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Cheese analogues: a review

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Abstract

Cheese analogues are usually defined as products made by blending individual constituents, including non-dairy fats or proteins, to produce a cheese-like product to meet specific requirements. They are being used increasingly due to their cost-effectiveness, attributable to the simplicity of their manufacture and the replacement of selected milk ingredients by cheaper vegetable products. Sales of cheese analogues are closely linked to developments in the convenience food sector, where they extend the supply and lower the cost. Moreover, there is an ever-increasing interest among consumers in food products which contain less total fat, saturated fat, cholesterol, and calories.

Development of cheese analogues involves the use of fat and/or protein sources other than those native to milk, together with a flavour system simulating as closely as possible that of the natural product. It is also necessary to develop a suitable processing regime capable of combining these elements to provide the required textural and functional properties. Cheese analogues may be regarded as engineered products.

Cheese analogues represent little threat to the continued consumption of natural cheeses: Their major role at present is undoubtedly in the cost-cutting exercises of pizza manufacturers. The dairy industry has to take the view that imitation products are the result of developments in product technology and market demand. Thus not to get involved would mean curtailment of product innovation and market opportunities. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Cheese analogues; Proteins; Fats; Ingredients; Processing regime; Texture; Melting properties; Flavour; Review

1. Introduction

The growth in the ready meals sector in recent years had been reflected in the increase in the demand for cheese as a food ingredient. Shredded, diced, sliced, and even liquid cheese has been developed to meet the needs of the modern food industry, as convenience foods continue to grow in popularity (Anonymous, 1999). Sales of cheese analogues are closely linked to developments in the convenience food sector (Anonymous, 1989). Cheese analogues are being used increasingly due to their cost-effectiveness, attributable to the simplicity of their manufacture and the replacement of selected milk ingredients by cheaper vegetable products (Eymery & Pangborn, 1988). Cheese analogues extend the supply and lower the cost (Ahmed, Hassan, Salama, & Enb, 1995).

Unfortunately, lack of any detailed statistics makes it impossible to indicate what the total importance of cheese analogues on the world dairy market actually is (Anonymous, 1989). A substantial market has developed in the United States, particularly for industrial food uses where, because of the large quantity processed, the price difference with natural cheese is a decisive factor (Anonymous, 1989; Shaw, 1984). The major application is in compounded or formulated foods manufactured by catering or industrial establishments. The usage level of cheese analogues in the US has remained fairly stable, with the majority of production being mozzarella for use on pizza (McNutt, 1989). In terms of typical usage, the EU market is strikingly similar to the US. However, there are differences in Europe, for example, the cheese analogue market is almost non-existent (Hoogenkamp, 1996). It is a commonly held view in the United States that the introduction of cheese analogues has had rather an additive effect on the overall cheese market rather than the products being used as direct replacements for natural cheese (Shaw, 1984).

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Cheese analogues have gained importance in different areas. Firstly, largely because of a tremendous increase in the consumption of pizza pie and the fact that cheese is among the costliest components of a pizza pie, attention has focused on the development of cheese substitutes. In addition, the manufacture of an imitation cheese allows manufacturers greater scope in manipulating constituents toward nutritional, textural, and economic ends. A wide variety of formulated imitation cheeses in which non-fat milk solids and milk fat are replaced by caseinates and vegetable oils are available in the US (Kiely, McConnell, & Kindstedt, 1991). Secondly, due to rapidly increasing prices cheese is being gradually priced out of lower income groups. Making cheese-like products by substituting the higher priced milk-derived ingredients with lower priced ingredients from vegetable sources may be a possible solution for this economic problem (Guirguis, Abdel Baky, El-Neshawy, & El-Shafy, 1985). The cost of producing cheese analogues can be considerably less than that of their natural counterparts. As well as savings in the manufacturing process, raw materials are considerably cheaper than milk (Shaw, 1984). Thirdly, the short supply of milk production in some parts of the world has led to increased interest in the utilisation of substitute ingredients from vegetable sources in producing some dairy analogues (Ahmed et al., 1995; McNutt, 1989). In developing countries where dairy products are expensive and insufficient in quantity, dairy substitutes prepared from legumes provide a nutritious alternative (Santos, Resurreccion, & Garcia, 1989). Fourthly, there is an ever-increasing interest among consumers in food products which contain less total fat, saturated fat, cholesterol, and calories. Such products are useful in controlling body weight and reducing the risk of heart and artery disease (Kong-Chan, Hellyer, & Tafuri, 1991; Mortensen & McCarthy, 1991).

The review is rather phenomenological. The basic relationship between the composition and the functional properties of the analogues types is not fully elaborated. The scientist, who looks for detailed information to understand the physical properties of cheese analogues related to their structure, will have to investigate the relevant references in depth.

2. Definition

Cheese substitutes and cheese imitates are synonyms. There are two basic types of processes for manufacturing cheese substitutes (Fig. 1). The first uses a liquid "milk", and involves conventional cheesemaking methods, the products often being referred to as filled cheese. The second type, referred to as cheese analogues, is made by blending various raw materials together using techniques similar to those for processed cheese manufacture. The filled cheese process has certain disadvantages in that one is handling fairly large volumes of a low solids stream. The majority of cheese substitutes are manufactured by the blending process (Shaw, 1984).

Development of cheese analogues involves the use of fat and/or protein sources other than those native to milk, together with a flavour system simulating as closely as possible that of the natural product. It is also necessary to develop a suitable processing regime capable of combining these elements to provide the required textural and functional properties. Cheese analogues may be regarded as engineered products (Shaw, 1984).

Two broad classes of commercial food products can be distinguished: Foods that normally constitute part of a mixed diet and products that may constitute a sole source of nutrients for some patients or some consumer segments. Within each of these categories, there are ranges of scientific and regulatory issues (Fig. 2). Cheese analogues belong to foods for a mixed diet with restricted regulatory, scientific and medical complexity.

3. Opportunities and threats

Cheese analogues are gaining increasing acceptance with food processors and consumers because of many potential benefits. In the US cheese analogues are generally manufactured to have nutritional equivalence or in some cases to have nutritional advantages over the natural counterpart cheese. Vitamin and mineral contents can be as good as or superior to those of natural cheese through appropriate fortification (Shaw, 1984).

Consumer concerns with ingestion of sodium and saturated fats, have prompted testing of cheese and cheese analogues containing reduced levels of these ingredients. Since both fat and salts play important roles in the physical state of the product, reductions can alter appearance, texture, flavour, melting properties and other attributes (Eymery & Pangborn, 1988).

During the last decade consumers have become increasingly aware of the importance of maintaining adequate nutrition. Instead of trying to develop low calorie foodstuffs, it is better to formulate foods with ingredients that help to lower health risks, as in the case of substituting animal fats by vegetable fats and oils, to give foodstuffs low in cholesterol and saturated fats (Lobato-Calleros, Vernon-Carter, Guerrero-Legarreta, Soriano-Santos, & Escalona-Beundia, 1997). Thus, cheese analogues may offer an excellent opportunity for substituting a traditional product with a new one which offers the same or better nutritional and texture characteristics, by using caseinates as protein sources and the use of polyunsaturated vegetable fats and oils, which produce a cholesterol free product (Giese, 1992;

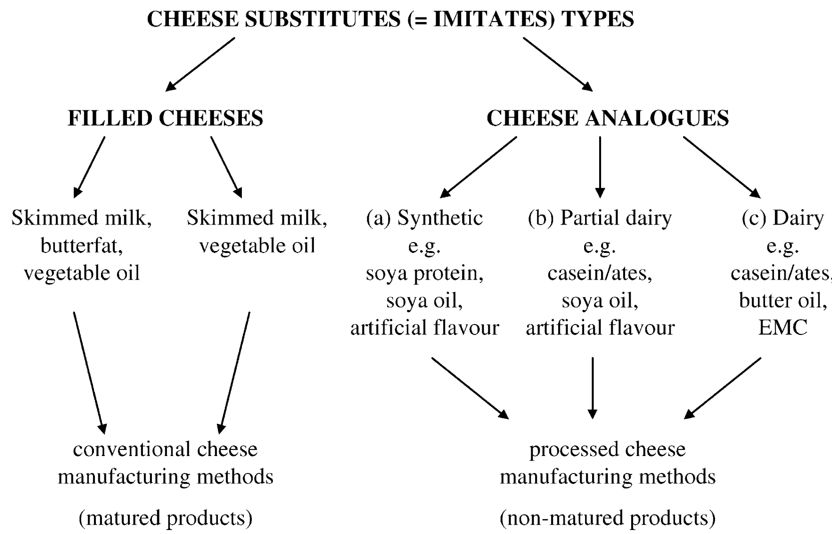

Fig. 1. Different types of substitutes according to Shaw (1984).

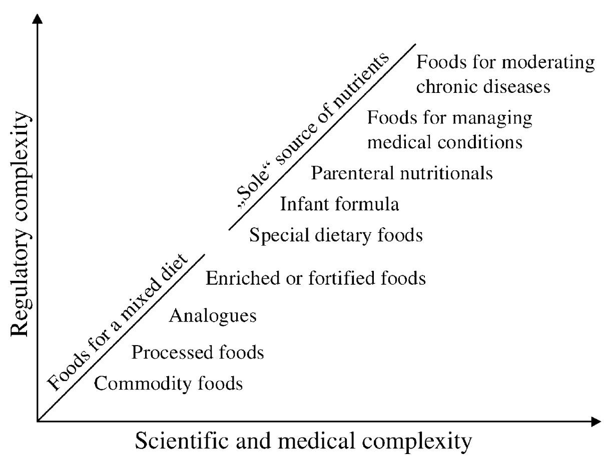

Fig. 2. Ranges of scientific and regulatory issues according to Moore (1987).

Kneifel, & Seiler, 1993). An important area of research for cheese analogues is to build up the polyunsaturated fat level, thus improving the health benefits of cheese analogues (McNutt, 1989). If unsaturated fats are used then the analogues may offer certain health or dietary advantages commonly associated with unsaturated and polyunsaturated fatty acids. Also, if no cheese or butteroil is added, then the analogues are virtually free of cholesterol (Shaw, 1984).

Polyunsaturated fatty acids (PUFA) are highly susceptible to oxidation, especially in the presence of catalytic metallic ions like iron or copper. This so called lipid peroxidation can be prevented by the addition of antioxidants like vitamin E, otherwise the shelf-life is limited. A high intake of PUFA can cause a lipid peroxidation also in vivo. Because no precise information on the optimal intake of PUFA is available, the amount should not exceed the limit of 10% of total energy (Eritsland, 2000). Other recommendations are with the upper limit of 7% even more cautious (Zevenbergen & Rudrum, 1993). Besides, the n-6- and n-3-fatty acids should be in a ratio between 4:1 and 10:1 (British Nutrition Foundations' Task Force, 1992).

Cholesterin plays various roles in the human organism: it is important for lipid digestion and transport, for structure and functioning of membranes and it is a precursor of different hormones. The level of cholesterin in the blood serum is considered as one of many other risk factors of heart and artery disease, although it is only slightly influenced by dietary intake (Howell, McNamara, Tosca, Smith, & Gaines, 1997). Besides, with a daily intake of 200–300 mg of cholesterol a fractional absorption of about 60% was observed (McNamara et al., 1987). It is known that daily 500–1000 mg of cholesterol are synthesised by the human organism itself. Dietary cholesterol at various concentrations has been shown to have only minor effects on cholesterol synthesis, According to Jones (1997) any effect of dietary cholesterol concentration on biosynthesis is modest in humans. Sieber (1993) concluded that cholesterol removal from foods is not justified.

Proteins can be used at the same level as in natural cheese. The biological value of soy protein is higher than that of casein (Ahmed et al., 1995). Unfortunately, such relatively inexpensive vegetable proteins tend to impart characteristic undesirable flavours to the imitation cheese product, and also result in difficulties in the provision of the desirable cheese texture normally produced through the utilisation of casein or caseinates

(Kratochvil, 1986). Moreover the use of soybean as a human food is limited due to its anti-nutritional factors and development of flatulence after consumption. Anti-nutritional factors can be minimised by suitable heat treatment; flatulence can be overcome by fermentation (Singh & Mittal, 1984).

Another beneficial aspect of synthetic cheese products is the fact that many such products can be produced with an almost unlimited shelf life (Kong-Chan et al., 1991; Anonymous, 1989). Imitation mozzarella cheese was functionally more stable during refrigerated storage than natural mozzarella cheese. Such stability makes analogues very attractive to the food processing and service industries (Kiely et al., 1991). They have consistent quality, without seasonal variations, and they can be varied to meet desirable quality characteristics. Production can be scheduled to meet sales needs, eliminating or significantly reducing storage and refrigeration costs (Anonymous, 1982).

4. Protein sources

Calcium caseinates are being widely used in the manufacture of cheese analogues. The water-soluble phosphate groups of the caseinate are located at one end of the protein, while the other end carries non-polar fat-soluble groups. The so-called emulsifier salts operate as calcium-chelating agents which improve the emulsifying properties of caseinate by increasing its hydrosolubility (Eymery & Pangborn, 1988). Functional properties of caseinates in imitation cheese systems have been investigated by Hokes (1982). When the cheese analogue was prepared from sodium caseinate in place of calcium caseinate, the following characteristics were noted: higher pH, lower firmness, higher degree of fat emulsification, higher degree of casein dissociation (Cavalier-Salou & Cheftel, 1991). Fleming, Jenness, Morris, and Schmidt (1985) analysed commercial lots of calcium caseinate preparations differing in performance in imitation cheese for various characteristics. According to Chen, Wan, Lusas, and Rhee (1979) the specific melting and rheological properties of analogues prepared with caseinate as the sole or major protein source reflect directly those of the constituent caseinate(s). Also, reconstituted calcium para-caseinate (from rennet casein) and lactic acid casein (from sodium caseinate) are used (Nishiya, Tatsumi, Ido, Tamaki, & Hanawa, 1989a). Rennet casein and the various acid caseins are significantly different in their physical and chemical properties (Middleton, 1989). Dry rennet casein exhibits several advantages because of its flavour and storage stability (Abou El Nour, Scheurer, Omar, & Buchheim, 1996). Quite often blends of different caseins and/or caseinates are employed (Cavalier-Salou & Cheftel, 1991).

For several years, dried ultrafiltration retentates of skim milk, the so-called total milk protein (TMP), have gained increased importance as an alternative high milk protein product for various types of cheese analogues. Up to a replacement of 40% rennet casein by TMP the resulting processed cheese analogue revealed fully satisfactory organoleptic and texture properties (Abou El Nour et al., 1996). The replacement of rennet casein by milk protein concentrate (MPC, 85% protein) powders increased firmness and sliceability (resistance to cutting) but decreased the meltability of spread-type cheese analogue (Abou El Nour, Scheurer, & Buchheim, 1998).

Vegetable proteins are used in partial or total replacement of caseinate like soybean or- peanut protein isolate (Ahmed et al., 1995; Anonymous, 1982; Chen et al., 1979; Guirguis et al., 1985). The history of cheese-like products based on vegetable proteins dates back to ancient Chinese days with sufu, a fermented soy curd (Kim, Park, & Rhee, 1992). Soybean products such as soy milk and soybean protein play an important role in dairy industries as a low cost substitute for milk protein (Ahmed et al., 1995; El-Sayed, El-Samragy, & El-Sayed, 1991). Lee and Marshall (1981) replaced sodium caseinate with native or boiled soy protein concentrate. Curd containing boiled soy protein was more porous than the control curd or that containing native soy protein. Brander, Raap, and Gessler (1985) developed a cheese analogue product with soy milk, dairy whey and caseinate as protein sources. When utilising soy proteins in dairy food systems, one should be aware that soy proteins are considerably different from milk proteins in molecular and functional properties. Soy proteins are much larger in molecular size than milk proteins, possess complex quaternary structures, and unlike casein, they are not phosphoproteins. To improve functionalities for food applications, various modifications with proteases were studied and improvements in solubility, emulsifying capacity and heat coagulability were observed (Kim et al., 1992). Treatments of soy protein isolates with alcalase and trypsin were more influential in modifying textural properties of the resulting cheese analogues than those with other proteases studied (Kim et al., 1992). Kamata, Sanpei, Yamauchi, and Yamada (1993) used an immobilised protease reactor for cheese analogue production from soy milk. Soy milk curd was obtained from the soy milk hydrolysed with the immobilised enzymes (Kamata, Chiba, Yamauchi, & Yamada, 1992). The reactor developed was found to be expensive to run because of the expensive nature of the enzyme supports used. Ahmed et al. (1995) investigated the feasibility of using groundnut or soya protein as a partial replacement for casein in the manufacture of imitation cheeses. The cheeses became softer and less rubbery with increasing addition of plant proteins. Cheese-like products from peanut milk have had limited success mainly because milk-like extracts do not produce a coagulum firm enough for making hard-type cheese. Curds made from peanut milk were used in the preparation of a processed cheese-like spread (Santos et al., 1989).

5. Substitution of protein

Different procedures for cheese analogues with less or no protein are described. Zwiercan, Lacourse, and Lenchin (1986) prepared cheese analogues from pre-gelatinised or modified high-amylose starch in partial replacement of caseinate. Mounsey and O'Riordan (1999) manufactured imitation cheese with various levels of pre-gelatinised maize starch. Meltability decreased with increasing levels of starch. A mixture of sodium caseinate, soy protein isolate and corn starch has been used to prepare imitation cheese by Lee and Son (1985). Other manufacturers of imitation cheese have used modified starches or soy isolates and gelatin as caseinate replacement (Kiely et al., 1991).

6. Substitution of milk fat

For many years, synthetic cheese products have been made wherein the butterfat traditionally present in full-fat cheese was replaced with an alternative, less expensive, animal or vegetable fat. This practice became widespread in the early 1940s when advances in processing technology surfaced in, for example, the areas of homogenisation and fluid blending. In almost all cases, the synthetic cheeses are offered at lower cost, which was probably the most important single factor in the initial acceptance of synthetic dairy foods. In the last years, however, with the public's increased awareness of the dangers of cholesterol found in animal fats, synthetic cheese products wherein the butterfat is replaced with a vegetable fat have gained increased popularity (Kong-Chan et al., 1991).

Different procedures with hydrogenated vegetable oil such as soya bean, peanut, palm kernel, cotton seed, coconut or corn were developed (Arellano-Gomez, Lobato-Calleros, Aguirre-Mandujano, & Lobato-Calleros, 1996; Brander et al., 1985; Lobato-Calleros & Vernon-Carter, 1998; Shaw, 1984). The use of vegetable fats can give the cheese a consistency that makes it more suitable for certain applications (Anonymous, 1989). Soybean fat conferred hardness and adhesiveness to the cheese analogues, but decreased their cohesiveness and springiness, while the opposite effect was due to soybean oil and butterfat (Lobato-Calleros et al., 1997). Cheese analogues formulated with different proportions of butyric acid and/or soybean oil showed significant variations in texture (Arellano-Gomez et al., 1996). Melted peanut cheese analogue had stretchy characteristics like mozzarella cheese (Chen et al., 1979). When using blends of different fat types, the behaviour exhibited by a given textural characteristic is an average of that provided by each fat on its own (Lobato-Calleros et al., 1997). Using processed cheese analogue containing 4 fats of different hardnesses, it was demonstrated that the role of fat in texture depends on its physico-chemical properties (Marshall, 1991). The formation of small and numerous fat droplets has been related to softer cheese analogues, as the effect of the protein matrix upon the product texture is decreased due to a larger disrupture of its structure (Lobato-Calleros & Vernon-Carter, 1998). To prevent greasing, Hansen (1986) suggested coating of the fat globules with milk protein matter.

Kong-Chan et al. (1991) used a fatty substance which is non-digestible or partially digestible or lower in net-calorie efficiency in simulated cheese products with reduced animal fat and calories. Among the favoured low-calorie fatty materials for incorporation are polyol fatty acid polyesters. The most preferred low-calorie fatty materials for use in the simulated cheese products include sugar, sugar alcohol, and polyglycerol fatty acid polyesters.

Rybinski, Bixby, Dawson, and Woodford, (1993) provided a description of a non-fat cheese analogue with a total fat content of less than 0.5%. The non-fat cheese analogue was produced by combining a coagulated skim milk product with rennet casein, water and emulsifying salts. Kerrigan, Heth, and Hamann (1992) invented a process of making non-fat natural cheese by high-pressure homogenisation to provide a casein/gum dispersion. Muir, Tamime, Shenana, and Dawood (1999) studied the substitution of milk fat by starch or microparticulate whey protein on the perceived flavour of processed cheese analogue (spreadable type). The analogues incorporating anhydrous milk fat (AMF) were easily distinguished by their higher ratings for "creamy" and "buttery" flavour.

7. Food grade ingredients

In the available literature the utilisation of different wholesome food grade ingredients is described (40). Kong-Chan et al. (1991) described the addition of dietary fibre, seasonings, flavouring agents, binding agents, edible gums and hydrocolloids or mixtures thereof in cheese analogues.

In cheese analogues emulsification plays a key role. Buttermilk powder, which includes a substantial phospholipid content, is particularly preferred as emulsifying agent. Other conventional emulsification agents such as mono- and diglycerides, phospholipids, polysorbates, sorbitan esters and polyoxol esters may be utilised, and even emulsification agents such as non-fat dry milk, whey (protein), casein or caseinates may be used (Kratochvil, 1986). Rosenau, Calzada, and Peleg, (1978) prepared a processed, non-fermented cheese-like product by direct acidification of milk and heat coagulation of the curd. Modification of the textural properties was done by the incorporation of carrageenan. Kratochvil (1986) invented imitation cheese products using carrageenan and gelatin. There has also been substantial effort directed to development of cheese analogues from soy protein, gelatin, fat and a variety of gums, such as gum arabic, xanthan-locust bean gum and guar gum (Kratochvil, 1986).

Emulsifying salts are widely used in the production of cheese analogues. Compared with processed cheese, the effects of emulsifying salts on properties of cheese analogues are less clearly understood (Caric, Gantar, & Kalab, 1985). Less finely emulsified cheese analogues usually display better melting properties (Shimp, 1985). In the study of Cavalier, Queguiner, and Cheftel (1991) the degree of fat emulsification was dependent on type of salt, in the following decreasing order (at 1% salt concentration): tripolyphosphate > pyrophosphate = polyphosphate > disodium hydrogen phosphate > sodium citrate. In the same study casein dissociation increased with both concentration of emulsifying salt and degree of polymerisation of the phosphate salts. Sodium citrate always led to a higher degree of casein dissociation than phosphate salts at equal salt concentrations. Thus citrate appeared to chelate calcium ions effectively. The authors concluded that high degrees of casein dissociation depend both on higher pH-value and calcium complexation caused by the emulsifying salts. The degree of casein dissociation is probably related to the affinity of the emulsifying anion for calcium, since destruction of protein–calcium–protein interactions reduces aggregation. Since the binding of calcium to caseinate depends on the degree of phosphorylation of the casein, the addition of different calcium complexing salts may affect differently the solubility of different caseins. In combination with organic acids, the salts act as buffers to maintain pH above the isoelectric point of the protein (Eymery & Pangborn, 1988).

A food grade acid component may be used in the imitation cheese compositions to adjust the pH in the range from about 4.7 to about 6.0 and preferably from about 5.1 to about 5.7 for flavour considerations. Suitable food grade acids include adipic acid, citric acid, lactic acid, acetic acid, phosphoric acid and blends of them. Acidic components may be incorporated into or may be inherent in the ingredients, or may be added as a separate component during manufacture of the matrix to provide adjustment of the pH to the desired value (Kratochvil, 1986). Also malic acid, glutamic acid and hydrochloric acid are described (Kong-Chan et al., 1991).

Small amounts of appropriate vitamins and minerals can be added to the cheese analogues during the final stages of their preparation to achieve nutritional equivalence to natural cheeses (Middleton, 1989).

8. Processing regime

From a technological viewpoint the functionality of the final product can be controlled by careful selection of ingredients and by the method of manufacture. Therefore, it is possible to produce analogues, e.g. for shredding or slicing or to satisfy specific requirements for melting or straining (Abou El Nour et al., 1998). Methods for manufacture of cheese analogues vary somewhat, but generally speaking, processed cheese equipment can be utilised, for example, batch cooker/mixer or continuous scraped surface cooker (Shaw, 1984). Usually the following manufacturing procedure is applied: First the fat is melted, and its temperature is raised to 70°C. Next the stabiliser system is added and the water is blended into the oil and an emulsion is formed with fast stirring. Next the protein is slowly added, and development of texture begins. Then salt, flavour compounds and acid are added. The drop in pH has a strong effect on texture development. This basic type of processing can be developed to be more sophisticated (Shaw, 1984).

Basically, a cheese analogue is an oil-in-water emulsion, similar to natural cheese. Fat droplets are incorporated in a protein gel matrix which functions as an emulsifier (Eymery & Pangborn, 1988). A fairly simple formulation for a cheddar cheese type analogue is shown in Table 1. By changing the proportions of caseinates, acid, stabiliser and vegetable oil and by adjusting the processing parameters, it is possible to engineer a wide range of functional properties and produce analogues for shredding or slicing, or to satisfy specific requirements for melting or stringing, for example (Shaw, 1984).

Many of the techniques for making imitation cheese involve the use of natural cheese materials which

Table 1
Typical recipe for Cheddar cheese analogue

Ingredients	$g\,100\,g^{-1}$
Sodium caseinate	13.0
Calcium caseinate	13.0
Vegetable oil	25.0
Lactic acid	1.0
Stabiliser/emulsifier	1.0
Salt	1.5
Flavour	1.5
Water	34.0
Cheddar cheese	10

constitute a substantial portion of the imitation or synthetic cheese product. Obviously, the elimination of the natural dairy cheese or milk components would represent a cost saving (Middleton, 1989).

In addition to ingredient alteration, cheese analogues are influenced by processing parameters including heating times and temperatures and physical factors such as the speed of blending (Eymery & Pangborn, 1988). The process represents a thermal treatment that profoundly affects proteolytic and physicochemical changes during ageing. The fate of the coagulant, through its contribution to primary proteolysis, is a major driving force for functional changes during ageing (Kindstedt & Guo, 1997). Hokes, Hansen, and Mangino (1989) found the best cheese emulsions to depend on rapid swelling and particle disintegration plus pseudoplastic behaviour over an extended range of shear rates. Recent studies have confirmed that the stretching process plays a critical role in the development of functional characteristics through its impact on several key aspects of pizza cheese (Kindstedt & Guo, 1997).

In the production of cheese analogues extruders are widely used. Cavalier et al. (1991) found it possible to prepare cheese analogues by extrusion-cooking of calcium caseinate and butter oil, with or without emulsifying salts. Compared to batch-prepared cheeses of the same composition, the extruded cheese strips displayed a similar texture, but a somewhat lower degree of fat emulsification and a higher degree of casein dissociation. The authors explained these differences with a lower intensity of thermal and mechanical processing during extrusion. Cheftel, Kitagawa, and Queguiner (1992) reported, that emulsified and gelled cheese analogues, with textures ranging from hard blocks to soft spreads, were obtained with a single extruder pass, starting from cheddar or from caseinate plus various fats. The extents of fat emulsification and of casein "reassociation", and the melting ability, depended on composition and process parameters. The extrusion of fibrous products similar to mozzarella-based string cheese were attempted. Although primarily used at low moisture levels, extrusion cooking with twin-screw extruders also applies to food mixes with 40–80% moisture. Such levels reduce or prevent viscous dissipation of energy and product expansion, but facilitate operations such as fat emulsification, sterilisation, protein gelation, restructuring, shaping and microcoagulation and/or fibrillation of specific protein constituents (Cheftel et al., 1992).

9. Texture and melting properties

The various components of the physical properties can be estimated directly by subjective sensory means, but instrumental measurements are preferable as they are easier to standardise and to reproduce. Instrumental measurements are also potentially more useful as they can generate absolute rheological data provided care is taken to understand the types of forces exerted and the output obtained (Green et al., 1986). The composition of cheese analogues largely determines its texture (Lobato-Calleros et al., 1997). According to Cavalier et al. (1991) water content, fat content, pH range and emulsifying agents are of crucial importance. Marshall (1990) showed that differences found in the texture of cheese analogues can be related to the way the fat and protein are distributed. The moisture in the protein network acted as a plasticiser making it more elastic and less easily fractured (Marshall, 1990). A higher fat content resulted in softer, less springy, more cohesive and adhesive cheese analogues (Stampanoni & Noble, 1991b). Increasing the amount of citric acid or sodium chloride caused a significant decrease in cohesiveness and springiness and an increase in firmness (Stampanoni & Noble, 1991a). Salt (NaCl) influences texture through ionic strength and Na^+/Ca^{2+} competition (Eymery & Pangborn, 1988) and enhances the migration of intact (i.e. unhydrolysed) caseins and mineral constituents from the paracasein matrix into the serum phase (Kindstedt & Guo, 1997).

Eymery and Pangborn (1988) measured an increase in springiness, hardness and crumbliness with increasing fat content. This contrasts with the previous results, e.g. Chen et al. (1979) who reported that increasing oil content augmented firmness and decreased cohesiveness, adhesiveness and springiness of cheese analogues. In the study of Lobato-Calleros et al. (1997) the variation in springiness in the analogues were pinpointed to the differences in the degree of adsorption of the protein onto the fat surface, depending on the degree of unsaturation of the fat being used. The high content of saturated fatty acids in butterfat promotes the adsorption of lipophylic groups of the protein, around adjacent fat droplets in the emulsion, forming a reticulated structure that conferred springiness to the product. In general, the use of dephosphorylated sodium caseinate resulted in a simulated cheese with greater firmness and restricted meltability (Strandholm, 1991). Firmness of cheese analogues from calcium caseinate increased with degree of phosphate polymerisation (Cavalier-Salou & Cheftel, 1991). In the study of Eymery and Pangborn (1988) the springiness was inversely proportional to the amount of citric acid, while crumbliness first decreased then increased as a function of the amount of citric acid.

The driving force for the dynamic growth of mozzarella consumption is the increasing popularity of pizza, what has stimulated a surge in research activity. The functional attributes of importance for pizza cheese include the ability to shred cleanly, melt sufficiently rapidly, and exhibit the desired degrees of flow, stretchability, chewiness, oiling-off and/or browning on baking (Guinee, O'Callaghan, & O'Donnell, 1999). These properties are influenced by composition and by the plasticizing and kneading process which the curd is subjected to during manufacture. Many studies of the textural characteristics of natural and imitation Mozzarellas have been reported (Nolan, Holsinger, & Shieh, 1989). Interactions between food ingredients and their effect on texture have been widely studied by scanning electron microscopy and transmission electron microscopy, and rheological techniques (Tamime, Muir, Shenana, Kalab, & Dawood, 1999). The research has mainly focused on the functional characteristics and their relationship to compositional and manufacturing factors. A number of reviews have been published in recent years (Kindstedt, 1993; Kindstedt & Guo, 1997).

Savello, Ernstrom, and Kalab (1989) concluded that melting properties of a model cheese analogue were affected by the type and concentration of emulsifying salts and by the nature of casein used. According to Hokes (1982), close interactions between fat and the hydrophobic zones of proteins may prevent melting. In the study of Cavalier et al. (1991), firmness and melting ability of cheese analogues from calcium caseinate were inversely related. Melting ability of cheese analogues from calcium caseinate correlated with high pH, soft texture, high degree of casein dissociation and low degree of fat emulsification. The comparison of cheese analogues from calcium caseinate (with or without emulsifying salts) and from sodium caseinate (with $CaCl_2$ added) indicated that the melting ability depends on a low Ca^{2+}/Na^{+} molecular ratio. Addition of emulsifying salts (1% sodium citrate or 2% disodium phosphate) in either batch or extruded cheese analogues based on calcium caseinate and butter oil increased the degree of fat emulsification and imparted melting properties (Cavalier et al., 1991). In cheese analogues from sodium caseinate, soy protein isolate, soybean oil and corn starch, the melting properties were strongly influenced by proportions of lactic acid and disodium phosphate (Lee & Son, 1985). In Mozzarella or cooking-type cheese used on pizza or the like, the optimum "string" and melt are provided by a calcium salt such as calcium chloride. In the case where little or no string is required or desired, no added calcium salt is used or required (Middleton, 1989). Mozzarella imitation cheese prepared from lactic acid casein showed good meltability, whereas cheese from calcium paracaseinate or from sodium caseinate required sodium citrate for adequate meltability (Nishiya et al., 1989a, b).

Partial enzymatic hydrolysation of soy protein isolate improved the melting ability of imitation Mozzarella cheese (Nishiya et al., 1989b). In pizza cheeses, as for most cheeses, stretchability increases during the first few weeks of ripening and then gradually deteriorates, to a greater or lesser extent, depending on the level of proteolysis which occurs in the cheese (Guinee et al., 1999). The elastic moduli of cheese analogues decreased on storage indicating softening of the matrix while apparent relaxation times decreased suggesting transformation of the viscoelastic material to a more viscous character (Mulvihill & McCarthy, 1993). Chymosin is a relatively heat-sensitive enzyme, residual rennet activity in rennet casein is negligible. However, Richardson and Elston (1984) showed that rennet casein contains substantial amounts of plasmin. Plasmin content of the casein significantly influenced the proteolytic and rheological changes occurring during storage of cheese analogues (Mulvihill & McCarthy, 1993, 1994). Proteolysis may not be the only engine that drives functional changes in pizza cheese during ageing; physicochemical changes may also represent a distinct driving force behind the functional changes. Pizza cheese that is made without starter culture through direct acidification undergoes very limited secondary proteolysis, and significantly less browning during baking than cultured pizza cheese (Kindstedt & Guo, 1997). Mulvihill and McCarthy (1993) concluded that many of the compositional factors that influence natural cheese quality, by their influence on proteolysis and rheology, did not influence proteolysis and rheology of cheese analogues.

10. Flavour

The most important negative property of imitation cheese is its flavour, which cannot approach the flavour of real cheese (Anonymous, 1989). However, consumer panelist in one study were not able to distinguish readily between natural and imitation cheese as eaten on pizza (Lindsay, Hargett, & Graf, 1980). Flavour systems are broadly used to increase the resemblance of the imitation cheese to their natural counterparts, some being artificial whereas others might be of natural origin such as the range of enzyme-modified cheeses (EMC) presently available (Shaw, 1984; Middleton, 1989). By the addition of suitable enzymes or microorganisms after heat treatment, and allowing ripening at favourable temperature, imitation cheeses of almost any flavour can be prepared (Van Gennip & van der Sommen, 1986). Cheese products in which a proteolytic micrococcus, a self-limiting lipase and a flavour culture are utilised are also particularly desirable flavouring components of the imitation cheese products (Kratochvil, 1986). These flavour systems are still insufficiently developed to the point where the analogues could be consumed as "cheese board" products (Shaw, 1984).

Protein bases made from high protein skimmed milk powder affected the flavour and aftertaste of cheese analogues possibly due to residual plasmin activity and extra-cellular protease activity originating from the milk powder (Muir et al., 1999). An invention was directed to a method for manufacture of an imitation cheese using an acid casein or rennet casein which has been treated to remove stale flavours (Engel, 1992).

The flavour was found to be the most important attribute that affected the acceptability of a cheese analogue containing soy milk (Pereira, Antunes, & dos Santos Ferreira da Silve, 1992). The use of soybean as a human food is limited due to its beany flavour (Singh & Mittal, 1984).The fermented ground soybean showed significantly improved flavour and texture compared to non-fermented material when used to replace non-fat dry milk in an imitation cream cheese (Hofmann & Marshall, 1985). Among various vegetable sources, peanut shows a promising potential as a source of both protein and oil due to its bland flavour and light colour (Chen et al., 1979).

11. Distinguishing natural from imitation cheese

Cheese can be identified on the basis of the gross composition when not only dairy ingredients are used (Pellegrino, Resmini, Denoni, & Masotti, 1996). Furosine is a suitable marker of ingredients that contain lactose and are prepared under thermal conditions that initiate early stages of the Maillard reaction (Resmini, Pellegrino, & Masotti, 1993). A highly significant distinction between natural Mozzarella cheese and imitations, even those that did not contain added milk protein, could be achieved by the lysinoalanine index (Pellegrino et al., 1996). Scanning electron microscopy studies revealed an agglomeration of lipids in the imitation samples, whereas the natural cheese had an uniform dispersion of fat globules. The addition of the caseinate apparently affected the crystallisation of the fat, leading to the enthalpy reduction. Electrophoresis and atomic absorption procedures did not differentiate between natural and imitation samples (Tunick, Basch, Maleeff, Flanagan, & Holsinger, 1989). Further options are spectroscopic and chromatographic techniques for the identification of plant pigments in food products (Schoefs, 1999) and the determination of phytosterols (Ling & Jones, 1995).

12. Conclusions and future trends

Analogues have not made much impact on the retail market, and this is thought to be for several reasons. Firstly, the manufacturers are still faced with quality problems. The flavour systems are still insufficiently developed to the point where the analogues could be consumed as "cheese board" products. Consumer demand for imitation cheese as "cheese board" products is limited to a small group (including vegetarians) (Anonymous, 1989). Secondly, there is psychological resistance to change on the part of the consumer. Cheese analogues suffer very much from their unnatural image even though they can be nutritionally equivalent and cheaper. Thirdly, the lack of regulations, varying state laws and labelling problems contribute to slow growth rate at the retail level. That is why cheese analogues represent little threat to the continued consumption of natural cheeses: Their major role at present is undoubtedly in the cost-cutting exercises of pizza manufacturers. However the dairy industry should not be complacent. With continuing development of the cheese analogues and, in particular, their flavour systems, coupled with lower costs, dietary considerations and the inevitable move to more informative product labelling, these products could find their way into the retail market in the not too distant future (Shaw, 1984). There is a strong and growing need for clear labelling. Efforts must be made to ensure that the appearance of imitation products will not convey a misleading impression on the consumer (Anonymous, 1989).

The dairy industry continues to provide attractive options for food formulators. In spite of this, vegetable proteins are providing alternative solutions and have made strong gains in several of the application areas that have been a traditional forte for casein and caseinates. In the longer term, environmental concerns in some areas and reductions in institutional subsidies will further reduce the consumption of milk proteins. In this situation the competition between isolated soy protein and casein and caseinates will intensify in application areas like cheese analogue, non-dairy topping bases and the rapidly expanding nutraceutical food business. The situation for all participants in the industry will also be greatly affected by advances in plant and animal gene technology and the impact which genetic engineering has on the cost profile of the various functional proteins (Hoogenkamp, 1996). According to Mortensen and McCarthy (1991) it would be unrealistic not to accept that imitation cheese products will offer competition for a share of the cheese market. He concluded that imitation cheese will compete with dairy cheese on a increasing scale. The dairy industry has to take the view that imitation products are the result of developments in product technology and market demand. Thus not to get involved would mean curtailment of product innovation and market opportunities.

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