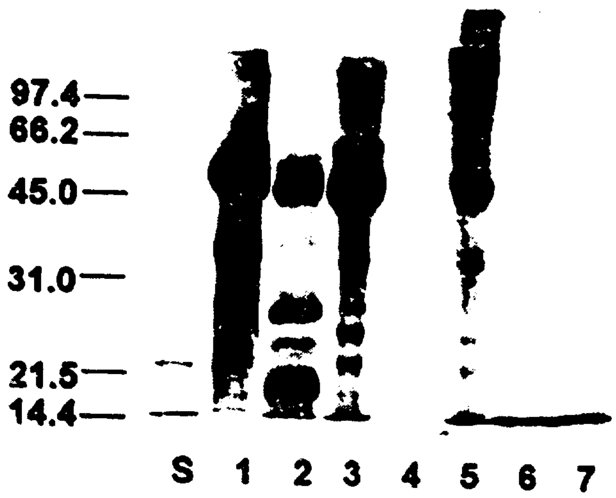

Figure 7. SDS-PAGE profiles of coconut proteins in (1) water-soluble, (2) NaCl-soluble, (3) IPA-soluble, (4) HAc-soluble, (5) NaOH-soluble, (6) residue fractions from the meal in the absence of 2-mercaptoethanol. "S" is a molecular weight standard.

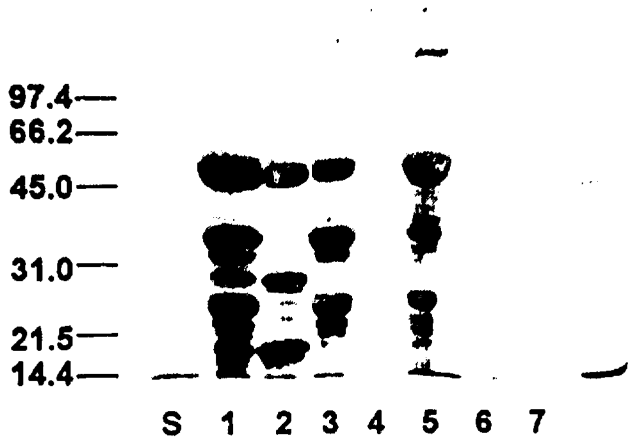

Figure 8. SDS-PAGE profiles of coconut proteins in (1) water-soluble, (2) NaCl-soluble, (3) IPA-soluble, (4) HAc-soluble, (5) NaOH-soluble, (6) residue fractions from the meal in the presence of 2-mercaptoethanol. "S" is a molecular weight standard.

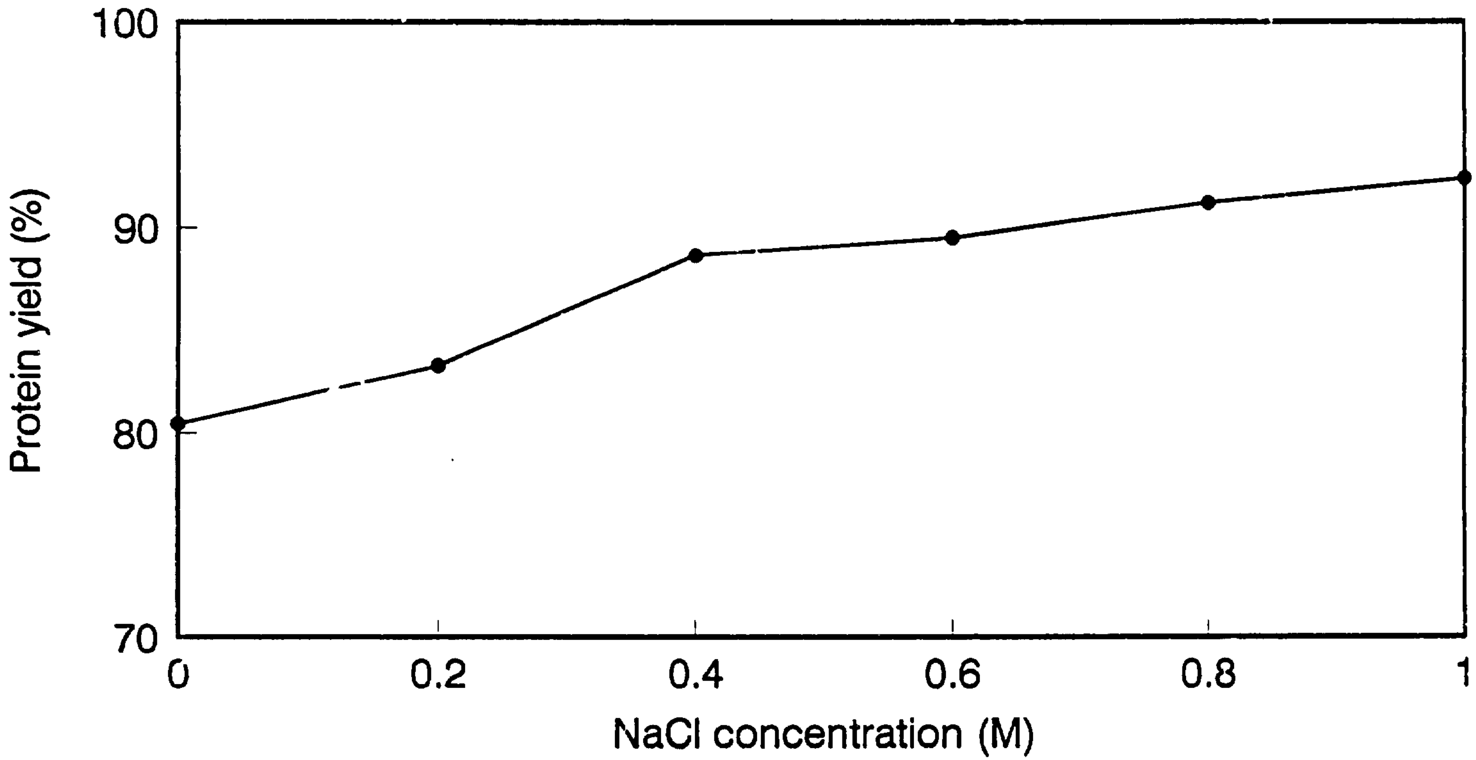

Figure 9. Yields of coconut protein at various NaCl concentrations.

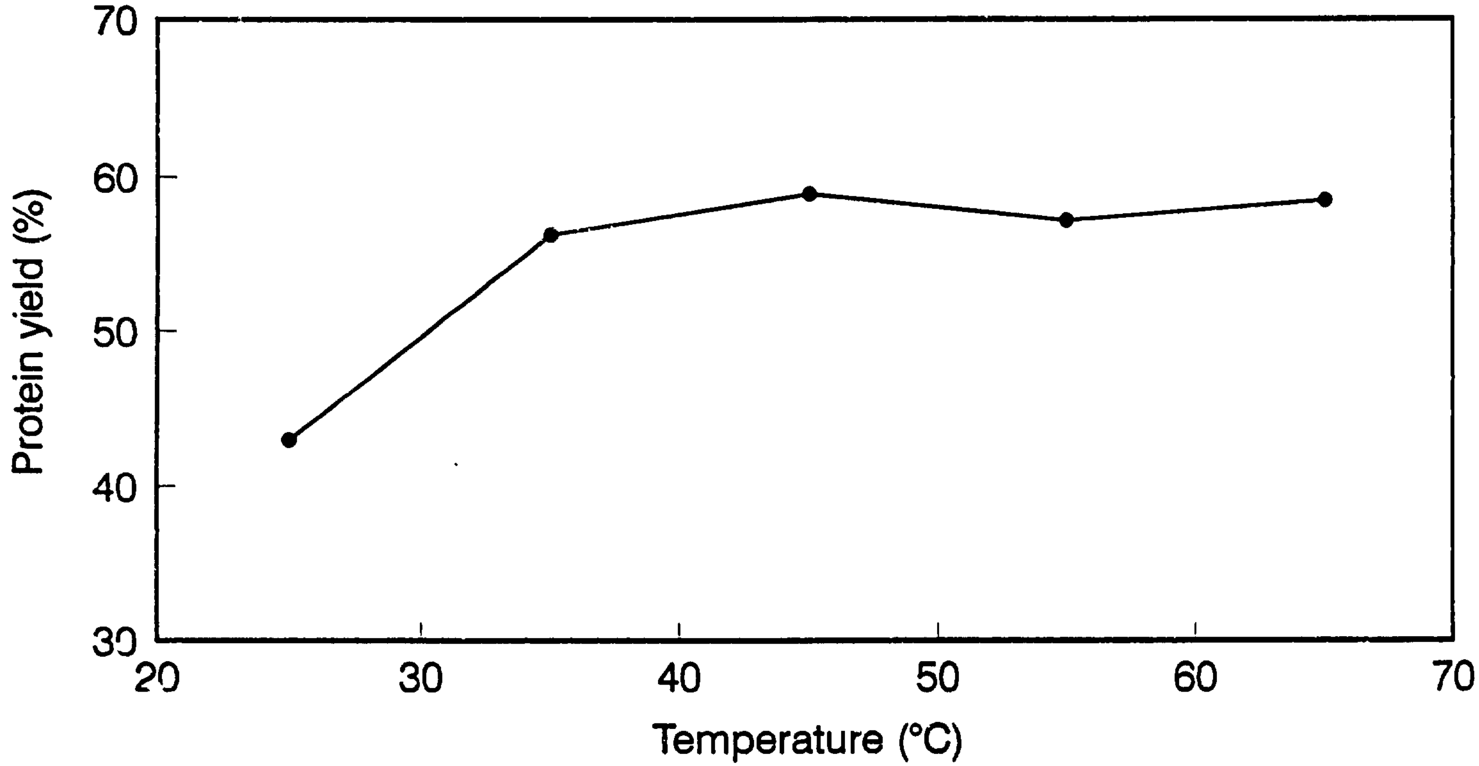

Figure 10. Effects of extraction temperature on protein yield.

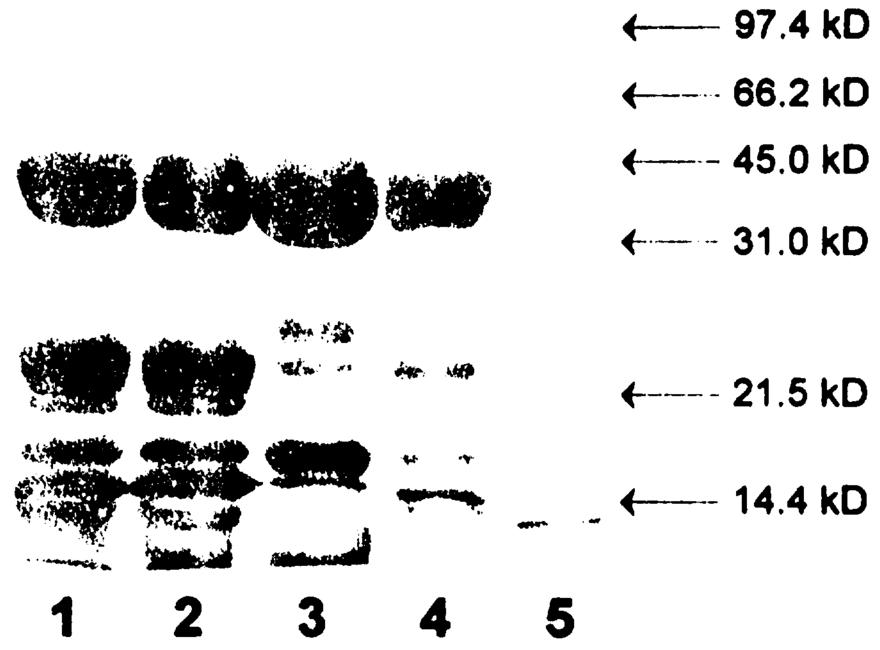

Figure 11. SDS-PAGE patterns of proteins in (1) coconut meat, (2) full-fat coconut milk, (3) centrifugally defatted coconut milk, (4) tofu-type product, and (5) molecular weight standards.

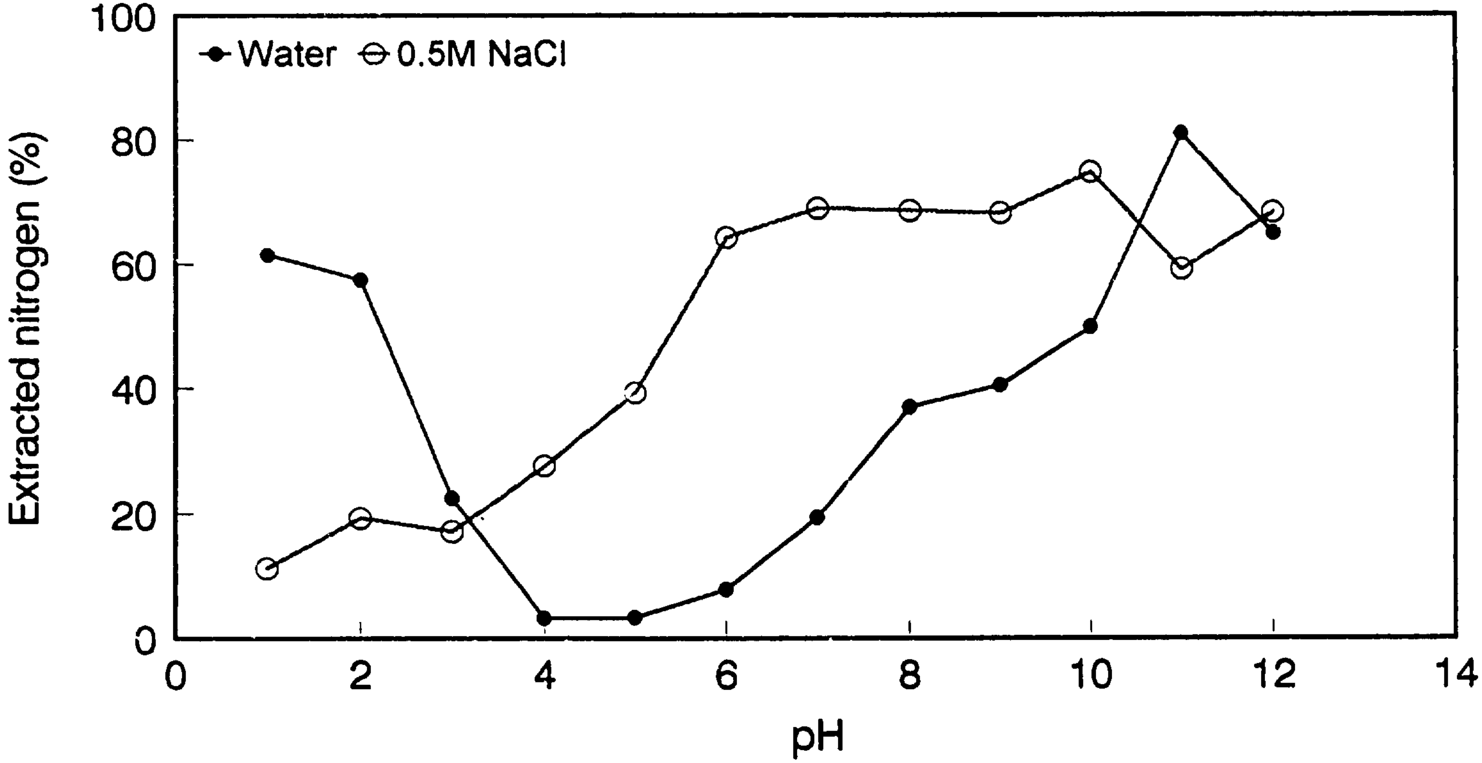

Figure 12. Percent nitrogen extracted from defatted flour in water and 0.5M NaCl at various pH's.

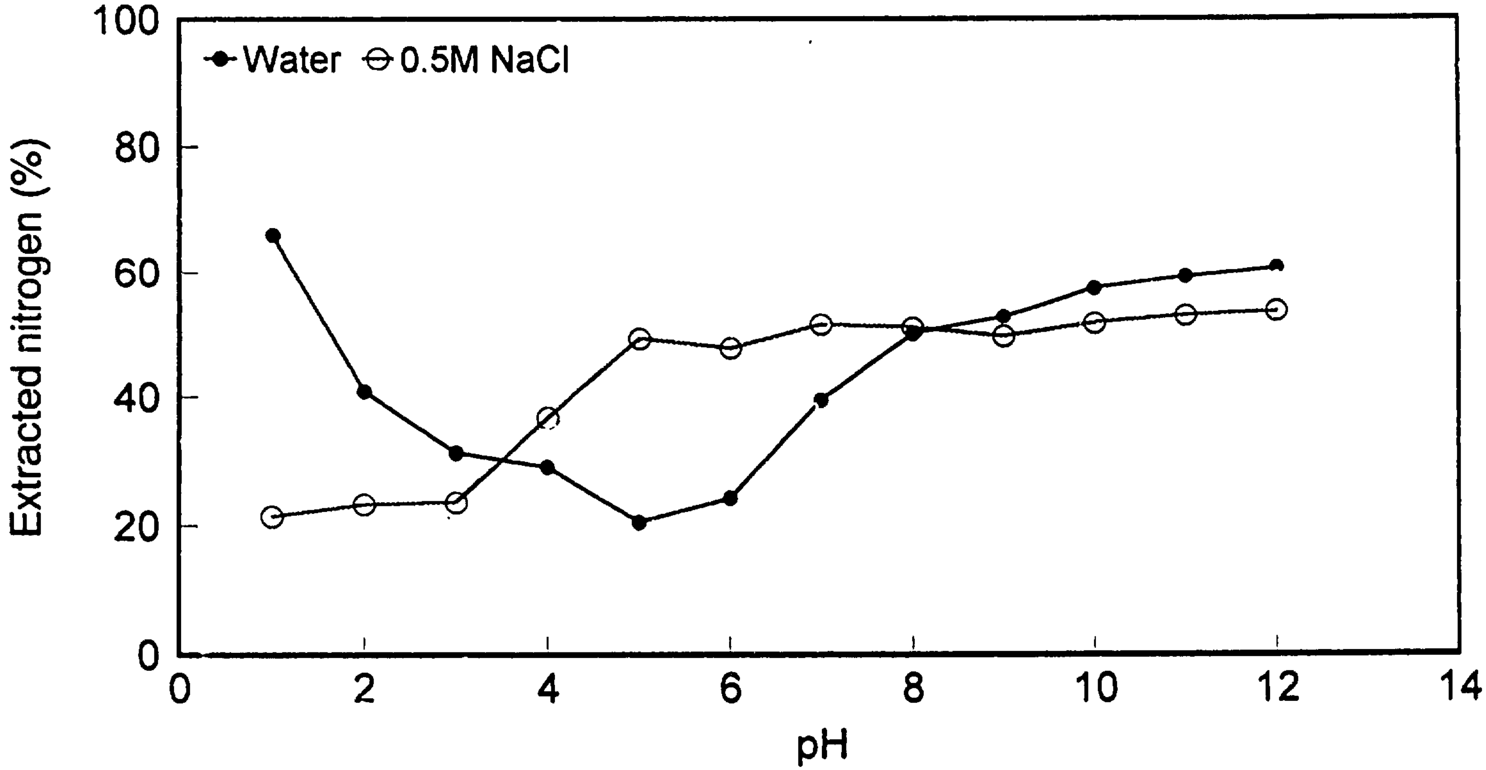

Figure 13. Percent nitrogen extracted from the coconut meat in water and 0.5M NaCl at various pH's.

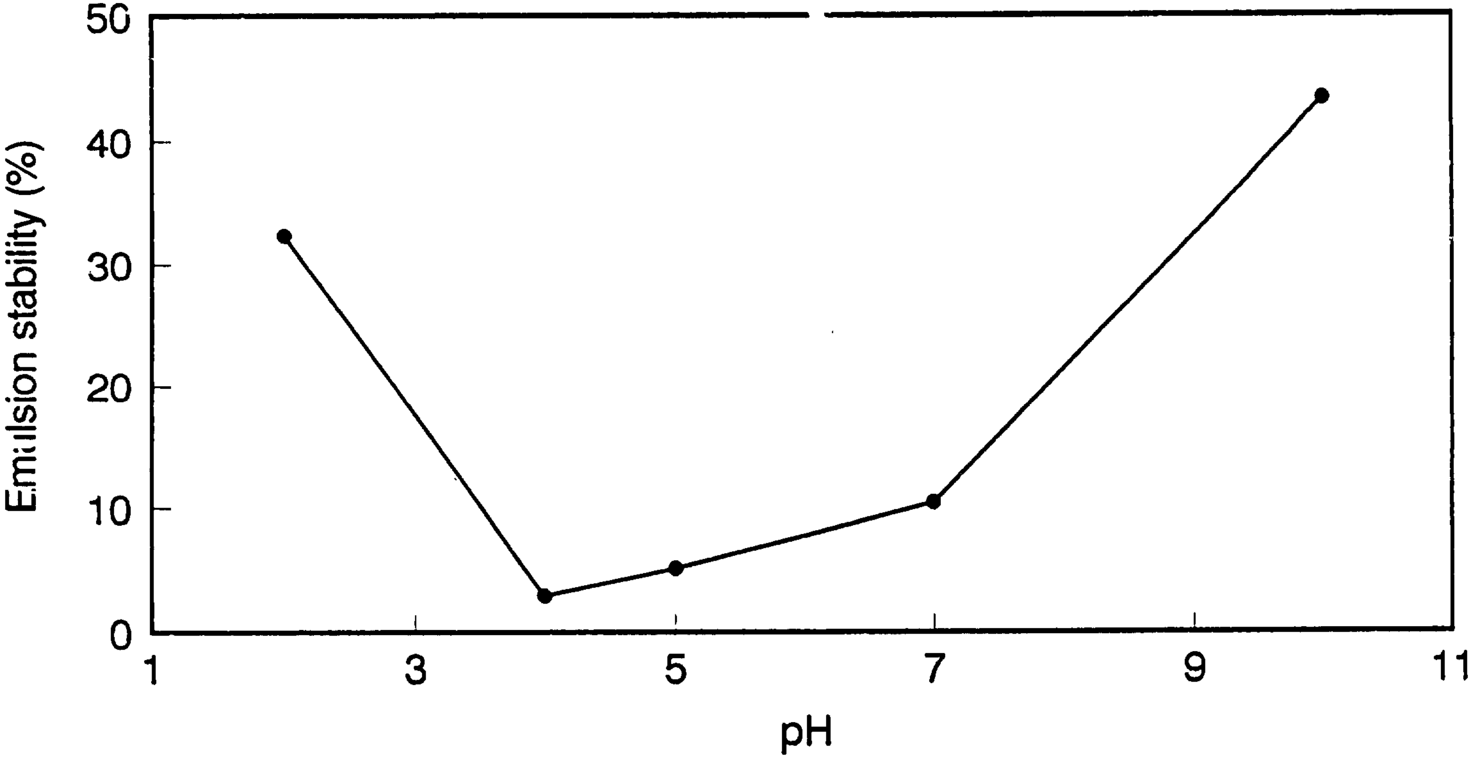

Figure 14. Effects of pH on emulsion stability of coconut protein concentrate.

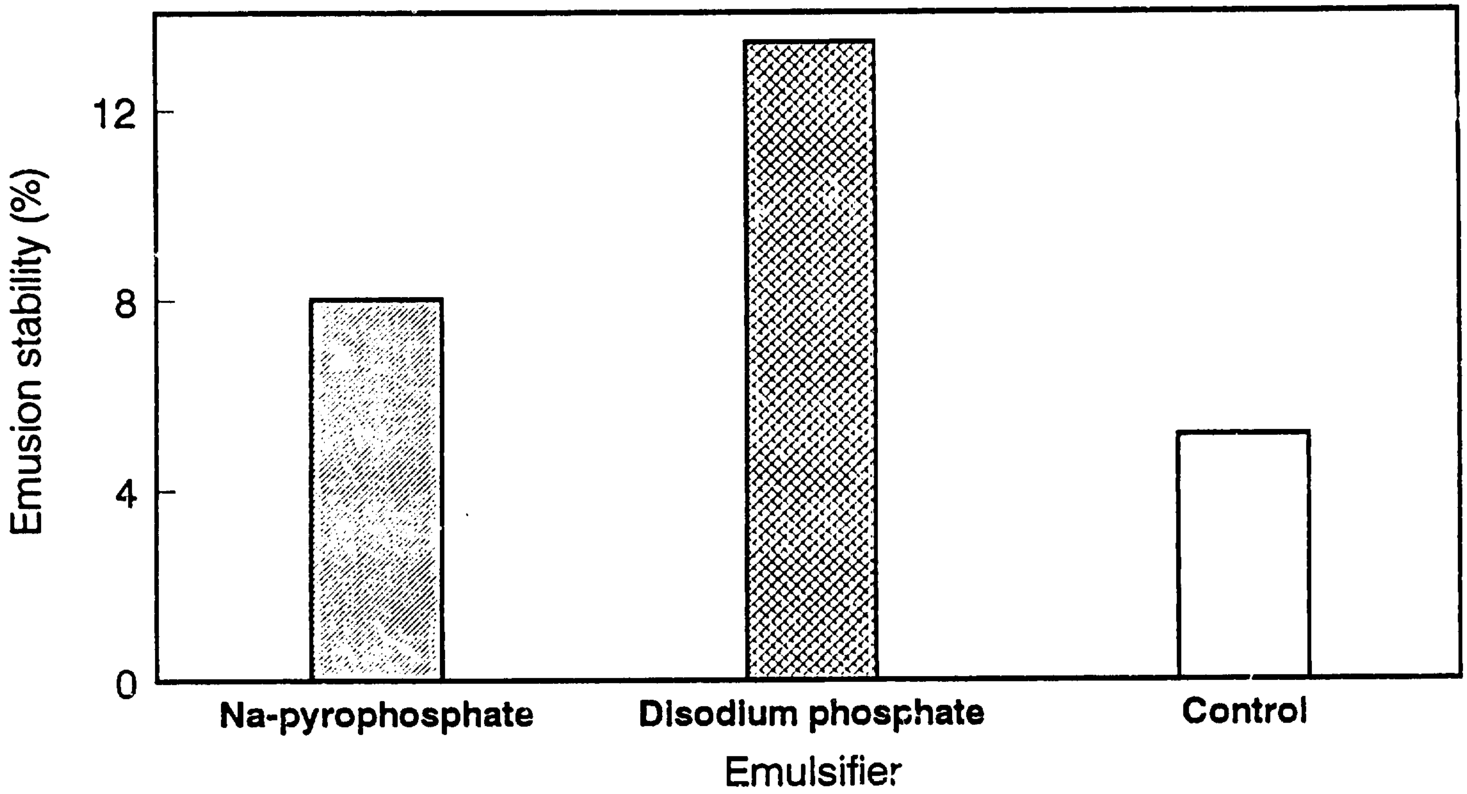

Figure 15. Effects of emulsifiers on emulsion stability of coconut protein concentate.

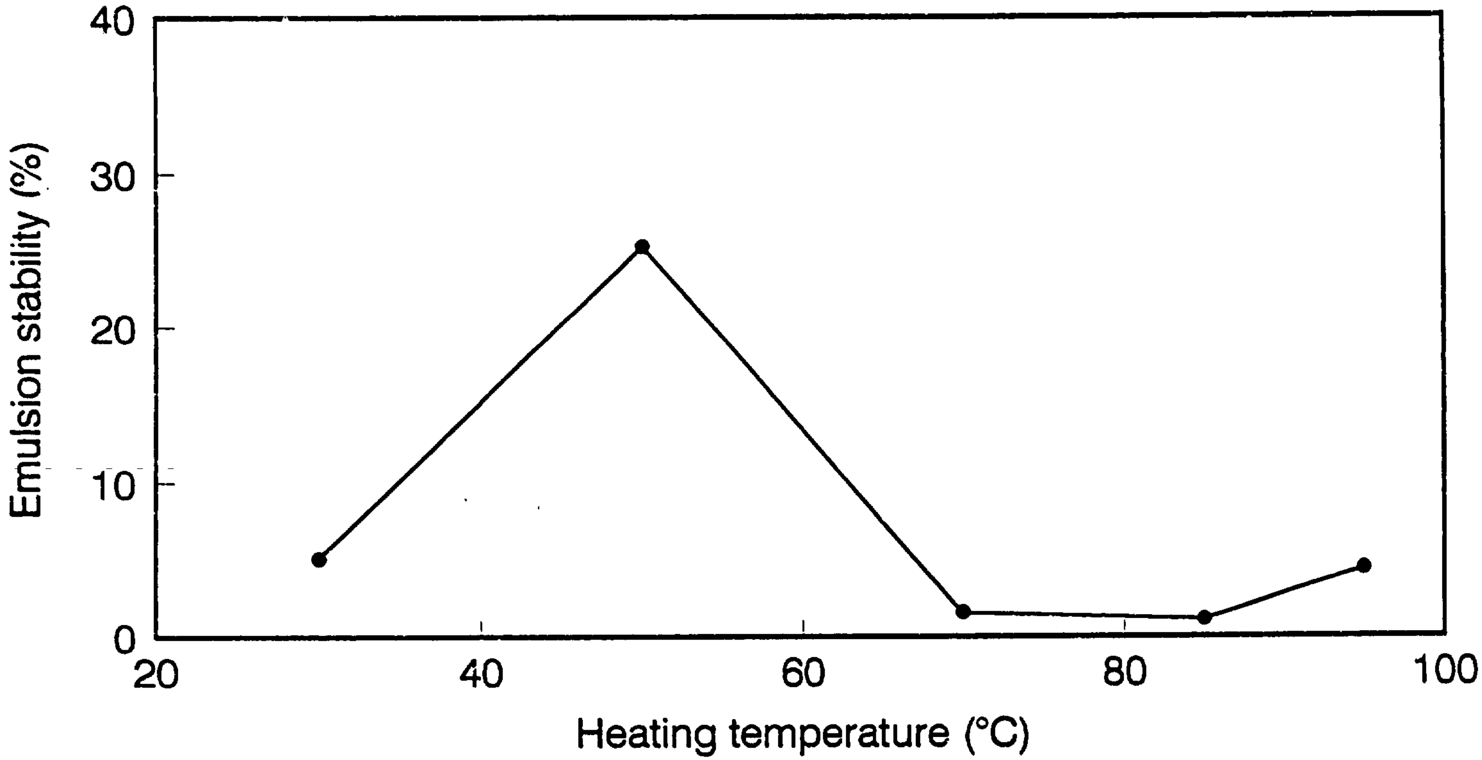

Figure 16. Effects of heating temperature on emulsion stability of coconut protein concentrate.

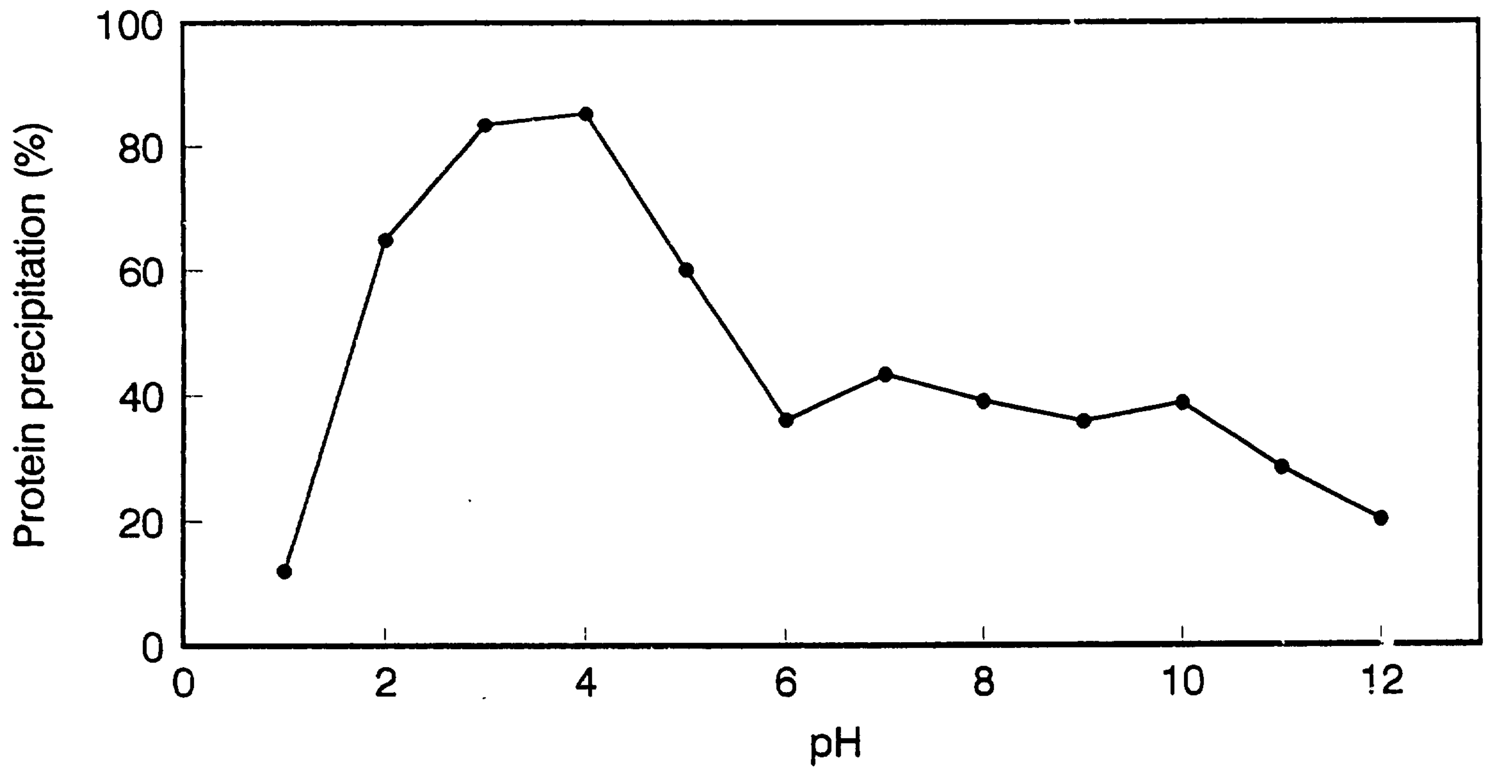

Figure 17. Precipitability profiles of coconut proteins at various pH's.

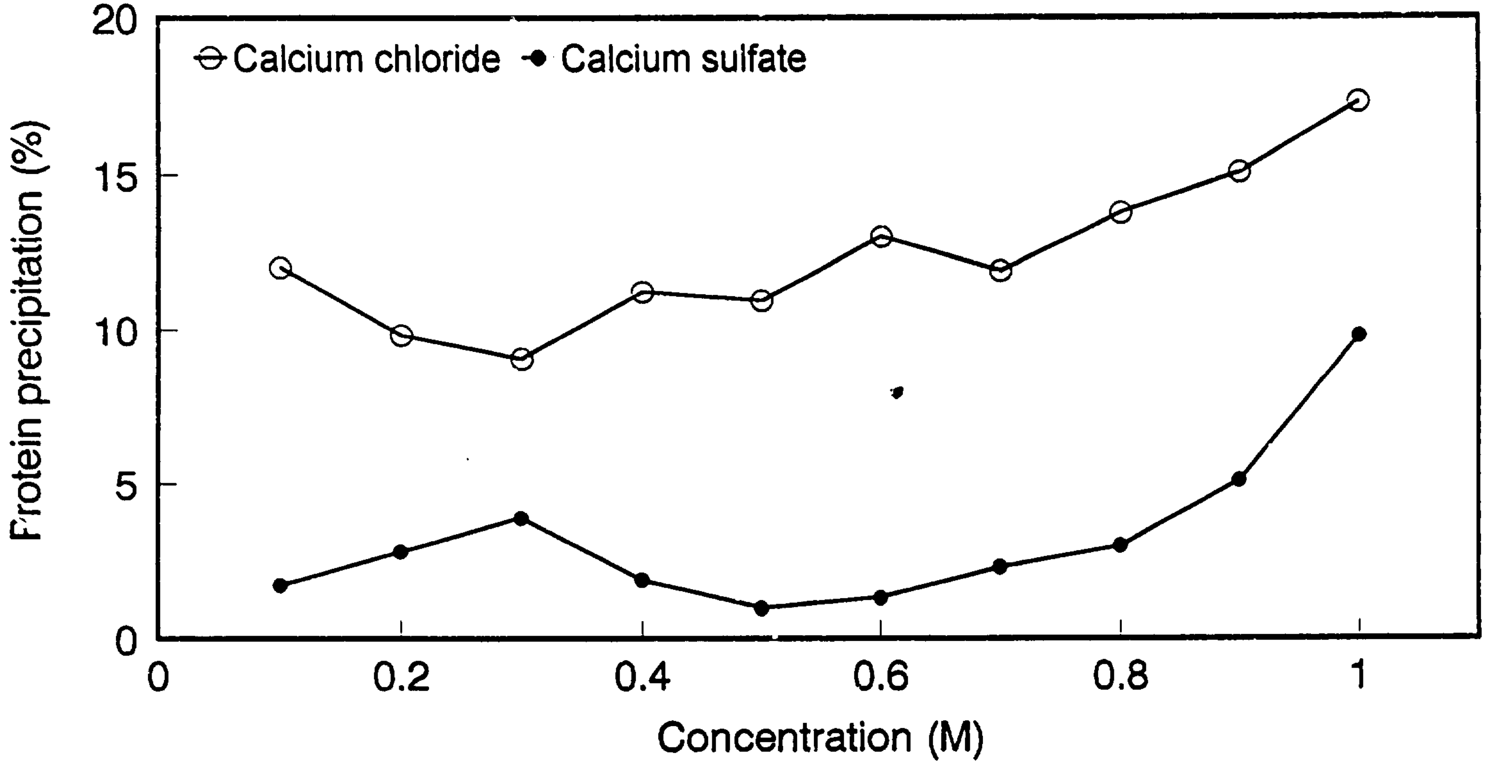

Figure 18. Effects of salt types and concentrations on the precipitability of coconut protein.

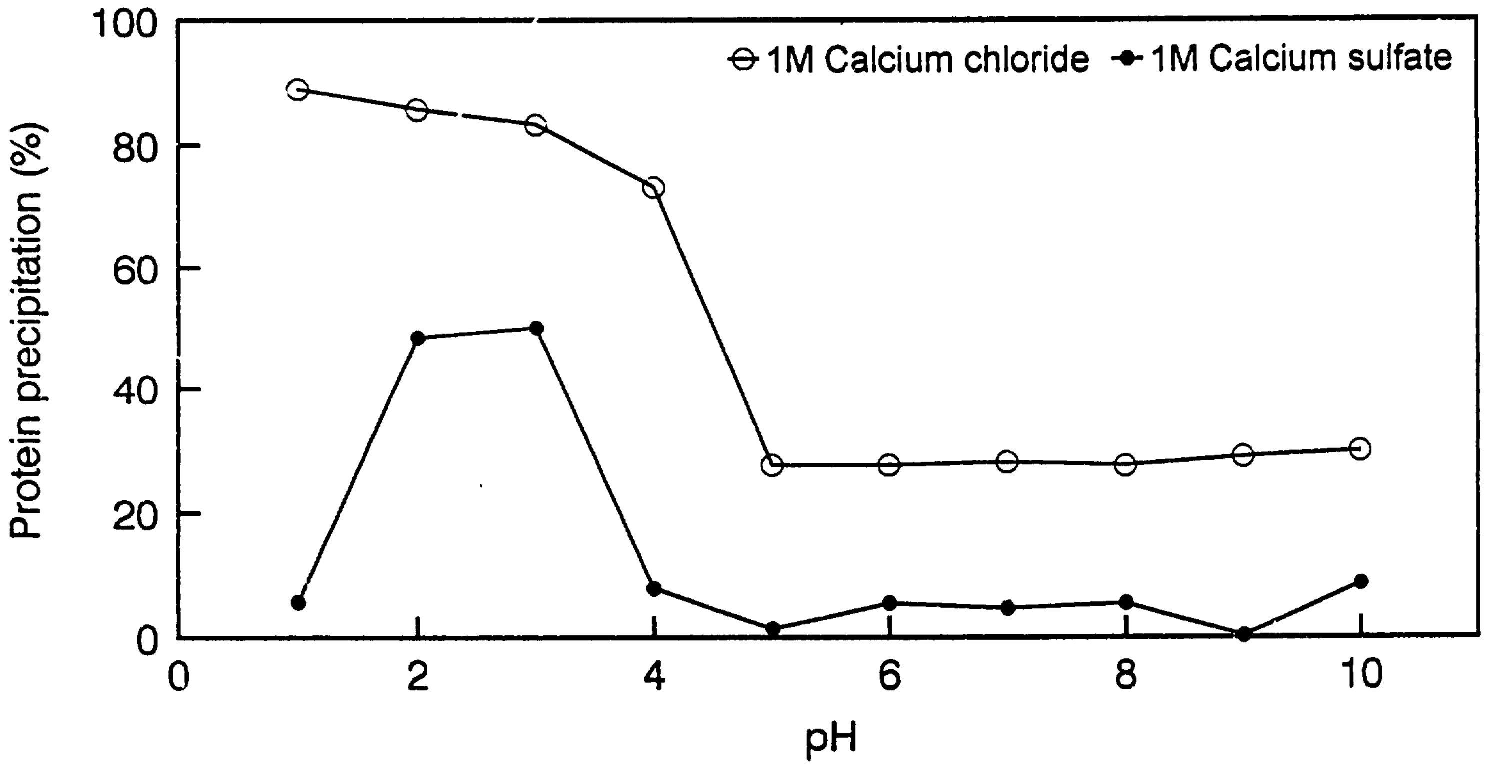

Figure 19. Effects of calcium salts on the precipitability of coconut proteins at various pH's in the presence of 0.5M-NaCl.

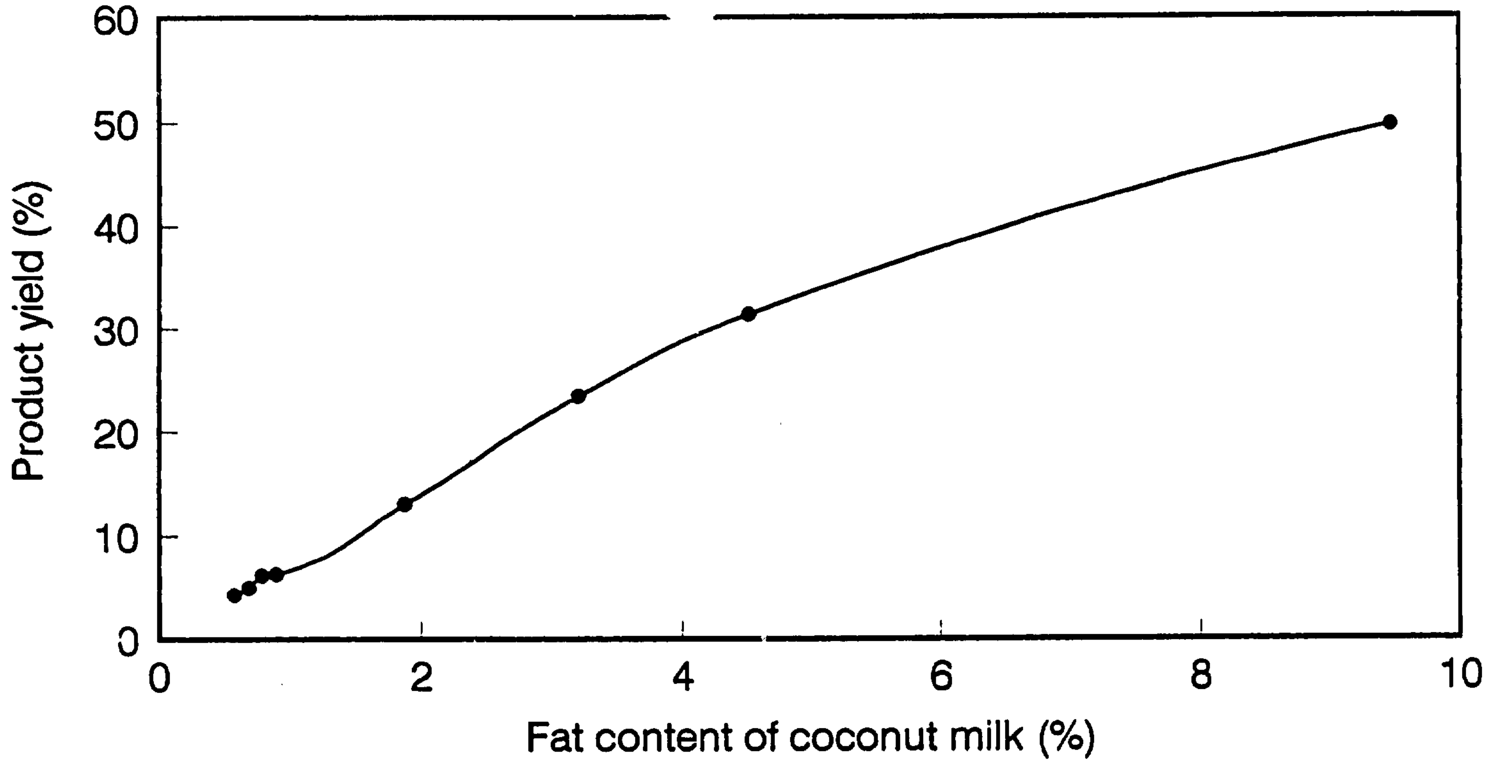

Figure 20. Effects of fat content of coconut milk on the yield of tofu-type product.

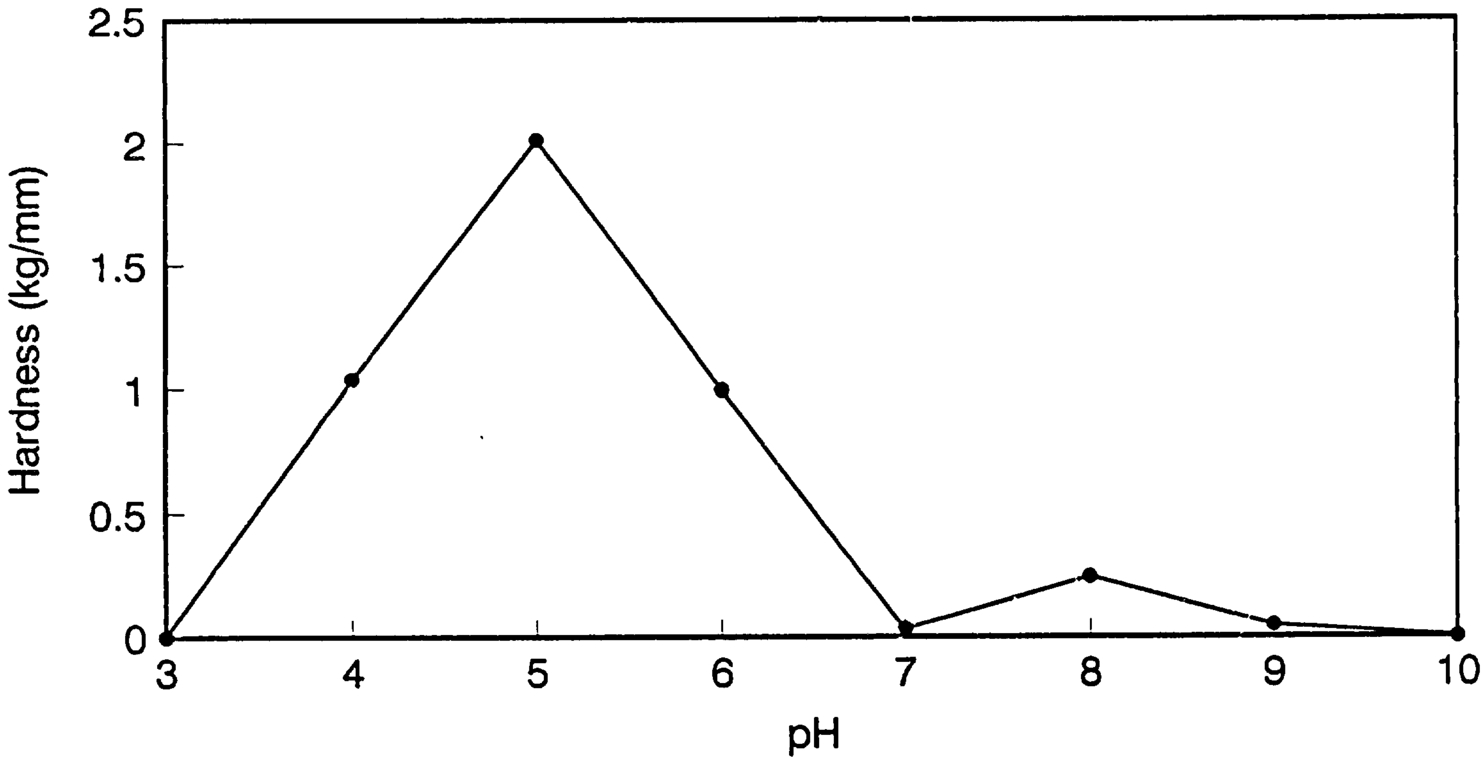

Figure 21. Effects of pH on the hardness of tofu-type curds.

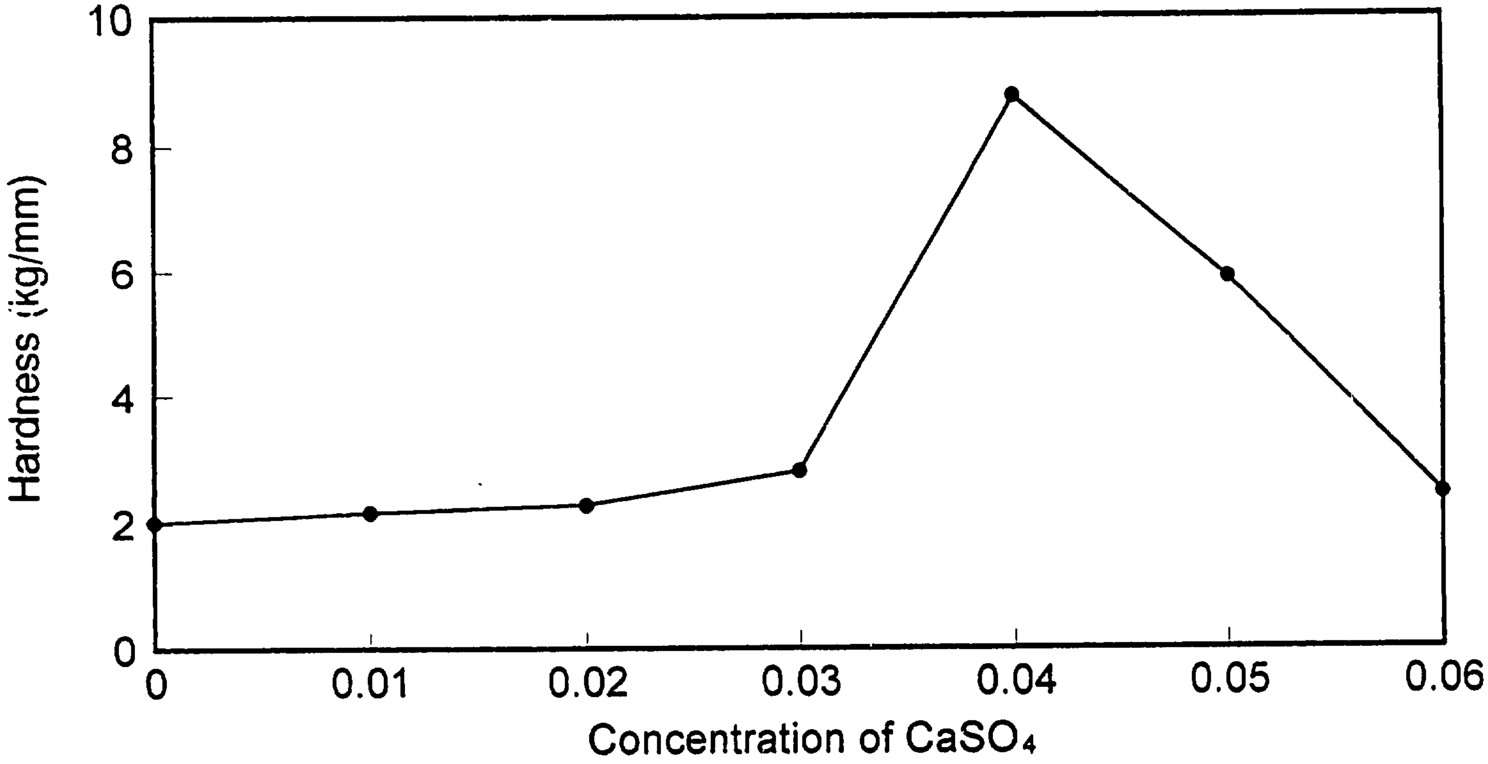

Figure 22. Effects of $CaSO_4$ concentration on the hardness of tofu-type curds.

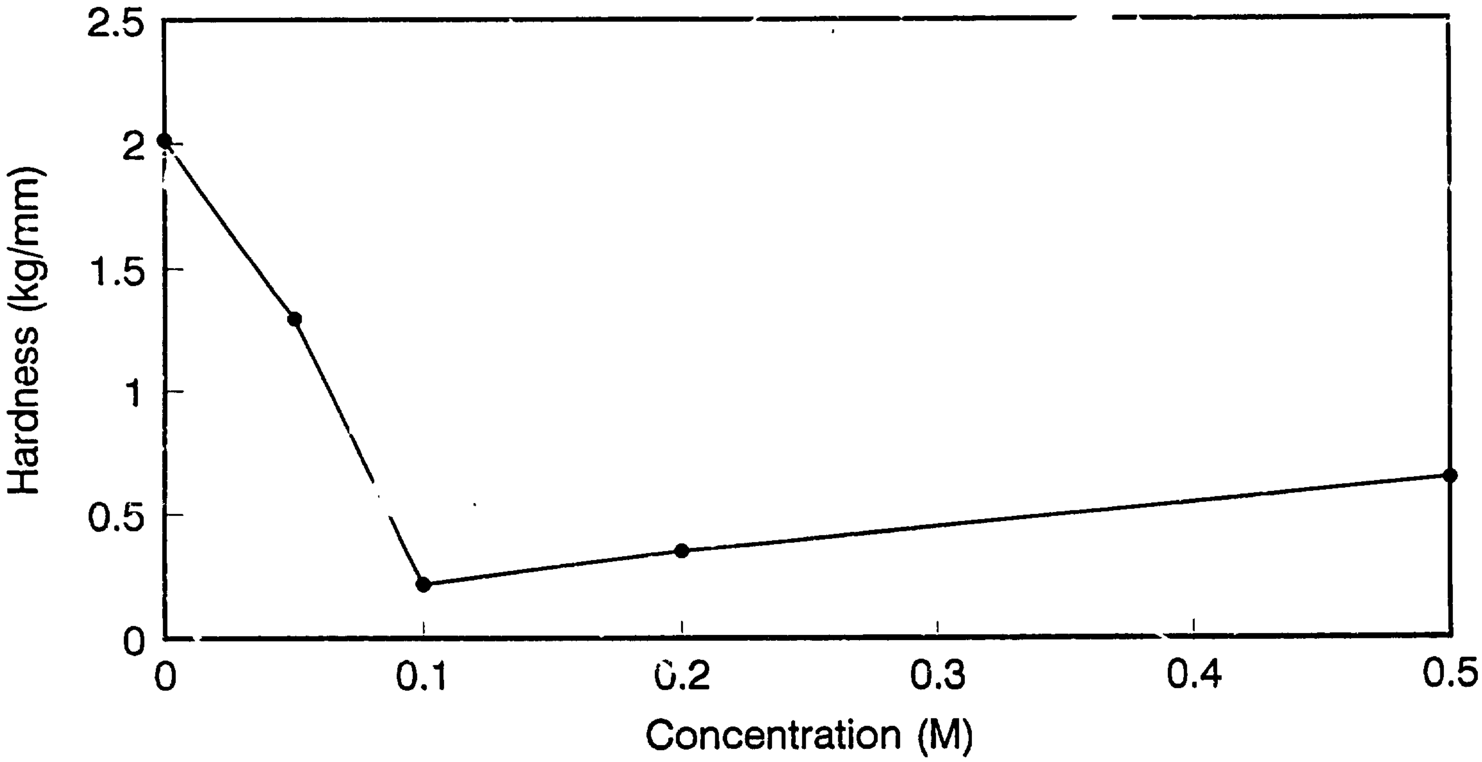

Figure 23. Effects of NaCl concentration on the hardness of tofu-type curds.

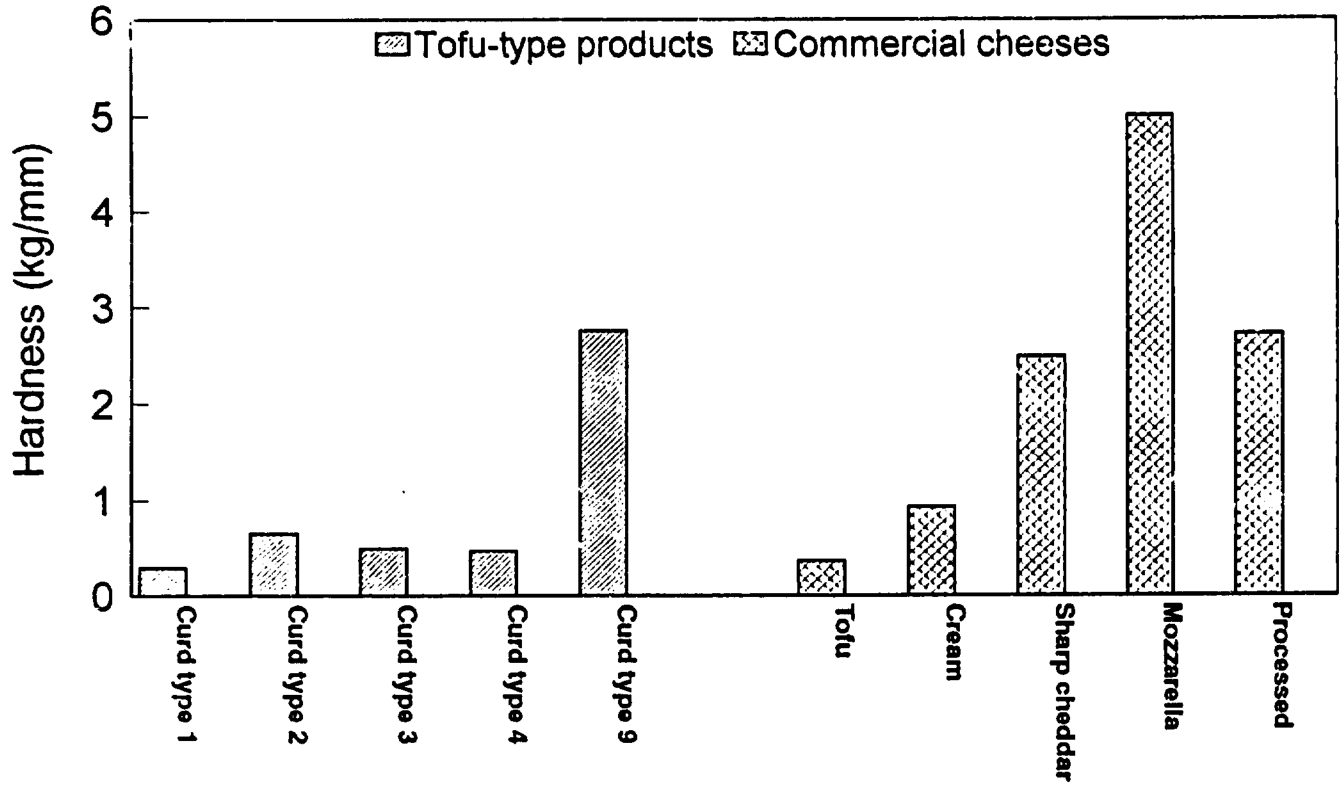

Figure 24. Comparison of hardness among different tofu-type products and commercial cheeses as determined by the texture profile analysis curve.

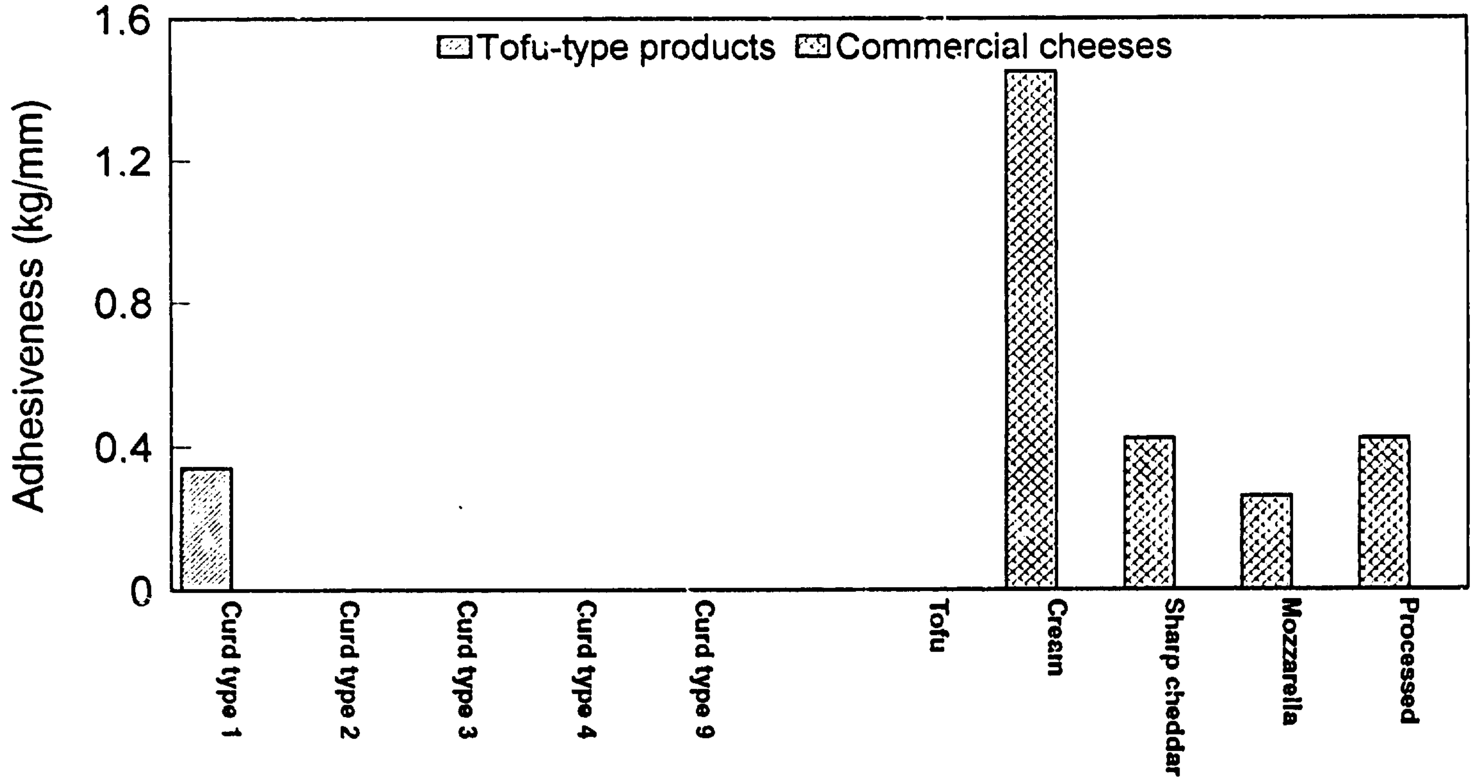

Figure 25. Comparison of adhessiveness among different tofu-type products and commercial cheeses as determined by the texture profile analysis curve.

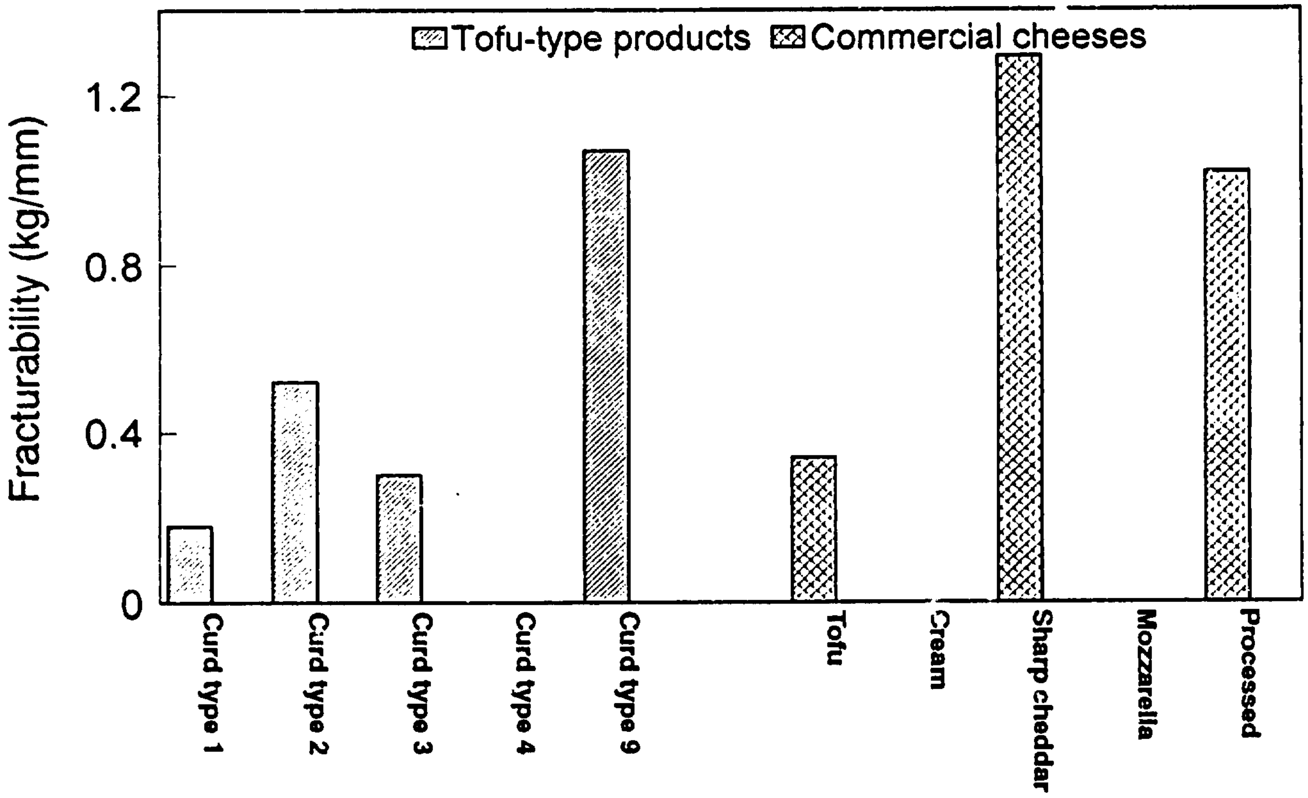

Figure 26. Comparison of fracturability among different tofu-type products and commercial cheeses as determined by the texture profile analysis curve.

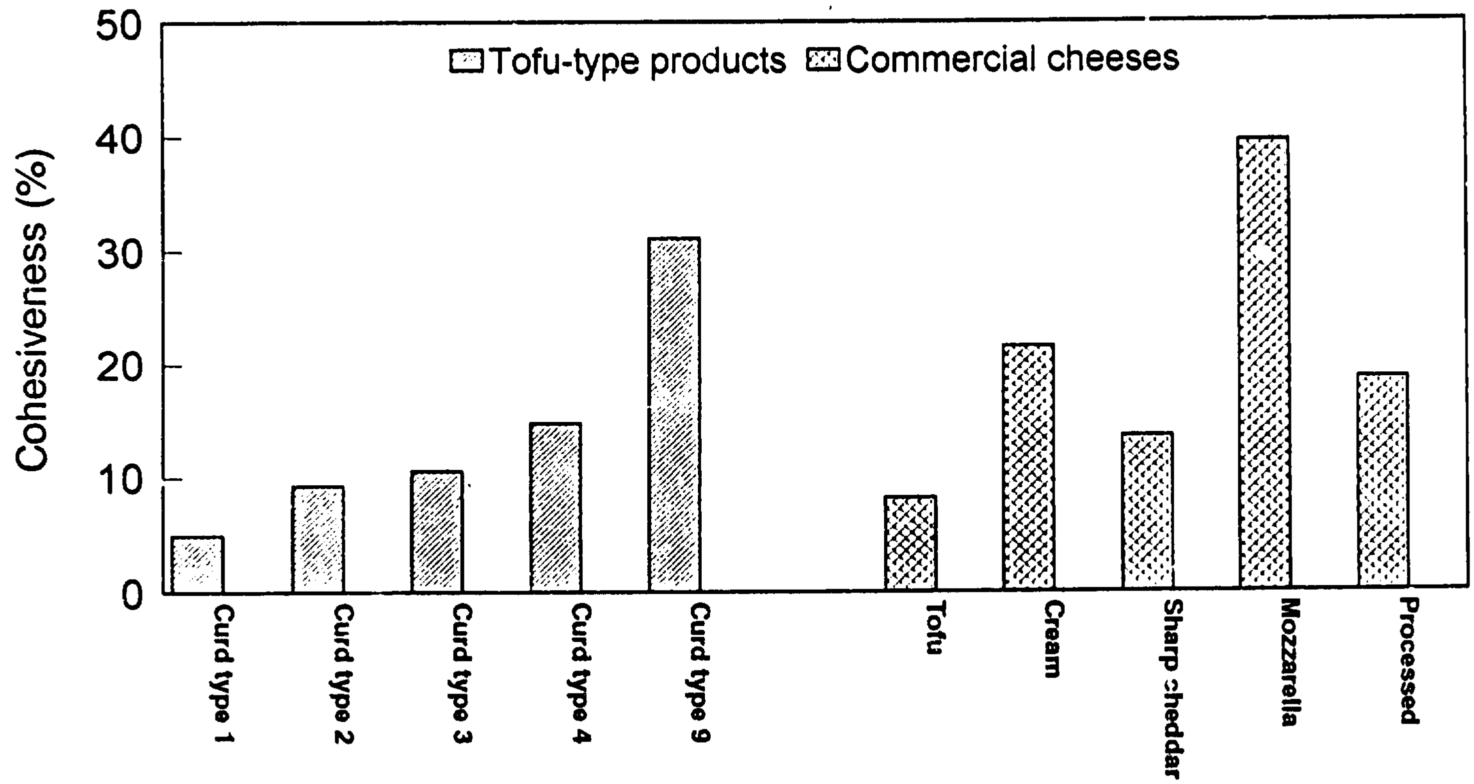

Figure 27. Comparison of cohesiveness among different tofu-type products and commercial cheeses as determined by the texture profile analysis curve.

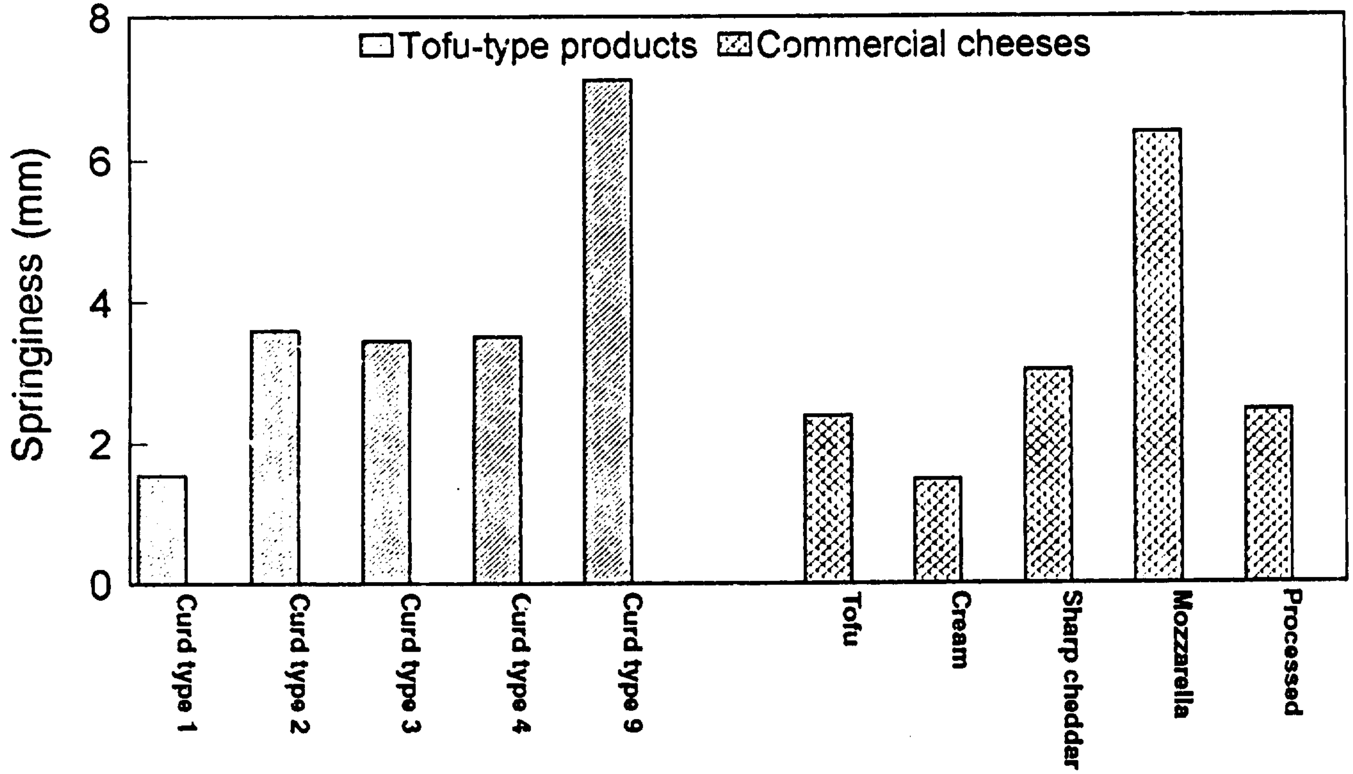

Figure 28. Comparison of springiness among different tofu-type products and commercial cheeses as determined by the texture profile analysis curve.

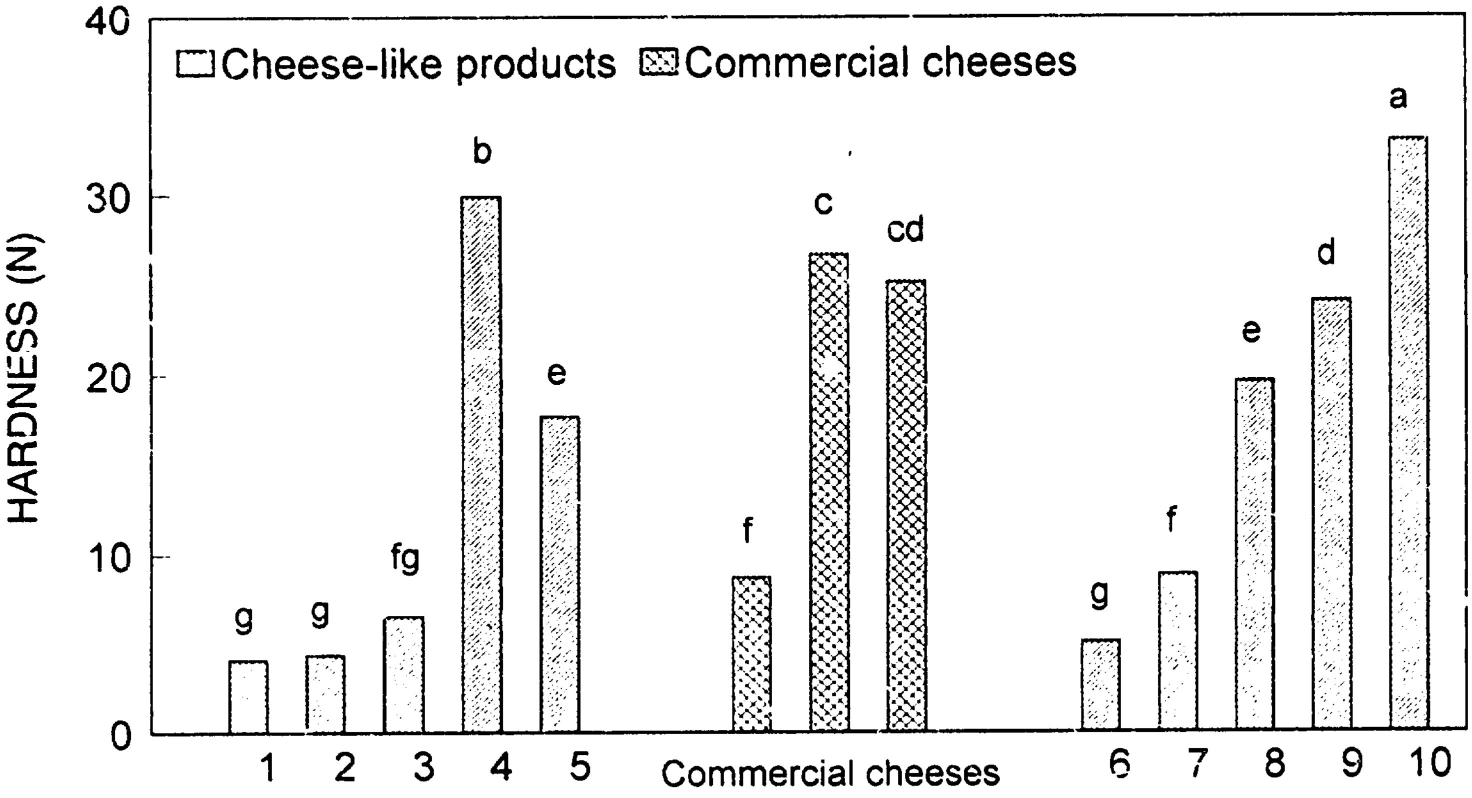

Figure 29. Comparison of hardness as determined by the Texture Profile Analysis between cheese-like products and commercial cheeses: 1 to 5 -- cheese-like products containing 0%(1),10%(2), 20%(3), 30%(4) Na-caseinate, and 15%(5) non-fat dry milk. Commercial cheeses from left to right -- Cream, Processed, and Sharp Cheddar. 6 to 10 -- cheese-like product containing different levels of coconut protein ingredients. Data with a common letter do not differ significantly (P> 0.05)

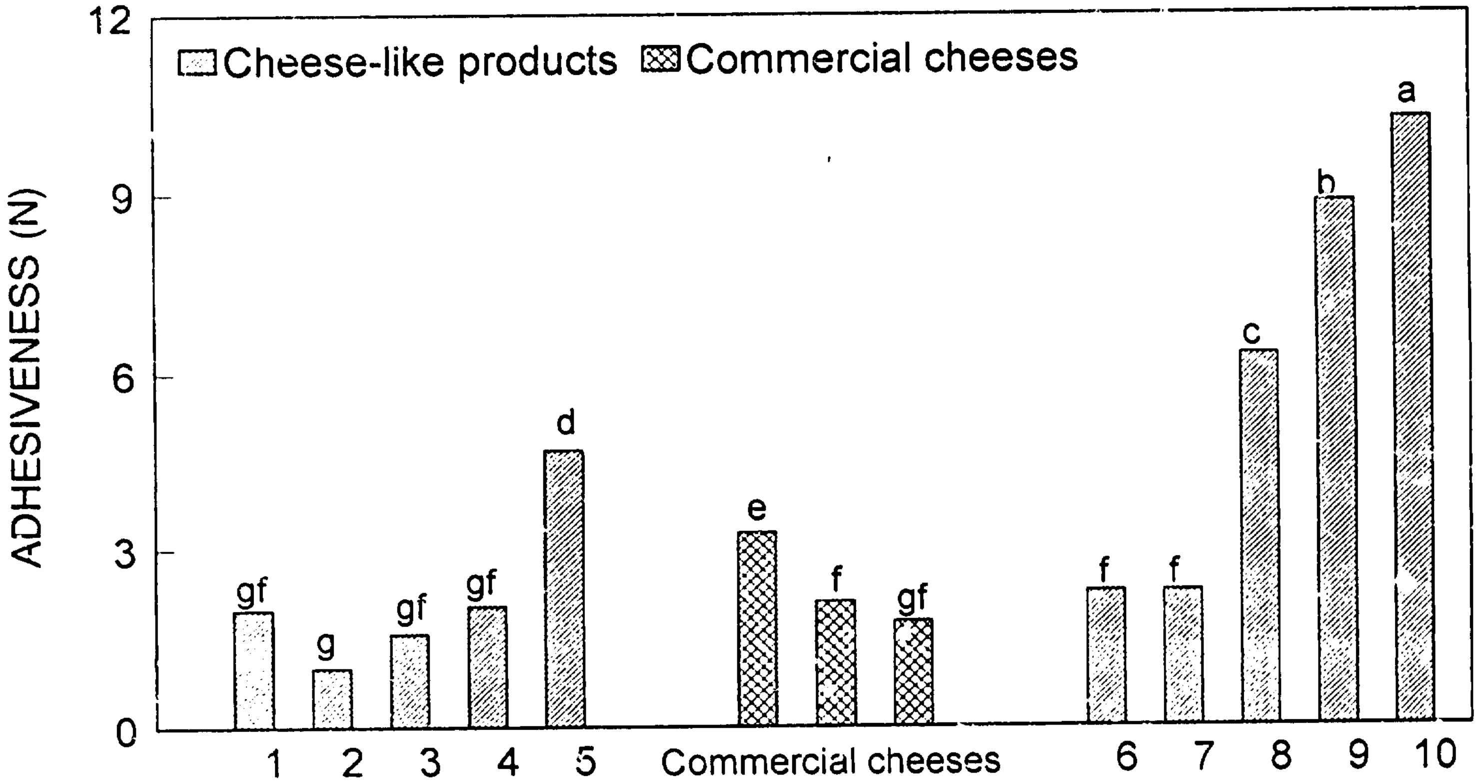

Figure 30. Comparison of adhesiveness as determined by the Texture Profile Analysis between cheese-like products and commercial cheeses: 1 to 5 -- cheese-like products containing 0%(1), 10%(2), 20%(3), 30%(4) Na-caseinate, and 15%(5) non-fat dry milk. Commercial cheeses from left to right -- Cream, Processed, and Sharp Cheddar. 6 to 10 -- cheese-like products containing different levels of coconut protein ingredients. Data with a common letter do not differ significantly (P> 0.05)

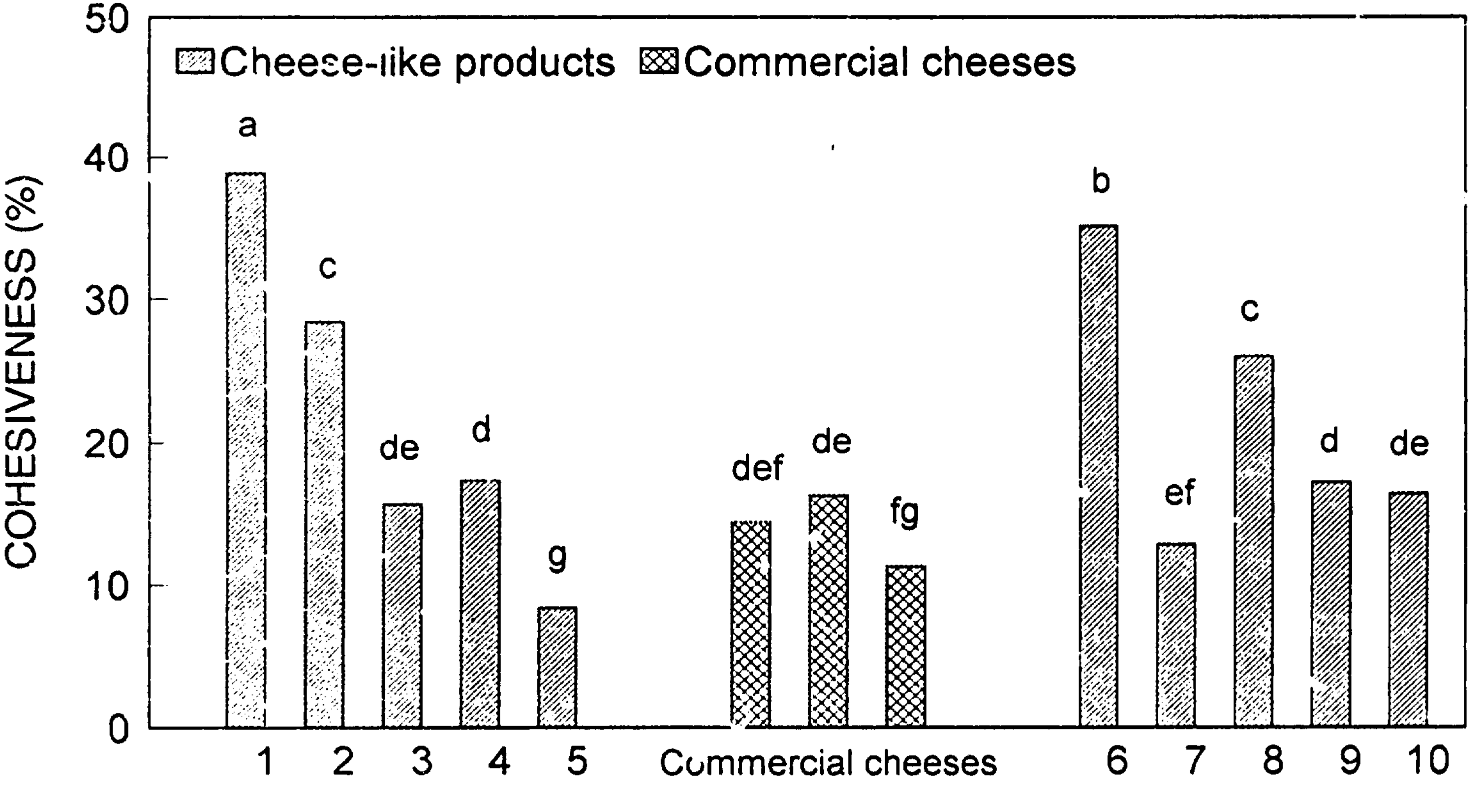

Figure 31. Comparison of cohesiveness as determined by the Texture Profile Analysis between cheese-like products and commercial cheeses: 1 to 5 -- cheese-like products containing 0%(1), 10%(2), 20%(3), 30%(4) Na-caseinate, and 15%(5) non-fat dry milk. Commercial cheeses from left to right -- Cream, Processed, and Sharp Cheddar. 6 to 10 -- cheese-like products containing different levels of coconut protein ingredients. Data with a common letter do not differ significantly (P> 0.05)

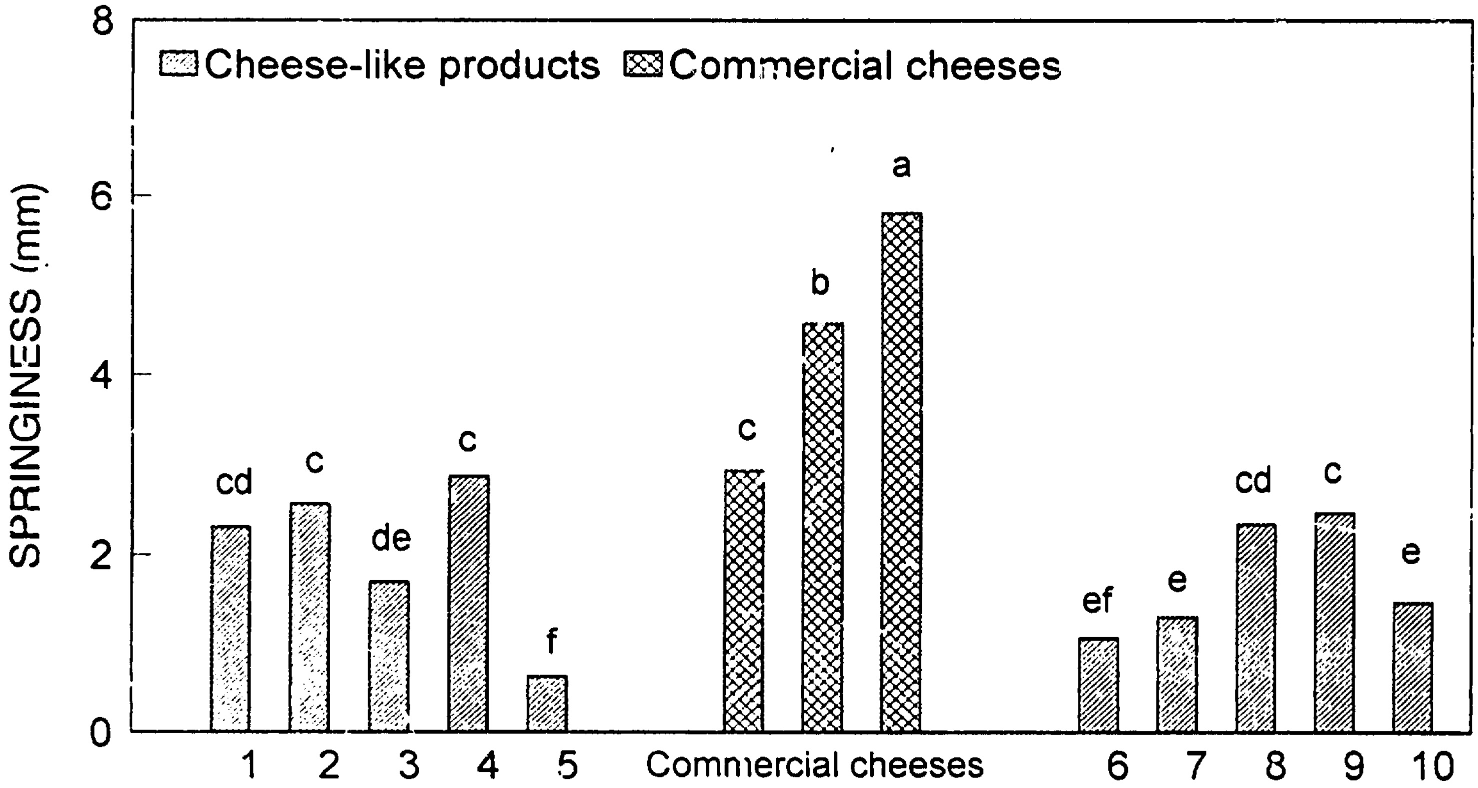

Figure 32. Comparison of springiness as determined by the Texture Prpfile Analysis between cheese-like products and commercial cheeses: 1 to 5 -- cheese-like products containing 0%(1), 10%(2), 20%(3), 30%(4) Na-caseinate, and 15%(5) non-fat dry milk. Commercial cheeses from left to right -- Cream, Processed, and Sharp Cheddar. 6 to 10 -- cheese-like products containing different levels of coconut protein ingredients. Data with a common letter do not differ significantly (P> 0.05)

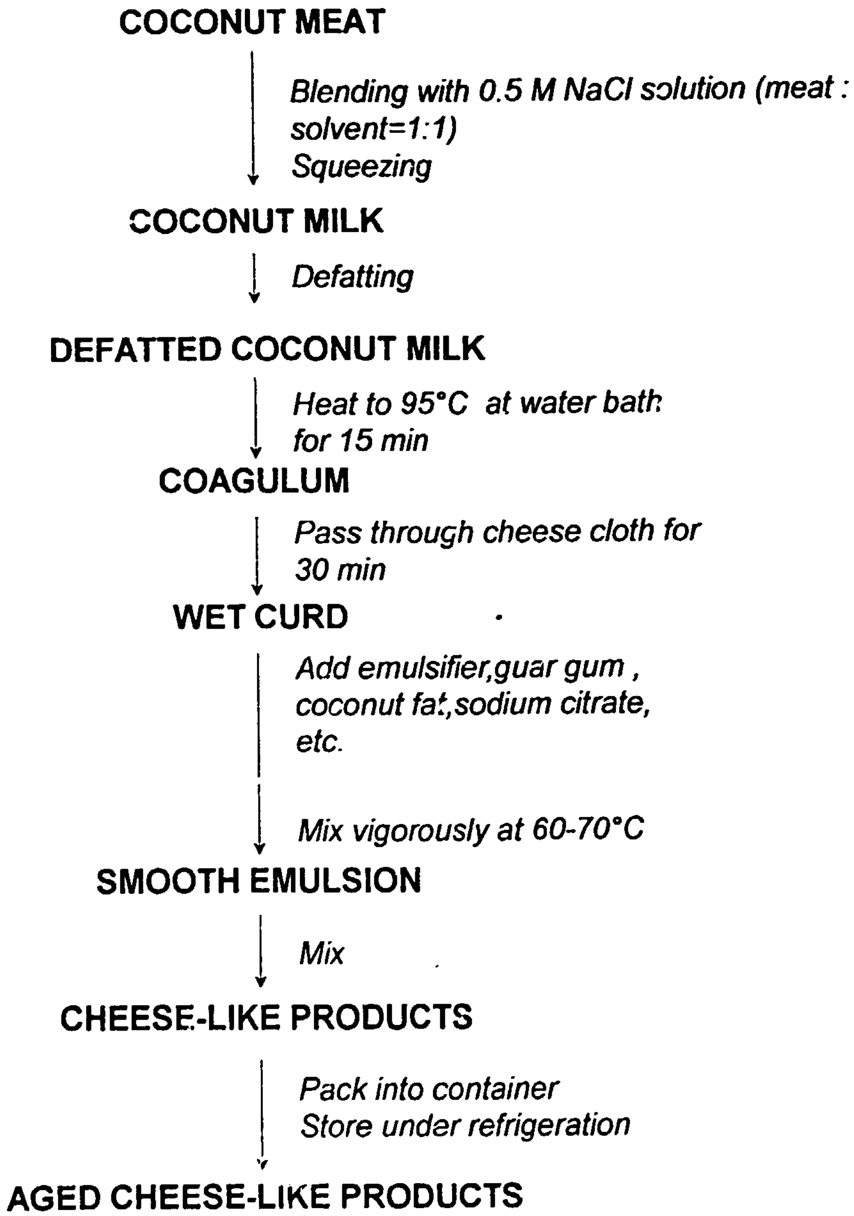

Figure 33. Schematic diagram for manufacturing cheese-like products from coconut curd and guar gum.

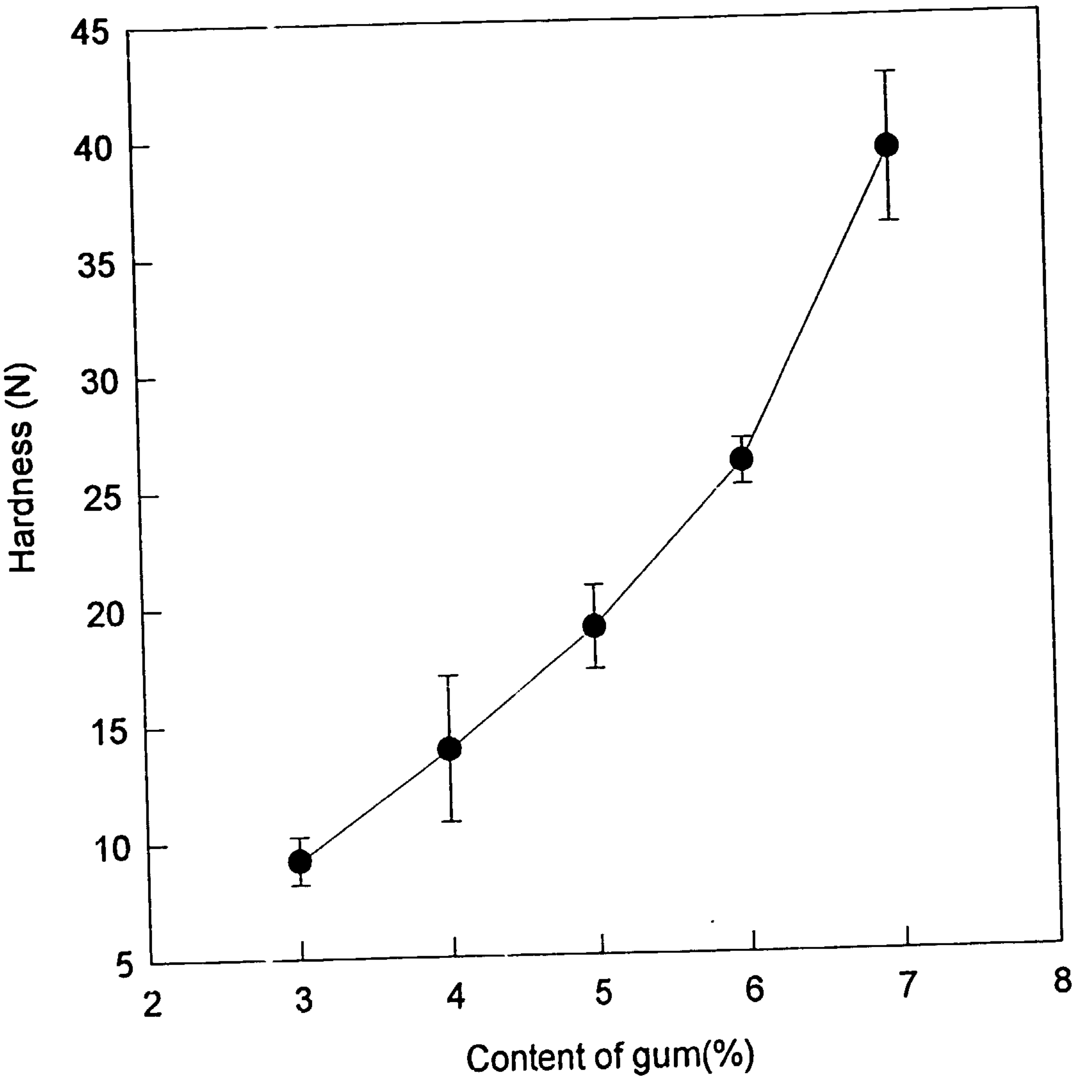

Figure 34. Hardness of coconut cheese-like product from coconut curd at various guar gum contents.

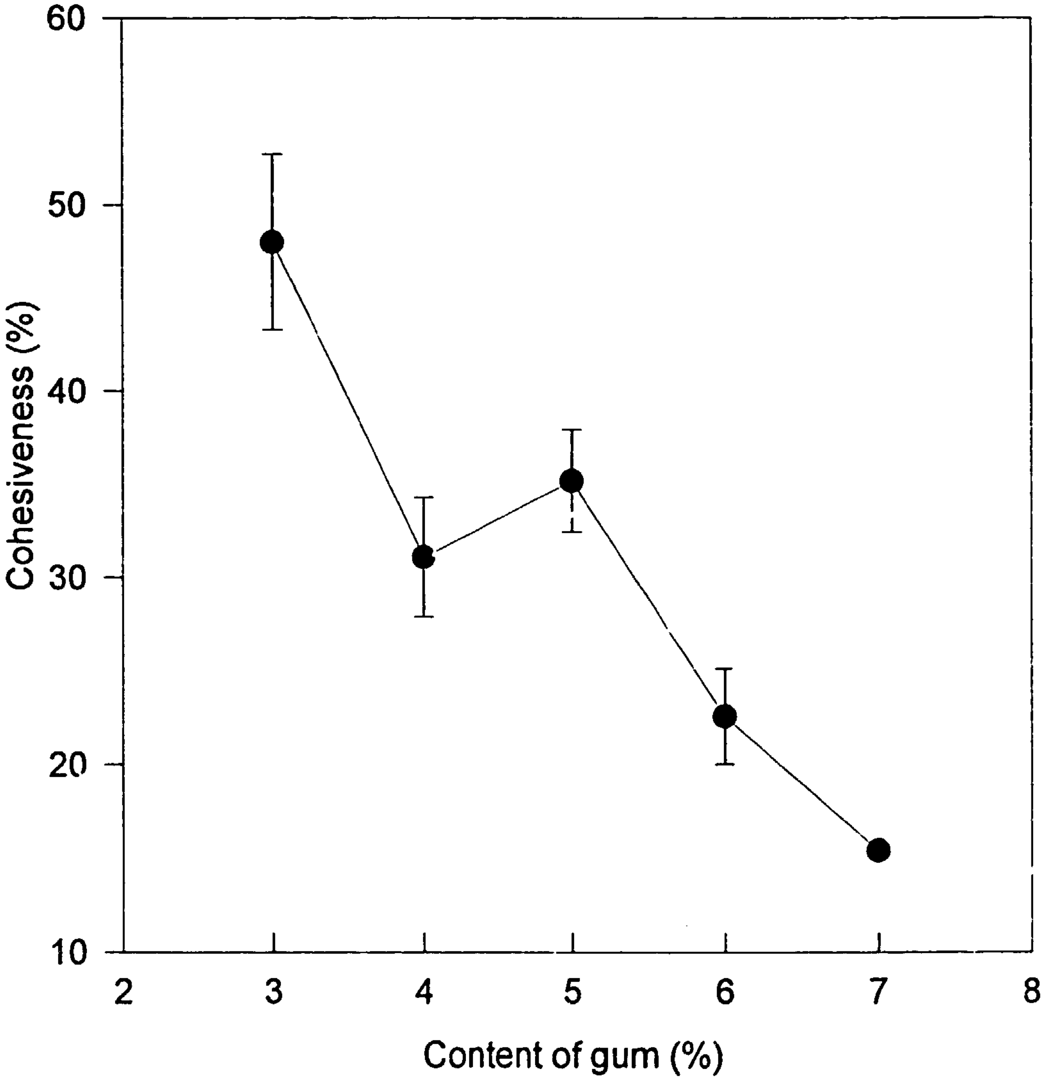

Figure 35. Cohesiveness of coconut cheese-like product from coconut curd at various guar gum contents.

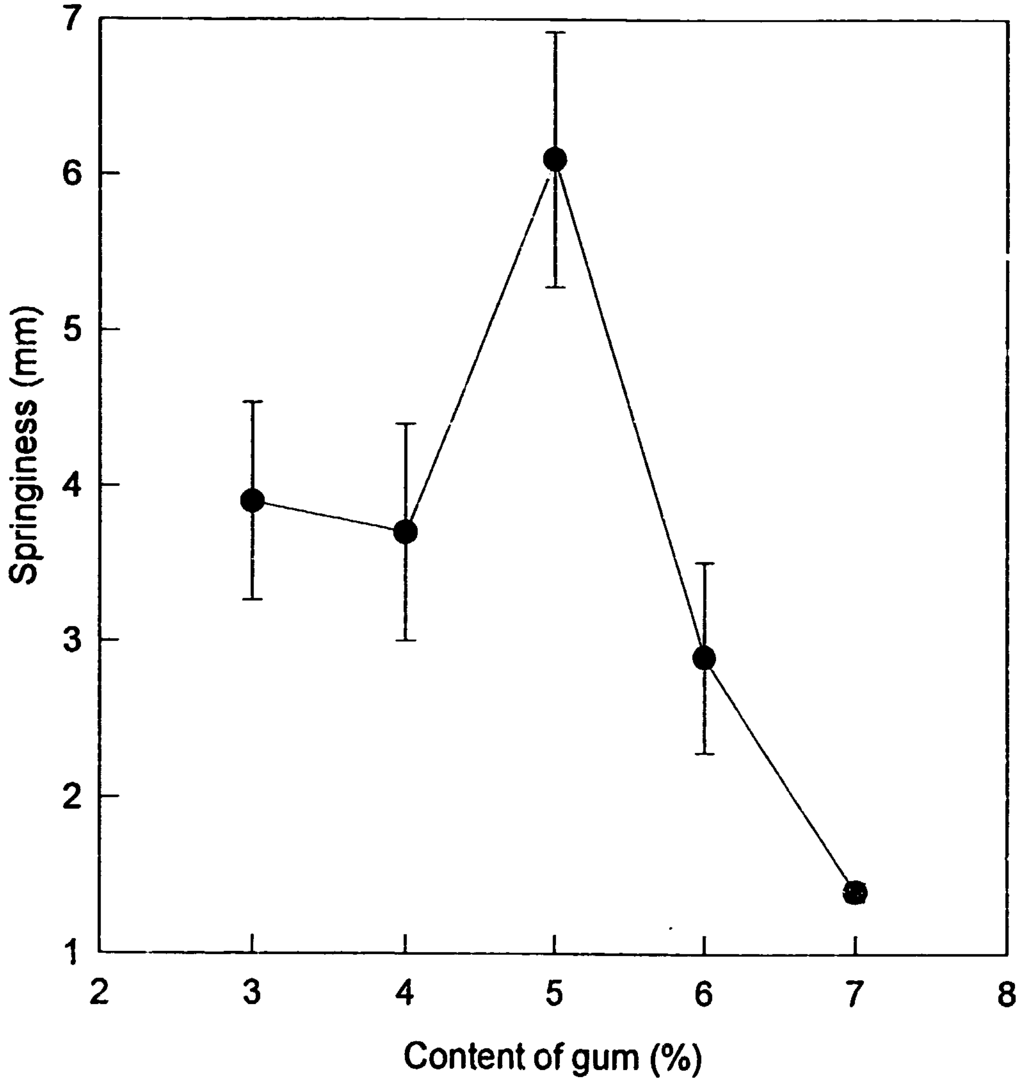

Figure 36. Springiness of coconut cheese-like product from coconut curd at various guar gum contents.

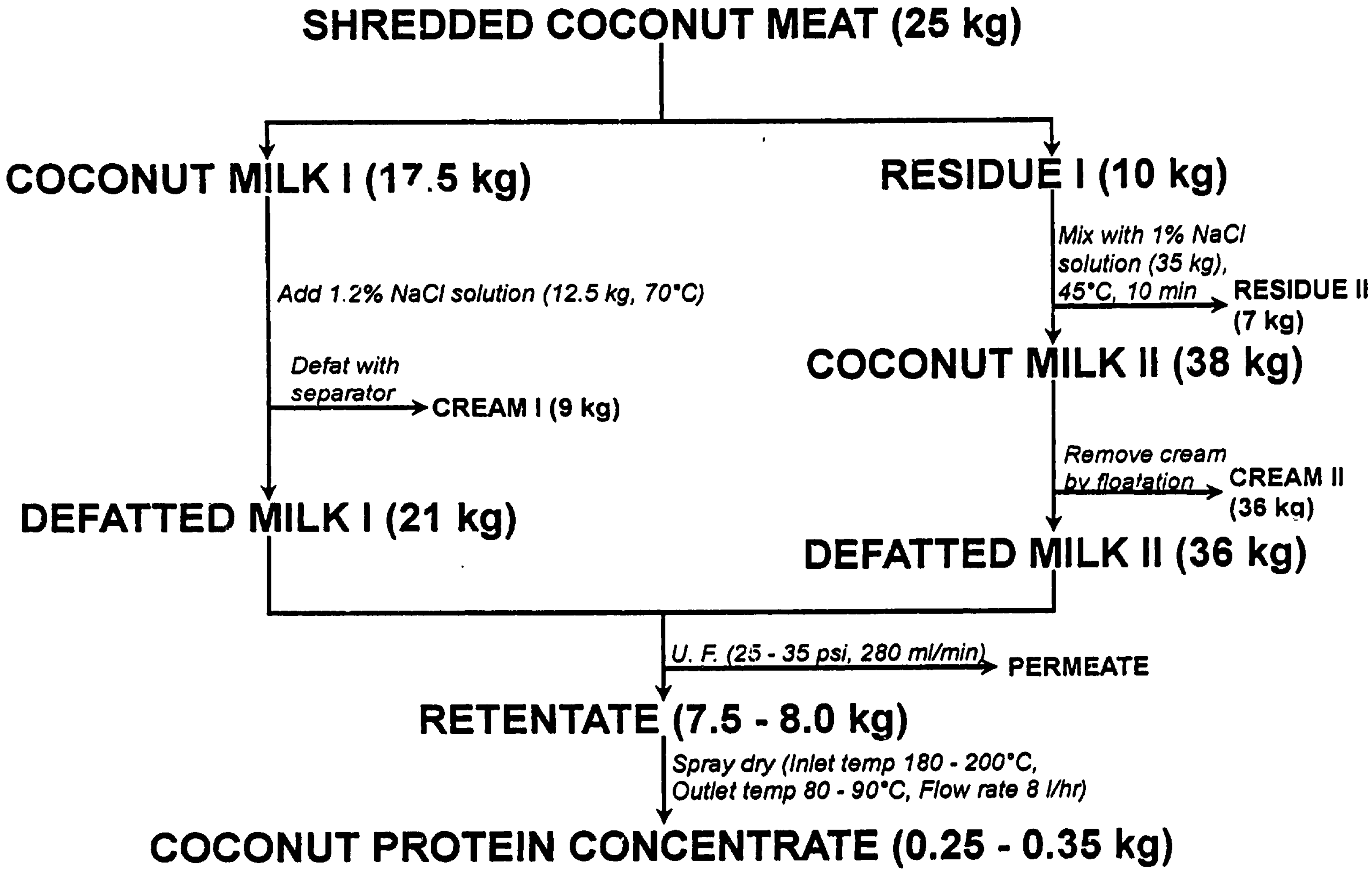

Figure 37. Schematics for coconut protein concentrate preparation and yield(Thailand).

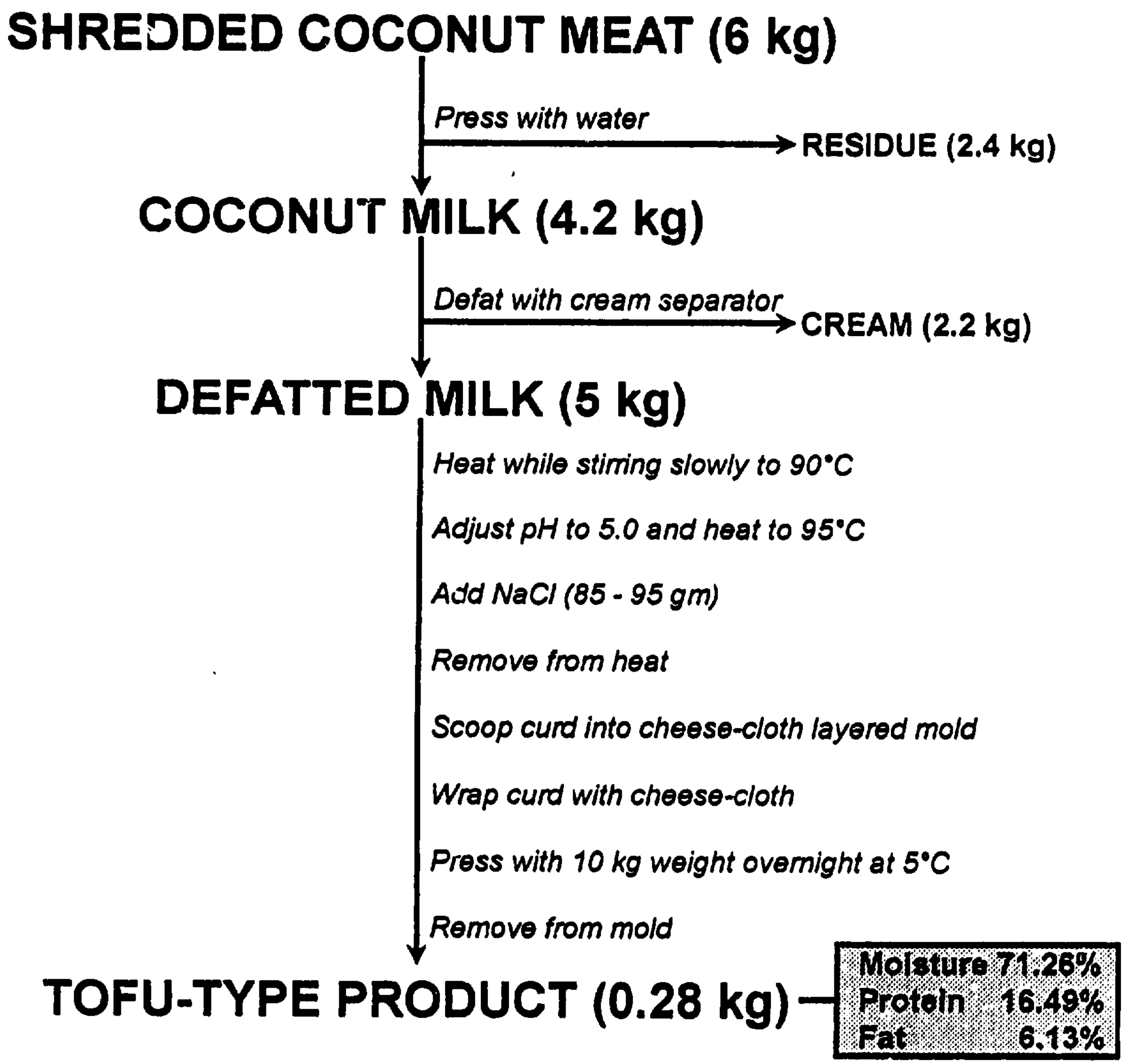

Figure 38. Schematics for tofu-type coconut curd processing and yield (Thailand).

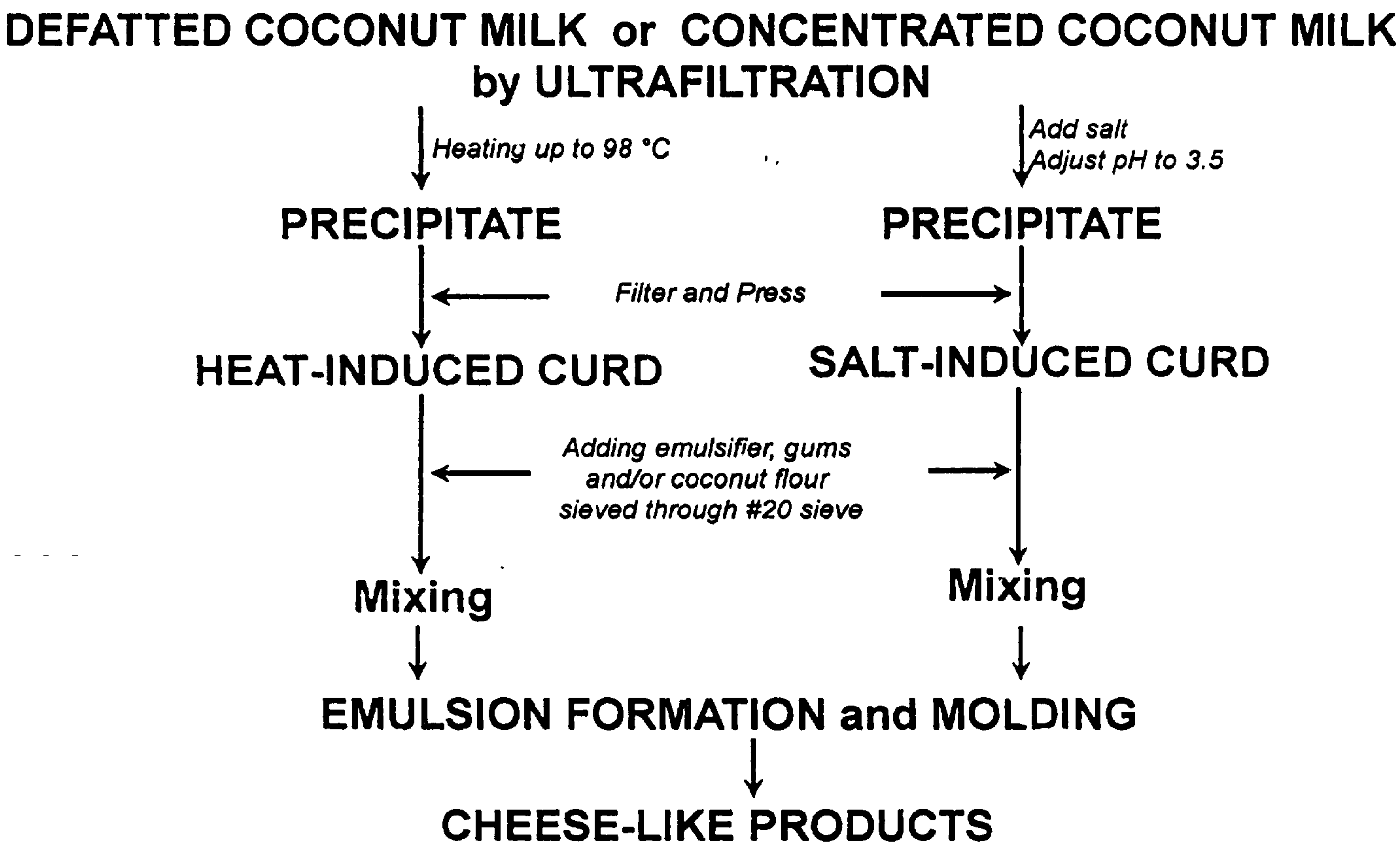

Figure 39. Schematic diagram for manufacturing cheese-like products from coconut protein curd (proposed).

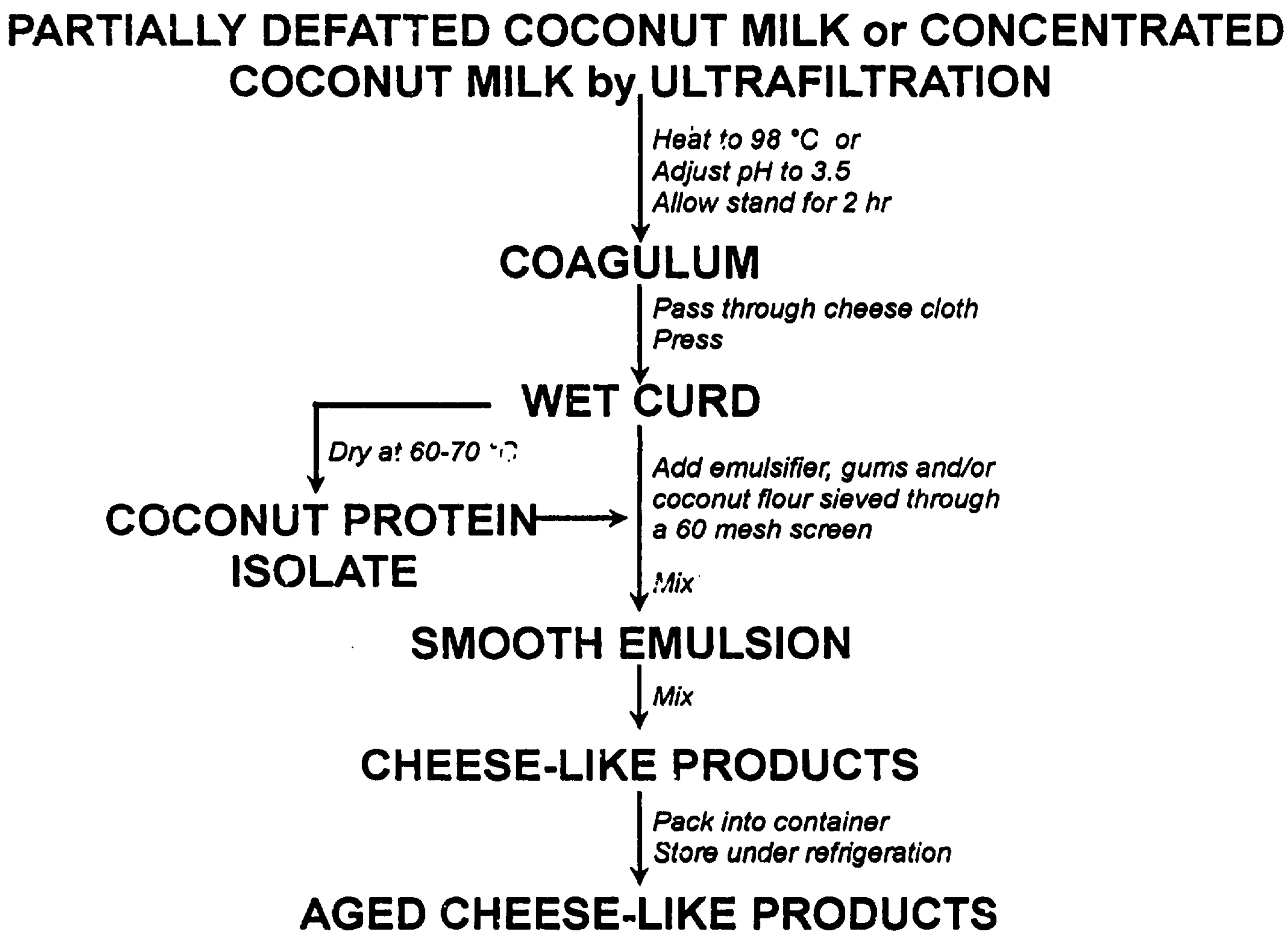

Figure 40. Schematic diagram for manufacturing cheese-like products from coconut milk (proposed).

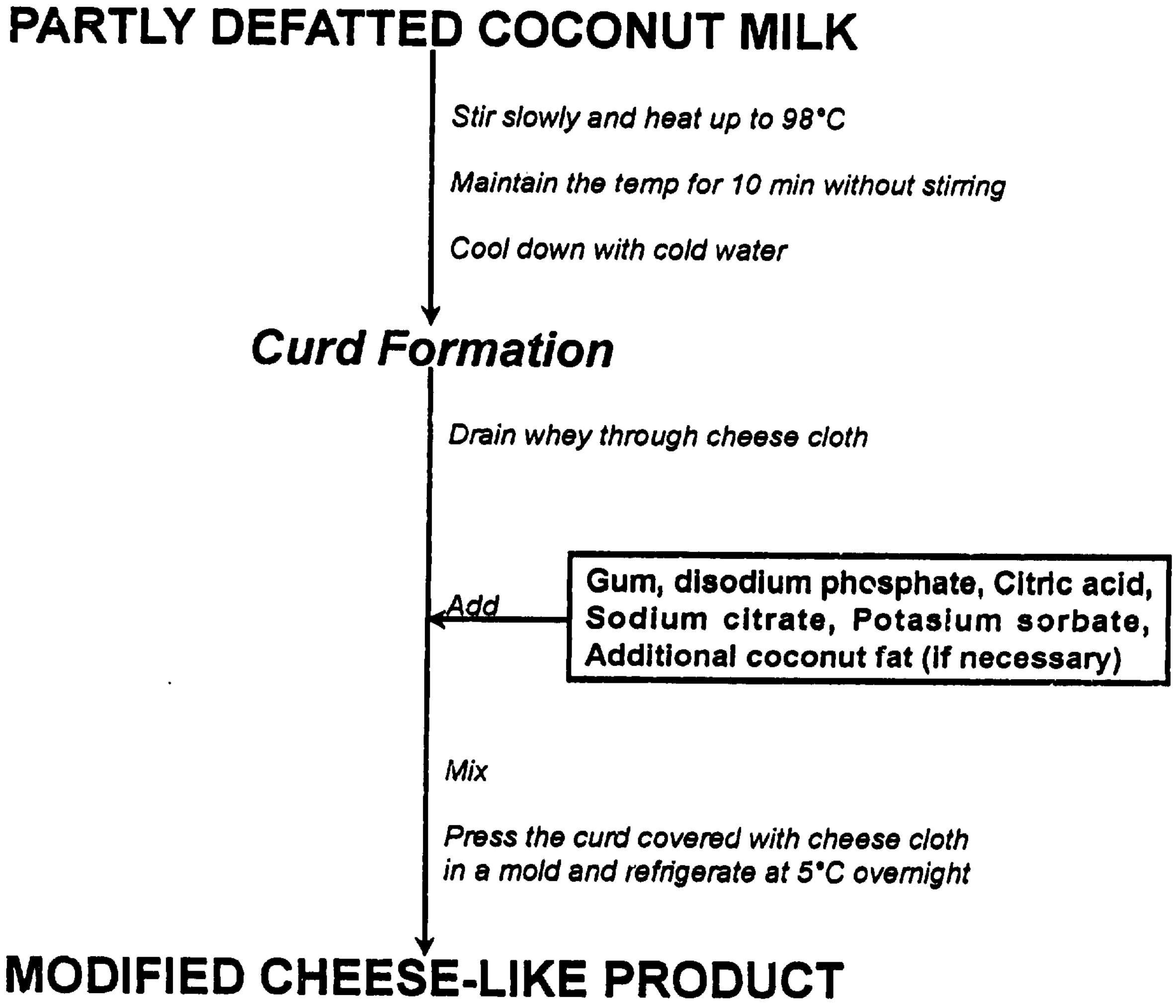

Figure 41. Application of processed cheese-like product formulations to tofu-type processing (proposed).