DAIRY SUBSTITUTES

1. Introduction

Dairy products have been an important component of the human diet for thousands of years. The popularity of dairy products is due to the wide range of diverse products (in both texture and flavor) that can be made from milk, and to the high nutritional value of milk and milk products. In part, this popularity has led to the emergence of a market for dairy substitute products, which offer a similar texture and taste to traditional dairy products, but may have differentiated properties, eg, low or no lactose, reduced fat, or may be completely dairy free. The market for these products has been driven at least in part by the negative health image of saturated animal fats, and the increasing demand for vegetarian and vegan products. In addition to this, a number of consumers will have allergies or intolerance to certain dairy foods–ingredients. Dairy substitutes allow them to enjoy dairy-like foods without the negative health implications.

There are no universally accepted definitions of substitute dairy foods, which are referred to as imitations, simulates, substitutes, analogues, and mimics, and are associated with terms, such as filled, nondairy, vegetable nondairy, and artificial milk, cheese. The term nondairy has been used indiscriminately to describe both imitation dairy products and products legally defined as not being imitation dairy products. Dairy substitutes can be divided into three types: those in which an animal or vegetable fat has been substituted for milk fat; those that contain a milk component, eg, casein or whey protein, and those that contain no milk components. The first two types make up most of the substitute dairy products.

The International Dairy Federation (IDF) has defined the following terms (1,2).

1. Substitute dairy foods. A substitute dairy product is a food stuff where the intended use is to substitute for milk or dairy foods that have legal standards of identity. In some countries, the term substitute requires that the food be nutritionally equivalent to the product for which it substitutes.
2. Imitation dairy foods. An imitation dairy food is a substitute dairy product in which the general composition, appearance, characteristics, and intended use is similar to milk or to a dairy food that has a legal standard of identity. Filled milk products are included under this definition.
3. Synthetic products. These are made in semblance of a dairy product and do not contain a milk component, although some include sodium caseinate. Sodium caseinate is classified as nondairy because of its industrial usage.
4. Filled. Filled imitation dairy products are made in semblance of a dairy product. A vegetable or animal fat is used to substitute for milk fat.
5. Nondairy. Milk–protein-based imitation dairy products are made to resemble a dairy product and contain one or more proteins derived from milk. Nondairy in this case has previously referred to imitation dairy products that contain proteins derived from casein because the FDA has ruled that such proteins are chemicals and cannot be considered dairy products.

More recently, the term nondairy has been used for products that contain whey proteins derived from milk, using the same rationale as for casein.

2. Ingredients

To reproduce the texture and properties of dairy products, manufacturers of substitute and imitation dairy foods make use of a range of functional ingredients. The major ingredients are fats–oils, emulsifiers, proteins, polysaccharides and sugars, and salts. Careful selection of ingredients is an essential part of the formulation of imitation products, as the properties of the product are controlled by these. Each component of a formulation is added for a specific function, but often there is a synergistic interaction between different ingredients that contribute to product texture. The major ingredients of dairy substitutes are discused below.

2.1. Fats and Oils. Fats and oils play a large role in determining the texture of imitation dairy products. For example, the creamy mouthfeel of fluid milks and substitute milks comes from the properties of the fat emulsion (3). The distinction between fats and oils is one of physical state. Fats are solid at room temperature, while oils are liquid. At the molecular level, fats have a higher melting temperature than oils due to differences in the fatty acid composition of the constituent triglycerides. Fats have a higher proportion of unsaturated fatty acids, while oils are rich in polysunsaturated fatty acids. In general, fat are derived from animal sources, eg, bovine milk fat, while oils are plant derived (eg, soya bean oil, palm oil). The melting point of a fat is an important consideration for its use in dairy substitutes. Fats with a melting point in the range 31–36°C are favored since these will melt in the mouth and contribute to flavor and mouthfeel of a product. It is common practice to modify the melting properties of vegetable oils by hydrogenation, which converts unsaturated to saturated fatty acids, thus turning an oil into a fat.

There are several properties that a fat or oil must possess if it is to be used in an imitation dairy product. These are bland flavor, low peroxide value and good flavor stability, low levels of free fatty acids, resistance to hydrolysis, and a desired solid fat content over the use temperature range of the product. The common fats used in substitute dairy foods are hydrogenated coconut, cottonseed, soybean, groundnut, palm kernel, and various blends of these products. The solid fat content is particularly important in products, such as whipped toppings and imitation whipped creams, where hardened oils are used to give optimum whipping properties (4). For powdered coffee whitener, a long shelf-life is desirable, and so good oxidative stability is a prerequisite for the fat (4).

2.2. Emulsifiers. The term emulsifier is usually taken to denote an ingredient that helps in the formation of a dispersed fat emulsion. As such, the term includes both low molecular weight emulsifiers and protein emulsifiers. In many dairy substitutes, the fat is found in the form of discrete droplets dispersed in an aqueous phase. This is termed an emulsion. In this state, the fat is only kinetically stable, and there is a thermodynamic tendency for the fat to separate out from the aqueous phase. To stabilize the fat droplets and to impart a satisfactory shelf-life on fluid emulsion products, emulsifiers are added that adsorb to the surface of the emulsion droplets and protect them from coalescence (5). In other products, eg, margarine, the aqueous phase forms droplets, dispersed in a continuous fat phase. To stabilise these so-called water-in-oil emulsion droplets requires the use of a different type of emulsifier compared to those needed to stabilize oil-in-water emulsion droplets.

Food grade low molecular weight emulsifiers are usually amphiphilic esters that contain a hydrophilic and hydrophobic region. The hydrophobic region is usually a fatty acid (commonly stearic, palmitic, oleic, or lionoleic acids) while the hydrophilic character often comes from hydroxyl or carboxyl groups. In dairy substitutes, common emulsifiers are mono- and diglycerides, lactic acid and fatty acid esters of glycerol, polyglycerol esters of fatty acids, sorbitan esters of fatty acids, polyoxyethylene esters of fatty acids, and propylene esters of fatty acids. Frequently, a combination of emulsifiers are used to achieve the desired characteristics in the final product.

Selection of emulsifiers for a particular function is often an empirical excericse informed by the experience of the formulator. To aid in this exercise, a system of classification of emulsifiers has been devised called the HLB (Hydrophile–Lipophile Balance) system (6). In simple terms, it is a measure of the relative hydrophobicity or hydrophilicity of an emulsifier, and it can be used to predict whether an emulsifier will stablize oil-in-water or water-in-oil emulsions. The HLB number for a particular emulsifier is estimated from the molecular formula by using the group contribution method proposed by Davis (7). The HLB values for emulsifiers range from 1 to 20, with higher values denoting a more hydrophilic character. Emulsifiers that promote oil-in-water emulsions typically have HLB values in the range 8–28, and those that form water-in-oil emulsions 3–8. The HLB numbers for a range of emulsifiers are shown in Table 1.

In addition to the role of emulsifiers in aiding formation of emulsion droplets, there are several other functions attributed to emulsifiers. In whipped topping, imitation cream and ice cream the emulsifiers are required to destabilize the fat emulsion so that when it is whipped the fat droplets are able to adsorb to the surface of the air bubble and to stabilize them (8). In fluid milks and milk substitutes emulsifiers aid in the heat stability of the fat emulsion (9). While in powdered formulations emulsifers are used both to give heat stability during drying, and to act as wetting agents to aid redispersion of the powder in water (10). In coffee whitener formulations, emulsifier blends of sodium stearoyl lactylate and and monoglycerides are used as a replacer for sodium caseinate (11). The emulsifier here forms a complex with the remaining caseinate (12), which gives improved fat encapsulation in the dried powder state, thus allowing a cost saving through the reduction in caseinate concentration.

2.3. Proteins. Proteins play a role as both functional ingredients in substitute dairy products. In addition to emulsification, proteins are also used as gelling agents, thickeners, for water binding, to improve melting properties, and for foaming–whipping properties.

Protein from a wide range of sources can be used in dairy substitutes. These include: animal proteins, ie, skim milk in liquid, condensed, or dry form (filled products); casein, caseinates, and coprecipitates; whey proteins; oil-seed proteins, fish proteins; and blood proteins. Oil-seed protein sources include soybean protein concentrates and isolates, groundnut protein, cottonseed protein, and sunflower seed, rapeseed, coconut, and sesame seed proteins. Other sources are leaf and single-cell proteins. Of these protein sources, milk and soybean proteins are most widely used. Protein usage is based on economics, flavor, functionality, and availability.

Milk Proteins. Many dairy substitutes still contain a considerable proportion of dairy derived protein ingredients. Of these, the various casein and whey protein products, and skim milk powder (SMP) are the most important, although newer milk protein products that contain both casein and whey, but at a higher protein content than SMP, are finding increasing use in the food industry.

Skim Milk Powder (Non-fat Dried Milk). To prepare skimmed milk powder (SMP), whole milk is first separated in a centrifugal separator to produce a skim milk stream with a fat content of $\sim$0.1%. The skim milk is then concentrated to 45–50%, and then dried to a powder. Three forms of SMP (high heat SMP, medium heat SMP, and low heat SMP) are manufactured depending on the severity of the heat treatment given during processing. The three types of product find different applications. Low heat SMP is favored for dairy and imitation dairy products. A preheat treatment is usualy given to the skim milk before concentration as this is believed to protect the casein micelles against extensive heat damage (13).

Casein and Caseinates. The caseins in milk are found in the form of the a supramolecular association structure, the casein micelle. Casein micelles are stabilized in milk by a hydrophilic layer of κ-casein at the surface. This is highly charged and provides both electrostatic and steric stabilization. To separate the casein protein from milk, one can either remove the charge from the stabilizing layer, or remove the layer itself. Both charge neutralization with acid, or hydrolysis of κ-casein with rennet enzyme will precipitate the casein micelles, and allow separation from the whey stream of the milk.

In the prepartion of casein, the first stage is defatting (skimming) of the milk. This stage is followed by precipition with either a mineral acid to give sulfuric or hydrochloric casein, with lactic acid to give lactic casein or with rennet to give a rennet casein. The precipitate formed is either pressed and dried to form a casein powder, or it is further processed by heating with a food grade alkali (sodium, calcium ammonium, or potassium hydroxide) to form a caseinate. Sodium caseinate has a higher solubility than casein and makes an excellent emulsifying agent. It is used in many product for this function (14). Calcium caseinate has a highly aggregated structure, due to interactions between calcium and phosphoserine. This reduces its solubility, making it a less potent emulsifying agent. It is, however, favored in imitation cheese applications. Typical compositions for the various casein types are given in Table 2.

Whey Protein Concentrates and Isolates. Whey is the name given to the liquid left over after the precipitation of casein from milk. Two general types of whey are formed: sweet whey from cheese manufacture, and acid whey from casein manufacture. The composition of whey can be variable as it depends on the conditions used to separate the casein. For sweet whey, the composition depends on the type of cheese that is being made since this determines the coagulation pH, and thus the structure of the curd (15). Similarly, acid whey composition depends on the acid type used for coagulation (16). Different curd structures retain differing amounts of whey and thus influence the final whey compositon. The way in which the curd is handled after precipitation also affects whey composition, eg, the inclusion of washng steps, and the method of separation of coagulum from the whey.

Dried acid whey contains ~12.5 wt% protein, 11.0 wt% ash, and 59 wt% lactose, whereas sweet whey contains 13.5 wt% protein, 1.2 wt% fat, 8.4 wt% ash, and 74 wt% lactose.

Whey proteins have been used in dairy substitutes only since the development of technology to remove nonprotein components of whey, which allows the production of high protein dried powders. Two types of high protein whey powder are available, whey protein concentrate and whey protein isolate. Concentrates are made by concentrating the whey using ultrafiltration. This is a membrane-filtration process where the membranes are selected so as to retain protein, but allow water, lactose, and minerals to pass through and be removed. After drying, protein content up to ~80 wt% protein can be achieved. Whey protein isolates use a different processing technique, whereby the protein components of the whey are selectively removed using ion-exchange onto specially selected resins to achieve high purity and proten content. This process is expensive, and means that isolates are only used in high value-added products where their cost can be justified.

An increasing number of WPI products are now being manufacturerd using membrane process, eg, microfiltration and a combination of ultrafiltration and diafiltration.

Whey proteins have a functionality that is significantly different from that of the caseins. Being globular proteins, they denature, aggregate, and gel when heated, and so can be used as thickeners and gelling agents. Unlike the caseins, whey proteins are stable at acid pH and can be used as emulsifiers in acidic environments. Whey protein concentrates are utilized in a limited number of substitute dairy products; ice cream and other frozen desserts, fermented products, coffee whiteners, whipped toppings, and infant and enteral formulations. In infant and enteral formulations the whey proteins are often hydrolyzed to aid digestion, and to reduce the intolerance that some infants have to the protein β-lactoglobulin. A range of hydrolysate powders have been produced to service this application.

Whey proteins that have been heat precipitated under very high shear have a particle size between 1 and 3 μm, and give the impression of fat in some products. These microparticulated whey proteins are being used as fat replacers in frozen desserts and processed cheese substitutes.

Milk Protein Concentrates. Milk protein concentrates (MPC) have been developed over the last few decades as a way of utlizing both the casein and whey protein fractions in a single product without the need for a two-stage preparation of casein and whey powders. Their production uses ultrafiltration to remove lactose and minerals from skimmed milk. The resultant high solids concentrate is dried to produce MPC powder Depending on the degree of concentration by ultrafiltration, the protein content in the powder can typically be in the range 56–85%. The processing conditions are relatively mild compared to casein manufacture, and therefore the casein in MPC retains much of its micellar structure. The highly aggregated state of the casein protein means that MPC is a relatively poor emulsifer compared to sodium caseinate, although it is comparable to SMP (17).

The micellar nature of much of the casein, however, means that it is possible to coagulate MPC solutions with rennet, and therefore it has found application in imitation cheese manufacture and as a cheese milk extender (ie, it is added to milk to increase the yield of cheese). Other applications of MPC exploit the low lacotse content of the powders (eg, nutritional protein bars).

It is possible to take the membrane filtration of skim milk a stage further by using microfiltration to remove not only the lactose and minerals, but also the whey protein. Although the dried powder contains very high levels of micellar casein, it suffers from severe solubility problems and has not found application in substitute dairy products.

Coprecipitates (Total Milk Protein/Proteinates). Total milk protein or proteinates are another form of milk powder that contains both casein and whey protein. The manufactures usually involves a heat treatment of skim milk that induces the formation of a disulfide bonded complex between β-lactoglobulin and κ-casein at the surface of the casein micelle. Subsequent acid precipitation leads to the incorporation of β-lactoglobulin in the coagulum. This is then dried to form a total milk protein. The coagulum can also be put through a caseinating process that increases the solubility and forms a total milk proteinate. Precipiation of the heated skimmed milk can also be achieved by addition of calcium.

Total milk protein has found applications in whipped toppings, coffee whiteners, and as cheese milk extenders.

Soya Protein Products. Soya protein products can be classified into three groups (18): soy flour with a protein content of $<65\%$; soy protein concentrates with a protein content 65–89%; and soy protein isolates with a protein content of $>90\%$.

The production of soy protein concentrate involves the defatting of ground soybean flakes by extraction with hexane. Then water soluble components (mainly sugars) are removed either by ethanol washing, acid washing, or steaming–water washing. The treated flakes are then dried to make soy protein concentrate with a typical protein content of 70%. The remaining components in soy protein concentrate are mainly fibrous material in the form of cellulose and hemicellulose. Soy protein isolates are formed when the fibrous material is removed. Soy protein isolate manufacture involves alkali extraction of the defatted soy beans, followed by removal of insoluble fibrous mateial using filtration or centrifucation. The remaining protein material is acid precipitated, neutralized, and spray dried to an isolate powder with a typical protein content of $>90\%$.

For substitute dairy products, the concentrates and isolates are the more important. A particular problem with soy-based products is the retention of a beany flavor after processing. The flavor quality of the products improves with increased protein content, but only the isolates approach a flavor quality sufficient for most imitation dairy foods when used at the same protein level as milk proteins in substitute products. Additional processing steps can further improve flavor, but at considerable expense. Continued improvement in flavor of soy protein products can be expected.

2.4. Polysaccharide Stabilizers. Polysaccharides are complex carbohydrate polymers that have variety of structural or storage functions in plants. In the food industry, a particular group of polysaccharides called gums are valued for their ability to form highly viscous solutions and gels. They are often called stabilizers, as their vicosity increasing properties help to prevent separation of fat droplets, or sedimentation of solid particles in fluid foods. Their gelling and thickening properties have allowed them to be used in dairy substitutes to provide viscosity control and improve mouthfeel, to improve whipping properties (a more viscous cream holds air better prior to stabilization by adsorbed fat droplets, and exhibits reduced foam drainage), and to alter the melting characteristics of imitation cheese (gums and proteins can form composite gels). The viscosity modifying properties of gums arise from their ability to bind water. This also leads to another useful property of gums in frozen products. The water bound by gums has altered freezing properties due to its restricted mobility. This finding means that gums are widely used in frozen desserts to control the ice-crystal size in the product. This improves the mouthfeel of a product by keeping ice crystals small. In additon, gums can be used in other emulsion products, when frozen, to improve freeze–thaw stability. Gums can be classified as neutral and acidic, straight and branched chain, gelling and nongelling. Acidic polysaccharides, eg, carrageenan are particularly useful in acid environments, as they are stable at low pH. Therefore they have found use as stabilizers of proteins in acid environments. This ability of gums to interact with proteins and to alter their properties also has an affect on the heat stability of protein systems. Protein stabilized substitute dairy emulsions have added polysaccharides to improve heat stability, although not all polysaccharides have this effect (19).

The principal gums and the functions in imitation dairy products are listed in Table 3. A listing of gum applications in dairy foods that apply to imitation products is given in Table 4 (20).

2.5. Salts. Citrates and phosphates are used in substitute dairy products for one or more of the following purposes (20): to alter buffering capacity of the system; to improve the stability of the protein to calcium ions; to improve the heat stability of the protein; to minimize the age gelation of ultrahigh temperature (UHT)-processed substitute products; to serve as emulsifying salts in imitation cheese manufacture; and to modify the water-binding capacity of proteins and improve solubility. Common phosphate salts (and their CAS registry numbers) used in these foods are monosodium phosphate [7558-80-7] (MSP), disodium phosphate [7558-79-4] (DSP), trisodium phosphate [7601-54-9] (TSP), disodium pyrophosphate [7558-16-9], tetrasodium pyrophosphate [7722-88-5] (TSPP), sodium tripolyphosphate [7758-29-4] (STP), $Na_5O_{10}P_3$, sodium hexametaphosphate [10124-56-8] (SHMP), sodium trimetaphosphate [7785-84-4], $Na_3O_9P_3$, and sodium tetrametaphosphate [13396-41-3] (20). Although there are similarities in some functional uses, phosphates are more broadly used than citrates in substitute dairy foods.

Phosphates, which react with calcium to reduce the calcium ion activity, assist in stabilizing calcium-sensitive proteins, eg, caseinate and soy proteinate, during processing. Phosphates also react with milk proteins. The extent of the reaction depends on chain length. Casein precipitates upon addition of pyrophosphates, whereas whey proteins do not. Longer chain polyphosphates cause the precipitation of both casein and whey proteins. These reactions are complex and not fully understood. Functions of phosphates in different types of dairy substitutes are summarized in Table 5.

3. Composition and Processing

3.1. Milk Substitutes. A wide range of substitute milk products can be found either on the supermarket shelf, or in specialist health and vegetarian stores. The most common of these are soya milks, although analogous products made from oats, rice, almond, and coconut can be found. A distinguishing feature of these substitute products is that they contain no lactose, and thus are suitable for individuals who are lactose intolerant. These substitutes vary in price and composition, with almond and coconut milk being the most expensive. Soya milk is perhaps the most popular alternative to cows milk. It is lower in fat and carbohydrate than whole milk, but also lower in calcium and vitamin D. At least part of its popularity arises from the presence of certain compounds believed to reduce the risk of cancer. Of the other substitutes, rice, almond, oat, and coconut milk are lower in protein, and often deficient in essential vitamins and minerals. Many of these products are fortified to improve their nutritional profile.

The traditional process for making soya milk is relatively simple, and involves the boiling of dehulled soya beans in water, and the collection of the aqueous extract. The details of the process are critical to obtaining a satisfactory product. Whole soya beans are usually boiled in water prior to grinding into a pulp. This heating process prevents formation of the beany flavor so typical of soya products, and inactivates the trypsin inhibitor found in soya bean. After heating, the extract can be filtered to make clarified soya milk. This filtration removes the fibrous material (termed okara). The unfiltered product is called suspended soya milk. Further diversification of the product can be achieved by sweetening the soya milk, or by addition of various flavors to make a product similar in taste to dairy milk.

Improvements on the traditional process have usually introduced new methods for deodorizing the ground soya bean pulp.

3.2. Infant Formulations. Infant or pediatric formulations are fluid milk-like products that are optimized to have a composition that meets the nutritional requirements of infants. Normal cows milk is unsuitable for some infants due to intolerance to lactose and the bovine whey protein β-lactoglobulin. In addition the proportions of other essential nutrients differ between human and bovine milk and these must be supplemented in infant formulations (21). Formulations based on milk protein are manufactured with a whey protein/casein ration of 60:40 (22). This is higher than found in bovine milk, but matches that for human milk. The milk proteins in infant formulations are usually hydrolyzed, which has a number of beneficial effects in the product. Hydrolyzed β-lactoglobulin is not allergenic, while in its native form it has been linked to cow's milk intolerance in infants (23,24). In addition, the hydrolyzed protein fragments are more easily digested in the gut (25). Finally, hydrolysis prevents heat-induced denaturation of globular milk proteins. These would be particularly susceptible to heat damage in infant formulations since they require a very intense heat treatment to ensure total microbial sterility. Extensively hydrolyzed proteins do not form very stable emulsions, and are thus unable to adequately stabilize the fat in these products. Therefore it is common to add other ingredients to the formulation (in addition to proteins and other essential nutrients) to aid in emulsion stability. These include low molecular weight surfactants and polysaccharide stabilizers.

Soya-based infant formulations have also been developed that do not have the intolerance problems associated with milk-based formulations. They are made with soy protein isolate, and are formulated with the same nutrient levels as milk protein-based products.

3.3. Coffee Creamers and Coffee Whiteners. Coffee creamers and whiteners have several functions. They give coffee a white color, reduce bitter taste by complexation of the tannic acids with milk proteins, and give the coffee a cream-like flavor (26). The distinction between a creamer and a whitener has become indistinct over the years. Generally, however, a creamer is a liquid product formed either by concentration of milk to a fat content of 10–20% or by recombination (27). Whiteners, on the other hand, can be powdered or liquid and usually contain vegetable oils rather than milk fat.

Creamers based on concentrated milk are UHT processed and aseptically packed for a long shelf-life. Recombined products require a more complex process and these have been found to require the addition of low molecular weight emulsifiers to form a stable product. A typical formulation for a recombined coffee creamer is given in Table 6 (28). The emulsifiers are believed to have a dual role in the manufacturing process (6,28). They probably aid in the formation of fine oil-in-water emulsion droplets, and help to preserve emulsion stability during heat treatment.

The particle size of a coffee creamer is critical to its whitening power, and the homogenization stage is important in controlling this process. Recombined coffee creamers require an optimum fat droplet size range (0.2–1.0 μm) and a narrow particle size distribution (4). Overhomogenization of a recombined coffee creamer results in a loss of whitening power.

Coffee whiteners are popular in both liquid and powder form. Formulations for both liquid and dry powder coffee whiteners are given in Table 7 (4). The dried powder form requires modifications to the formulation to ensure a stable product during spray drying and storage. The emulsifiers are an important component of coffee whitener. In both liquid and powdered products, they aid in the formation and heat stability of the product. In the dried powder, they are believed to play a role in improving powder solubility, dispersibility, and whitening ability. The GMS has been found to improve powder dispersibility, while Tween 60 improves the rate of powder dissolution in coffee (29). It has also been found to give the optimum whitening power (4).

Additional protein emulsifier (sodium caseinate) is required to maintain a stable dried product, since a protein layer around the oil droplets is better able to withstand the high temperatures of drying (26). Since sodium caseinate is relatively expensive, ways of reducing the quantity used have been sought. The emulsifers sodium or calcium stearoyl-lactylate and sodium stearoyl-fumarate have been found to be particularly important in this respect. A 2.5 wt% GMS plus sodium stearoyl lactylate blend (in the ratio GMS/SSL of 7.3:1) allows for a 60% reduction in sodium caseinate concentration (11). The SSL is believed to form an interfacial complex with casein molecules that increases the rigidity of the adsorbed protein layer, thus making it better able to withstand intense heat treatment, giving improved fat encapsulation (10).

3.4. Imitation Frozen Desserts and Cultured Imitation Products. Imitation frozen desserts and whipped toppings are a common alternative to ice cream in the United States, but are less popular in the United Kingdom and Europe. Imitation frozen desserts are processed in the same way as ice cream, but with vegetable fat substituted for milk fat. Frozen desserts based on casein or whey protein have not been widely marketed as there is no economic advantage to do so. Soybean-based products are similarly not widely produced due to flavor problems.

Nondairy yogurts have been produced from soy, rice, and oats, altough soy yogurts are still the most common. The latter are flavored to mask the beany aftertaste.

3.5. Imitation Whipping Cream and Whipped Toppings. Imitation whipping creams are equivalent to recombined dairy whipping creams, but they contain vegetable fats–oils instead of milk fat. Like recombined whipping creams, vegetable fat-based creams rely on the presence of low molecular weight emulsifiers for their whipping properties. In natural whipped cream, the air bubbles are stabilized by a partially coalesced layer of milk fat globules, and a gel-like network of partially coalesced globules that span the aqueous phase between air bubbles (30). In combination, this gives the semisolid like texture of whipped cream. For partial coalescence of the fat globules to occur, the protein-containing membrane (the milk fat globule membrane MFGM) that surrounds the fat globules must be disrupted, so the fat emulsion becomes unstable. Destabilization of the MFGM can be achieved by cooling the nonwhipped cream to a temperature of $\sim 4^{\circ}C$. The phospholipids components of the membrane then undergo a phase transition that leads to expulsion of water and protein, which leaves it susceptible to shear (whipping) induced instability. A satisfactory whipped structure also requires that the fat globules do not fully coalesce, but form a structure where a substantial proportion of the fat globule structure is maintained. Thus, the liquid-fat content in the milk fat must be low, but sufficient to lead to only partial coalescence of the fat droplets. A whipping temperature of $4^{\circ}C$ gives sufficient liquid fat in the globules for this to occur. In recombined creams, where the natural MFGM is not present, the protein adsorbed layer around the fat droplets is not disrupted by cooling, and the emulsion will not whip. To achieve a satisfactory whipped product, low molecular weight emulsifiers are added, usually mono- and diglycerides, and polysorbitan esters (Tweens). In recombined products, a combined protein–emulsifier adsorbed layer is formed. When this is cooled the added emulsifiers undergo a phase transition and expel protein from the adsorbed layer, which makes it susceptible to whipping induced destabilization. In addition, as for natural cream the solid/liquid fat ratio is important for foam structure. Therefore, the use of vegetable oils is only possible if they are hardened, to give the correct solid/liquid fat content at the whipping temperature. Polysaccharide stabilizers are also often added to these products and they have the effect of thickening the aqueous phase and thereby reducing the rate of drainage from the lamellae between the air bubbles in the foam.

Powdered whipped toppings are a popular alternative to dairy creams. Whipped toppings also rely on proteins and emulsifiers for their emulsion stability and whipping properties, although the mechanism of whipped topping stability is very different to that of whipped cream. Evidence suggests that part of the fat in spray-dried topping powders is in a supercooled state (31–33) that spontaneously recrystallizes when the powder is reconstituted. This leads to protein displacement and instability of the fat droplets. Stabilization of the air bubbles in the foam is via a layer of crystalline fat at the bubble surface, along with regions of crystalline fat in the lamellae between the bubbles. The kinetics of fat crystallization is controlled by the emulsifiers present in the formulation. Common emulsifiers in whipped toppings are propylene glycol esters of monoglycerides, acetic acid esters of monoglycerides, or lactic acid esters of monoglycerides (4). Table 8 gives a typical formulation for a whipped topping emulsion (4).

3.6. Imitation, Processed, and Soya-Based Cheese. A number of different cheese analogues are available on the market. These range from products where milk is substituted for nondairy ingredients, and then processed in the same way as cheese, through processed cheese products and cheese analogues manufactured from a green skim milk curd or rennet casein, through to traditional soya-based tofu. These products have different textures and tastes depending on the market they are manufactured for. Cheese substitutes can be made from soy, rice, nuts, seeds, or a combination of nondairy protein sources with casein. Because of its predominance of the market, only soya-based cheese will be discussed further as an example of a nondairy cheese.

Imitation Cheese. Filled cheese was made traditionally by adding vegetable fat to skim milk and homogenizing at low pressure to make a uniform emulsion, followed by traditional cheese making procedures. With the development of cheese processing, filled cheese was made from skim milk curd to which was added oil, flavoring, and phosphate, and citrate emulsifying salts. The mixture was heated to $\sim$55–66°C and then packaged. Skim milk curd was frequently treated with proteolytic enzymes to obtain a body similar to that obtained when processing aged cheese. The casein-based imitation cheeses are based on these processes. A variety of approaches have been suggested for making these products, and a typical method is shown in Fig. (34). The types of cheese that are commonly imitated are cheddar and mozzarella.

Processed Cheese. The origins of processed cheese date back $\sim$100 years. The processing of cheese was used as a way of extending the shelf-life of cheese, and as a way of utilizing low quality cheese (35). Nowadays, it is a popular product in its own right. Processed cheese is made with a similar process to filled imitation cheese, except that the protein source is cheese (or a mixture of cheese and rennet curd) rather than a skim milk curd or rennet casein.

The cheese is chopped, and heated at 70–82°C with water and polyphosphate or citrate emulsifying salt, which help to solubilise the cheese through chelation of calcium. The pH of the mix is altered to 5.6–5.8 by careful selection of a blend of polyphosphate emulsifying salts (36). The final product can have 15–25% fat and up to 58% water. Table 9 gives a typical composition for a processed cheese (37).

Processed cheese is manufactured in three forms, block cheese that is similar in texture to hard cheese, processed cheese food (slices), and spreads. The texture and flavor of these is controlled by the relative proportions of different cheese types (young cheese, medium or aged, ie, mild, medium, and strong cheese flavor). Typically block processed cheese would contain 50–60% mild, 20–30% medium and 10–20% aged cheese, cheese food 30–40% mild, 50–60% medium and 10% aged, and spread 50–60% mild, 30–40% medium and 10% aged (38).

Soya-Based Cheese. Soy cheeses (called tofu in English) were originally developed in China, and are prepared from soybean milk curd (39). Their manufacturing process is similar to that for dairy cheese, although the coagulation is via $CaSO_4$ (Chinese style), $MgCl_2$ (Japanese style), or glucono-δ-lactone rather than rennet and lactic acid bacteria. The process involves two heating steps where the soymilk is heated at neutral pH followed by heating of the pressed curds at acidic pH.

Fermentation of some types of tofu eg, furu is achieved by inoculation of the surface of curds with moulds, eg, *Actinomucor elegans, Mucor hiemalis*, and *M. silvaticus* (39). A general manufacture process for tofu is given in Fig. 2.

Fermentation of soymilk with lactic acid bacteria can produce a cheese with a flavor closer to that of dairy cheese (40), but development of curds with similar texture to that obtained by acidification of dairy milk has proven difficult (41).

Soy protein is a relatively inexpensive protein substitute in dairy analogue cheeses, and has the added advantage that its biological value is higher than that of casein (41). It has proven difficult to use soy protein in cheese analogues and to achieve a texture that is comparable to that of dairy cheese produced with casein or caseinates (42). Lee and Marshall (43) replaced sodium caseinate with native or boiled soy protein concentrate in a cheese analogue and showed that the boiled soy protein concentrate gave a more porous curd than that containing native soy protein.

3.7. Margarine. Margarine was originally developed as a substitute for butter, but due to it having properties desirable to the consumer (eg, the ability to spread straight from the fridge, and being vegetable oil-based and thus potentially high in polyunsaturated fats) it has developed an identity and market niche of its own. There are three types of margarine, block margarine, soft (tub) margarine, and reduced-fat margarine. The formulations used differ between the three types, in particular with respect to the oil blends used.

Margarine consists of two phases, an aqueous phase, and an oil phase. The aqueous phase is composed of skim milk (or SMP plus water) and salt, plus various other minor ingredients such as acidity regulators and flavors. The oil phase is a blend of various vegetable oils (eg, soyabean, sunflower, canola, corn, palm, rapeseed oils), the composition of which is selected to give a margarine with the desired texture. Fat blends typically used in margarine manufacture are listed in Table 10 (44). Since most vegetable fats are liquid at room temperature those used in margarine blends are hydrogenated to change their melting properties so as to give a semisolid texture. The aqueous and oil phase are mixed in an agitated tank in the weight ratio 1:4 at 40°C, where an emulsion of water droplets in oil is formed. In batch systems, the emulsion is rapidly supercooled to ~7°C in a scraped surface heat exchanger where partial crystallization of the fat phase occurs. It is important for product stability that the correct triglyceride structure (the so-called β' structure) is formed, where small crystals are formed that give a smooth texture. The β' crystal growth is encouraged by partial crystallization in the scraped surface heat exchanger. The selection of the oils in the oil phase also helps to promote the correct crystal growth. Vegetable oils that contain a certain level of palmitic acid (eg, cottonseed and palm oil) also promote a stable β'-crystal form. When insufficient palmitic acid is present, the β' crystals change to larger β crystals that can be detected as a gritty texture. The partially crystalline emulsion is then passed through a second heat exchanger where further crystallization and solidification occurs.

In addition to traditional margarines, the following are also available: whipped margarine, margarine containing 15–40 vol% of finely and uniformly dispersed gas; liquid margarine, margarine that pours and is made by one of several methods that modify the fat system (45–47); and low fat margarine, margarine having a fat content <80 wt% and generally 30–65 wt%, ie, imitation margarine or spread. By regulation margarine contains 80 wt% fat. A number of imitation margarines have been introduced that have fat contents of 35–65 wt% (48). In most cases, these products contain sodium caseinate, whey protein, or soybean proteins as the protein portion of the aqueous phase; emulsifiers; and sometimes gums. Emulsifiers of choice are generally mono- and diglycerides. Some spreads are made from a blend of vegetable fat and butter and butterfat. The addition of small amounts of butter to margarines has been reported to improve flavor.

4. Economic Aspects

Substitutes exist for most dairy products. In the United States, commercial dry mixes or bases without fat that are available include the following: filled buttermilks, filled cheese, filled coffee creams, filled dip products, filled eggnog, filled frozen desserts, filled milk, filled sour cream, filled whipping cream, imitation ice cream, imitation milk and milk products, and imitation coffee cream. Complete dry mixes available include imitation coffee cream, imitation flavored dips, imitation frozen desserts, imitation half-and-half, imitation milk and milk drinks, imitation sour cream, and imitation whipping cream. In addition, filled and imitation products are sold under generic names, eg, chip dips, coffee whiteners, margarine, spreads, and whipped toppings. These dairy substitutes have identities apart from dairy products. Many are sold under fanciful or trade names, eg, coffee whiteners are sold under a wide range of trade names that include: Coffee Light, Coffee Mate, Coffee King, Complement, Cremora, and Crodamix. Most of these substitute products, including margarine, often contain a milk component.

Of the filled and imitation products, margarine has made the greatest penetration into the sale of dairy foods. The market share of butter, margarine and spreads in different countries is shown in Table 11 (49). In Great Britain, up to 50% of the butter and creams sales have been replaced by margarine. The amount of replacement is greater in the United States, reaching $\sim$82% in 1987. However, United States per capita consumption of butter increased between 1977 and 1987. Indeed, spreads and blends of butter and margarine have increased sales (2).

Other dairy substitutes have penetrated the U.S. market to the extent of 1% for fluid whole milk, 58% for creams, <1% for lowfat milk, 6–7% for cheeses, 10% for evaporated and condensed milks, and 2% for ice cream (50). About 60% of the substitute and imitation cheese sold in the United States is being used as the cheese material for pizza (2).

In the Philippines, the sale of filled milk had become 85% of the dairy products market by the early 1970s, reflecting convenience as a purchase incentive rather than price. Filled condensed and evaporated milk has a market share of 10, 27, 54, 69, and 77% in the Netherlands, Mexico, Malaysia, Phillipines, and Thailand, respectively (50). Imitation cream has an 8% market share in the United States, 11% in Spain, and 33% in Canada (2). Areas in the world expected to show the greatest growth in the sale of substitute and imitation dairy products are Canada, Ireland, and Mexico (50).

Based on brand name products, the total number of branded substitute and imitation dairy products worldwide is estimated to >1000. Almost all multinational food companies market one or more dairy substitutes.

Cost is a significant factor in the consumer's acceptance of substitute dairy foods. Table 12 shows the relative cost of substitute fat and protein in the various substitute foods (46). A comparison of retail prices of selected dairy products and corresponding substitutes in four supermarkets in the midwestern United States in the Fall of 1992 are shown in Table 13. In all cases, the prices for the substitutes are lower than the prices of the respective dairy product. The smallest price margin is in the area where the substitute products are advertised as fat-reduced or cholesterol-free.

Based on ingredient cost comparisons, the fat cost in dairy products is 40–90% of the total ingredient costs. In contrast, fat makes up 16–30% of the ingredient cost of substitute products. This result is related to both the higher price of milk fat and the higher amount of fat that is generally in dairy products as compared to substitutes. The cost of milk fat has been declining, however. But as milk fat price goes down, milk protein prices increase, shifting the emphasis from milk fat substitution to milk protein substitution.

5. Regulatory Aspects

The legal status of dairy substitutes varies widely among countries. In the United States, the U.S. Food and Drug Administration (FDA) has held that filled products should be nutritionally equivalent to the products they resemble. In the case of imitation milks, the FDA proposed regulations for nutritional equivalency (51). A section of the Food, Drug and Cosmetic Act defines misbranded foods, and the FDA has set up standards of identity for foods under this part of the law that includes standards for imitation milks, cheese, and creams.

The definition of margarine varies from country to country (52). The U.S. Code of regulations on margarine is given in Ref. 52 and on imitation ice cream, called mellorine, in Ref. 53. Regulations on food labeling, proposed in 1991, have not as of this writing been promulgated.

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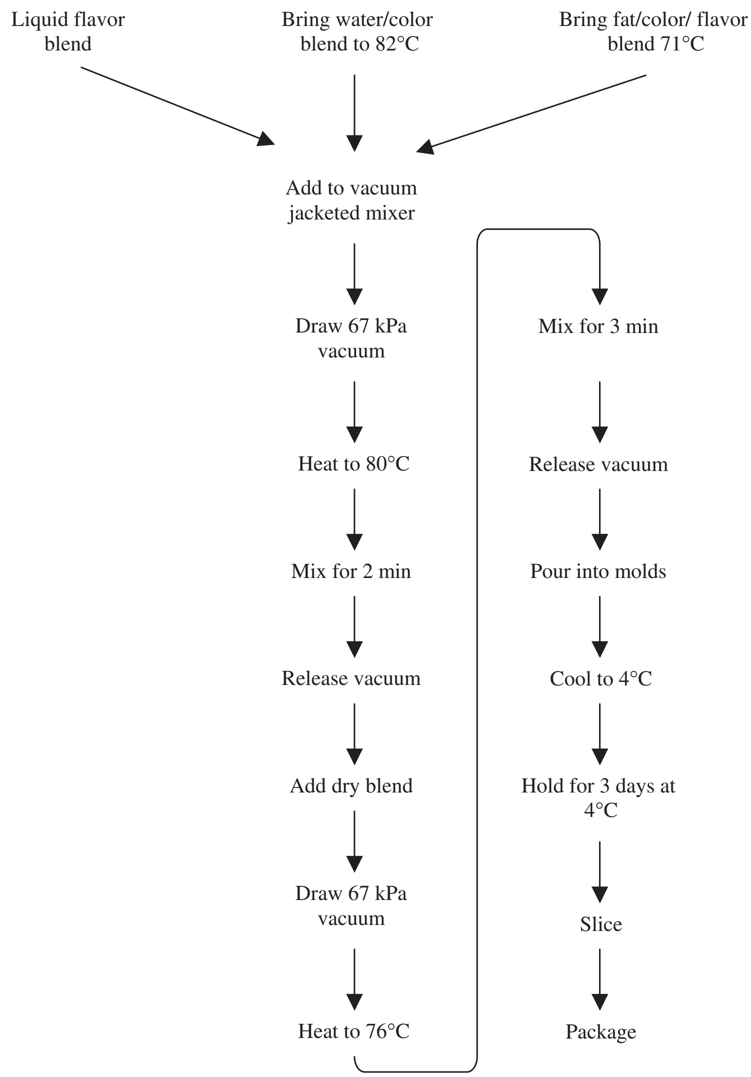

Fig. 1. Schematic process flow diagram for an imitation cheese product having the following formulation: dry ingredients, calcium caseinate or (rennet casein), 24.5 wt%; tapioca flour 3.0 wt%; salt, 2.16 wt%; adipic acid, 0.6 wt%; vitamins and minerals, 0.1 wt%, sorbic acid (mould inhibitor), 0.5 wt%; fat-color blend, soybean oil hydrogenated to a Wiley melting point of 36°C, 21.3 wt%; lactylated monoglycerides, 0.05 wt%; red-orange colouring, 0.01 wt'%; and flavoring blend, 0.23 wt% (34).

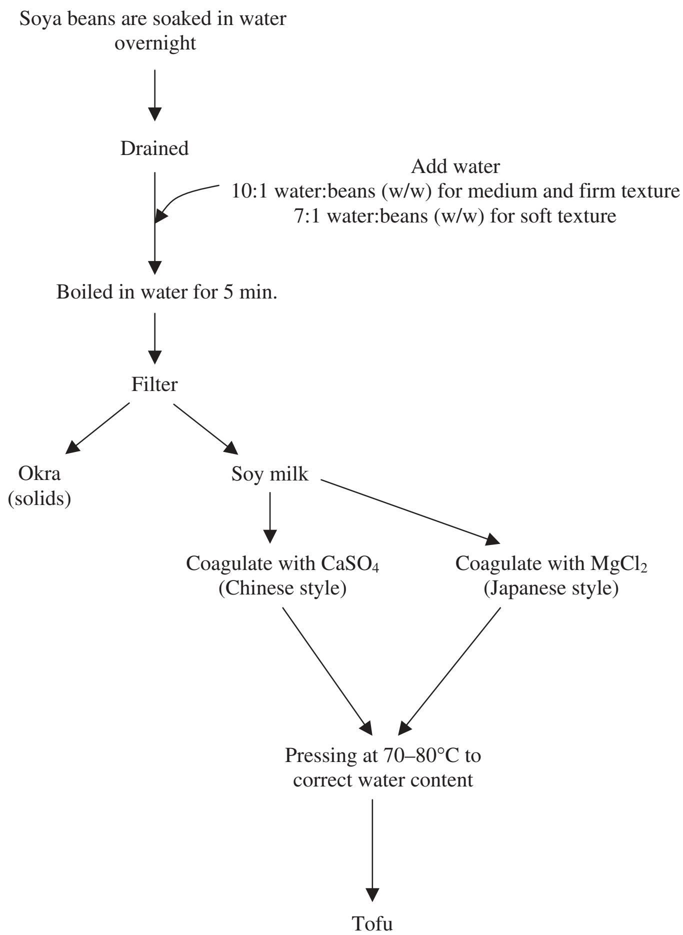

Fig. 2. A flow diagram for the production of tofu.

Table 1. **Typical Emulsifiers Used in Dairy Substitutes**

Emulsifier	EEC number	US FDA (2ICFR)	HLB number
mono- and diglycerides	E471	182.4505	3.8
lactylated monoglyceride	E472	172.852	
propylene glycerol monoester	E477	172.854	1.8
sorbitan monolaurate (Span 20)	E493	178.348	8.6
sorbitan monopalmitate (Span 40)	E495	178.340	6.7
sorbitan monostearate (Span 60)	E491	172.842	4.7
sorbitan monooleate (Span 80)	E494	173.75	4.3
polyoxyethylene sorbitan monostearate (Tween 60)	E435	172.836	14.4
polyoxyethylene sorbitan monooleate (Tween 80)	E433	172.840	15.4
calcium stearoyl lactylate	E482	172.844	5.0
sodium stearoyl lactylate	E481	172.846	21
sucrose esters	E173	172.859	1–16
lecithin	E322	184.140	2–10

Table 2. **Typical Compositions of Dried Dairy Protein Products**

	Protein, %	Fat, %	Lactose, %	Ash, %	Water, %
whole milk powder	26.4	27.5	38.2	5.9	3.0
skim milk powder	35.9	0.8	52.3	8.0	3.5
acid casein	88.0	1.0	0.1	2.2	9.0
rennet casein	85.0	1.0	0.1	4.0	11.0
calcium caseinate	90.9	1.0	0.1	4.5	3.5
sodium caseinate	91.4	1.0	0.1	4.0	3.5
whey protein concentrate	80.5	6.0	5.0	5.0	3.5
whey protein isolate	93.0	0.5	1.0	2.0	3.5

Table 3. **Gums and Associated Functions in Dairy Substitutes**

Gum	Imitation product use	Function
alginates	ice cream	aeration, reduce whip time
	cheese	texture modifier, prevent oil separation
carrageenan	milk puddings	gelation
	ice cream	prevent wheying off
	infant formulas	stabilize proteins to heat
	evaporated milk	stabilize proteins to heat
locust bean gum	ice cream	smooth melt down, freeze-thaw resistance
	cheese spread	texture modifier
guar gum	ice cream	water binding, body control
carboxymethyl cellulose	ice cream	prevent ice crystal growth
	whipped topping	aeration, protective colloid
xanthan gum	sour cream	prevent wheying off

Table 4. **Application of Gums in Dairy Products**[a]

Product	Agar	Alginate	Carageenan	Furcelaran	Arabic	Xanthan	Tragacanth	HPC[b]	LB[c]	Guar	CMC[d]	MC[e]	Karays
ice cream stabilizer	X	X	X	X	X		X		X	X	X	X	X
ice milk	X	X	X	X	X		X		X	X	X	X	X
milk shake	X	X	X				X		X		X		
sherbets	X	X	X	X	X		X		X	X	X		X
chocolate milk		X	X	X	X	X	X		X	X	X		
puddings	X	X	X	X	X	X			X	X			X
cream cheese	X	X	X		X				X	X			
cheese spread		X	X		X	X	X	X	X	X	X		X
neufchatel process cheese	X	X	X		X		X		X	X			X
whipped cheese		X	X			X		X	X				X
yogurt	X		X		X				X	X			

[a]Ref. 20.
[b]Hydroxypropyl cellulose = HPC.
[c]Locust bean gum = LB.
[d]Carboxymethyl cellulose = CMC.
[e]Methyl cellulose = MC.

Table 5. **Function of Phosphates in Dairy Substitutes**

Imitation dairy food	Phosphate group	Function
milk-based pudding	SHMP, STP, TSPP, TSP	gelation
milk	DSP	heat stability
coffee whitener	DSP, DKP[a], Poly[b], SALP[c]	pH control, reduce feathering, reduce oiling off
whipped topping	DSP, DKP, TSPP	pH control, whip stability, overrun improvement
sour cream	DSP, DKP, TSP, TSPP	improve body, reduce wheying
ice cream	DSP	protein stability
cheese	MSP, DSP, TSP, TSPP	modify protein, emulsifier

[a]Dipotassium phosphate = DKP.
[b]Poly = Polyphosphate.
[c]Sodium aluminum phosphate = SALP.

Table 6. **Formulation for a Recombined Coffee Creamer**[a]

Ingredient	Composition, wt%
skim milk powder	3.0
buttermilk powder	4.5
anhydrous milk fat	19.0
carrageenan	0.03
GMS	0.05
tween 60	0.1
water	73.32

[a]Ref. 28. Reprinted by permission of the International Dairy Federation, Diamant Building, Boulevard Auguste Reyers 80, 1030 Brussels, Belgium, www.fil-idf.org.

Table 7. **Typical Formulations for Liquid and Powdered Coffee Whiteners**[a]

	Composition, wt%	
Ingredient	Liquid	Powder
fat	10.0	30.0
sodium caseinate	1.0	4.0
maltodextrin (DE28)	10.0	62.0
monoglycerides	0.2	~1.5
tartaric acid esters of monoglycerides	0.2	0.5
carrageenan	0.05	
sodium alginate		0.05
K_2HPO_4	0.2	1.5
flavor	300 ppm	1000 ppm
water	to 100%	

[a]Ref. 4.

Table 8. **Typical Whipped Topping Powder Composition**[a]

Ingredient	Composition, %
hardened coconut or palm kernel oil (melting point 31–36°C)	32.0
maltodextrin	32.0
sodium caseinate	8.0
emulsifiers	8.0

[a]Ref. 4.

Table 9. **Typical Composition of a Processed Cheese**[a]

Component	Proportion of formulation, g/100 g
dry matter	51.3
of which fat	25.6
protein	11.6
emulsifying salts	3.0
others (salt, lactose, minerals)	11.1
moisture	48.7

[a]Ref. 37.

Table 10. **Composition of Margarine Fat Blends**[a]

	Margarine					
Fat	A	B	C	D	E	F
palm kernel	32	37	36			55
coconut	37	36	40	50		
palm						15
hydrogenated cottonseed[b]				18		
groundnut	20	16			11	
hydrogenated groundnut	11	5			69[c]	30[d]
soybean		6	24	22	7	
sesame				10	13	
total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

[a]Ref. 44.
[b]Melting point 34°C.
[c]Melting point 30°C.
[d]Melting point 40°C.

Table 11. **World Market Share of Butter, Margarine, and Spreads**[a]

Country	Butter, %	Margarine, %	Spreads[b], %
Australia	34	60	2
Finland	50	35	10
Japan	18	80	2
United Kingdom	29	57	14
United States	16	82	2
Sweden	15	57	28

[a]Ref. 49.
[b]Spreads are products with fat reduced <80% required by standards of identity for butter and margarine.

Table 12. **Relative Composition and Ingredient Costs of Dairy Products and Substitutes**[a]

	Component relative to dairy product %		Cost relative to dairy product %	
Substitute[b]	Fat	Protein	A	B[c]
filled milk	86	100	70	72
coffee whitener	56	80	27	40
whipped topping	78	100	33	59
ice cream	100	86	52	55
cheese	76	89	70	51

[a]Ref. 46.
[b]Products other than filled milk based on caseinate.
[c]Corrected to same fat and protein level as dairy product.

Table 13. **Prices of Dairy Products and Substitutes in 1992**

	Price, US$/100g	
Category	Dairy food	Dairy substitute
coffee cream		
liquid	0.35	0.15–0.28
frozen	0.35	0.24–0.32
dried	1.23[a]	0.35–0.76
whipped toppings		
aerosol	0.95	0.79–0.87
frozen	0.48[b]	0.31–0.66
sour cream	0.44	0.26–0.34
butter	0.35	
margarine		0.07–0.19
lite-spreads		0.29–0.33
spreads[c]	0.35	0.31–0.33
shredded cheese	1.05[d]	0.57–0.83

[a]Dried whole milk.
[b]Heavy cream (nonfrozen).
[c]Spreads citing the word butter on the label.
[d]Cheddar.