Processed Cheese: Basics and Possibility for the Development of Healthier Products

Aly S., Eman El Dakhakhny, El Saadany K., Nassra Dabour & Kheadr, E.

Functional Foods and Nutraceuticals Laboratory (FFNL), Dairy Science and Technology Dept., Fac. of Agric., El-Shatby, 21545, Univ. of Alexandria, Alex., Egypt.

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ABSTRACT

Processed cheese gains continuous popularity due to its diverse composition and wide applications. The diversity of ingredients used for its formulation permits the production of a wide variety of cheeses with different flavours, textures and functions. Presently, more attention has been paid to processed cheese as a promising food vehicle able to deliver specific nutrients into human body. This review focuses on the following topics: market development, main ingredients of processed cheese (mainly natural cheeses, milk protein and emulsifying salts), processed cheese analogue (classification, formulation and important protein and fat substitutes) and previous attempts for production of healthier processed cheese.

Key words: Processed cheese, natural, reduced-fat, imitated cheese, healthier product.

INTRODUCTION

The innovation of processed cheese was originated from the desires to extend the shelf-life of natural cheese, recycle defected cheese and/or to develop a cheese with distinct texture, flavour and functional properties. The production of processed cheese started in Europe early in the last century. The first attempt for making processed cheese was made in Switzerland in 1911 by Walter Gerber and Fritz Stettler from Swiss cheese (Kapoor & Metzger 2008). At this time, the process described simply as melting Swiss cheese using one additional ingredient which was sodium citrate as an emulsifying salt. James Lewis Kraft, a Canadian-American entrepreneur and inventor, was the first to patent processed cheese in 1916 (Kapoor & Metzger 2008). The process was described as a combination of heating and stirring of Cheddar cheese pieces to form a homogenous warm emulsion which was then packed in glass jars or cans.

There are numerous definitions describing processed cheese. Among them, the definition proposed by Guinee *et al*. (2004) is the most frequently used and the simplest one. The authors defined processed cheese as "the cheese which can be produced by blending natural cheese of different ages and degrees of maturity in the presence of emulsifying salts and other dairy and nondairy ingredients followed by heating and continuous mixing to form a homogeneous product". Processed cheese production increased steadily during the last century leading to the development of wide variety of products worldwide. Based on the physical characteristics of the final product, processed cheese was generally grouped into two different categories as processed cheese and spreadable processed cheese (Smith, 1990).

According to Carić & Kaláb (1999), processed cheese has numerous advantages over natural cheeses due to:

1– Reduction of refrigeration cost during storage and transportation,

2– Improvement of keeping quality with less changes in cheese characteristics during storage,

3– The possibility of producing cheese with different intensity of flavour and functional properties for various applications,

4– The possibility of adjusting packaging for various usage, economical needs,

5– The suitability for home use as well as for snack restaurants, e.g. in cheeseburgers, hot sandwiches, pizza and dips for fast foods.

Processed cheese market

The production of processed cheese has a continuous growth in some region worldwide, while remains relatively constant in other regions. The growing markets of today are located in the Middle East, Russian Federation, South America and North Africa. However, Western Europe, United States and Japan are considered relatively stable markets (Table 1).

In Egypt, processed cheese production is considered to be one of the most active and dynamic sector among Egyptian food industries. Economically, Egyptian processed cheese industry contains approximately 24 large factories and represents 20-25% of the entire Egyptian cheese industry with continuous increased exportation value. This dairy product showed huge growth abilities in terms of produced, local consumed and exported quantities of cheese. In year 2005, Egypt exported approximately 180 tons of processed cheese which increased in year 2011 to 62,282 tons equivalent to 225 million US dollars (FAO statistics, 2011). Processed cheese gained popularity among Egyptian people as consumption per capita increased from approximately 2 kg in year 2003 up to 2.46 kg in 2010 (Table 2).

The huge diversity of ingredients that can be incorporated in cheese blends permits the production of a wide variety of processed cheeses with diverse flavours, textures and functions. Thus, processed cheese itself can be used as an ingredient for convenience food application or in the production of other foods such as snacks. This ability makes processed cheese production among the most innovated industry in dairy sector. Actually, the market of the area of processed cheese needs innovations related to "improvement of nutritional value", "health", and "labelling" issues.

Processed cheese types

Processed cheeses can be classified into 2 main groups (pasteurized and substitute/ imitation processed cheese) according to their composition, water content and consistency. Each group is further classified based on ingredients used for the formulation of each cheese category as shown in Figure (1).

Processed cheese manufacture

The main processing steps involved in processed cheese manufacture are illustrated in Figure (2). The processing steps can be divided into two main stages as 1) ingredient selection and formulation and 2) processing and storage (Kapoor & Metzge, 2008). The first stage includes selection and shredding of natural cheese, fat standardization, selection of appropriate emulsifying salts and other ingredients and blending ingredients in order to meet the targeted gross chemical composition. The second stage concerns the technological steps in processing including, cooking (heat and mixing), packaging, cooling, cartoning and storage.

Main ingredients of processed cheese

Natural cheese

The type, characteristic and age of the natural cheese have major role in controlling the textural, viscoelastic, functional, microstructural, and sensorial properties of processed cheese (Glenn *et al.*, 2003, Acharya & Mistry, 2005). Blends of cheese

Table 1: Growth of processed cheese market volume (1000 tons) in some selected countries worldwide

Country	2003	2004	2005	2006	2007	2008	2009	2010
United States	248.40	263.50	279.40	197.00	323.80	356.00	380.80	407.10
Canada	74.80	74.50	74.00	73.60	73.30	73.10	72.90	72.70
Argentina	35.60	39.30	41.00	42.80	44.50	46.20	47.90	49.60
Brazil	11.40	16.20’	18.00	20.10	22.70	25.50	28.20	30.80
Japan	102.00	106.00	110.70	115.10	119.20	123.20	127.20	130.90
Australia	23.80	24.60	25.40	26.40	27.60.	28.50	29.50	0.40
China	7.60	8.40	9.50	11.00	12.70	14.70	16.90	19. 40
India	6. 60	1.7.10	7.10	8.60	9.60 %	10.80	11.90	13.10
Republic of Korea	7.40	8.10	8.80	9.40	9.90	10.30	10.80	11.20
New Zealand	9.40	9.60	9.60	9.70	9.80	9.90	9.90	9.90
Philippines	5.40	5.60	5.90	6.30	6.70	7.20	7.70	8.20

Source: Datamonitor 2011 (from Maurer and Scheurer 2012).

Table 2: Growth of processed cheese consumption (in kg) per capita in some selected countries worldwide

Country	2003	2004	2005	2006	2007	2008	2009	2010
Saudi Arabia	2.31	2.36	2.46	2.51	2.57	2.64	2.70	2.78
Morocco	1.99	2.08	2.18	2.28	2.38	2.45	2.52	2.59
Egypt	1.99	2.00	2.03	2.12	2.22	2.30	2.38	2.46
South Africa	0.72	0.74	0.79	0.84	0.90	0.96	1.02	1.10
Hungary	1.60	1.84	2.05	2.28	2.50	2.61	2.72	2.83
France	1.74	1.74	1.74	1.74	1.75	1.75	1.75	1.75
Ukraine	0.54	0.63	0.71	0.81	0.90	1.00	1.11	1.21
Spain	1.13	1.16	1.20	1.24	1.28	1.30	1.32	1.34
Poland	0.74	0.82	0.89	0.97	1.04	1.09	1.15	1.22
Czech Republic	1.40	1.32	1.27	1.23	1.20	1.20	1.21	1.22
Germany	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18
Finland	0.90	0.91	0.92	0.92	0.94	0.95	0.96	0.98
Netherlands	0 68	0.71	0.75	0.79	0.84	0.85	0.87	0.89
Belgium	0.75	0.76	0.78	0.80	0.82	0.83	0.85	0.86
United Kingdom	0.66	0.65	0.65	0.65	0.65	0.64	0.64	0.64
Austria	0.54	0.56	0.57	0.58	0.59	0.60	0.62	0.63
Turkey	0.16	0.17	0.19	0.20	0.22	0.24	0.26	0.27
Russia	0.70	0.77	0.85	0.90	0.94	0.96	1.00	1.04
Canada	2.32	2.29	2.26	2.22	2.20	2.17	2.14	2.12
Uruguay	1.19	1.27	1.31	1.36	1.40	1.45	1.49	1.53
United States	0.86	0.90	0.94	1.00	1.08	1.17	1.24	1.32
Argentina	0. 92	1.00	1.104	1.07:	1.10	1.14	1.17	1.20
Australia	1.21	1.23	1.26	1.30	1.35	1.38	1.42	1.45
Japan	0.80	0.83	0.87	0.90	0.94	0.97	1.00	1.03

Source: Datamonitor 2011 (from Maurer and Scheurer 2012).

may contain one or more varieties of cheese with different degrees of maturation (Guinee *et al*., 2004, Kapoor & Metzger, 2008). Cheddar cheese was and still the major type of natural cheese used for manufacturing processed cheese. The amount of natural cheese in blend depends on the type of processed cheese and the amount of natural cheese required in a processed cheese formula varies from 51% to >80% of the final processed cheese (Food and Drug Administration, 2006).

The general practice in processed cheese manufacture is to use 2 types of natural cheese with different degree of maturation (e.g. young: mild: mature or semi mature cheese). The ratio between the two groups of cheese play the major role in controlling the physical characteristics of the resultant processed cheese. The general formulation for block-type is composed of 3:1 mild: semi mature or mature cheese, respectively (Thomas, 1977), while a mixture of young: mild: matured cheeses at ratio of 55:35:10 is recommended for the production of processed cheese in slices where a high content of un-hydrolysed protein is necessary (Kosikowski, 1982). On the other hand, the production of cheese spreads requires cheese with increased content of hydrolysed protein (semi mature and mature). In this case, a ratio of 30:50:20 of young: semi-matured: matured cheeses, respectively has been suggested by Kosikowski (1982). In general, the increased content of young cheese in the production of processed cheese may have some advantageous including, cost reduction and good slicing properties. The disadvantages related to increased portion of young cheese in cheese blend are the possible production of a tasteless and firmer processed cheese (Carić & Kaláb, 1999). However, the increased content of matured cheese in the blend improves flavour intensity, flow properties and melting of the resultant processed cheese (Thomas, 1977). The excessive incorporation of matured cheese in the blend may lead to the formation of sharp flavour, low emulsion stability and soft consistency.

Natural cheese contributes significantly to overall quality of processed cheese *via* its content of intact casein which is inversely related to the natural cheese age (Shimp, 1985). As the natural cheese ages, milk indigenous enzymes, residual rennet and residual starter or nonstarter lactic acid bacteria present in the cheese hydrolyze the proteins present in natural cheese into peptides, thereby reducing the amount of intact casein (unhydrolyzed form). In general, the increased content of intact casein in processed cheese blend resulted in cheese with firm texture and increased elasticity (Purna *et al*., 2006).

Indeed, a wide variety of natural cheeses can be used for the formulation of processed cheese.

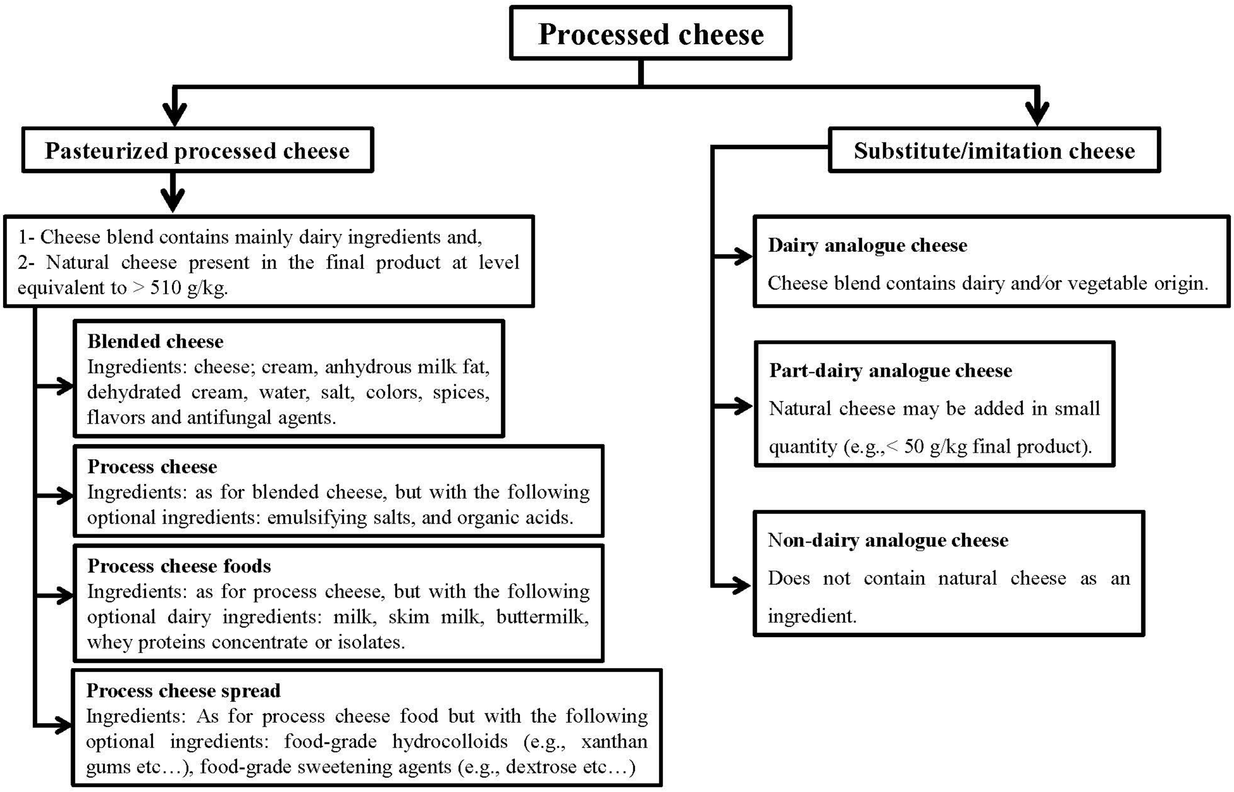

Fig. 1. Classification of processed cheese products based on ingredients used. Adapted form Fox *et al*. (2000).

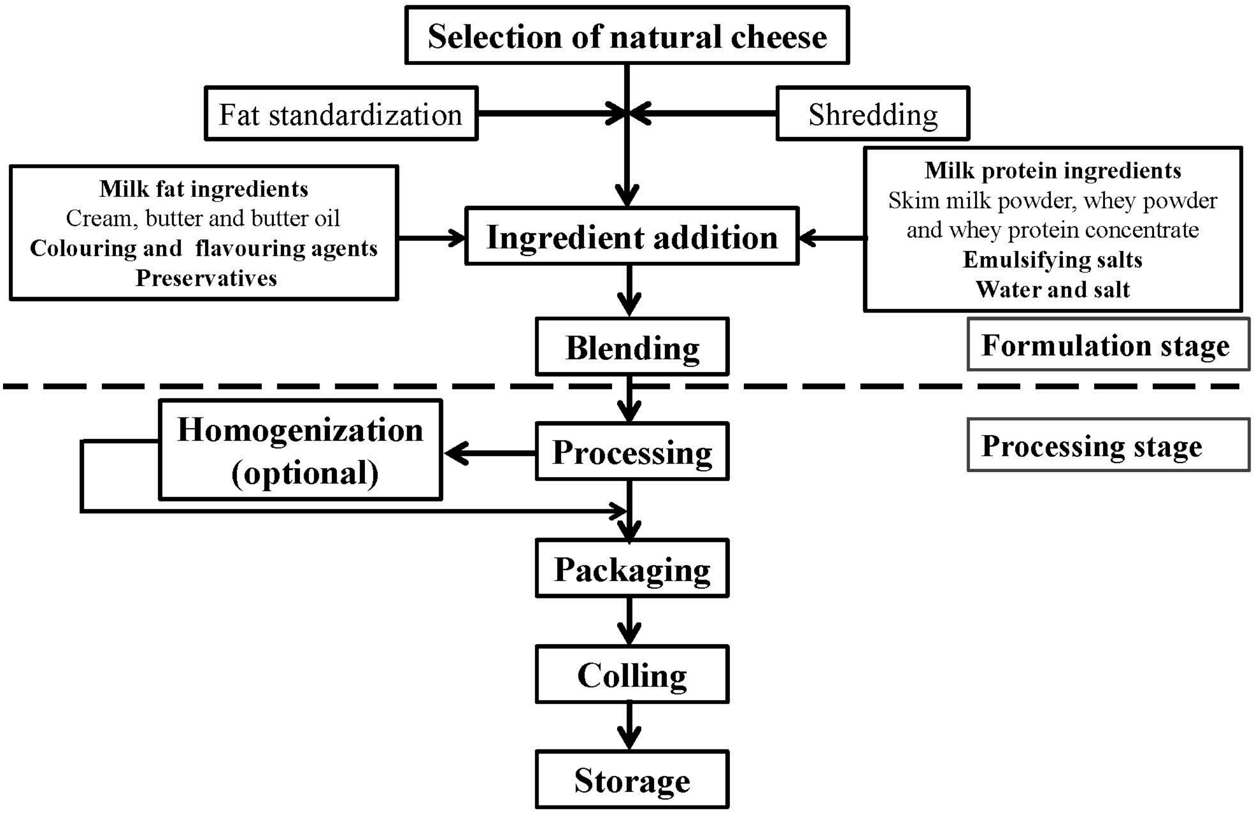

Fig. 2. Schematic flow chart showing the main manufacturing stages of natural processed cheese

The proper selection of natural cheese is the most important factor to produce processed cheese with desired properties. The selection is based on many criteria including, cheese type (hard or soft), flavour intensity, maturity, consistency, texture and acidity or pH (Carić & Kaláb, 1999). In Egypt, Cheddar, *Ras* and *Karish* cheeses are most frequently used in the formulation of processed cheese. Common natural cheeses used in processed cheese formulation are as follows:

Cheddar cheese proved to be the most suitable and unproblematic ingredient in the manufacture of processed cheese. It has lower calcium content, compared to other hard cheeses, due to the acidification process taken place during production. Cheddar has ideal melting properties and difficult creaming ability. These two characteristics make Cheddar the first choice in the formulation of sliceable processed cheese recipes (Guinee 2009). Lipase-treated Cheddar was recommended to be used as a flavour enhancer for processed cheese (Kapoor & Metzger, 2004, Gustaw & Mleko, 2007).

***Ras* cheese** is an Egyptian hard cheese, similar to Caskawal cheese in body and flavour, made from cows' milk and is being extensively used for production of processed cheese (Abdel Hamid *et al*., 2000 a, b and c, El-Shibiny *et al*., 2007). Abdel Hamid *et al*. (2000a) produced processed cheese spreads using *Ras* cheese and various added emulsifying salts. In terms of organoleptic and structural attributes, the most acceptable processed cheese spreads could be produced using emulsifying salt mixture containing Na-pyrophosphate + Na-polyphosphate + Na-orthophosphate + Na-tripolyphosphate at ratio of 50:20:20:10, respectively.

***Karish* cheese** is an Egyptian soft cheese made from skim milk *via* acid coagulation, has been extensively used for the production of processed cheese. El-Shibiny *et al*. (2007) prepared low fat processed cheese spreads from mixture of fully ripened *Ras* and *Karish* cheeses at ratio of 2:3, respectively. In another trial, *Karish* was replaced by rennet cured prepared by rennet coagulation of ultrafiltered skim milk retentate (20% total solids). Results revealed that the colour and organoleptic attributes of low fat cheese spreads made with *Karish* cheese were inferior to those of full-fat or low-fat cheeses with added rennet curd. However, rennet curd containing cheese showed organoleptic scores close to those for full fat cheese.

Ultrafiltrated cheese contains, compared to traditional cheese, increased amount of whey proteins which make its processing to processed cheese difficult. This should be taken into account when used in processed cheese production. The application of ultrafiltrated cheese is recommended for the production of cheese spreads but not for the production of sliceable cheeses.

Rubin & Bjerre (1984) manufactured processed cheese using the cheese base product made from pasteurized whole milk by ultrafiltration or diafiltration. The authors recommended the use of such base at a ratio of 4:1 with ripe cheese in the production of processed cheese. At this ratio, processed cheese could be made from ultrafiltrated milk had less flavour and texture acceptability compared with the control cheese. Mixing ultrafiltered cheese base and matured Gouda cheese (at ratio of 3:7, respectively) in the production of processed cheese spreads gave cheese with more acceptable physicochemical, organoleptic and textural characteristics similar to those of the control cheese (Kycia *et al*., 2006). However, the addition of cheese base at 50% tended to lower pH and protein content of spreads as well as unfavourably increases the hardness of the cheeses.

Milk proteins

Milk proteins have significant nutritional and functional impact in the manufacture of processed cheese. Many commercial ingredients of milk proteins and their derivatives (either from casein or whey proteins) are extensively used in the production of natural processed cheese and cheese analogue. The following products are among the most important ingredients implicated in the production of processed cheese and cheese analogue.

Skim milk powder particularly that prepared *via* spray drying is an important ingredient for processed cheese formulation. It contains approximately 35% protein and 48% lactose. When used in processed cheese preparations, the resultant cheese would have many adventurous over other cheese made with no added skim milk powder including, better creaming properties and consistency, improved stability and spreadability and fresher and more neutral taste (Carić & Kaláb, 1999).

Whey proteins have many interesting technological properties including foam formation, emulsifying capacity and water binding ability. The highly functional whey proteins available in the market are existed as concentrates or isolates, and both can be used in processed cheese preparations. The total protein content in whey protein concentrates and isolates ranged from 30 to 38% (Jiménez *et al*., 2012) and from 90 to 95% (Etzel, 2004), respectively. Whey protein isolates are commercially available as pure β-lactoglobuline or pure α-lactalbumine. Depending on desired type of cheese and functionality, whey protein isolates and concentrates are usually added to processed cheese blends at rates ranged from 0.3 up to 2% (calculated on the finished product). The incorporation of whey proteins in processed cheese blends improves creaming and melting properties of the final product (Solowiej *et al*., 2010). In the manufacture of processed cheese spreads, Pinto *et al*. (2007) replaced partially Cheddar cheese solids by whey protein concentrate (38% protein) solids at levels of 1.5, 3.0 and 4.5%. Body and texture scores given to cheese increased as the concentration of whey protein concentrate increased. Results also indicated that cheese with good meltability properties was obtained from blends contained 4.5% whey protein concentrate.

Rennet casein is prepared from skim milk *via* rennet coagulation. It is used for the manufacture of processed cheese as a substitute for natural cheese. Rennet casein can build up a cheese like structure as it contains high ratio of intact protein. Consequently, it is suitable for the production of products which should show elasticity, good re-melt, or stringiness such as processed cheese blocks and slices. Rennet casein is neutral in taste and cannot interfere with the flavouring agents incorporated in processed cheese recipe (Abou El Nour *et al*., 1996).

Acid casein is prepared *via* acid coagulation of skim milk. This type of coagulation is accompanied by the dissolution of the calcium out of the sub-micelles leading to the complete disintegration of casein network structure. At functional level, acid casein can act naturally as fat emulsifier. Unlike rennet casein, and due to the loss of important amount of calcium in the whey, acid casein is not able to rebuild up the typical cheese structure and can be thus used as a filling agent in the processed cheese analogue recipes. Acid casein has shown the ability to improve meltability properties of cheese analogs particularly with increasing pH values of cheese blend from 5.0 to 7.0 (Solowiej *et al*., 200 8).

Calcium caseinates are extensively used in the manufacture of processed cheese analogues. Cheese containing calcium caseinate has been shown to have high pH, soft texture, high degree of casein dissociation and low degree of fat emulsification. In addition, calcium caseinate affects inversely cheese firmness and melting ability (Cavalier-Salou & Cheftel, 1991).

Sodium caseinate has no ability to form micelle-like structure but able to form gel structure commonly known for most proteins. It has an excellent capacity to emulsify fat and to develop products with firm consistency and high pH (Cavalier-Salou & Cheftel, 1991). Sodium caseinate is usually used as fillers like casein particularly in cheese analogues.

Emulsifying salts

Emulsifying salts are considered to be the most important ingredient in processed cheese blend. The amount, type and composition of emulsifying salts can significantly affect pH, textural, microstructural, melting, functional and sensorial properties of processed cheese (Glenn, *et al*., 2003, Acharya & Mistry, 2005). Two main groups of emulsifying salts (citrate-based and phosphate-based salts) are commonly used for the manufacture of processed cheeses.

Citrate-based salts

Citric acid is tri-basic acid, contains 3 acidic hydrogen atoms, which can produce 3 probabilities of salt formation according to the number of neutralized acidic hydrogen atoms. The replacement of one, two and three acidic hydrogen atoms with a cation Na^+ results in the formation of mono-, di- and tri-sodium citrate, respectively. Indeed, citrate-based salts were the first emulsifiers used in processed cheese manufacture (Zehren & Nusbaum, 1992). Among citrate salts, tri-sodium citrate is one of the most important emulsifying salts in processed cheese manufacture and is often used for the manufacture of slices (Zehren & Nusbaum, 1992). On the other hand, other citrate salts such as potassium or ammonium citrates were evaluated for the production of low-sodium processed cheese (Gupta *et al*., 1984). The high levels of these salts tended to produce bitterness in the final cheese.

Phosphate based salts

The majority of commercial emulsifying salts currently used for the manufacture of processed cheese are based on phosphate salts. Phosphoric acid salts can be divided into two main groups: 1) mono-phosphates (orthophosphates) and 2) condensed polyphosphates which can be further subdivided into (i) polyphosphates, (ii) metaphosphates - rings and (iii) condensed phosphates - rings with chains and branches.

One of the earliest study to understand the role of phosphate based emulsifying salts in processed cheese was that made by Gupta *et al*. (1984) who evaluated seventeen emulsifier salts (belong to di-potassium phosphate, and tetra-potassium pyro-phosphate) for their emulsifying capacity in experimental processed cheese by the same criteria for the commercial samples including textural and flavour properties of the resultant cheeses. Results revealed that each tested emulsifying salt contributed differently to properties of processed cheese and it should be useful to develop blends of emulsifier salts to produce processed cheeses possessing with a wide range of physical properties.

Abdel Hamid *et al*. (2000c) tested three mixtures of emulsifying salts including, (1) Na-pyrophosphate + Na-polyphosphate, (2) Na-pyrophosphate + Na-polyphosphate + Na-tripolyphosphate and (3) Na-pyrophosphate + Na-polyphosphate + Na-orthophosphate + Na-tripolyphosphate in the production of processed cheese spreads using 2 month old acidified *Ras* cheese. Results revealed that cheese pH values tended to decrease with increasing polyphosphate ratio in the salt mixture and with prolonging the storage period. The soluble nitrogen content increased with increasing the pyrophosphate ratio in the emulsifying mixture. Emulsifying salts appeared to affect the buffering capacity of cheeses in a salt mixture depending manner. In conclusion, the authors reported that emulsifying mixtures (1) 70+30%, (2) 60+30+10% and (3) 50+20+20+ 10% can be recommended for producing the spreadable processed *Ras* cheese with acceptable chemical properties. Chen & Liu (2012) investigated the effect of different types and concentrations of emulsifying salts (trisodium citrate, tetra-sodium pyrophosphate, sodium tripolyphosphate, sodium hexametaphosphate and disodium orthophosphate) on the physicochemical properties of processed cheese made from Mozzarella cheese. Results revealed that cheese hardness, degree of casein dissociation, and pH increased as the concentration of emulsifying salts increased. The fat particle size (4.68 μm) of processed cheese made with sodium hexametaphosphate was the largest as compared to cheeses with other emulsifiers. Cheeses made with added phosphate salts were darker than that prepared with tri-sodium citrate. The nuclear magnetic resonance measurement indicated that the moisture in cheese was mainly bound water combined with the fat globule.

In addition, Shi*ras*hoji *et al*. (2010) studied the effect of the concentration of hexametaphosphate (0.25–2.75%) on the textural and rheological properties of pasteurized processed Cheddar cheese. The meltability of processed cheese, made with different concentrations of hexametaphosphate (from 0.25 to 2.75%) decreased with an increase in the concentration of emulsifying salt, while hardness increased. The insoluble calcium and total and insoluble phosphorus contents increased as concentration of hexametaphosphate increased.

Orthophosphates include monosodium dihydrogen phosphate, disodium hydrogen phosphate and trisodium phosphate. The corresponding potassium salts of previous compounds can be used to reduce sodium content of the resultant processed cheese. Due to their excellent buffering capacity, monosodium and trisodium phosphates are usually used for the manufacture of processed cheese mainly to bring cheese pH to the correct value (Zehren & Nusbaum, 1992).

Long-chain polyphosphates, incorrectly known as hexametaphosphates, are not used in processed cheese manufacture. However sodium hexametaphosphates, a member belongs to this category has potential application in food industry particularly in processed meat sector (Molins 1991). The application of hexametaphosphates in processed cheese production resulted in cheese with low pH and poor textural and structural attributes especially melting characteristic (Gupta *et al*., 1984, Carić *et al*., 1985). However, elevation cheese pH can significantly improve meltability of processed cheese made with hexametaphosphates (Lu *et al*., 2007). Meanwhile, Shi*ras*hoji *et al*. (2006b) reported that the incorporation of sodium hexametaphosphate in sliced processed cheese recipe resulted in significant reduction in pH to 5.3 as compared with cheeses with added citrate, orthophosphate or pyrophosphate salts where pH ranged from 5.9 to 6.0. Also, sodium hexametaphosphate had negative impact on cheese texture due to the formation of crumbly and mushy defects in the resultant cheese.

Antimicrobial activity of polyphosphate salts

The food-grade long-chain polyphosphate food grade formulations (JOHA HBS sodium polyphosphate glassy, HBS-l and HBS-9) have shown antibacterial activity against wide range of microorganisms including spore formers (*Clostridium tyrobutyricum* and *Bacillus cereus*), Gram positive bacteria (*Staphylococcus aureus* and *Listeria monocytogenes*), Gram-negative bacteria (*Samlonella typhimurium* and *Escherichia coli*) and yeasts (*Saccharomyces cerivisiae*). Lössrier *et al*. (1997) evaluated the antibacterial activity of polyphosphate formulations (JOHA HBS, HBS-l and HBS-9) against a panel of 21 Gram-positive and 11 Gram-negative bacteria. Results revealed that 17 of 21 of the Gram-positives and yeasts could be inhibited by concentration ranged from 0.05 to 0.3% of tested polyphosphates but none of the tested Gram-negatives were affected. The *Staphylococcus aureus* could be inhibited at 0.05%, while *Saccharomyces cerivisiae* showed to be inhibited at 0.3% of tested polyphosphates. Maier *et al*. (1999) studied the mechanism of action by which polyphosphate can exert growth inhibition, morphological changes and lysis of *Bacillus cereus*. Results indicated that at a concentration of 0.1% or higher, polyphosphate had a bacteriocidal effect on log-phase cells, in which it induced rapid lysis and reductions in viable cell counts of up to 3 log units. Also, a concentration of 0.1% inhibited spore germination and a higher concentration (1.0%) was even sporocidal. This antimicrobial activity was completely stopped by the addition of divalent metal ions (Mg^{+2} and Ca^{+2}) which can immediately stop lysis and reinitiate rapid cell division and multiplication. The sub-lethal concentration (0.05%) of polyphosphate appeared to cause morphological changes in *Bacillus cereus* leading to the formation of elongated cells (approximately 70 µm length). The complete lack of septum formation within the filaments was confirmed by electron microscopy examination. Indeed, similar mechanisms of action could be postulated for other microorganisms including, *Clostridium tyrobutyricum*, *Staphylococcus aureus* and *Listeria monocytogenes* (Lee *et al*., 1994, Zaika *et al*., 1997, Lössrier *et al*., 1997).

The antibacterial activity of polyphosphates has been proven in processed cheese by Lössrier *et al*. (1997). Two different cheese spread formulations were fortified with 0.1% to 1.0% polyphosphates, inoculated with 5×10^5 (blend A) or 2.5×10^6 (blend B) *Clostridium tyrobutyricum* spores per gram and incubated at 35°C for up to 7 weeks. Determination of viable cell counts was carried out at days 1, 9, 19 and 49 (cheese blend A) and 8, 16, 27, 35 and 50 (cheese blend B). While, 0.1% polyphosphate had little effect, higher concentrations were increasingly inhibitory to spore germination and gas formation. With 0.5% polyphosphate, onset of growth was delayed for about 3 weeks in cheese blend A, while this concentration was able to inhibit the organism in cheese blend B. The authors concluded that 0.5% polyphosphate may be sufficient to control *Clostridium tyrobutyricum* growth under "normal" conditions, where initial spore counts are rather low, and storage temperatures are usually at or below 20°C. However, a concentration of 1.0% polyphosphate resulted in a complete inhibition of *Clostridia* growth, indicating the usefulness of these polyphosphates for prevention of butyric blowing in pasteurized processed cheese spreads.

Principle activities of emulsifier salts

Principle activities of emulsifier salts in processed cheese (Lucey *et al*., 2011) are:

Calcium binding and ion exchange capacity: This is accomplished through the ability to form 1) a complex with calcium present in the serum phase or removed from casein (Shi*ras*hoji *et al*., 2006a) and 2) cross-links among the network of the processed cheese leading to tightness of cheese structure (Zehren & Nusbaum, 1992),

The pH adjustment and buffering capacity: The final pH and buffering capacity of processed cheese are principally determined by the type and amount of used emulsifying salts. The emulsifying salts are commonly basic in nature and used to rise pH of cheese blends from 5.2 (common pH of natural cheeses used in processed cheese manufacture) to approximately 5.5-6.0 (pH range of final processed cheese) (Carić & Kaláb, 1999). This pH modification is important to improve configuration and solubility of casein and the ability of the emulsifying salts to bind calcium molecules, leading to the formation of processed cheese with better textural and microstructural properties. On the other hand, processed cheese with high buffering capacity can tolerate pH changes that take place during storage. Emulsifying salts can significantly improve cheese buffering capacity to avoid adverse effects of pH changes on cheese textural and microstructural characteristics.

Casein dispersion and hydration: Casein can easily disperse during cooking process of processed cheese due to heat and mechanical energies applied to the cheese mass (Glenn *et al*., 2003). The dispersed proteins are helpful in fat emulsification process by coating the surfaces of dispersed free fat globules (Guinee *et al*., 2004). The dispersion of casein is mainly attributed to emulsifying salts which can bind calcium ions and increase cheese pH leading to the increased charge repulsion between caseins (Shi*ras*hoji *et al*., 2006a).

Fat emulsification: Is another important function of emulsifying salts which is based on their ability to emulsify fat within the cheese matrix to avoid its separation causing defect known as oiling off. Cheese made with no added emulsifying salts would have rough texture and considerable oiling-off defect (Lucey *et al*., 2011).

Structure formation: The dispersion of casein due to addition of emulsifying salts and heat treatment during cooking of processed cheese are both capable of destroying the structure of the original cheese and predisposing conditions for the formation of new structure with unique characteristics upon cooling cheese. Emulsifying salts can significantly affect cheese structure and the correct amount should be added depending on age of original cheese and type of emulsifier. The over emulsification is usually accompanied by an increase in fat surface area covered by casein leading to the formation of hard processed cheese (Shimp, 1985) , However, low concentration of emulsifying salts (under- emulsification) would accompany by poor casein dispersion and fat emulsification leading to creaming defect (Shi*ras*hoji *et al.,* 2006a).

Antimicrobial activity: Most emulsifying salts commonly used for processed cheese manufacture possess antimicrobial activity to some extent. Citrate salts have been shown to have antifungal activity (Davidson *et al*., 2002), whereas pyrophosphates and polyphosphates have antimicrobial activity against Gram-positive bacteria (Tanaka *et al*., 1986). The antimicrobial activity of both citrate and phosphate emulsifiying salts has been attribute to their ability to chelate metal ions (Lössrier *et al*., 1997, Davidson *et al*., 2002).

Crystal formation: Emulsifying salts, under certain circumstances, can be crystallised with cheese calcium. The formed crystals are distributed mainly throughout the cheese body with little appear on the cheese surface. The possible factors that may contribute to crystal formation by emulsifying salts include the excessive use and/or the presence of un-dissolved emulsifying salt along with high pH of cheese and/or high cooking temperature (Lucey *et al*., 2011). The formation of crystals depends mainly on the type of emulsifying salts used and reported to be in the order citrate > orthophosphate > polyphosphate (Scharpf & Kichline, 1968 and 1969).

Emulsifier selection

Selection of the proper emulsifier mixture, concentration and type of emulsifying salts, depends on many factors including,

Those related to cheese that will be used in processed cheese manufacture such as its age and composition (Hassan *et al.*, 2004),

Those related to the resultant processed cheese, including the desired composition, characteristics and type of cheese (blocks, slices, spread, etc…. (Lucey *et al.,* 2011),

Other factors including price of emulsifying salts and cooking condition (time and temperature) (Lucey *et al*., 2011).

Processed cheese analogue

The concept of cheese substitution or imitation describes the process that tends to the production of products 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). Indeed, food legislation authorities do not allow the application of vegetable proteins or oils in the manufacture of natural processed cheese. However, these substitutes are allowed for the manufacture of cheese substitutes, imitates or analogues and should be mentioned clearly on the packaging materials. Substitute or imitated cheese should not be nutritionally inferior to the original cheese. However, in many circumstances, substitutes or imitation lead to the formation of cheese with health promoting and nutritional advantages as compared with the original cheese, for example, cheeses with higher unsaturated fatty acids, no cholesterol and low calorie (Mc Carthy, 1990). Processed cheese analogue containing soybean paste is considered to be a functional food (health improving product) due to the incorporation of isoflavonoides and polyunsaturated fatty acids in cheese as well as proteins which are known to have cholesterol decreasing effect (Teixeira *et al*., 2000).

Substitute/ imitated cheese products are classified into three categories: (a) analogue cheeses, (b) filled cheeses and (c) tofu-based cheese origin (Fox *et al*., 2000). Analogue cheese can be further classified, based on the ingredients used and the manufacturing procedures, into 3 categories (Fox *et al*., 2000) as shown in Figure (1):

1- **Dairy analogues products** are made from blends containing casein, caseinate and butter oil. They are not produced in large quantities because their cost is relatively high,

2- **Partial dairy products** include products containing mainly vegetable oils (such as oils from soya bean, palm or rapeseed, and their hydrogenated equivalents) and dairy based proteins (such as rennet casein or caseinate), and

3- **Nondairy analogues** include products in which both fat and protein are vegetable derived.

In addition to nutritional and health advantages, substitute/ imitated cheese products have many important technological and economical impacts due to their:

1- Implication in the production of wide variety of fat foods in which processed cheese is used as one of the functional ingredient,

2- Low cost,

3- Ability to offer diverse functionality range (e.g. flowability, melt resistance, shredability, etc), and

4- Ability to be designed to meet special dietary needs through changes in formulation (such as low fat, calorie and cholesterol and/or vitamin, fiber or mineral-enriched products).

Vegetable proteins

The main sources for vegetable proteins used in the formulation of processed cheese analogues are those from legumes particularly soy bean, lupine and chickpeas (Ahmed *et al*., 1995). Legume proteins are commercially available in concentrate and isolate forms with a protein content of about 70 and 90 %, respectively (Tiwari *et al*., 2011). In the hydrolysates, the enzymatic hydrolysis of the legume proteins leads to the formation of a wide product variety of different functional properties. In addition to the functional properties also the nutritional aspects play a great role for the selection of the protein source.

Soybean protein isolate was one of the earliest vegetable proteins used for partial or total replacement of caseinate for the formulation of processed cheese analogue (Ahmed *et al*., 1995). The low cost of this product makes it one of the important substitutes for milk proteins (El-Sayed *et al*., 1991). In comparison to milk proteins, soy proteins are larger in molecular size and do not have phosphate residues in their structure (Brander *et al*., 1985). Consequently, main characteristics of soy proteins (emulsifying capacity, heat coagulability and solubility) are different from those for milk proteins. Treatments with enzymes (e.g., alcalase, trypsin, etc...) are the common practice to improve previous functionalities of soy proteins (Kamata *et al.,* 1993).

El-Sayed (1997) assessed to replace skim milk powder (at levels of 5, 10 and 15%) in processed cheese blends by three plant protein isolates (from chickpea, sesame and peanut). The author also evaluated some functional properties of plant protein isolates including emulsion activity, water absorption capacity and water-oil absorption index. Results revealed that emulsion activity index of different isolates were in the order: sesame < chickpea < peanut. Water absorption capacity of the tested protein isolates ranged from 196 to 329 g water/100 g protein. The water-oil absorption index for chickpea, peanut and sesame protein isolates were 7.6, 0.48 and 0.90, respectively. Changes in chemical composition of cheeses containing different levels of plant protein isolates occurred only in total nitrogen content, while, the other constituents such as total solids, fat and salt were not affected. Sensory evaluation of the processed cheese revealed that total score gradually decreased with increasing plant-protein isolate levels up to 15% but still preferable for the consumer. This decrease in the total score regards the flavour but not to the colour or body and texture.

Awad *et al.* (2014) used lupine paste to substitute 25, 50, 75 and 100% of cheese in base formula of processed cheese analogue. Chemical composition and physical and sensory properties of cheese were analysed during 3 months of storage at 5 ±2°C. The authors also evaluated the histopathological effect of lupine-containing cheese in alloxan diabetic albino rats. The incorporation of lupine paste in processed cheese analogue increased ash and protein contents while meltability and penetration values of resultant products were found to decrease. The addition of lupine past increased the oil index and firmness of the resultant cheese. Body and texture scores of lupines-containing cheeses were the mostly affected by increasing lupine ratio in formula without significant difference up to 50% substitution of the cheese base. On the other hand, rats fed on cheese-containing lupine showed marked improvements in langerhans islands structure and lowered blood glucose as compared to rats fed on basil diet (negative control).

Vegetable oils

The replacement of milk fat with vegetable oils and fats in processed milk products has gained increased popularity in the early 1990s due to increased public's awareness of the dangers of cholesterol found in animal fats (Kong-Chan *et al*., 1991). The main vegetable oils and fats used for replacing milk fat in processed cheese analogue recipes were those extracted from soy bean, sunflower, palm and coconut. The selection of vegetable fat source is based mainly on availability, price and stability against oxidation and temperature.

Indeed, different procedures have been developed to incorporate hydrogenated vegetable oil (from soya bean, peanut, palm kernel, cotton seed, coconut or corn) in processed cheese analogue recipes (Brander *et al*., 1985, Arellano-Gomez *et al*., 1996, Lobato-Calleros & Vernon-Carter, 1998). The application of vegetable fats can give distinct structural characteristics to cheese that make it more suitable for certain applications (Anonymous 1989). For example, the incorporation of soybean fat into cheese blend conferred hardness and adhesiveness to the resultant cheese analogues, but led to decrease their cohesiveness and springiness. However, the opposite effects were recorded for cheese in which soybean oil was added instead of milk fat (Lobato-Calleros *et al*., 1997). The formulation of cheese analogues using blends of different vegetable fats resulted in cheese in which the physicochemical and textural characteristics were an average of that provided by each fat alone (Lobato-Calleros *et al*., 1997). In Egypt, palm oil is still considered to be the first choice to replace milk fat in the formulation of processed cheese analogue particularly in block-type cheeses. However, the incorporation of palm oil in the production of processed cheese spread caused adverse effects on the sensorial characteristics of the final cheese (Salam 1988 a & b, Azzam 2007, Calvo *et al*., 2007).

Healthier processed cheese

Processed cheese can be re-designed by incorporating untraditional ingredients with potential biological activity to exert specific benefits beyond its nutritious value. Various nutritive molecules have been incorporated in blends used for processed cheese manufacture including, minerals, vitamins, fibers and biologically active molecules and oils.

Iron. Although milk and its products contribute significantly to human health by providing our bodies with high nutritive components including, protein, fat, minerals and vitamins but could not provide iron to human diets. Zhang & Mahoney (1991) fortified processed cheese with Fe-casein, Fe-whey protein, or ferric chloride to final concentration of 40 mg iron/kg cheese. The quality of the processed cheese was determined by thiobarbituric acid assay and taste panel evaluation. Thiobarbituric acid numbers were slightly lower in the unfortified cheese. A taste panel of 94 subjects did not detect any differences in oxidized off-flavour or cheese flavour among cheeses stored up to 3 months. Iron-fortified and unfortified cheeses had similar hedonic scores to the flavour, texture and overall quality.

Branched chain amino acids. Patients with advanced liver disease are generally characterized by the presence of low levels of circulating branched chain amino acids (BCAAs) (Mesejo *et al*., 2008). In an attempt to enrich in BCAAs, El-Shazly *et al*. (2010) used a protein substitution technique to synthesize a new processed cheese as a dairy source rich in BCAAs, with low phenylalanine content. A commercial phenylalanine-free milk formula was used for the replacement of cheese proteins at the rate of 2.5%, 5%, 10%. L-Phenylalanine was selected to induce hepatic and brain affections in Begg Albino strain c (BALB/c) mice model. Results revealed that animals fed on 10% protein substitution showed the highest content of BCAAs along with least phenylalanine content as well as a remarkable improvement in histopathological findings of both liver and brain tissues.

Microalgae. In an attempt to re-formulate processed cheese analogue, Mohamed *et al*. (2013) incorporated the *Chlorella vulgaris* (microalgae recognized as a rich source of protein, fatty acids, fiber, ash and essential vitamins and minerals) in blends used for processed cheese manufactures. This microalgae has health benefits including, assisting disorders such as gastric ulcers, wounds, constipation, anemia and hypertension and possess immune-modulating and anticancer properties. Cheese analogue trials with *C. vulgaris* biomass at levels 1, 2 and 3% were evaluated for chemical, physical and sensory properties during three months of cold storage. Results revealed that cheeses containing the microalgae were richer in the protein, carbohydrates and fiber contents than the control samples. On the other hand, addition of *Chlorella* biomass to the cheese gave products higher firmness and stronger network leading to lower oiling off and meltability values than the control. The sensory evaluation indicated that addition of 2% *C. vulgaris* did not adversely affect the overall acceptability of the resultant cheese which encourages the addition of untraditional additive for the production of healthier cheese.

Vitamins. Fortification of processed cheese with vitamins is another way to produce functional dairy products with improved nutritional value and potential ability to deliver vitamins to certain individuals especially children and elderly. The majority of attempts dealing with vitamin fortification were interested in the addition of vitamin D to dairy products. Vitamin D, fat-soluble vitamin exists in two forms as D_2 and D_3, has important health benefits and its deficiency can cause many health risks including, cancer, cardiovascular disease and severe asthma in children. Also, vitamin D is crucial for healthy bone development, maintenance of bone density and bone strength, and prevention of osteoporosis (softening of the bones in adults) (Johnson *et al.*, 2005). The earlier attempt to fortify processed cheese with vitamin D was conducted by Upreti *et al.* (2002). In that study, pasteurized processed cheeses fortified with commercial water- or fat-dispersible forms of vitamin D_3 at a level of 100 IU per serving (28 g) were manufactured and stored for 9 months at 21 to 29°C and 4 to 6°C. There was no loss of vitamin during storage of the fortified cheeses stored at either temperature range. However, a loss of 25-30% of the vitamin was recorded after heating cheeses at 232°C for 5 min. Also, vitamin D_3 fortification did not impart any off flavours to the fortified cheeses. There were no differences between the water and fat-dispersible forms of the vitamin in the parameters measured in fortified cheeses including chemical composition and vitamin distribution within cheese matrix. In 2005, Johnson *et al.* conducted two studies to determine the effect of vitamin D-fortified cheese on vitamin D status and the bioavailability of vitamin D in cheese. The first study was conducted to determine the impact of daily consumption of vitamin D_3 (600 IU/d)-fortified processed cheese for 2 months on serum 25-hydroxyvitamin D, parathyroid hormone and osteocalcin concentrations among 100 older (≥ 60 year) men and women. Participants were randomized to receive vitamin D-fortified cheese, non-fortified cheese, or no cheese. The serum levels of 25-hydroxyvitamin D, parathyroid hormone and osteocalcin were measured at the beginning and end of the studyt. Results revealed that the vitamin D-fortified cheese group had a greater decrease in 25-hydroxyvitamin D than other groups, due to higher baseline 25-hydroxyvitamin D. The second study was conducted to determine whether the bioavailability of vitamin D_2 in cheese (delivering 5880 IU of vitamin D_2/56.7-g serving) and water (delivering 32,750 IU/250 mL) is similar and whether absorption differs between younger and older adults. For this purpose, 2 groups of 4 participants each (younger and older group) have been designed to receive single acute feedings of either vitamin D_2-fortified cheese or water. Serial blood measurements were taken over 24 h following the acute feeding and results revealed plasma concentration of vitamin D in younger (23 to that 50 years) and older (72 to 84 years) adults was similar, and vitamin D_2 was absorbed more efficiently from cheese than from water. The authors concluded that vitamin D in fortified process cheese was bioavailable, and that young and older adults had similar absorption rate. In older individuals, the consumption of 600 IU of vitamin D_3 daily from cheese for 2 months was insufficient to increase serum 25-hydroxyvitamin D with limited sunlight exposure.

Inulin, as a soluble dietary fiber, could be successfully incorporated in processed cheese spread formulation to enhance its functionality and nutritive value. Giri *et al.* (2014a) studied the effect of inulin (0, 4, 6 and 8 %) on textural and melting properties of the processed cheese spread. In general, as the levels of inulin increased, cheese firmness and work shear increased, while the stickiness and work of adhesion decreased.

The hypocholesterolemic effect of inulin containing processed cheese spread has been evaluated by Giri *et al.* (2015) using rat model. In that study, 4 animal groups were designed including, group 1 (control) fed on a synthetic diet, whereas groups 2, 3 and 4 fed on a cholesterol-enriched diet for 30 days. Thereafter, groups 2, 3 and 4 were, respectively, fed with synthetic diet, the control cheese spread and inulin (6%) containing processed cheese spread for 30 days. Results revealed that feeding animals with cheese containing inulin resulted in decrease in serum total, low and very low density lipoproteins cholesterol, and atherogenic index as well as significant reduction in liver cholesterol and triglycerides contents as compared to other groups. It was also reported that feeding on cholesterol-enriched diet correlated with increased liver, spleen, and heart weights, whereas feeding with inulin containing cheese led to reduction in weight of those organs due to reduction in deposition of triglycerides and cholesterol.

Phytosterols, plant steroids similar to cholesterol with potential hypocholesterolemic effect, are other bioactive molecules which could be integrated in processed cheese formulation to enhance its functionality. The addition of phytosterols has been found to affect textural attributes of processed cheese spread. The inclusion of 3% and 4% of phytosterols in cheese blends increased the firmness and work of shear of the resultant cheese as compared with no added phytosterols (Giri *et al*., 2014b).

Rice bran. A functional processed cheese containing rice bran, source of dietary fibers and bioactive photochemicals, has been developed by El-Shibiny *et al*. (2013). The authors studied the effect of adding 2, 4 and 6 % rice bran to processed cheese spread blend on the chemical composition, microbiological, oiling off, colour and texture profile of the resultant cheese. Generally, addition of 4 and 6% rice bran resulted in remarkable and significant adverse effects on the most of the studied characters. However, no significant differences in colour attributes, oiling off and sensory properties were found between cheese with added 2% rice bran and the control. The authors recommended the addition of 2% rice bran in processed cheese spread formulation to produce functional product with a decreased production cost. Indeed, the addition of rice bran would improve the nutritive value and health attributes of processed cheese since the resultant cheese contains several bioactive compounds such as phenolic compounds and fiber.

Cholesterol-reduced processed cheese spread was made by cross-linking β-cyclodextrin. This treatment led to removal of 91.5% of cholesterol. The composition of cholesterol-reduced cheese spread was similar to that of the control cheese. Cholesterol-reduced cheese had significantly higher total free amino acids content and also higher gumminess, brittleness, yellowness and elasticity scores over all storage periods than those in the control. However, processed flavour and slimy texture were significantly lower in cholesterol-reduced cheese spread (SooYun *et al*., 2009).

Low-sodium processed cheese spread was made from ultrafiltered Edam cheese (i.e. the brine was prepared from a mixture of NaCI and KCI at a ratio of 1:1). The low-sodium processed cheese had low meltability, high oiling off and high sensory score as compared with the control cheese (Amer *et al*., 2010).

CONCLUSION

Processed cheese manufacture is an effective strategy to extend the shelf-life of natural cheese, recycle of defected cheese and to develop cheeses with distinct texture, flavour and functional properties. Processed cheese is mainly composed of natural cheese, emulsifying salts, flavouring agents, salt and water. Among ingredients, emulsifying salts have major role in determining pH, textural, microstructural, melting, functional and sensorial properties of the resultant cheese. The consumption of processed cheese has been increased steadily in some regions in the world especially in Middle East and Asia. Due to the increased public's awareness of the dangers of cholesterol found in animal fats and the desire to reduce costs related to production, processed cheese analogous has gained increased popularity. It can be produced by partial or whole replacement of milk constituents (fat, protein or both) by non-milk based alternatives, principally of vegetable origin. This concept has also initiated the research to incorporate unusual ingredients into processed cheese blends in order to develop wide varieties of products with diverse applications. For example, processed cheese has a great ability to be used as a functional food by incorporating the desired functional molecules (minerals, vitamins, proteins, fats, fibers, etc...) in the cheese blend. Its composition (high total solid content and buffering capacity) can offer an effective protection for the target molecules against adverse conditions in human gastrointestinal tract. Consequently, it would be expected to see more and more functional processed cheese with potential health promoting activity in the market in the nearest future.

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الجبن المعامل: أساسيات وإمكانيته لتطوير منتجات أفضل صحياً

السيد علي، إيمان الدخاخني، خالد السعدني، نصرة دبور، إيهاب خضر
معمل الأغذية الوظيفية والأغذية العلاجية، قسم علوم وتقنية الألبان
كلية الزراعة (الشاطبي)- جامعة الإسكندرية، الإسكندرية، مصر

يحظى الجبن المعامل بقبول كبير لدى المستهلكين نظراً لتنوع مكوناته وكذلك لتعدد استخداماته مما يسمح بإنتاج العديد من المنتجات المتميزة بطعوم وتركيب وخواص وظيفية مختلفة. وفي الوقت الحاضر تم الاهتمام بالجبن المعامل كغذاء واعد قادر على إمداد الجسم بالعديد من المواد والعناصر الغذائية اللازمة. ويلقي هذا الاستعراض المرجعي الضوء على الموضوعات التالية: تطور إنتاج واستهلاك الجبن المعامل في مصر، المكونات الأساسية اللازمة لصناعة الجبن المعامل (الأجبان الطبيعية، بروتينات اللبن، أملاح الاستحلاب) علاوة على إلقاء الضوء على الجبن المعامل المشابه (من حيث تقسيمه، تركيبه، أهم مصادر البروتينات والدهون الداخله في صناعته). كما يشمل هذا الاستعراض المرجعي المحاولات السابقة والمنشورة في المراجع والتي تهدف إلى إنتاج جبن معامل وظيفي بإضافة بعض المواد النشطة حيوياً مثل الفيتامينات، الألياف الغذائية، الأنيولين، الاسترولات النباتية.