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Review

Coconut milk: chemistry and technology

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Summary Coconut milk, a generic term for the aqueous extract of the solid coconut endosperm, plays an important role in the cuisines of South East Asia as well as other parts of the world. This broad-spectrum review collates widely scattered information on the extraction, chemical properties (with special emphasis on the protein components), keeping quality, processing and preservation (particularly by canning, spray-drying and freezing) and new food uses of coconut milk.

Keywords Canning, coconut cream, coconut milk proteins, emulsion, freezing, spray-drying.

Introduction

Although oil recovery remains the major concern in the coconut industry, there appears to be increasing demand for the aqueous extract of the solid coconut endosperm, commonly called coconut milk, for use in the home and in the food industry. It has been estimated that 25% of the world's output of coconuts is consumed as coconut milk (Gwee, 1988). Despite the fact that coconut milk is an indispensable ingredient in many of the traditional cuisines of South East Asian countries, information on its chemistry and technology is comparatively sparse and widely scattered. There has been an upsurge of interest in this product in recent years and a collation of such information should prove most useful to researchers as well as food processors.

Terminology

There appears to be considerable confusion in the literature, in industry, and amongst consumers regarding the terms 'coconut water', 'coconut cream', and 'coconut milk' which, at times, have been used interchangeably. This problem is compounded by the use of different names indigenous to particular countries for the same or similar products (e.g. *santan* in Malaysia and *gata* in the Philippines). Such confusion is, of course, a consequence of the lack of standards of identity for the products in question or non-uniformity of such standards if they exist. In 1994, the Standards Task Force of the Asian and Pacific Coconut Community (APCC) proposed certain definitions for different aqueous coconut products. Attempts such as this to harmonize the standards of identity of aqueous coconut products would, it is hoped, resolve much of the confusion regarding terminology and, at the same time, facilitate international trade.

The authors agree with the views expressed by the Standards Task Force of the APCC (1994) that the term 'coconut water' should refer exclusively to the natural aqueous liquid endosperm of the drupe of *Cocos nucifera* L., while the terms 'coconut milk' or 'coconut cream' should refer to the aqueous products, essentially free from fibre, extracted from solid coconut endosperm, but which optionally may include some coconut water. The history of this terminological confusion between coconut water and coconut milk was, in fact, discussed much earlier by Pieris

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(1971). The Standards Task Force of the APCC (1994) has further classified the aqueous extracts of the coconut endosperm into (1) *concentrated coconut cream;* (2) *coconut cream concentrate* (undiluted coconut milk); (3) *coconut cream;* (4) *coconut milk* and (5) *light coconut milk* based on minimum coconut fat and non-fat solids, and maximum water contents. The Malaysian Food Regulations (Anon., 1985a, 1988) differentiate between coconut milk and coconut cream as follows: 'coconut milk (or *santan kelapa*) shall contain not less than 30% fat and 3% protein, and not more than 55% water while the cream, recovered through separation of the coconut milk emulsion by standing or centrifugation, shall contain not less than 50% fat and 5% protein derived from coconut'. It is not within the scope of this review to debate the semantics involved. However, for the sake of simplicity and for the purpose of this review, we shall adopt a rather broad definition in which the term 'coconut milk' is generically applied to the white, opaque protein–oil–water emulsion obtained by pressing grated or comminuted solid coconut endosperm, with or without addition of potable water or liquid endosperm (coconut water). Commercially, the use of the term 'equivalent coconut' may aid in product differentiation. The APCC (1994) has defined the standard equivalent coconut as being equal to '100 g of total coconut solids per coconut with a maximum proportion coconut fat of 82.5% of the total coconut solids'. The calculated equivalent coconut ratings for the aqueous extracts at different solids concentration and pack sizes are shown in Table 1.

We see little rationale in differentiating between the terms 'skim coconut milk' and 'coconut skim milk' as recommended by the Standards Task Force of the APCC (1994). As such, we will use these two terms interchangeably to indicate the aqueous liquid that remains after separation of virgin oil from coconut milk.

Extraction of coconut milk

The extraction of coconut milk begins with labour-intensive operations such as shelling and paring of fully mature coconuts. Paring removes the brown testa which imparts a brown colour and a slight bitter taste to the extracted milk. The coconut flesh or meat is then washed, drained and grated by machine. Arumughan *et al.* (1993) have recommended the washing of the meat in water containing 100 ppm H_2O_2, followed by blanching at 80 °C for 10 min to reduce the initial microbial load and to inactivate lipase, and the use of a hammer mill for size reduction. Home preparation of coconut milk usually involves the squeezing by hand of the freshly grated coconut meat, wrapped within a cheese cloth, to express the 'milk'. It is customary to repeat the extraction twice or thrice by adding water at room temperature, each time obtaining a more dilute milk. Such a procedure also maximizes the extraction of solubles from the endosperm. The extracts may be bulked or used separately for specific purposes.

Several procedures have been recommended for the extraction of coconut milk on an industrial or commercial scale. These have been described by Cancel (1979) and primarily involve variations in the amount and temperature of the water added prior to pressing the grated coconut, using a

Table 1 Equivalent coconut ratings for coconut milk at different solids concentration (values taken from APCC, 1994)

% Solids (m/m)	Package size (mL)				
	150	200	250	340	400
70.0	1.01	1.35	1.68	2.98	2.69
60.0	0.87	1.16	1.45	1.98	2.33
50.0	0.73	0.97	1.22	1.66	1.95
40.0	0.59	0.78	0.98	1.33	1.57
30.0	0.44	0.59	0.74	1.00	1.18
20.0	0.30	0.40	0.49	0.67	0.79
10.0	0.15	0.20	0.25	0.34	0.40
2.5	0.04	0.05	0.06	0.08	0.10

One equivalent coconut = 100 g total coconut solids with maximum coconut fat of 82.5 g. Density of total coconut solids is assumed to be equal to 0.95 g mL^{-1}.

hydraulic or screw press. The milk is then filtered through a cloth filter or centrifuged at low speed (using a basket centrifuge) to remove finely comminuted particles of coconut pulp without breaking the emulsion. The extraction of coconut milk from frozen coconut pulp has been investigated by Cancel *et al.* (1976a,b). The yield of coconut milk extracted from frozen pulp was found to be significantly lower than that from unfrozen pulp.

The extraction of coconut milk is, in fact, the first important step in the aqueous or wet processing of fresh coconuts, which is an alternative method to traditional mechanical pressing of copra, for the recovery of oil (Hagenmaier *et al.*, 1972a, 1973; Dendy & Grimwood, 1973; Gunetileke & Laurentius, 1974; Hagenmaier, 1980). In this case, breakage of the emulsion is crucial to the efficient recovery of both oil and protein. The production of coconut oil and protein by wet processes is given a brief mention here, but is technically beyond the scope of this review. However, the variables affecting the extraction of oil and protein by wet milling operations would have a bearing on the efficiency and optimization of milk extraction as well as the milk composition. These variables include the water/coconut meat ratio, milling temperature, pH, type of mill, and feed rate. The most commonly used mill appears to be the hammer mill (Cancel, 1979). The composition of the milk obtained would obviously vary with the amount of water added (Cancel *et al.*, 1971; Cancel, 1979). Variation of the milling temperature between 30 and 85 °C was found to have no significant effect on the overall extraction of oil and protein (Dendy & Timmins, 1973a,b). The 'whey' that remains, after separation of virgin oil from the whole milk by centrifugation, is a by-product termed coconut skim milk which can be further processed (e.g. aseptically packaged or spray-dried) (Hagenmaier *et al.*, 1974, 1975). The protein in the milk can also be recovered or isolated and used as a protein supplement in cases of protein malnutrition or as an ingredient in many food preparations (Dendy & Grimwood, 1973; Hagenmaier, 1983; Gonzalez, 1986).

Whole coconut milk and coconut skim milk may be produced as part and parcel of an integrated coconut processing plant, such as that designed by Alfa-Laval which is capable of processing up to 600 000 coconuts per day. Coconut water, virgin coconut oil, desiccated coconut and coconut shell charcoal are the other products that such a plant is capable of producing.

The by-products of coconut milk extraction pose a tremendous disposal problem to processors of coconut milk. The search for novel food and non-food uses for these by-products is an ongoing process. For example, the residual solids or presscake (called *sapal* in the Philippines) after milk extraction may be made into a flour which can be used as an ingredient in the preparation of several food products (Hagenmaier, 1983; Gonzalez, 1986). Arumughan *et al.* (1993) have used the powder obtained after drying of the presscake in ready-to-use food (e.g. curry and chutney) formulations.

Chemistry

It would be expected that the chemical composition of coconut milk, as reported in the literature, would show very wide variations because of differences in factors such as variety, geographical location, cultural practices, maturity of the nut, method of extraction, and the degree of dilution with added water or liquid endosperm (Cancel, 1979). Typical proximate compositions of the emulsion directly expelled from coconut kernel

Table 2 Proximate composition of undiluted whole coconut milk as reported by different sources

Constituent (%)	Nathaneal (1954)	Popper *et al.* (1966)	Jeganathan (1970)	Anon. (1984) (Univ. of Minn.)
Moisture	50.0	54.1	50.0	53.9
Fat	39.8	32.2	40.0	34.7
Protein (N × 6.25)	2.8	4.4	3.0	3.6*
Ash	1.2	1.0	1.5	1.2
Carbohydrates (by difference)	6.2	8.3	5.5	6.6

*N × 5.30.

Table 3 Chemical composition* of coconut milk obtained by cold or hot water extraction at different water proportions [recalculated from data presented by Cancel (1979)]

Proportion by weight of water to coconut pulp	Cold water (27–30 °C) extraction			Hot water (88–93 °C) extraction		
	% Water	% Fat	°Brix	% Water	% Fat	°Brix
0:4	45.1 ± 2.3	43.5 ± 1.4	11.6 ± 0.4	46.9 ± 0.3	41.7 ± 0.8	11.4 ± 0.1
1:4	62.6 ± 2.6	25.6 ± 0.7	8.9 ± 0.4	63.0 ± 3.3	28.7 ± 2.0	8.5 ± 0.4
2:2	76.3 ± 0.4	18.6 ± 1.4	5.7 ± 0.6	70.2 ± 0.8	21.5 ± 2.1	6.5 ± 0.8
3:4	77.9 ± 0.2	15.9 ± 0.2	4.0 ± 0.0	74.7 ± 2.7	19.0 ± 2.5	5.1 ± 0.1
4:4	78.7 ± 2.6	14.9 ± 0.2	3.8 ± 0.3	79.6 ± 3.7	13.9 ± 2.2	4.4 ± 0.3

*Means ± standard deviation ($n = 3$).

without any addition of water, reported by different workers, are given in Table 2. Variations in the water content, fat content, and °Brix of coconut milk extracted with cold water (27–30 °C) or hot water (88–93 °C), as reported by Cancel (1979), are shown in Table 3. At any particular proportion of water to coconut pulp used in the extraction, water temperature does not appear to be a significant factor affecting milk composition. The expected dilution effect is seen as the proportion of extraction water increases.

The main carbohydrates present are sugars (primarily sucrose) and some starch. The major minerals found in raw coconut milk appear to be phosphorus, calcium, and potassium (Anon., 1984). Freshly extracted milk will very likely contain small amounts of the water-soluble B vitamins and ascorbic acid. Coconut oil has been very well characterized and, as such, requires no further description, although it is to be expected that there will be minor differences between the oil derived from aqueous processing and that pressed from copra. Attention will, instead, be focused on coconut milk proteins which play important functional roles.

Coconut milk proteins

Based on their solubility characteristics, at least 80% of proteins in coconut endosperm would be classified as albumins and globulins (Samson *et al.*, 1971; Balachandran & Arumughan, 1992). These would also be the predominant proteins in coconut milk. The protein content of the undiluted milk ranges from 5 to 10% (on dry basis). According to Hagenmaier *et al.* (1972a), only about 30% of the protein in the filtered milk is dissolved in the aqueous phase. The undissolved protein, acting as an emulsifying agent, is closely associated with the oil globules.

Proteins in fresh coconut kernels have been found to separate into at least six protein bands using sodium dodecyl sulphate–polyacrylamide gel electrophoresis (SDS–Page) (Balasubramanium & Sihotang, 1979). Similarly, Balachandran & Arumughan (1992) have observed that the water-soluble proteins and salt-soluble proteins of the coconut endosperm resolved into six and four electrophoretic bands, with molecular weights ranging from 14 000–52 000 and from 17 500–45 000, respectively.

The major protein components in aqueous or 0.1 M NaCl coconut endosperm extracts have generally been reported to have minimum solubility over the pH range 4 to 7 (Hagenmaier *et al.*, 1972b; Balasubramanium & Sihotang, 1979). Minimum solubility was similarly observed at pH 4–5 in the case of coconut meal (Samson *et al.*, 1971; Strength, 1971), coconut skim milk (Hagenmaier *et al.*, 1974) and a coconut protein isolate (Gonzalez & Tanchuco, 1977). Balachandran & Arumughan (1992) have, on the other hand, observed minimum protein solubility at pH 2–3 in aqueous coconut extracts.

Differential scanning calorimetric (DSC) studies carried out on raw undiluted coconut milk with a total solids content of *c.* 50% (w/w) have revealed several (often overlapping) endothermic transitions, over the range of temperature 50–130 °C, which reflect the complex protein composition and thermal denaturation behaviour of the milk (Seow & Goh, 1994). The typical thermogram of a freshly extracted milk over the temperature range 80–120 °C, as shown in Fig. 1, normally exhibits two major transitions (designated as P_I and P_{II}), with peak or denaturation temperatures at about 92 and 110 °C, respectively. Recent work by Kwon *et al.* (1996) suggests that the higher temperature transition is due to denaturation of a globulin while the broad P_I endotherm may be attributed to overlapping transitions resulting from denaturation of the albumins and some globulins.

Figure 1 also gives a comparison of the DSC thermal profiles of three commercially processed coconut milk products (canned, aseptically packaged or UHT-treated, and spray-dried), the spray-dried form being reconstituted according to the manufacturer's instructions before being scanned. The canned and UHT products did not exhibit any of the major endotherms associated with protein denaturation, indicating that the proteins had been denatured by the thermal processes involved. Retention of the P_I and P_{II} proteins in their native state and therefore of certain functional properties, appears to be best accomplished through spray-drying, the DSC thermogram of the reconstituted milk showing both major endotherms.

The thermal stabilities (as measured by the denaturation temperature, T_d) of the two major protein components in coconut milk as a function of pH are shown in Fig. 2. Both these proteins appear to be most stable over the pH range 5 to 9. Seow & Goh (1994) also reported that the resistance to heat denaturation of these proteins was increased in the presence of sugars, polyols, and common salt (NaCl). Their thermal denaturation properties were, however, unaffected by sodium alginate and carboxymethyl cellulose added at a level of 1% (w/w) to the milk.

Table 4 shows the amino acid composition of the albumin and globulin fractions of coconut protein extracted from defatted coconut meal as determined by Kwon *et al.* (1996). In general, these proteins contain relatively high levels of glutamic acid, arginine, and aspartic acid but are deficient in methionine. Amino acid analysis on coconut skim milk protein also suggests that methionine is the major limiting amino acid (Hagenmaier *et al.*, 1974).

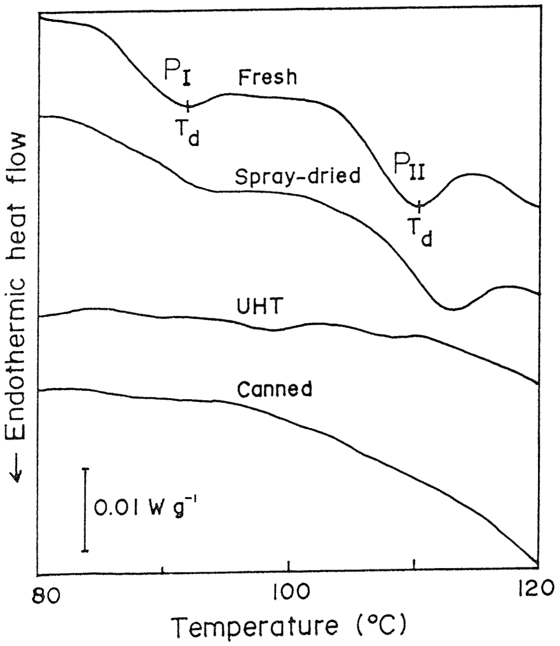

Figure 1 DSC thermograms of fresh (raw), and commercial spray-dried, UHT-processed, and canned coconut milk (Seow & Goh, 1994).

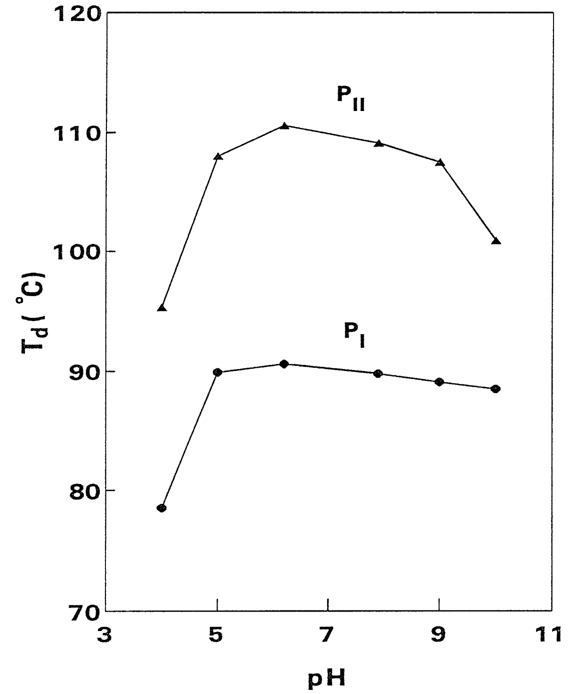

Figure 2 Effect of pH on the termal denaturation temperature (T_d) of the major protein components in coconut milk (Seow & Goh, 1994).

Table 4 Amino acid composition of the albumin and globulin fractions from defatted coconut meal (g 100 g^{-1} of protein) (Kwon *et al*., 1996)

Amino acids	Albumins	Globulins
Isoleucine	2.8	4.1
Leucine	3.9	6.5
Lysine	5.1	3.5
Methionine	1.2	2.9
Phenylalanine	2.7	5.9
Threonine	3.3	3.3
Valine	3.5	7.5
Histidine	1.8	1.9
Tyrosine	3.0	3.7
Aspartic acid	5.6	8.9
Proline	2.7	3.4
Serine	3.1	5.0
Glutamic acid	24.9	17.5
Glycine	4.0	4.9
Alanine	2.9	4.1
Arginine	17.9	15.0

Spoilage of coconut milk

Untreated coconut milk spoils rapidly even under chilled storage. The generation time for multiplication of bacteria in coconut milk was found to drop from 232 min at 10 °C to 44 min at 30 °C (Fernandez *et al*., 1970). Coconut milk is a very rich medium which can support the growth of all the common spoilage microorganisms, usually introduced via contaminated shells, utensils, processing equipment, handlers, etc. The common types of bacteria encountered include those from the genera *Bacillus, Achromobacter, Microbacterium, Micrococcus,* and *Brevibacterium* as well as some coliform organisms, while *Penicillium, Geotricum, Mucor, Fusarium*, and *Saccharomyces* spp. appear to be the predominant fungi isolated from coconut milk (Mabesa & del Rosario, 1979). Aerobic plate counts in coconut milk and coconut skim milk were observed to reach levels (1.2×10^6–1.7×10^8) that could be expected to pose serious organoleptic defects within 6 h of storage at 35°C (Kajs *et al*., 1976).

Under the Draft Standard for Aqueous Coconut Products (APCC, 1994), lipolytic organisms, enterococci, and coagulase positive staphylococci shall be less than ten per gram in all products. The standard plate count shall not exceed 50 000 microorganisms per mL in at least four of the five sample units tested, and shall not exceed 100 000 per mL in the remaining sample unit. *Escherichia coli* shall not be detected in 0.1 mL in at least four of five sample units, and shall not be detected in 0.01 mL in the remaining sample unit. *Vibrio cholerae* and *Salmonella* shall be negative per 25 g sample while *Listeria monocytogenes* shall be negative per 25 g sample in frozen or refrigerated products.

Apart from microbial spoilage, coconut milk is also highly susceptible to chemical (including enzymic) deterioration, primarily through lipid autoxidation and lipolysis which result in objectionable tastes and odours. The hydrolysis of acylglycerols can be particularly rapid when catalysed by the enzyme, lipase. The release of short-chain fatty acids such as butyric, caproic, caprylic, and capric acids gives rise to strong off-odours. On the other hand, medium-chain fatty acids such as lauric and myristic acids (which are typical of coconut oil) produce a distinctive soapy taste. Oxidative rancidity occurs when unsaturated fatty acids are oxidized.

Breakage of the oil-in-water emulsion is normally considered an unacceptable physical defect in both raw and processed forms of coconut milk. Coconut milk was found to display poor emulsion stability over a relatively wide pH range from 3.5–6.0 and to exhibit two stability maxima at pH 1.5–2.0 and pH 6.5 (Monera & del Rosario, 1982; del Rosario, 1988). The use of emulsifiers (e.g. sodium caseinate and stearoyl lactylate added at levels ranging from 0.5–2.5% of the milk), coupled with two-stage homogenization (e.g. at 2000/1000 psi), could effectively enhance emulsion stability (del Rosario & Punzalan, 1977).

Processing and preservation

Over the years, many attempts have been made to stabilize coconut milk against microbial, chemical and physical spoilage. Commercially, shelf-life extension of the milk has been achieved primarily through canning, aseptic packaging, and spray-drying.

Thermal processing

Heat processing is an effective means of extending the shelf-life of coconut milk. Short-term preservation is easily effected by pasteurising the milk at 72 °C for 20 min, but long-term storage can only be achieved by using a more stringent heating regime that ensures commercial sterility of the product. For example, while pasteurized coconut milk has a shelf-life of not more than 5 days at 4 °C (Gwee, 1988), canned coconut milk can last for at least 24 months under normal storage conditions (Anon., 1993).

In retorting, the milk is normally processed to an F_o of about five (Timmins & Kramer, 1977; APCC, 1994). Such a drastic heat treatment is required because raw coconut milk is a low-acid liquid food, with a pH of around 6.2. The recommended processing schedules in a still retort for low-acid aqueous coconut products preserved in lacquered tinplate cans contained in the Draft APCC STAN 2:1994B are given in Table 5. Martin *et al.* (1975) have sterilized bottled homogenized coconut milk, containing 0.3% sorbitol mono-oleate (*Tween 80*) and 0.4% carboxymethyl cellulose, at 115 °C for 45 min. Samples of coconut milk (containing 30% fat and 0.15% added carboxymethyl cellulose) have also been sterilized in 200-mL and 500-mL glass bottles at 121 °C for 60 min and 70 min, respectively (Teixeira-Neto *et al.*, 1985). Sterilization at 121 °C for 20 min has been found to be adequate in the case of products filled into 301 × 204 plain tinplate cans and processed in a rotary retort (Arumughan *et al.*, 1993).

The major problems encountered in the production of canned whole coconut milk are related to its instability both during heating and on prolonged standing. Coconut milk coagulates readily upon heating to 80 °C (Steinkraus *et al.*, 1968; Hagenmaier, 1983) due to denaturation of the more heat-labile proteins. This may produce unacceptable curdled products, particularly in the more concentrated forms of the milk (Seow & Goh, 1994). The elevated viscosity of coconut milk with high total solids content adversely affects heat transfer during processing of canned products in static retorts. Other factors being equal, a longer time is thus required to achieve the desired lethal effect in a concentrated milk as compared with a diluted one which can result in undesirable chemical changes such as non-enzymic browning (NEB). Sodium or potassium metabisulphite is often used as an NEB retardant in canned coconut milk. It also serves to prolong the shelf-life of the milk left unused after the can has been opened. Canning of diluted coconut milk poses much less problem than that of milk at the original (undiluted) strength. Efforts aimed at overcoming problems associated with canning of the latter have only been partially successful. The following measures, applied individually or in combination, help to mitigate the undesirable effects of thermal processing:

1 Preheating the milk to 90–95 °C for several minutes, followed by filtration and/or homogenization, prior to retorting, denatures most of the proteins and produces a smoother and more stable emulsion. Preheating serves also to reduce the microbial load of the milk before processing. However, such a treatment would be unlikely to affect the P_{II} protein component and might not even denature the P_I component if functional ingredients added to the milk have the effect of raising its denaturation temperature (Seow & Goh, 1994). The milk would then acquire a jelly-like consistency on subsequent retorting of the milk at a temperature (e.g. 115 or 121 °C) high enough to denature these proteins. The direct injection of pressurized steam into coconut milk, to raise its temperature to a level (say *c.* 115 °C) which is above the denaturation temperature of the P_{II} protein component, appears to be a feasible alternative thermal pretreatment worth exploring. The milk can then be homogenized to a smooth consistency at a lower temperature prior to retorting.

Table 5 Suggested processing schedules in a still retort for canned low-acid aqueous coconut products at two initial temperatures (IT) (APCC, 1994)

Can size	Time (min) at 115 °C		Time (min) at 121 °C		Equivalent lethality, F_0 (min)
IT	21 °C	71 °C	21 °C	71 °C	
211 × 400	36	30	22	18	4.85
307 × 409	40	35	27	22	4.94
401 × 411	46	39	30	25	5.08
603 × 700	61	51	42	33	5.39

The preheating treatment would also be much more effective if suitable additives could be found to destabilize the major proteins such that they will denature at the preheating temperature. Alternatively, these proteins may be stabilized by suitable additives such that they will not denature at retorting temperatures. However, the possibility of finding such suitable additives, which should not pose any harmful effects to human health or adversely affect the desirable characteristics of the product, appears remote. It has been reported that coagulation on boiling may be appreciably retarded by blending with skim (cow's) milk (Banzon, 1978; Davide, 1985). Certain gums were found to be good anti-coagulants (Timmins & Kramer, 1977, 1978).

2 Sterilizing the canned product in an agitating retort (Timmins & Kramer, 1978; Soler *et al.*, 1991; Arumughan *et al.*, 1993) would reduce processing time and produce milk with improved colour and texture. Curds formed may also be broken up by vigorous mechanical shaking of the cans after retorting.

Physical separation of canned whole coconut milk into an oil-rich phase and a water-rich phase during processing and storage may be retarded to some extent by the use of appropriate emulsifiers and stabilizers coupled with two-stage homogenization at 3500/500 psi (Timmins & Kramer, 1977, 1978). Certain canned coconut milks available commercially are known to contain polyoxyethylene sorbitan monostearate and/or sorbitan monostearate. Soy lecithin, alginates, carboxymethyl cellulose, casein, carrageenan, guar gum, karaya gum, and locust bean gum, individually or in various combinations, may also be used to stabilize and/or to modify the consistency of the product. Interestingly, a method of manufacture of sterilized coconut milk, stabilized by alginate, was patented earlier by Baudot (1971). Addition of skim milk powder has also been found effective in stabilizing the emulsion (Agrawal *et al.*, 1991). In their investigation of the influence of different types and quantities of emulsifiers and thickeners on the physical stability of sterilized bottled coconut milk, Soler *et al.* (1991) found that the most stable formulation involved the addition of 0.15% emulsifier (Tween 60 and Span 60 mixed to obtain a hydrophilic/lipophilic balance, HLB, of 10) plus 0.3% of a high viscosity carboxymethyl cellulose.

Preservation of coconut milk by acidification and pasteurization has been studied by Goncalves *et al.* (1984). Acidification of coconut milk to a pH of 4.5 eliminates the necessity for retorting of the canned product. The preheated and acidified product, processed in boiling water to an *F*-value of 5.9, was claimed to possess acceptable sensory qualities. Suitable acidulants include fumaric, tartaric and lactic acids.

In recent years, aseptically packaged ultra-high temperature (UHT)-treated coconut milk have found their way into both the industrial and retail markets. Consumer packs of 200–250 mL, usually in Tetra Brik® or Combibloc® containers, are now readily available in supermarkets. The milk may also be packaged in large aseptic bulk bags (e.g. Starasept®). The APCC, under Draft STAN 2:1994B, has recommended that aseptic continuous flow processing be conducted using an equiv-

Table 6 Chemical composition of commercially canned coconut milk from different countries

Component	Malaysia#	Singapore#	Thailand*	Western Samoa*
Moisture, %	78.8	84.4	76.2	75.8
Fat, %	14.0	11.0	15.0	18.4
Protein, %	0.3	0.5	0.3	0.9
Minerals, %	0.7	0.6	0.4	0.7
Carbohydrates, % (by difference)	6.2	3.5	8.1	4.2
Free fatty acids, %	n.d.	n.d.	0.2	0.5
pH	n.d.	n.d.	6.2	6.3

#Data from Arumughan *et al.* (1993).
*Authors' analysis.
n.d. = not determined.

alent lethality, F_o of 5.0 min at 121 °C. Processors are also cautioned that the coconut material may progressively coat heat exchangers, thereby increasing thermal resistance.

The chemical composition of canned coconut milk would be expected to show wide variations because of differences in the amount of water used in milk extraction as well as the types and amount of additives used for specific functional purposes. The analytical data of commercially canned coconut milk from different sources are given in Table 6. The rheological behaviour of thermally processed coconut milk has been studied by Vitali *et al.* (1986). All the samples studied exhibited mild time-dependent behaviour. At steady state, they were mildly shear-thinning fluids.

Dehydration

Spray-drying is the method of choice used in the commercial production of 'instant' coconut milk powder, a creamy white product which is easily dispersible in water at ambient temperature. A 60–100 g pack is usually equivalent to one coconut. The major producers of instant coconut milk or cream powder are the Philippines, Malaysia, Indonesia and Sri Lanka. Table 7 shows the chemical composition of commercial spray-dried coconut milk powders produced in Malaysia and the Philippines.

Additives such as maltodextrin, casein or skim milk, and/or corn syrup are added to the extracted milk (Hagenmaier, 1983; Ali Hassan, 1985; Gonzalez, 1986) and the mixture is pasteurized and homogenized before spray-drying (Anon., 1985b). Such additives aid the spray-drying process and help to convert a high-fat material such as coconut milk into flowable, but cohesive, powders through encapsulation of the fatty substances (Seow & Leong, 1988). The powder so obtained, with a moisture content of ≤2.5% (w/w), is immediately cooled and packaged in cans or flexible laminated aluminium foil bags. Some loss of flavour volatiles is inevitable in the drying process. It is interesting to note that the spray-drying of coconut milk is not a recent invention. Patents were obtained in the early 1970s by Noznick & Bundus (1970, 1971) for the production of spray-dried coconut milk to which were added an emulsifier (e.g. decaglycerol monostearate), sodium caseinate, and dextrin. A spray-drying process for the production of powdered coconut milk, fortified with certain vitamins and minerals, was also patented in the Philippines by Esconde & Chang (1978).

Table 7 Chemical composition of commercial spray-dried coconut milk powder as reported by different sources

Component (% w/w)	Seow & Leong (1988)	Gonzalez (1986)
Moisture	2.2	0.8–2.0
Fat	63.6	60.5
Protein (N × 6.25)	4.5	6.9
Ash	1.0	1.8
Carbohydrates (by difference)	28.7	27.3
Crude fibre	—	0.02

Lipid oxidation appears to be the major deteriorative factor limiting the shelf-life of the dried product to about 4 months when stored at 30 °C in laminated aluminium pouches (Bakar *et al.*, 1988). Problems associated with progressive loss of solubility also occur on storage of the dried milk. Improper packaging which allows absorption of water vapour from the atmosphere can lead to caking and loss of flowability (which may be alleviated by the incorporation of suitable anticaking and flow agents) as well as poorer reconstitutability of the product. The water vapour sorption behaviour, flowability, wettability, and solubility of spray-dried coconut milk powder have been studied by Seow & Leong (1988).

The spray-drying process may also be applied to the skim milk after separation of the oil from the whole milk by centrifugation (Kajs *et al.*, 1976). Liquid concentrates have been prepared by direct evaporation of coconut skim milk or by reconstitution of the spray-dried product (Hagenmaier *et al.*, 1975). An intermediate moisture product with a moisture content of *c.* 30% and a water activity of *c.* 0.74 and containing 0.1% added sorbic acid as an antimycotic agent was found to be reasonably stable (Hagenmaier *et al.*, 1975). Microbial challenge studies carried out with five individual microbial species found no increase in population in such a product even after storage at 35 °C for 25 days (Kajs *et al.*, 1976). A skim milk concentrate containing 15% sugar and 20% water, which was developed earlier by Buccat *et al.* (1974), was found to be organoleptically acceptable even after 8 weeks' storage.

Freezing

The frozen product is prepared by pasteurizing (at 116 °C for a few seconds) and then progressively cooling the milk to a sludge, filling it into containers, and blast freezing. It is said to retain its flavour and freshness even after storage at −10 °F (–23.3 °C) for one year (Cancel, 1979). Citric acid at a level of 0.01% (w/w) is usually added to the milk prior to pasteurization.

According to Cancel (1979), a frozen concentrated coconut milk (i.e. coconut cream) may be obtained by evaporation of the pasteurized single-strength milk in a falling film evaporator or vacuum kettle to the desired concentration, filling the concentrated milk into cans, and freezing in a blast freezer. Alternatively, a high speed continuous centrifuge may be employed to obtain a coconut cream with a fat content of 75%. This is packaged and blast-frozen to give a shelf-life of more than one year.

Imitation coconut milk

The extraction and preservation of coconut milk are fraught with difficulties. Large labour and cost inputs are necessary in the initial stages involving the dehusking and paring of fresh coconuts. Very stringent controls are required to ensure microbiological quality and safety of the highly perishable milk. Availability of raw materials can also be problematical in countries (such as Malaysia) which are not major producers of coconuts. These difficulties can be overcome to some extent by the development of imitation coconut milk products with organoleptic, functional and stability properties similar to or better than those of the genuine product. For example, an imitation spray-dried *santan* powder with similar functional and physical properties has been developed using partially hydrogenated RBD palm oil, which is abundantly available in Malaysia, as the fat base (Seow & Leong, 1988). Similarly, we envisage the development of other forms of preserved imitation coconut milk. As in the case of artificial dairy products, imitation coconut milk may find its niche market.

Food uses of coconut milk

Whole coconut milk or coconut skim milk is a major or essential ingredient in the preparation of a wide variety of dishes (e.g. curry), desserts, and products such as coconut jam/spread, coconut syrup, coconut cheese, bakery products, beverages (e.g. pina colada and cocosoy milk), and coconut *tofu* (Gonzalez, 1986; Gwee, 1988). Methods for preparing coconut syrup, which is primarily used for flavouring desserts and beverages, have been briefly described by Cancel (1979) and Gonzalez (1986). The latter author has also provided formulae for the preparation of sweetened condensed coconut skim milk and coconut honey (also derived from coconut skim milk); these can be used as toppings for pancakes and waffles.

Researchers in the Philippines have been at the forefront of efforts to develop new dairy foods using a combination of skim (cow's) milk and coconut milk (Banzon, 1978; Sanchez & Rasco, 1983, 1984; Davide, 1985; Davide *et al.*, 1985, 1986, 1990). Amongst the products developed, flavoured filled milk beverages, soft and blue cheeses, and low-fat fruit yogurt (named *niyogurt)* appear to show good commercial potential.

Other products that have been developed over the years include soy/coconut milk (Steinkraus *et al.*, 1968), a butter-like product (Husin & Hassan, 1978), and a *Lactobacillus*-fermented beverage (Fernandez & Samaniego, 1984). The addition of certain levels of coconut milk to soymilk has also been suggested as a simple, but effective, means of increasing the caloric density of *tofu* without affecting the acceptability of the product (Escueta *et al.*, 1985).

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