CHEESE SUBSTITUTES: AN ALTERNATIVE TO NATURAL CHEESE - A REVIEW

Rupesh S. Chavan and Atanu Jana

ABSTRACT

Cheese analogue is a substitute for milk cheese, which is similar in composition, appearance, characteristics and even in its intended use. In cheese analogues, the milk protein and milk fat are partly or wholly replaced by vegetable proteins (i.e. peanut protein, soybean protein) and vegetable fats and oils (i.e. partly hydrogenated vegetable fat like soybean, palm, etc). Cheese analogue are formulated and produced with desired nutritional, functional and storage properties as per the market and consumer needs. Cheese substitute can be suitably fabricated to have nutritional benefits. Analogue pizza cheese is manufactured in a manner similar to that for processed cheese manufacture, which finds application in baking as a topping on pizza and as slices in stuffed burgers. The degree of calcium sequestration and para-casein aggregation is controlled by using correct blend of emulsifying salts to give the desired degree of casein hydration/aggregation and fat emulsification in the analogue preparation. Casein-based analogue pizza cheeses were functionally more stable than natural Mozzarella cheese during refrigerated storage with respect to apparent viscosity and free oil. "Sufu" is an example of a soybean based cheese analogue with a spreadable creamy consistency.

Cheese substitutes or imitation cheese may be generally defined as the products that are intended to partly or wholly substitute for or imitate cheese and in which milk fat, milk protein or both are partially or wholly replaced by non-milk based alternatives, principally of vegetable origin (Fox et al., 2000).

A substitute cheese should not be nutritionally inferior to the cheese it is intended to mimic. Rather promoters of imitation cheese claim nutritional advantages compared with genuine cheese i.e., higher unsaturated fatty acids, no cholesterol, less calorie, etc (Mc Carthy, 1990).

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NEED FOR CHEESE ANALOGUES

The success of any analogue cheese product may be attributed to a number of factors:

i. Fast foods and ready-made conventional meals have become extremely popular wherein cheese is used as one of the preferential ingredient.

ii. Natural cheese costs more than substitutes. The low cost of analogues is due to low cost of vegetable oils compared with butter fat, the low cost of imported casein, relatively low cost of manufacturing equipment compared to that required for natural cheese and the absence of a maturation period for these types of products.

iii. Cheese substitutes offer diverse functionality range (e.g. flowability, melt resistance, shredability, etc), which is made possible by tailor-made formulations and they exhibit high functional stability during storage.

iv. Substitute products can be designed to meet special dietary needs through changes in formulation (e.g. lactose-free, low calorie, low in saturated fat and cholesterol and even vitamin and mineral-enriched).

CLASSIFICATION OF CHEESE ANALOGUES

Imitation/substitute cheese products arbitrarily are classified into three categories: (a) Analogue cheeses, (b) Filled cheeses, and (c) Tofu-based cheeses. Classification may also be based on the ingredients used and the manufacturing procedures followed (Fox et al., 2000). Cheese analogues may also be categorized as dairy, partial dairy or non dairy ones, depending upon whether the fat and or protein components are from dairy or vegetable sources as shown in Figure 1.

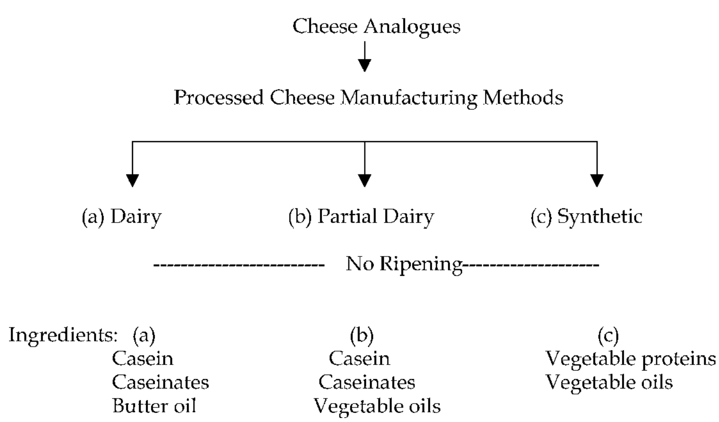

Fig. 1. Classification of cheese analogues.

Filled cheeses generally differ from the natural cheeses in that milk fat is partly or fully replaced by vegetable oils, which in turn could be partially hydrogenated to impart eating profile similar to that of milk fat. Moreover, filled cheese may be made in two ways: (a) using liquid milk, usually skimmed milk plus vegetable oil, or (b) totally synthetic (using vegetable proteins as well). Both involve conventional in-vat cheese making methods (Fox et al., 2000). Ghosh and Kulkarni (1996) prepared low cholesterol filled Mozzarella cheese using sunflower oil. Reconstitution of the dried milk to a higher than normal solids content improved the quality of filled cheese (Mohamed, 1980). "Stirred curd cheese" has been manufactured from filled milks containing soy bean oil, coconut oil and admixtures of both, however, the flavour and body and texture characteristics differed somewhat from conventional cheese (milk based).

There are few, if any, standards relating to permitted ingredients or manufacturing procedures for imitation cheese products.

VARIANTS OF CHEESE ANALOGUES AND THEIR APPLICATIONS

Analogue cheeses were introduced in the US in early 1970's. Cheese alternatives are being produced and sold in USA, UK, Sweden, France, Germany, Belgium, Switzerland and Australia. The annual production of Mozzarella cheese analogue (MCA) was estimated at 80,000 metric tones, which exceeded 20% of the total quantity of Italian type cheese produced in the US. The market share of imitation cheese had stabilized at about 7 % in the US and about 3% in Europe (Mc Carthy, 1990). About 60% of cheese substitutes are utilized in pizzas.

The manufacture of analogues of a wide variety of natural cheeses (e.g. Cheddar, Monterey Jack, Mozzarella, Parmesan, Romano, Blue and Cream) and pasteurized cheese products has been reported. The majorities of such products are substitute for or imitations of low-moisture Mozzarella, Cheddar and pasteurized processed Cheddar. These products find application mainly on cheese toppings for frozen pizza pie and slices in stuffed burgers. Other applications include use in salads, sandwiches, spaghetti sprinkling, cheese sauces, cheese dips and ready-made meals (Fox et al., 2000).

Formulation for cheese analogues

The major protein source in dairy-based Analogue Cheese Products (ACPs) is caseinate or rennet casein, with the former being used mainly for spreadable products. Rennet casein is favored for semi-hard block products and especially for APC where it generally imparts better stringiness and stretchability than acid casein or Na- or Ca-caseinates. By choosing the appropriate blend of emulsifying salts, the concentration of calcium cross-linking the paracasein molecules can be reduced to the desired level to render

Table. 1 Ingredients used in the manufacture of cheese analogues.

Ingredient	Main function/effect	Examples
Fat	Gives desired composition, texture and meltability characteristics, butter oil imparts dairy flavour	Butter, anhydrous milk fat, native or partly hydrogenated soybean oil, corn oil, palm kernel oil, etc.
Milk proteins	Gives desired composition, semi-hard texture with good shredability, flow and stretch characteristics	Casein, caseinates, whey proteins
Vegetable proteins	Gives desired composition and cost reduction.	Soyabean protein, peanut protein, wheat gluten
Starches	Substitution for casein and cost reduction	Native and modified forms of maize, rice potato starches.
Stabilizers		
i. Emulsifying salts.	Assist in the formation of physico-chemical stable product; modifies textural and functional properties	Sodium phosphate and sodium citrate.
ii. Hydrocolloids carrageenan.	Enhance product stability; modifies textural and functional properties	Guar gum, xanthan gum, carrageenan.
Acidifying agents	Assist control of pH in final product.	Organic acids e.g. lactic, acetic, citric, phosphoric.
Flavours and flavour enhancers	Imparts flavour; accentuates flavour.	EMC*, starter distillates, wood smoke extracts, spices, sodium chloride, yeast extract.
Colours	Impart desired colour	Annatto, paprika, artificial colours
Preservatives	Retards mould growth; prolongs shelf-life	Nisin, K-sorbate, Ca- or Na-propionate.
Mineralized vitamin preparations	Improved nutritive valve	Magnesium oxide, zinc oxide, iron, vitamin A palmitate, riboflavin, thiamine, folic acid.

EMC = Enzyme modified cheese

textural and cooking characteristic 'tailor-made' to suit the envisaged application of the product (Fox et al., 2000). An array of ingredients is used in the manufacture of cheese analogues as depicted in Table 1. The health attributes of imitation cheese could be improved by adding nutritionally beneficial ingredients such as fibre and by lowering the fat content. Resistant starch, a source of fibre, is widely used in the manufacture of imitation cheese (Phillips et al., 1995).

Hoffman et al. (2005) reported that the use of tri-calcium phosphate as an emulsifying salt, at incremental levels of addition in manufacturing of "low-fat Mozzarella analogue" from acid casein resulted in decrease in cohesiveness, hardness and gumminess of the resultant product. There was no noticeable difference between cheeses analogues containing acid casein and rennet casein when observed through electron microscopy (Cavalier-Salou and Cheftel, 1991)

Substitution of casein/caseinates

Researchers are tempted to substitute part of casein/caseinates since the vegetable proteins or starches are much cheaper than these ingredients. Increasing the level of substitution of rennet casein by total milk proteins, in the range of 0-50 % resulted in a progressive increase in the firmness and a decrease in the flowability of ACP. Replacing 20.0% of rennet casein with native phosphocasein prepared by microfiltration and diafiltration increased the flowability of the melted ACP (Abou-El-Nour et al., 2001). Incorporation of whey proteins in ACP as a substitute for cheese or casein impaired the flowability and increased the firmness of product. Hence, whey proteins should be restricted to 1-3% w/w levels in applications where flow-resistant ACPs is required (e.g. cheese insets in burger).

Vegetable proteins e.g., soyabean, peanut or wheat protein gives varying results depending on the ingredients preparation (e.g. soy flour or soy isolate, pH, fat content) and the type and level of other ingredients (e.g. hydrocolloids) used in the formulation. Substitution level greater than 20.0% w/w of the total protein as vegetable protein, is generally found to give inferior quality ACP compared to that made using exclusively casein. Some of the problems encountered when utilizing vegetable proteins at higher levels include lack of elasticity, lower hardness, adhesive/sticky body, impaired flow and stretchability and often associated with poor flavour (Guinee et al., 2004).

Starch has been incorporated into imitation cheese, mainly to replace the more expensive casein (Zwiercan et al., 1987; Mounsey and O' Riordan, 2001). Native maize starch is preferentially used commercially, with starches from other sources and with different types of modifications (pre-gelatinized and/or chemically or enzymatically modified) being used less frequently. Native starch can be used at levels of 2-4% to replace about 10-15% of total casein in cheese analogue. Starches (e.g. maize, wheat) with a high ratio of amylose to amylopectin tend to retrograde and undergo gelation more readily than those (e.g. waxy maize, rice, potato) with a lower level of amylose, during storage of analogue cheese (Mounsey and O' Riordan, 2001). Mounsey and O' Riordan (2001) observed reduced meltability and cohesiveness in imitation cheese containing increasing level of starch. The hardness of analogues increased when using wheat, potato and maize starch, but got reduced by use of waxy-maize or rice starch.

Manufacturing technique of cheese analogue

A typical manufacturing procedure involves the following steps: simultaneous addition of required quantities of water and dry ingredients (e.g. casein, emulsifying salts), addition of oil and cooking to about 85^{O}C (using direct steam injection), while continuously shearing until a uniform homogenous, molten mass is obtained. The flavouring materials (e.g. enzyme modified cheese (EMC), starter distillate) and pH regulator (e.g. citric acid) are then added and the mixture is blended for further few minutes and then hot-packed. Horizontal twin-screw cookers (e.g. Damrow, Blentech), operating at a typical screw speed of about 40 rpm are used in the manufacture of APC (Guinee et al., 2004).

Addition of the acid at the end of manufacture, ensures a high pH (8-9) in the blend during processing which helps in greater sequestration of calcium by the emulsifying salt (i.e. sodium phosphate) during processing, higher negative charge on the casein and higher degree of para-casein hydration. All of these lead to better emulsification of vegetable oil in the protein matrix. The addition of flavoring ingredients, such as EMC towards the end of processing, minimizes the loss of flavour volatiles at the high temperature of processing.

Behaviour of cheese analogue in cooking applications

On cooking cheese, the functional properties such as flow and stretch involve the partial displacement of contiguous layers of the paracasein on application of stress. The level of displacement on cooking of APC depends on the concentration of calcium, cross-linking the casein molecules in the final product. Rennet casein has high calcium/casein ratio (~36 mg Ca/g casein). The degree of calcium sequestration and para-casein aggregation is controlled by using correct blend of emulsifying salts to give the desired degree of casein hydration/aggregation and fat emulsification in the analogue preparation (Guinee, 2002). Compared to rennet casein, caseinates tend to over hydrate, resulting in a degree of casein aggregation, which yields good flowability but is too low to achieve satisfactory stretchability.

NON-DAIRY ANALOGUES

In non-dairy analogues, both the fat and protein are derived from vegetables sources, by substituting the higher priced milk derived protein and fat ingredients (Anon., 1968; Dietz and Ziemba, 1972; Burkwall, 1973). Marketable products of

Table. 2 Typical formulation for analogue pizza cheese

Ingredients	**Analogue I***	**Analogue II****	**Analogue III****	**Analogue IV******
Acid casein	-	21.00	-	28.41
Ca/Na caseinate	23.00	-	14.39	-
Peanut protein isolate	-	-	14.39	-
Vegetable oil (part hydrogenated)	25.00	12.50	20.17	16.65
Starch	2.00	5.00	-	-
Emulsifying salts	2.00	2.50	0.75	1.49
Sodium chloride	-	1.50	1.83	1.60
Emulsifier	-	0.15	-	-
Stabilizer	-	0.42	-	-
Flavor	2.00	0.30	-	
Flavor enhancer	1.00	-	-	
Acidifying agent	0.40	0.27	1.38	0.58
Color	0.04	-	-	
Preservative	0.10	-	-	0.09
Calcium chloride	-	0.36	-	-
Water	38.50	56.40	46.81	42.99
Condensate	7.00	-	-	-

Source:
* Fox et al. (2000)
** Jana (1998),
*** Krishnaswamy et al. (1971),
**** Montesinos-Herrero et al. (2006)

Cream, Mozzarella and American processed cheese have been successfully imitated, without ripening procedures. Among various vegetable sources, peanut shows potential as a source of both protein and oil due to its bland flavor and light color. However, most of the peanut cheese-like products have been prepared by ripening methods using microbial inoculation (Krishnaswamy and Patel, 1968; Krishnaswamy et al., 1971). The formulation employed for preparing peanut-based cheese analogue is furnished in Table 2.

Edible products derived from soybeans have been slow to gain acceptance in western culture. The refined soya products such as ground soyabean and soya milk are particularly considered less desirable in terms of flavor and texture. Few attempts have been made to produce flavor and texture associated with cultured buttermilk or cream cheese products using ground soyabean or soyamilk as substrates (Hoffman and Marshall, 1985).

SPECIFIC CHEESE ANALOGUE PRODUCTS

There are varied types of natural cheeses which have been imitated to produce the analogue cheese for a given food application. Some of these are discussed herein:

1. Imitation cream cheese

The imitation cream cheese product has been prepared using water, vegetable oil, non-fat dry milk (NFDM), salts, emulsifiers, stabilizers and acidulants. In a typical application, fermented or non-fermented ground soyabean, which comprised of 4.2% of finished product, was able to replace 33.0% of NFDM. The vegetable oil is heated to 57ºC and the ground soyabean added to it. Water is preheated to 43ºC and NFDM, salts, emulsifiers and stabilizers are dispersed in it. The dispersion is then heated to 57ºC and the soya oil blend added to it. Lactic acid is added to have a pH of 4.6–4.8. The imitation cream cheese is then homogenized in two stages (i.e. 2100 + 500 psi) and then poured into containers and cooled (Hoffman and Marshall, 1985).

2. Analogue Pizza Cheese

A typical manufacturing process for Analogue Pizza Cheese (APC) is shown in Figure 3. APC is manufactured using ingredients like casein, emulsifying salts, vegetable oil, water, acid regulator and flavouring materials. All of these ingredients are blended step by step in a horizontal twin-screw cooker with simultaneous injection of steam to raise the temperature to 85^{0}C (Figure 2). Many of the gross compositional parameters of analogue pizza cheese are similar to those of 'low-moisture Mozzarella cheese' (LMMC); the former generally has lower level of protein and higher level of fat on dry

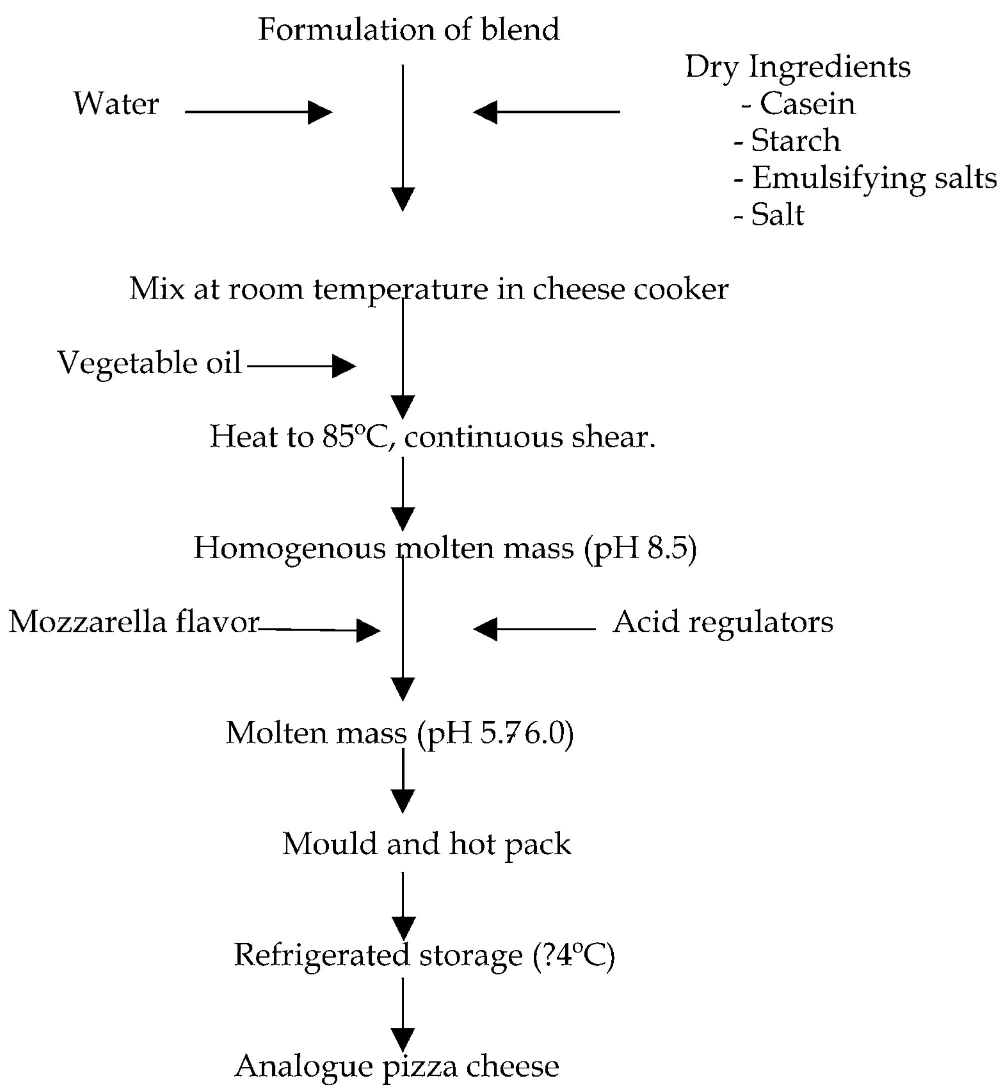

Fig. 2. Typical manufacturing process for analogue pizza cheese.
Source: Guinee et al. (2004)

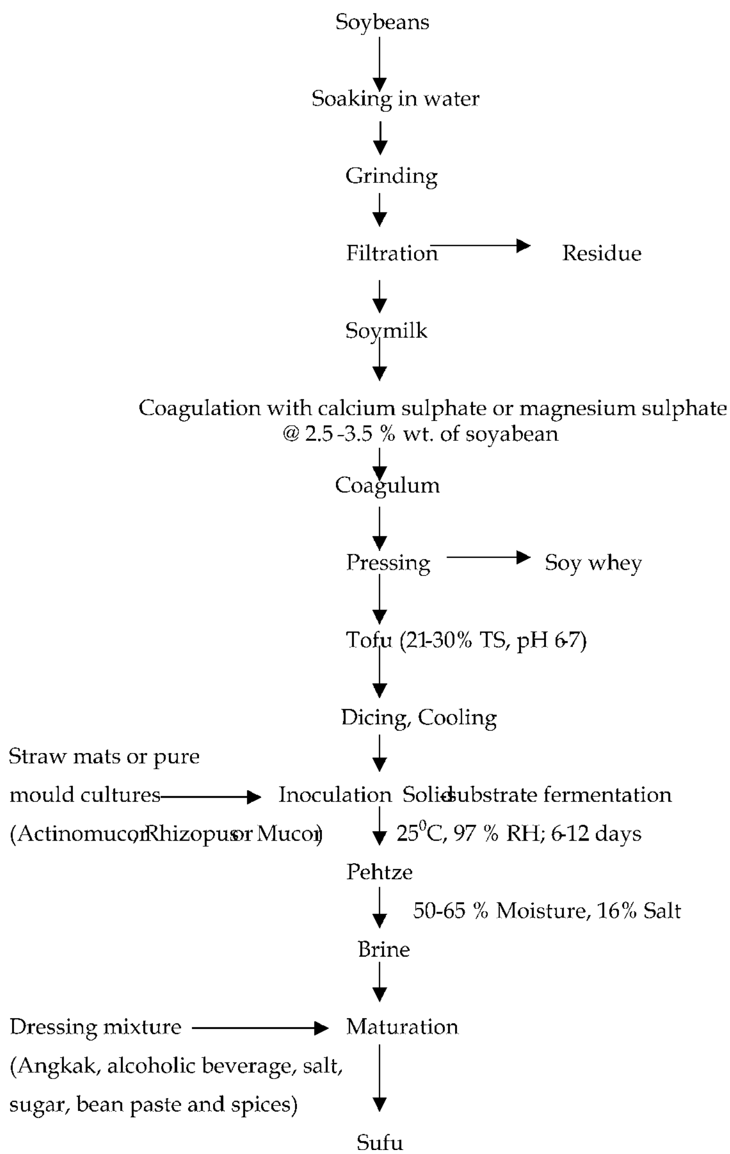

Fig. 3. Schematic diagram for production of Sufu (Source: Wang and Hesseltine, 1970)

matter, calcium and phosphorus as depicted in Table 3 (Fox et al., 2000, Sherkat and Walker, 2002).

Table 3. Typical composition of low-moisture Mozzarella cheese and Analogue pizza cheese.

	Cheese types			
	Fox et al. (2000)		Jana (1998)	
	Low-moisture mozzarella cheese	**Analogue pizza cheese**	**Natural mozzarella cheese**	**Analogue mozzarella cheese**
Moisture %	46.40	48.80	47.53	53.35
Protein %	26.00	18.50	23.06	20.13
Fat %	23.20	25.00	24.56	15.23
Fat on dry matter %	44.60	49.00	46.81	32.66
Salt %	-	-	1.29	0.90
Salt in moisture %	3.10	3.50	-	-
Ash %	3.90	4.20	3.18	3.91
Ca, mg/100g	27.50	34.40	0.62	0.39
pH	5.50	6.10	5.36	5.66

The optimum conditions for making APC from caseinate included using Na-/Ca-caseinate, 75:25 and keeping fat on dry matter of 39.8% and moisture of 52.3% (Christiansen et al., 1986). The ideal parameters arrived at in preparing APC from soya protein isolate were: avoiding pH adjustment of soy base, keeping 10.0% fat from solid coconut oil (Hydrol-100) and using soya base-gelatin-gumarabic in 5:2:2 proportion (Taranto and Yang, 1981; Yang and Taranto, 1982).

NATURAL VS ANALOGUE PIZZA CHEESE

Plasticizing of cheese curd in pasta filata cheeses (e.g. Mozzarella) leads to limited degree of aggregation and contraction of the paracasein gel matrix, culminating in formation of para-casein fibers which physically entraps cheese fat. In contrast, the conditions used in the manufacture of APC are designed to disaggregate and hydrate the paracasein aggregates of rennet casein and caseinates. The hydrated para-caseinate immobilizes large quantities of water along with emulsifiers and vegetable oil, thereby contributing to physico-chemical stability of the product. The relatively large fat globule size (e.g. 5-25 ¼m) in analogues ensures sufficient degree of oiling-off from the analogue pizza cheese topping, when baked on pizza. This in turn, limits dehydration of cheese topping and is conducive to satisfactory flow and succulence characteristics (Guinee et al., 2000). The comparison of composition of an analogue and natural Mozzarella cheese is depicted in Table 3.

Storage changes in analogue cheese vis-à-vis natural cheese

Kiely et al. (1991) reported that casein-based analogue pizza cheese were functionally more stable than natural low moisture Mozzarella cheese (LMMC) during storage at 4ºC for 28 days with respect to apparent viscosity and free oil. Such stability makes analogues very attractive to the food processing and service industries. However, casein-based analogues containing high level of starch (>40g/kg) usually lose their functionality relatively rapidly (e.g. after 4 weeks) during storage at 4ºC, an effect possibly associated with the retrogradation of amylose. The loss of functionality is reflected by the increase in loose moisture upon shredding, loss of meltability and flowability, and burning or crusting upon baking (Fox et al., 2000).

The functional properties of LMMC changes markedly during refrigerated (4ºC) storage. Initially, during the first 1-5 days, the cheese is non-functional and burns or crusts during baking. After 5-10 days of ripening, the cheese acquires desired functionality, as reflected by the decrease in melt time and apparent viscosity (chewiness) and an increase in flowability and stretchability. However, prolonged storage (e"75 days) is associated with excessive flowability, loss of chewiness and a "soupy" consistency in grilled or baked cheese.

3. Sufu

'Sufu' or 'furu' is a fermented soybean product originating in China. It is a cheese-like product with a spreadable creamy consistency and a pronounced flavour. The annual production of sufu products is estimated over 300,000 metric tons in China. Sufu is made by fungal solid-state fermentation of tofu (soybean curd), followed by aging in brine containing salt and alcohol. Sufu is consumed as an appetizer and a side dish, e.g. with breakfast rice or steamed-bread. Several types of sufu exist, according to processing method or colour and flavour. Choice of processing can result in mould fermented sufu, naturally fermented sufu, bacterial fermented sufu or enzymatically ripened sufu. Depending on the choice of dressing mixture red, white or grey sufu may be obtained (Wang and Fang, 1986). The composition of sufu is depicted in Table 4.

Mould-fermented sufu and naturally fermented sufu: The manufacturing steps involve preparing tofu, preparing pehtze with pure culture mould fermentation or by

Table 4. Proximate composition of commercial sufu.

Constituents	Percent
Moisture	58-70
Crude protein	12-17
Crude lipid	8-12
Crude fibre	0.2-1.5
Carbohydrate	6-12
Ash	4-9
Food energy (k.cal./100g)	110-179

Source: Su (1986).

natural fermentation in naturally fermented sufu, followed by salting and ripening. Actinomucor elegans and Aspergillus moulds are preferentially used for pehtze production commercially.

Bacteria-fermented sufu: This comprises of preparing tofu, pre-salting, preparing pehtze with a pure culture bacterial fermentation, salting and ripening. Pehtze is prepared by pure cultured Bacillus species or Micrococcus species at 30-38°C for about 1 week. To retain the shape of final product, pehtze is dried at 50-60°C for 12 hours before salting. The ripening time normally takes less than 3 months.

Enzymatically ripened sufu: The technique involves preparing tofu, salting and ripening. Since there is no fermentation before ripening, some Koji (Aspergillus oryzae or A. soyae) is added in the dressing mixture for enzymatic ripening. The ripening time required is from 6-10 months.

Nowadays, Sufu is manufactured at an industrial scale (Figure 3).

CONCLUSION

The varieties of cheese substitutes which are commonly available in the market are those of Mozzarella, Process American, Provolone, Parmesan, Process cheese food and cheese spread substitutes. In addition, fabricated cheese substitutes offering dietary benefits such as those with polyunsaturated fats and lower calories are also available. Thus, the dairy industry can now produce 'tailor-made' cheese analogues as per the specifications of the user at a price competitive to the natural counterpart. The largest user of cheese substitutes is the pizza industry and the formulated and processed foods industry. Pizza manufacturers are increasingly using Mozzarella cheese substitutes, tempted by the economic advantages, the physical and microbiological quality, the performance and the storage stability of the substitutes. Cheese substitutes in slices, as shreds and in the other innovative forms will be introduced in the time to come.

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