International Journal of Dairy Science

ISSN 1811-9743

Academic
Journals Inc.

www.academicjournals.com

International Journal of Dairy Science 10 (6): 249-265, 2015
ISSN 1811-9743 / DOI: 10.3923/ijds.2015.249.265

Low-Fat Cheese: A Modern Demand

Ashraf Gaber Mohamed
Department of Dairy National Research Centre, Dokki, Giza, Egypt

ABSTRACT

Nowadays, there is growing awareness about reduced fat food as well as free fat products. Low fat milk products, particularly low fat cheese represents a good choice for the development of new products with functional properties. Consumers are always looking forward to desirable and healthy products. Therefore, consumer's demand for low-fat/calorie products has significantly raised in an attempt to limit health problems, to lose or stabilize their weight and to work within the frame of a healthier diet. Low fat cheese often suffers from undesirable flavor and texture. So, for these reasons, there are many strategies to overcome these defects with the using of additives such as stabilizers and fat replacers. Another solution is using exo-polysaccharide which produced from lactic acid bacteria (EPS-producing cultures) to improve functional low fat cheese product. Several studies highlighted the positive effect of EPS-producing cultures on the physical and functional properties of reduced fat Cheddar cheese. The objective of this review is to establish low fat cheese, their characteristics and technological it's manufacturing.

Key words: Low-fat cheese, reduced fat dairy product, dietary fat, properties of low fat cheese

INTRODUCTION

The amount and type of fat consumed is important to the etiology of several chronic disease such as obesity, cardiovascular disease and cancer. As a result, consumers more readily adhere to nutritional guidelines concerning fat consumption (Katsiari *et al*., 2002a; Kucukoner and Haque, 2006). This association has created an increased awareness and a dramatic increase in the demand and supply for low-fat foods including cheese varieties (Katsiari *et al*., 2002b).

Recently a worldwide tendency for the consumption of low-fat foods has been observed in a variety of countries, due to public concern about the excess ingestion of calories and fats, leading to an increase in the consumption of diet and light foods (Oliveira and Assumpcio, 2000). Dairy processors have also taken noted of this tendency, which it reflects in development of and sensorial evaluation of several low fat cheeses (Nelson and Barbano, 2004; Koca and Metin, 2004; Madadlou *et al*., 2005; Kilcawley *et al*., 2007).

As El Soda (2014) mentioned that difficulties arise when attempts are made to produce low fat variants of cheeses that are popular and established in the market as full fat varieties. In producing low fat variants of standard fat cheeses such as Cheddar, processing parameters must be altered substantially in order to produce an acceptable texture and flavor. So, different strategies were described to overcome both texture and flavor defects, which include the retention of higher moisture in the curd, which can partially replace fat and improve texture through cutting into larger cubes, lowering the cooking temperature draining and milling at a higher pH. Stabilizers and fat replacers were also used to improve texture. This practice was often followed by off flavor development.

However, low-fat cheeses, that exhibit the characteristics of conventional full-fat cheeses are needed for consumer markets. Cheese with reduced fat content may exhibit dilute flavor and poor texture For this reason, many research development around the world have contributed to improvements in the quality of low-fat cheeses, many patents have been issued worldwide involving the manufacture of low-fat cheeses. The major objective in developing these procedures is to produce low fat cheeses that are similar in characteristics to their full-fat counter parts (Drake *et al*., 1999).

Consequently, exo-polysaccharides-producing lactic acid bacteria (EPS-producing cultures) have been used to improve product functionality in the dairy industry by binding free water. They have been suggested for low fat Cheddar cheese making for several reasons. They have the ability to bind water and to increase moisture, exo-polysaccharides increase moisture retention by water binding or entrapment within their 3-dimensional network. In addition, EPS seem to act as nuclei for the formation of large pores in cheese, they also increase the viscosity of the aqueous phase in cheese and modify its flow characteristics. In addition, EPS interfere with protein-protein interactions physically or through their interaction with proteins (El Soda, 2014).

On the other hand, EPS produced by starter cultures are hetero polysaccharides. Perry *et al.* (1997) found that EPS-producing *Streptococcus thermophilus* could increase moisture retention in low-fat Mozzarella cheese. The EPS were responsible for the water-binding properties of this bacterium in cheese (Low *et al.,* 1998). It was also confirmed that encapsulated and ropy EPS-producing *S. thermophilus* strains can be utilized to increase the moisture level of cheese. However, only the encapsulated EPS can improve these properties without adversely affecting whey viscosity (Broadbent *et al*., 2001; Petersen *et al.,* 2000). Some other EPS-producing strains, for example, *Lactococcus lactis* spp. *cremoris* also could contribute to the modification of cheese texture, microstructure (Dabour *et al.,* 2006) and melting properties (Awad *et al.,* 2005). These and similar researches devoted their efforts to low fat cheeses because such cheeses tend to become tough, rubbery and have poor stretching properties (Mistry and Anderson, 1993).

FUNCTIONAL ROLE OF DIETARY FAT

Dietary fats is a major energy source is essential for growth and development and provides essential fatty acids needed for maintaining structure of cell membrane and for prostaglandin synthesis. In addition, fat aid in the absorption of fat-soluble vitamins and other phyto-chemicals. Fat is a multifunctional constituent in food as it plays an essential role in flavor, texture and color. Fat flavor consists of a large number of constituents. The main compounds are short chain fatty acids and their esters, Υ and б-lactones, ketones and aldehydes (Kinsella, 1975). Fat in food has multiple functions during cooking processes. Its heat transfer enable rapid heating and attainment of very high temperatures. Fat absorbs many flavor compounds and rounds the flavor by reducing the sharpness of acid ingredients. Also, the structure of food and its composition play a dominant role in flavor perception. The basic edible sensations of fat-containing foods are viscosity (thickness, body and fullness), lubricity (creaminess, smoothness), absorption/adsorption and other factors such as cohesiveness (Sandrou and Arvanitoyannis, 2000).

Functionally, fats affect the melting points, viscosity and body, crystallinity and spreadability of many foods (Drewnowski, 1998). Fat impacts a velvety mouth feel to products such as ice creams, desserts and cream soups. Smoothness in ice creams and some cadies is due to fat preventing the formation of large water or sugar crystals. Fat removal from cheeses results in a pasty curd or a rubbery texture. Low fat puddings, salad dressing, soups and dairy products are watery without the addition of fat extenders or mimics. Fats are responsible for the aroma and texture of many foods, thereby affecting the overall palatability of the diet. Although fat in food may increase acceptance, high fat foods and diets are also high in calories (Jonnalagadda, 2005), which may be problematic for the majority of individuals struggling with energy balance.

CHARACTERISTICS OF LOW FAT CHEESE

Low-fat cheeses are considered to be less acceptable to consumers than their full-fat counterparts due to texture, functional properties and flavor defects.

Flavor: The lack of flavor in low-fat cheese may be due to the lack of precursors from the fat, the lack of fat as a solvent for flavor compounds or differences in the physical structure of low-fat cheese that inhibits certain enzymic reactions essential for the formation of flavor compounds (Urbach, 1997). Fatty acids in cheese originate mostly from lipolysis of the milk fat. Several studies have identified. Deficiencies in butanoic and hexanoic acids in low-fat cheeses (Banks *et al*., 1998; Dimos *et al*., 1996) whets in full. Fat cheddar optimum levels of these compounds are critical to the intensity of cheddar flavor (Barlow *et al*., 1989). In a comparison of volatiles from full and reduced fat cheddar, Dimos *et al*. (1996) found that the concentration of methane thiol in cheese was highly correlated with flavor grade, which suggested that the lack of flavor in reduced-fat cheddar was due mainly to the lack of methane thiol.

Deficiency in milk fat-derived flavor compounds including short to medium-chain-carboxylic acids, methyl ketones and 8 and σ lactones has been associated with poor flavor development in a 50% fat-reduced cheddar (Wijesunda and Watkins, 2000).

Bitter peptides are formed by the action of various proteinases on the Caseins. Bitterness occurs in cheese when these peptides accumulate to an excessive concentration as a result of either overproduction or inadeyuate degardation by microbial peptidases. Although, bitter peptidase can orginate from $\alpha\ s_1$ or B casein, it is action of chymosin and/or the lactococcal cell envelope proteinase on the hydrophobic c-terminal region of B-casein that is mainly associated with production of bitter peptides (McSweeney, 1997). Reduced partititioning of hydorphobic bitter peptides in the fat phase of low-fat cheeses may be the causative factor in increasing the susceptibility of low-fat cheeses to bitter off-flavors (McSweeney, 1997).

Development of bitterness can be minimized by increasing salt-in-moisture (Banks *et al*., 1993; Mistry and Kasperson, 1998) but this can inhibit proteolysis and increase the firmness of the cheese (Mistry and Kasperson, 1998). While it is generally accepted that bitterness in cheese results from the accumulation of an abnormally high concentration of hydrophobic peptides other compounds such as some amino acids, amides, long-chain ketones and some monolgy cerdies may contribute (McSweeney, 1997).

Texture and functionality: Textural defects include increasing firmness, rubberness, hardness, dryness and graininess (Olson and Johnosn, 1990) fat has a major effect on the microstructrue, texture and functionality of cheddar cheese (Guinee *et al.,* 2000).

Texture development in cheese occurs due to the breakdown of αs_1 Casien during ripening (Lawrence *et al*., 1987). Furthermore, milk fat normally provides atypifcal smoothness to a full fat cheese by being evenly distributed within the casein matrix of cheese. When fat is removed, as in low fat cheeses, casein plays a greater role in texture development (Fig. 1). In low fat variants there is in adequate breakdown of casein and therefore, the cheese appears to have relatively firm texture. The extent of hydrolysis depends on the moisture and salt content of the cheese (Mistry and Kasperson, 1998). Higher pH of whey at draining and lower cook temperatures normally employed in low fat cheese manufacture lead to a lower retention to chymosin in cheese and lower plasmin activity. This is also partly the reason for a lower extent of protein breakdown during ripening. Another outcome of these manufacturing conditions is the relatively higher level of calcium retention in cheese, which imparts firmness to cheese (Nauth and Ruffie, 1995).

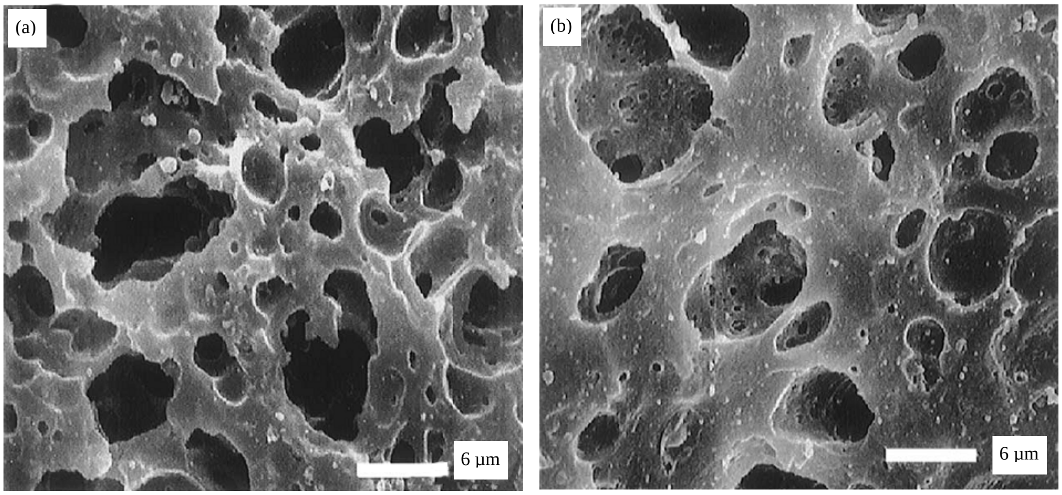

Fig. 1: Scanning electron micrographs of (a) Full fat and (b) Low fat Cheddar cheese. Full fat cheese has a more open structure than low fat cheese

Reduction in fat content resulted in increases in the apparent viscosity and melt time and a decrease in the flow ability of the baked cheese at most ripening times throughout a 180 day ripening period. Changes in the rheology and functionality were attributed to the decrease in the quantity of free oil released on cooking and the increases in the content of intact para-casein and the volume fraction of the casein matrix associated with the reduction in fat content.

Studies and cheddar found no association between the breakdowns of αs_1-casein and melt but degradation of B-Casein correlated with increased melting of the cheese (Bogenrief and Olson, 1995). Shakeel-Ur-Rehman *et al.* (2003) suggested that meltability is influenced by continued hydrolysis of α s_1 and B-casien into small peptides rather than by the initial hydrolysis of intact proteins. These studies suggest that degradation patterns of cheese proteins, particularly $\alpha_{s1\text{-}}$casein may vary and thereby play an important role in functionality.

Difficulties in melting low or reduced-fat shredded mozzarella can be overcome by lightly coating the cheese shred surface with a small amount oil to prevent surface dehydration (Rudan and Barbono, 1998). A barrier to block moisture loss using a thin hydrophobic surface coating on the shred produces excellent melting and browning of fat-free and low-fat mozzarella cheese during pizza baking (McMahon and Oberg, 1998; Rudan and Barbono, 1998).

Though Mozzarella cheese is not considered a ripened cheese, a small degree of casein breakdown is required for body and texture development and functionality. For example, when fat content was reduced to below 15% proteolysis during storage decreased and the hardness of cheese increased, which in turn also adversely affected its functionality (Rudan *et al.*, 1999).

Yield of cheese: The composition of milk for manufacturing low fat cheeses differs markedly from that of full fat cheeses in a number of ways. The total fat content of milk is obviously lower, therefore, the percentage total protein in milk is slightly higher. The net result is lower total solids in the milk. The ratio of casein to fat will also be much higher in milk for low fat cheese making. While it is true that fat in cheese is replaced by moisture, the total yield of cheese (kg cheese per kg milk) is lower for low fat cheeses because the total amount of fat removed is not equal to the amount of moisture added. Rudan *et al.* (1999) demonstrated that the yield of Mozzarella cheese of 5% fat was 30% lower than that of a cheese of 25% fat.

Fat and nitrogen recoveries in cheese are also important in cheese yield. The percentages of expected recoveries depend on variety and are affected by a number of cheese making factors. For Mozzarella fat recovery is 85% (Rudan *et al.*, 1999) and Cheddar it is 93% (Kosikowski and Mistry, 1997). Nitrogen recoveries for many hard cheeses are near 75%. Nitrogen recoveries for low fat cheese making are not affected to the same degree as fat. As the targeted fat content of cheese is lowered, the percentage fat recovered in cheese is lowered and may be controlled partly by adjusting the casein to fat ratio in milk. At optimum rennet curd firmness at cutting, fines losses and hence fat losses are reduced.

TECHNOLOGY OF LOW FAT CHEESE MANUFACTURING

Procedures developed for manufacturing low fat cheeses involve three broad approaches that include (a) Processing techniques, (b) Adjunct cultures, (c) Use of additives such as fat replacers and (d) novel fat removed method. Combinations of these procedures are also used.

Processing techniques: The fat content of milk used for manufacturing low fat cheeses depends on the desired fat content in the cheese and generally ranges from 0.5 to approximately 1.8%. Milk may be fortified with nonfat dry milk or may be condensed to up to 1.8 (Anderson *et al.*, 1993), directly ultra-filtered (McGregor and White, 1990) or fortified with dried ultra-filtered or micro-filtered retentate (St-Gelais *et al.*, 1998). Rodriguez *et al.* (1999) concluded that semi-hard low fat cheeses made with milk concentrated by microfiltration had sensory qualities similar to full fat counterparts because of the retention of less (35%) whey proteins.

The ratio of casein to fat in milk is also important. For manufacturing a 33% fat reduced Cheddar cheese a ratio of 1.58 is desirable (Kosikowski and Mistry, 1997), whereas for Mozzarella cheese with 50% fat reduction a ratio of 2.4 was suggested (Merrill *et al.*, 1994).

Other primary cheese making parameters that may be manipulated include temperature of cooking, time of holding during cooking, pH at milling and rate of salting (Johnson and Chen, 1995).

The general goal is to replace fat in cheese with moisture without adversely affecting cheese yield and quality. This is accomplished in part by lowering cooking temperatures. In low fat Cheddar cheese making the cook temperature is 30-351°C, depending on the moisture content desired (Banks *et al.*, 1989). Further moisture retention is attained by employing a high pH at mill (Kosikowski and Mistry, 1997). For low fat Cheddar this pH may range between 5.6 and 5.8. Washing curd with cold water (221°C) also helps retain moisture, remove excess lactose and solubilize calcium, which helps soften cheese texture. This step helps in preventing excessive acid development during aging.

Disadvantages include the loss of cheese flavor compounds, resulting in a cheese with a bland flavor and the development of off flavors during ripening such as meaty-brothy and unclean (Johnson *et al.*, 1995). Chen and Johnson (1996) have addressed these effects. The procedure involves the cutting of rennet curd when very firm, high pH at drain (6.45) and high pH at mill (5.9). By eliminating curd washing, an increased retention of calcium phosphate retention increases buffering capacity and restricts the development of an excessively low pH. Excessive calcium, on the other hand, adversely affects functional properties of cheeses such as Mozzarella. Nauth and

Hayashi (1995) suggest lowering the pH of milk by adding rehydrated cultured skim milk. This lowers the pH of milk and converts colloidal calcium to the soluble form, which is eventually removed into the whey during drainage.

Other methods to increase moisture retention include the inclusion of whey proteins and sweet buttermilk in cheese. Whey proteins denatured by high heat treatment (>801°C) have increased water absorption capacity and have been used in the manufacture of reduced fat Havarti-type cheese (Lo and Bastian, 1998) and low fat Edam cheese (Schreiber *et al*., 1998). Excessive whey protein addition is likely to interfere with rennet curd formation and ultimately adversely affect cheese quality (Guinee *et al*., 1998). Schreiber *et al.* (1998) suggested use of 0.5% whey protein aggregates. In addition to an increase in cheese moisture, cheese yield is also increased. This approach of denatured whey protein inclusion has been used cheese as well for low fat Mozzarella without any apparent effect on physical and sensory properties of cheese (Punidadas *et al*., 1999).

Inclusion of sweet buttermilk in low fat cheese also helps retain moisture. This is accomplished by the direct addition of sweet buttermilk to milk (Mayes *et al*., 1994). This process requires the addition of relatively large amounts of buttermilk, up to 30% (Madsen *et al*., 1966). An alternative approach is to use sweet buttermilk that has been concentrated by ultra-filtration. This approach has been applied to low fat Cheddar cheese (Mistry *et al*., 1996), low fat Mozzarella (Poduval and Mistry, 1999) and low fat process cheese (Raval and Mistry, 1999). The amounts used were up to 5% ultrafiltered buttermilk, which helped retain moisture and also improved the body and texture of cheeses perhaps because of the inclusion of the milk fat globule membrane in the buttermilk. Concentrated buttermilk also lowered free oil in melted cheese.

Processes involving homogenization have also been developed with the specific goal of improving the body and texture of low fat cheeses. Tunick *et al.* (1993) reported on the use of milk homogenized at 10,300 and 17,200 kPa for manufacturing low fat Mozzarella cheese. Improvements in textural and melting characteristics of cheeses were reported by such treatment. Homogenization of milk not only reduces the size of milk fat globules the interfacial forces at the new fat globule surface may disrupt casein micelles (Darling and Butcher, 1978) and lead to curd shattering and yield loss. Metzger and Mistry (1995) developed a procedure in which 40% fat cream is homogenized and blended with skim milk to the desired fat content for the manufacture of low fat Cheddar cheese. Homogenization in this manner has minimal effect on milk proteins but provides the needed reduction in fat globule size and consequently an increase in fat globule surface area and numbers. Cheeses had excellent body and texture, less free oil in melted cheese than in control cheeses and improved yield due to increased fat and protein recovery.

Adjunct cultures: Adjunct cultures not only have a role in flavor development in ripened cheeses but may also be used to enhance functionality of low fat cheeses. For example, the proteolytic activity of *Loctobacillus casei* subsp. *Casei* is also useful in development of functional properties of low-fat mozzarella cheese (Merrill *et al*., 1996).

Tungjaroenchai *et al.* (2001) evaluated the effects of four adjunct cultures with differing levels of amino-peptidase activity on the flavour and texture of a reduced-fat Edam cheese (20% fat) Amino-peptidase activity of *Loctobacillus lactis* spp. *diacety lactis* was higher than that of *Lactobacillus helveticus* (LH 212), *Lactobacillus reuteri* and *Brevibacterium linens* (BL 2), respectively but cheeses containing *L. helveticus* developed the highest levels of free amino acids. Beneficial texture effects were obtained using *Loctobacillus helveticus* (LH 212) and *L. reuteri.*

The flavor and texture of a low-fat (9%) ewes milk kefalograviera type cheese were improved significantly by selection of a commercial culture that produced acetate, diacetyl and acetoin from citrate fermentation (Katsiari *et al*., 2002b). Acetate is the dominant free fatty acid in full-fat Kefalograviera cheese and comprises 34% of all free fatty acids in the mature cheese. The selected commercial culture improved the body and texture and greatly enhanced the flavour intensity of low-fat high-moisture kefalograviera-type cheese compared with the commercial regular starter used in full-fat cheese production.

Katsiari *et al.* (2002c) found that low-fat Feta-type cheese with flavour similar to that to the full-fat cheese can be made by adding the commercially available adjunct culture cr-213 to the cheese milk. However, the overall quality of this cheese is significantly lower than of the full fat cheese. Low-fat Feta-cheese contain more lactic and citric acids but less butyric acid than the full fat control.

The addition of the adjunct culture had appositive affection butyric acid, propionic acid and acetone content. It is concluded that the use of the adjunct culture could enhance the production of organic acid in low-fat Feta-type cheeses, eventually giving a positive effect on their sensory properties (Manolaki *et al*., 2006).

Low-fat cheese can be manufactured using the freeze-shocked *L. helveticus* or *L. casei*. These attenuated culture have not affected the general composition of the chesses but accelerated the ripening of the cheese samples more distinct effect with *L. helveticus*. When sensory properties are considered, *L. casei* has provided more favorable results for the manufacture of low-fat Kasar cheese (Gursoy, 2009).

Use an exo-polysaccharide-producing culture to help improve structure and texture of cheese “Textural attributes are believed to be important criteria in determining the identify and quality of cheese and its consumer acceptability”. The texture and fracture properties of a cheese are largely determined by the nature and arrangement of its structural network (Dabour *et al*., 2006). Exo-polysaccharide acted comparable to a gum. It helped glue the cheese particles together.

The increased exo-polysaccharide improved the pliability of the cheese. Improved the flavor conducts by Agrawal and Hassan (2007) involved the process of ultra-filtration of milk to remove the bitter taste of reduced-fat cheddar cheese made with an expoly saccharide producing culture. The ultra-filatration process helped diminish the bitter and unpleasant taste from reduced-fat cheese by squeezing all of the extra tasteless liquid from the cheese contents.

Use of encapsulated or ropy exo-polysaccharide (Eps) producing cultures showed improved sherd fusion, meltability and reduction in surface scorching of low-fat Mozzarella cheese (Zisu and Shah, 2007). Upon baking, cheese made with EPS producing cultures exhibited reduced surface scorching and increased sherd fusion after 45 day of storage and maturation to 90 days not required. Given that capsular and ropy forms of EPS have similar beneficial effects an low-fat Mozzarella cheeses when milk is pre-acidified, the selective use of the capsular EPS producing strains over the ropy type is rational when considering the implications associated with slime formation.

The use of an exo-polysaccharide-producing strain of *S. thermophilus* in Mexican panela cheese increased moisture retention and when higher total solids milk was used, it also increased the fat retention within the cheese matrix. This was reflected in a greater yield of the cheeses obtained and a lower tendency to syneresis. Scanning electron microscopy showed that the EPS bound to the protein matrix of the cheese, the micro organisms and milk fat globules, leading more opened structure of the cheese and producing a network which helped increase the water and fat retention. The higher water and fat content of the ropy cheeses changed its sensory characteristics, giving a softer texture and a creamier product than the control cheeses which was acceptable to the panelists (Jimenez-Guzman *et al*., 2009).

Fat replacers and other additives: Fat replacers are generally categorized into two groups: fat substitutes and fat mimetic. Fat substitutes are ingredients that have a chemical structure somewhat close to fats and have similar physiochemical properties (Lipp and Anklam, 1998; Kosmark, 1996; Peters *et al*., 1997). They are usually either indigestible or contribute lower calories on a per gram basis. Fat mimetic are ingredients that have distinctly different chemical structure from fat. They are usually carbohydrate and/or protein-based. They have diverse functional properties that mimic some of the characteristic physiochemical attributes and desirable eating qualities of fat: viscosity, mouth feel and appearance (Johnson, 2002; Duflot, 1996). The classification of fat replacers by nutrient source, energy density, specific application and functional properties reported by Ognean *et al.* (2006) shown in Table 1.

Table 1: Classification of fat replacers by nutrient source, energy density, specific application and functional properties

Type of fat replacer	Nutrient source	Energy density	Specific application	Functional properties
Fat substitutes (derived from fat)				
Olestra/Olean	Sucrose polyester of 6-8 fatty acids	Noncaloric (not absorbed)	Savory snacks	Texturize, provide flavor and crispiness
Caprenin	Caprocaprylobehenic triacylglyceride	5 kcal g^{-1}	Soft candy, confectionary coatings	Simulating properties of cocoas butter (emulsify, texturize)
Salatrim	Short and long acyl triglyceryde molecule		Chocolate-flavored coatings, deposited chips, caramels and toffees, fillings and inclusions for confectionary, peanut spread	Range melting points, hardness, appearance
		5 kcal g^{-1}	Baked goods, fillings and inclusions for baked goods	Emulsify, provide cohesiveness, tenderize carry flavor, replace shortening, prevent staling, prevent starch retrogradation, condition dough
			Savory dressings, dips, sauces	Emulsify, provide mouthfeel and lubricity, hold flavorants
			Dairy desserts, cheese	Provide flavor, body, mouthfeel, and texture, stabilize, increse overrun
Fat mimetics				
Derived from protein				
Simplesse	White egg protein, milk protein		Yogurt, cheese, sour cream	Stabilize, emulsify
			Baked goods	Texturize
Simplesse100	Whey protein		Frozen dessert products	Texturize stabilize
		4 kcal g^{-1}	Frostings	Provide mouthfeel, texturize
			Salad dressing, dips, mayonnaise	Texturize, provide mouthfeel
			margarine	Texturize
			Sauces, soups	Texturize
LITA	Zein	1-4 kcal g^{-1}	dairy products	Stabilize, emulsify
Trailblazer	White egg protein, serum protein mixed with xanthan gum		Soups, sauces	Texturize
N-Flate	Non fat milk, gums, emulsifiers and modified starch		Salad dressing	Texturize, provide mouthfeel
			Icings, glazes, desserts, ice cream	Texturize, stabilize
Derived from carbohdrate				
			Ground beef	Texturize, provide mouthfeel, water holding
Guar	Galactomannan extracted from leguminous seed	Noncaloric	Baked goods	Retain moisture, retard staling

Table 1: Continue

Type of fat replacer	Nutrient source	Energy density	Specific application	Functional properties
Xanthan	Microbial polisaccharide produced by aerobic fermentation of Xantomonas campestris			
Locust bean	Extracted from seeds of the tree Ceratonia silique			
Carrageenan	Sulphated polysaccharides extracted from red seaweed (marine algae of the class Rhodophyta)		Salad dressings	Increase viscosity, provide mouthfeel, texturize
Gum arabic	Dry exude from Accacia tree			
Pectins	Cell wall polysaccharides extracted from apple pomace, citrus peel, sugar beet pulp, sunflowers heads		Sauces Texturize	Thicken, provide mouthfeel
Starch: native, modified by acid or enzymatic hydro-lysis, oxidation, dextrinization, crosslinking, or mono-substitution; available in pregelatinized or instant forms	Common corn, high amylose corn, waxy maize, wheat, potato, tapioca, rice, waxy rices	4 kcal g^{-1}	Margarine, spreads, dressings, sauces, baked goods, frostings, fillings, meat emulsions	Modifying texture, gelling, thickening, stabilizing, water holding
Cellulose				
Microcrystalline cellulose	Obtained by mechanical grinding from various plant sources	Noncaloric	Salad dressings frozen desserts sauces dairy products	Contributes body, consistency and mouthfeel, stabilizes emulsions and foams, Controls syneresis, adds viscosity, gloss and opacity to foods
Powdered cellulose	Obtained by chemical depolymerization from various plant sources		Frying	Reducing the fat in fried batter coatings and fried cake donuts
			Baked goods	Increasing the volume of baked goods because it can stabilize air bubbles and minimize after baking shrinkage
Methyl cellulose	Obtained by chemical derivitization from various plant sources		Baked goods frozen desserts dry mix sauces	Impart creaminess, lubricity, air entrapment and moisture retention
Hydroxypropyl methyl cellulose	Obtained by chemical derivitization from various plant sources	Sauces, dressings		Impart pouring and spooning qualities
Maltodextrins	Produced by partial hydrolysis of starch (corn, potato, oat, rice, wheat, tapioca)	4 kcal g^{-1}	Table spreads, margarine imitation sour cream, salad dressings, baked goods, frostings, fillings sauces, processed meat, frozen desserts	Build solids and viscosity, bind/control water, contribute smooth mouthfeel
Polydextrose	Randomly-bonded polymer of glucose, sorbitol, and citric or phosphoric acid	1 kcal g^{-1}	baking goods and baking mixes, chewing gum, confections, frostings salad dressing, frozen dairy desserts and mixes gelatins, puddings and fillings, hard and soft candy, peanut spreads, fruit spreads, sweet sauces, toppings and syrups	bulking agent, formulation aid, humectant, texturizer smoothness in high-moisture formulation, fat-sparing effect
β-glucan	Soluble fiber extracted from oats (sometime barley)	kcal g^{-1} 1-4	baked goods and a variety of other food products	Adding body and texture

The fifth method focused on the criticism that reduced-fat cheese is too dry and lacks a creamy texture. Banks (2004) stated that fat mimetic or water-dispersible fat replacers can help solve this problem". Fat mimetic consist mainly of micro particulates whey protein or carbohydrate-based material. They mimic the properties of fat by entrapping water and giving a sense of lubricity and creaminess". Fat replacers improved the dry, low moisture cheese by creating a smooth, more pliable consistency that was more palatable to consumers.

Reduced fat processed cheese with Lecithin was more similar to full fat control processed cheeses. The use of 0.05% granular soy lecithin or hydrogenated soy lecithin improved texture properties of reduced fat cheese without negatively affecting acceptance scores. Reduced fat processed cheeses containing lecithin were less firm more slippery and smoother than reduced fat control cheeses. Lecithin associated flavors and aromas were present in cheeses containing lecithin as determined by a trained sensory panel but consumer flavor and acceptance scores were not affected. Granular soy lecithin gave more texture improvements to reduced fat processed cheese than hydrogenated soy lecithin. The use soy lecithin improved texture properties without negatively affecting acceptance (Drake *et al*., 1999).

Abd El-Hamid *et al*. (2001) replacing milk fat in mozzarella cheese making with Novagel. Dairy-Lo or maltodextrin. Addition of fat replacers enhanced the meltability, lowered oil separation and cheese firmness and improved the microstructure of low-fat Mozzarella cheese. Fat replacers altered the cheese protein matrix and increased the openness of the cheese structure.

The textural properties of 3-mouth old low-fat cheddar cheese manufactured with a B-glucan hydrocolloidal composite denoted as Nutrim, anutraceutical fat replacer were studied by Konuklar *et al*. (2004). Texture attributes of the cheeses from the sensory panel evaluated by hand feel were all similar. Texture attributes of the cheeses from the sensory panel evaluated by mouth feel were similar for creamy, chewy and grainy, however, the Nutrim cheeses were significantly morepasty. There were not any significant differences for cohesiveness and springiness among the cheeses. In flavour attributes, significant differences were record for buttery, bitter and slarchy characteristics.

Use of commercial oat B-glucan concentrate in low-fat white-brined cheese product affected cheese appearance and flavor in comparison with the control samples. For the cheeses made with the B-glucan concentrate, the yield and extent of proteolysis increased compared to their low-fat counterpart. Moreover, the fortified products exhibited higher levels of short chain fatty acids (lactic, acetic and butyric). The rheological and sensory measurements showed an improvement in the texture of the low fat cheese containing the B-glucan preparation. However, the color, flavor and overall impression scores were significantly inferior to those of atypical white-brined cheese product (Volikakis *et al*., 2004).

The influence of exo-polysaccharide (EPS), pre acidification and use of two fat replacers, FR1 and FR2 on the textural and functional characteristics of Mozzarella cheese were studied (Zisu and Shah, 2005). Moisture in low-fat Mozzarella cheese was increased with the use F FR1 and FR2 fat replacers leading to improved yield and textural characteristics. Pre-acidification of the cheese milk and use of FR1 further increased the moisture content and yield. Pre-acidified cheese also had on increased level of proteolysis and subsequent hydration of the protein matrix improved their functional behavior. The nature of the fat replacer, however, it had the greatest influence on the microstructure of cheese and its impact on the textural the functional characteristics, FR1 containing cheese showed better melt, stretch and pizza bake performance as compared to FR2 containing cheeses. By combining EPS cultures with the appropriate fat replacer and pre-acidification it is possible to increase the yield of low-fat Mozzarella cheese and reduce maturation time, there by reducing storage periods.

Hennelly *et al.* (2006) studied the possibility of using inulin gels or solution to replace fat in imitation cheese. Inulin was successfully incorporated into the imitation cheese matrix at a level of 3.44 g/100 g cheese gel or aqueous solution. At this level, it directly replaced 63% of the total fat in the formulation without any significant effect on the melting characteristics. It is recommended, primarily for reasons of convenience and process (temperature) control to add inulin as a hot (80°C) solution rather than a cooled gel.

El-Shibiny *et al.* (2007) made low-fat processed cheese spreads of good sensory properties comparable to the full-fat cheese spreads with use of Jursalium artickake, whey protein concentrates and simples (R) as a fat replacer. The use of different emulsifying salts had no marked effect on the chemical composition, microbilogical quality, rheological properties and sensory properties of the produced processed cheese spreads.

Lobato-Calleros *et al.* (2007) used emulsified canola oil and whey protein as fat replacer. Scanning electron micrographs showed that the total or partial substitution of the milk fat by emulsified canola oil and or whey protein concentrate produced cheese with different structures from that of the full-milk fat cheese. When whey protein concentrates predominated denser, compact and continuous protein matrix was produced. In contrast, when emulsified canola oil predominated, looser, more disrupled protein matrix was formed. These different cheese microstructure exhibited differing textual characteristics, Increasing Concentration of the emulsifiers blend (indirectly canola oil), whey protein concentrate and/or milk fat increased the values of the textural characteristics of the cheeses.

Use of Arabic Gum improves the textural and rheological properties of Iranian low-fat white cheese. The cheese treated with 0.5 g of Arabic gum was close to full fat control cheese. However, by increasing Arabic gum's concentration to 0.75 g, these indices showed high promotion and were close to reduced fat control cheese. Arabic gum in low level concentration can be used as a fat replacer to decline energy producing feature and its texture improvement as well (Shendi *et al.*, 2010).

Novel fat removed method: Whetstine *et al.* (2006) stated that the flavor release is different in the mouth with reduced-fat products than in full-fat products because hydrophobic flavor compounds have a higher sensory threshold in oil than they do in water. When fat molecules are extracted from milk before cheese is made, there are less fat molecules for the sensory compounds to bind to, resulting in a lack of flavor reduced-fat cheese.

Nelson and Barbano (2004) preceded Whetstine *et al.* (2006) and designed a method that physically removed the fat content from full-fat aged cheddar cheese after it had been processed. Full-fat cheddar cheese contains the full maturity of flavor and by extracting the fat after the cheese has aged, the researchers theorized that the non-fat cheese would retain the original flavor, thus making low-fat cheese comparable in taste to full-fat cheese. The process was constructed as follows: for the extraction method, the researchers selected three samples of palatable Full-fat cheddar cheese. The cheese was grated, weighed and placed in separate bottles with a combination of volatile compounds. Each bottle was mixed for 30 min by Roto mix and centrifuged for ten minutes, which allowed the fat to separate from the cheese. The cheese, after purification like process, was served to panel of 12 to evaluate the flavor. There were only slight differences in taste between the full-fat and reduced-fat cheese. The process allowed the researchers to remove 50% of the fat from the full-fat cheddar cheese, while maintaining the same nutty flavor of the original block of cheese. The reduced fat cheese made from the fat removal process was also softer and had a comparable melting profile to full-fat cheese (Fig. 2 and 3).

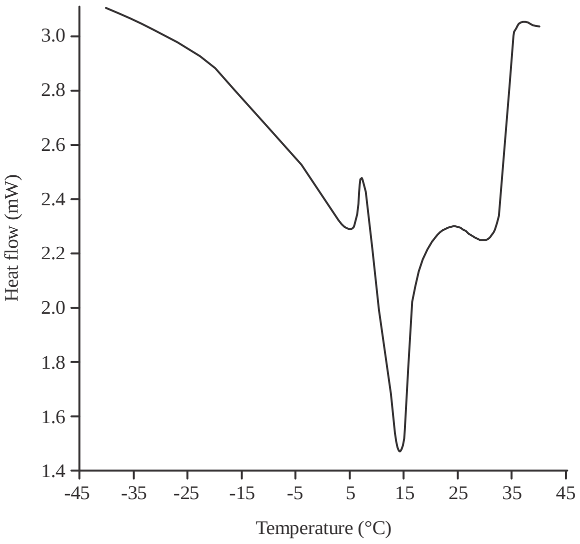

Fig. 2: Typical melting outline of fat from full-fat Cheddar cheese

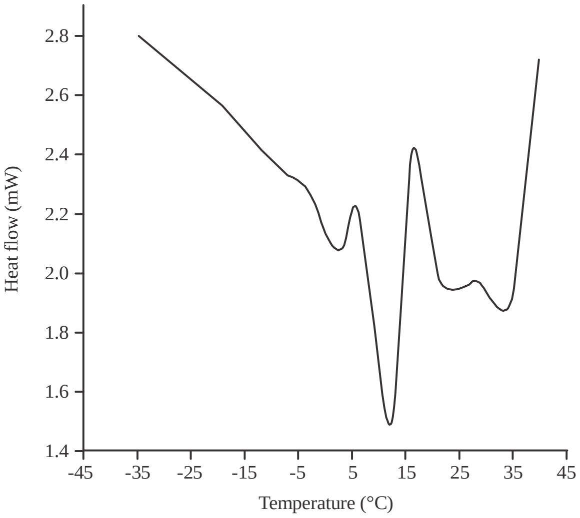

Fig. 3: Typical melting outline of fat from reduced-fat Cheddar cheese produced by the fat removal process

Supercritical Fluid Extraction (SFE) technology can be used in the dairy industry to develop low-fat cheese with flavor to match that of full-fat cheese (Yee *et al.*, 2007). The SFE from mature cheddar and parmesan cheeses allowed for the reduction in total fat, with no need for modification in formulation. A maximum fat reduction of 51% for cheddar cheeses and 55.56% fat reduction for parmesan cheese. The objective of this investigation was to develop lower fat cheddar and parmesan grated cheese using SFE and characterize its flavor profile comparative to a full-fat product. Specifically, enabling flavor compounds partition between the matrices of cheese and extracted lipids.

CONCLUSION

- In the near future all of the concern for low-fat cheese will be solved with new technology. Dairy research would allow consumers to enjoy their cheese without feeling guilty, from the high fat content. The research would also benefit producers who value high-quality products
- Each method was built off another idea for creating healthful and flavorful cheese. Producers must take risks to create products that meet the consumers need. Consumer could soon be on the way to eating nutritious and delicious food with the onset of dairy research

REFERENCES

Abd El-Hamid, L.B., A.E. Hagrass, R.A. Awad and O.A. Zammar, 2001. Physical and sensory properties of low calorie Mozzarella cheese with fat replacers. Proceedings of the 8th Egyptian Conference for Dairy Science and Technology, November 3-5, 2001, Cairo, Egypt, pp: 283-298.

Agrawal, P. and A.N. Hassan, 2007. Ultrafiltered milk reduces bitterness in reduced-fat cheddar cheese made with an exopolysaccharide-producing culture. J. Dairy Sci., 90: 3110-3117.

Anderson, D.L., V.V. Mistry, R.L. Brandsma and K.A. Baldwin, 1993. Reduced fat cheddar cheese from condensed milk. 1. Manufacture, composition and ripening. J. Dairy Sci., 76: 2832-2844.

Awad, S., A.N. Hassan and K. Muthukumarappan, 2005. Application of exopolysaccharide-producing cultures in reduced-fat cheddar cheese: Texture and melting properties. J. Dairy Sci., 88: 4204-4213.

Banks, J.M., 2004. The technology of low-fat cheese manufacture. Int. J. Dairy Technol., 57: 199-207.

Banks, J.M., E.A. Hunter and D.D. Muir, 1993. Sensory properties of low fat cheddar cheese: effect of salt content and adjunct culture. J. Soc. Dairy Technol., 46: 119-123.

Banks, J.M., E.Y. Brechany and W.W. Christie, 1989. The production of low fat Cheddar-type cheese. Int. J. Dairy Technol., 42: 6-9.

Banks, J.M., I. Roa and D.D. Muir, 1998. Manipulation of the texture of low-fat chedder using a plant protease extracted from *Cynara cardunculus*. Aust. J. Dairy Technol., 53: 105-105.

Barlow, I., G.T. Lloyd, E.H. Ramshaw, A.J. Miller, G.P. McCabe and L. McCabe, 1989. Correlations and changes in flavour and chemical parameters of Cheddar cheeses during maturation. Aust. J. Dairy Technol., 44: 7-24.

Bogenrief, D.D. and N.F. Olsen, 1995. Hydrolysis of B-casien increases cheddar cheese mutability. Milchrwissenschaft, 50: 678-682.

Broadbent, J.R., D.J. McMahon, C.J. Oberg and D.L. Welker, 2001. Use of exopolysaccharide-producing cultures to improve the functionality of low fat cheese. Int. Dairy J., 11: 433-439.

Chen, C.M. and M.E. Johnson, 1996. Process for manufacturing reduced-fat Cheddar cheese. United States Patent No. 5554398, September 10, 1996.

Dabour, N., E. Kheadr, N. Benhamou, I. Fliss and G. LaPointe, 2006. Improvement of texture and structure of reduced-fat cheddar cheese by exopolysaccharide-producing lactococci. J. Dairy Sci., 89: 95-110.

Darling, D.F. and D.W. Butcher, 1978. Milk-fat globule membrane in homogenized cream. J. Dairy Res., 45: 197-208.

Dimos, A., G.E. Urbach and A.J. Miller, 1996. Changes in flavour and volatiles of full fat and low fat cheeses during maturation. Int. Dairy J., 6: 981-995.

Drake, M.A., V.D. Truong and C.R. Daubert, 1999. Rheological and sensory properties of reduced-fat processed cheeses containing lecithin. J. Food Sci., 64: 744-747.

Drewnowski, A., 1998. Energy density, palatability and satiety: Implications for weight control. Nutr. Rev., 56: 347-353.

Duflot, P., 1996. Starches and sugars Glucose polymers as sugar/fat substitutes: Duflot, P. (Roquette Freres SA, France) French patent application FR 2 712 891 1A [in French]. Trends Food Sci. Technol., 7: 206-206.

El Soda, M., 2014. Production of low fat cheddar cheese made using exopolysaccharide-producing cultures and selected ripening cultures. Adv. Microbiol., 4: 986-995.

El-Shibiny, S., M.E. Shenana, G.F. El-Nagar and S.M. Abdou, 2007. Preparation and properties of low fat processed cheese spreads. Int. J. Dairy. Sci., 2: 13-22.

Guinee, T.P., M.A. Fenelon, E.O. Mulholland, B.T. O'Kennedy, N. O'Brien and W.J. Reville, 1998. The influence of milk pasteurization temperature and pH at curd milling on the composition, texture and maturation of reduced fat cheddar cheese. Int. J. Dairy Technol., 51: 1-10.

Guinee, T.P., M.A.E. Auty and M.A. Fenelon, 2000. The effect of fat content on the rheology, microstructure and heat-induced functional characteristics of cheddar cheese. Int. Dairy J., 10: 277-288.

Gursoy, A., 2009. Effect of using attenuated lactic starter cultures on lipolysis and proteolysis in low fat Kasar cheese. Tarim Bilimleri Dergisi, 15: 285-292.

Hennelly, P.J., P.G. Dunne, M. O'sullivan and E.D. O'Riordan, 2006. Textural, rheological and microstructural properties of imitation cheese containing inulin. J. Food Eng., 75: 388-395.

Jimenez-Guzman, J., A. Flores-Najera, A.E. Cruz-Guerrero and M. Garcia-Garibay, 2009. Use of an exopolysaccharide-producing strain of *Streptococcus thermophilus* in the manufacture of Mexican Panela cheese. LWT-Food Sci. Technol., 42: 1508-1512.

Johnson, B.R., 2002. Whey protein concentrates in low-fat applications. U.S. Dairy Export Council, American Dairy Products Institute, Arlington, VA.

Johnson, J.A.C., M.R. Etzel, C.M. Chen and M.E. Johnson, 1995. Accelerated ripening of reduced-fat Cheddar cheese using four attenuated *Lactobacillus helveticus* CNRZ-32 adjuncts. J. Dairy Sci., 78: 769-776.

Johnson, M.E. and C.M. Chen, 1995. Technology of Manufacturing Reduced-Fat Cheddar Cheese. In: Chemistry of Structure-Function Relationships in Cheese, Malin, E.L. and M.H. Tunick (Eds.). Plenum Press, New York, pp: 33-338.

Jonnalagadda, S.S., 2005. Position of the American dietetic association: Fat replacers. J. Am. Dietetic Assoc., 105: 266-275.

Katsiari, M.C., L.P. Voutsinas and E. Kondyli, 2002a. Improvement of sensory quality of low-fat Kefalograviera-type cheese with commercial adjunct cultures. Int. Dairy J., 12: 757-764.

Katsiari, M.C., L.P. Voutsinas and E. Kondyli, 2002b. Improvement of sensory quality of lowfat kefalograviera-type cheese by using commercial special starter cultures. J. Dairy Sci., 85: 2759-2767.

Katsiari, M.C., L.P. Voutsinas, E. Kondyli and E. Alichanidis, 2002c. Flavour enhancement of low-fat Feta-type cheese using a commercial adjunct culture. Food Chem., 79: 193-198.

Kilcawley, K.N., P.B. O'Connell, D.K. Hickey, E.M. Sheenan and T.P. Beresford *et al*., 2007. Influence of composition on the biochemical and sensory characteristics of commercial cheddar cheese of variable quality and fat content. Int. J. Dairy Technol., 60: 81-88.

Kinsella, J.E., 1975. Butter flavor. Food Technol., 29: 82-98.

Koca, N. and M. Metin, 2004. Textural, melting and sensory properties of low-fat fresh kashar cheeses produced by using fat replacers. Int. Dairy J., 14: 365-373.

Konuklar, G., G.E. Inglett, K. Warner and C.J. Carriere, 2004. Use of a β-glucan hydrocolloidal suspension in the manufacture of low-fat Cheddar cheeses: Textural properties by instrumental methods and sensory panels. Food Hydrocolloids, 18: 535-545.

Kosikowski, F.V. and V.V. Mistry, 1997. Cheese and Fermented Milk Foods. Vol. 1, F.V. Kosikowski, Westport, CT., ISBN: 9780965645607, Pages: 1058.

Kosmark, R., 1996. Salatrim: Properties and applications. Food Technol., 50: 98-101.

Kucukoner, E. and Z.U. Haque, 2006. Physicochemical properties of low-fat and full-fat Cheddar cheeses. Int. J. Dairy Technol., 59: 166-170.

Lawrence, R.C., L.K. Creamer and J. Gilles, 1987. Texture development during cheese ripening. J. Dairy Sci., 70: 1748-1760.

Lipp, M. and E. Anklam, 1998. Review of cocoa butter and alternative fats for use in chocolate-part A. Compositional data. Food Chem., 62: 73-97.

Lo, C.G. and E.D. Bastian, 1998. Incorporation of native and denatured whey proteins into cheese curd for manufacture of reduced fat, Havarti-type cheese. J. Dairy Sci., 81: 16-24.

Lobato-Calleros, C., J. Reyes-Hernandez, C.I. Beristain, Y. Hornelas-Uribe, J.E. Sanchez-Garcia and E.J. Vernon-Carter, 2007. Microstructure and texture of white fresh cheese made with canola oil and whey protein concentrate in partial or total replacement of milk fat. Food Res. Int., 40: 529-537.

Low, D., J.A. Ahlgren, D. Horne, D.J. McMahon, C.J. Oberg and J.R. Broadbent, 1998. Role of *Streptococcus thermophilus* MR-1C capsular exopolysaccharide in cheese moisture retention. Applied Environ. Microbiol., 64: 2147-2151.

Madadlou, A., A. Khosroshahi and M.E. Mousavi, 2005. Rheology, microstructure and functionality of low-fat Iranian white cheese made with different concentrations of rennet. J. Dairy Sci., 88: 3052-3062.

Madsen, F.M., G.W. Reinbold and W.S.H. Clark, 1966. Low fat cheese. Manufactured Milk Prod. J., 57: 18-22.

Manolaki, P., M.C. Katsiari and E. Alichanidis, 2006. Effect of a commercial adjunct culture on organic acid contents of low-fat Feta-type cheese. Food Chem., 98: 658-663.

Mayes, J.J., G. Urbach and B.J. Sutherland, 1994. Does addition of buttermilk affect the organoleptic properties of low-fat Cheddar cheese? Aust. J. Dairy Technol., 49: 39-41.

McGregor, J.U. and C.H. White, 1990. Optimizing ultrafiltration parameters for the development of a lowfat cheddar cheese. J. Dairy Sci., 73: 314-318.

McMahon, D.J. and C.J. Oberg, 1998. Influence of fat, moisture and salt on functional properties of Mozzarella cheese. Aust. J. Dairy Technol., 53: 98-101.

McSweeney, P.L.H., 1997. The flavour of milk and dairy products: III. Cheese: Taste. Int. J. Dairy Technol., 50: 123-128.

Merrill, R.K., C.J. Oberg and D.J. McMahon, 1994. A method for manufacturing reduced fat Mozzarella cheese. J. Dairy Sci., 77: 1783-1789.

Merrill, R.K., C.J. Oberg, W.R. McManus, M. Kalab and D.J. McMahon, 1996. Microstructure and physical properties of a reduced fat mozzarella cheese made using*Lactobacillus casei*ssp.*casei*Adjunct culture. LWT-Food Sci. Technol., 29: 721-728.

Metzger, L.E. and V.V. Mistry, 1995. A new approach using homogenization of cream in the manufacture of reduced fat Cheddar cheese. 2. Microstructure, fat globule distribution and free oil. J. Dairy Sci., 78: 1883-1895.

Mistry, V.V. and D.L. Anderson, 1993. Composition and microstructure of commercial full-fat and low-fat cheeses. Food Struct., 12: 259-266.

Mistry, V.V. and K.M. Kasperson, 1998. Influence of salt on the quality of reduced fat Cheddar cheese. J. Dairy Sci., 81: 1214-1221.

Mistry, V.V., L.E. Metzger and J.L. Maubois, 1996. Use of ultrafiltered sweet buttermilk in the manufacture of reduced fat cheddar cheese. J. Dairy Sci., 79: 1137-1145.

Nauth, K.R. and D. Ruffie, 1995. Microbiology and Biochemistry of Reduced-Fat Cheese. In: Chemistry of Structure-Function Relationships in Cheese, Malin, E.L. and M.H. Tunick (Eds.). Plenum Press, New York, pp: 345-358.

Nauth, K.R. and K. Hayashi, 1995. Method for manufacture of low fat pasta filata cheese. United States Patent No. 5431931, July 11, 1995.

Nelson, B.K. and D.M. Barbano, 2004. Reduced-fat cheddar cheese manufactured using a novel fat removal process. J. Dairy Sci., 87: 841-853.

Ognean, C.F., N. Darie and M. Ognean, 2006. Fat replacers-review. J. Agroalimen. Process. Technol., 12: 433-442.

Oliveira, S.P. and B.V. Assumpcio, 2000. Low/reduced fat foods. Evol. Concept Cons. Hig. Alim., 14: 36-41.

Olson, N.F. and M.E. Johnson, 1990. Light cheese products: Characteristics and economics. Food Technol., 44: 93-96.

Perry, D.B., D.J. McMahon and C.J. Oberg, 1997. Effect of exopolysaccharide-producing cultures on moisture retention in low fat Mozzarella cheese. J. Dairy Sci., 80: 799-805.

Peters, J.C., K.D. Lawson, S.J. Middleton and K.C. Triebwasser, 1997. Assessment of the nutritional effects of olestra, a nonabsorbed fat replacement: Introduction and overview. J. Nutr., 127: 1539S-1546S.

Petersen, B.L., R.I. Dave, D.J. McMahon, C.J. Oberg and J.R. Broadbent, 2000. Influence of capsular and ropy exopolysaccharide-producing streptococcus thermophilus on mozzarella cheese and cheese whey. J. Dairy Sci., 83: 1952-1956.

Poduval, V.S. and V.V. Mistry, 1999. Manufacture of reduced fat Mozzarella cheese using ultrafiltered sweet buttermilk and homogenized cream. J. Dairy Sci., 82: 1-9.

Punidadas, P., J. Feirtag and M.A. Tung, 1999. Incorporating whey proteins into mozzarella cheese. Intl. J. Dairy Technol., 52: 51-55.

Raval, D.M. and V.V. Mistry, 1999. Application of ultrafiltered sweet buttermilk in the manufacture of reduced fat process cheese. J. Dairy Sci., 82: 2334-2343.

Rodriguez, J., T. Requena, J. Fontecha, H. Goudedranche and M. Juarez, 1999. Effect of different membrane separation technologies (ultrafiltration and microfiltration) on the texture and microstructure of semihard low-fat cheeses. J. Agric. Food Chem., 47: 558-565.

Rudan, M.A. and D.M. Barbano, 1998. A model of Mozzarella cheese melting and browning during pizza baking. J. Dairy Sci., 81: 2312-2319.

Rudan, M.A., D.M. Barbano, J.J. Yun and P.S. Kindstedt, 1999. Effect of fat reduction on chemical composition, proteolysis, functionality and yield of Mozzarella cheese. J. Dairy Sci., 82: 661-672.

Sandrou, D.K. and I.S. Arvanitoyannis, 2000. Low-fat/calorie foods: Current state and perspectives. Critical Rev. Food Sci. Nutr., 40: 427-447.

Schreiber, R., S. Neuhauser, S. Schindler and H.G. Kessler, 1998. Incorporation of whey protein aggregates in semi-hard cheese. Part 1: Optimizing processing parameters. Detsch. Milchwirtschaft, 49: 958-962.

Shakeel-Ur-Rehman, N.Y. Farkye and M. Drake, 2003. Reduced-fat cheddar cheese from a mixture of cream and liquid milk protein concentrate. Int. J. Dairy Technol., 56: 94-98.

Shendi, E.G., A.K. Asl, A. Mortazavi, H. Tavakulipor, A.G. Ebadi and H. Afshari, 2010. The effect of Arabic gum using on improving of texture and rheological properties of Iranian low fat white cheese. Am. Eurasian J. Agric. Environ. Sci., 8: 607-614.

St-Gelais, D., D. Roy and P. Audet, 1998. Manufacture and composition of low fat Cheddar cheese from milk enriched with different protein concentrate powders. Food Res. Int., 31: 137-145.

Tungjaroenchai, W., M.A. Drake and C.H. White, 2001. Influence of adjunct cultures on ripening of reduced fat Edam cheeses. J. Dairy Sci., 84: 2117-2124.

Tunick, M.H., E.L. Malin, P.W. Smith, J.J. Shieh, B.C. Sullivan, K.L. Mackey and V.H. Holsinger, 1993. Proteolysis and rheology of low fat and full fat Mozzarella cheeses prepared from homogenized milk. J. Dairy Sci., 76: 3621-3628.

Urbach, G., 1997. The flavour of milk and dairy products: II. Cheese: Contribution of volatile compounds. Int. J. Dairy Technol., 50: 79-89.

Volikakis, P., C.G. Biliaderis, C. Vamvakas and G.K. Zerfridis, 2004. Effects of a commercial oat-β-glucan concentrate on the chemical, physico-chemical and sensory attributes of low-fat white-brined cheese product. Food Res. Int., 37: 83-94.

Whetstine, M.E.C., M.A. Drake, B.K. Nelson and D.M. Barbano, 2006. Flavor profiles of full-fat and reduced-fat cheese and cheese fat made from aged cheddar with the fat removed using a novel process. J. Dairy Sci., 89: 505-517.

Wijesunda, C. and P. Watkins, 2000. Milkfat is essential for the development of cheddar cheese flavour. Aust. J. Dairy Technol., 55: 86-91.

Yee, J.L., H. Khalil and R. Jimenez-Flores, 2007. Flavor partition and fat reduction in cheese by supercritical fluid extraction: Processing variables. Le Lait, 87: 269-285.

Zisu, B. and N.P. Shah, 2005. Textural and functional changes in low-fat Mozzarella cheeses in relation to proteolysis and microstructure as influenced by the use of fat replacers, pre-acidification and EPS starter. Int. Dairy J., 15: 957-972.

Zisu, B. and N.P. Shah, 2007. Texture characteristics and pizza bake properties of low-fat Mozzarella cheese as influenced by pre-acidification with citric acid and use of encapsulated and ropy exopolysaccharide producing cultures. Int. Dairy J., 17: 985-997.