Food Research International 86 (2016) 93–102

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Review

Strategies to develop healthier processed cheeses: Reduction of sodium and fat contents and use of prebiotics

L.L. Ferrão [a], E.B. Silva [a], H.L.A. Silva [b], R. Silva [c], N. Mollakhalili [d], Daniel Granato [e], M.Q. Freitas [b], M.C. Silva [c], R.S.L. Raices [c], M.C. Padilha [f], P.B. Zacarchenco [g], M.I.M.J. Barbosa [a], A.M. Mortazavian [d], A.G. Cruz [c,*]

[a] Universidade Federal Rural do Rio de Janeiro (UFRRJ), Departamento de Tecnologia de Alimentos (DTA), Seropédica, 23890-000, Rio de Janeiro, Brazil
[b] Universidade Federal Fluminense (UFF), Faculdade de Medicina Veterinária, 24230-340 Niterói, Rio de Janeiro, Brazil
[c] Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ), Departamento de Alimentos, Rua Senador Furtado, 171, 20270-021, Rio de Janeiro, Maracanã, Brazil
[d] Shahid Beheshti University of Medical Sciences, National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Department of Food Science and Technology, 19395-4741, Tehran, Iran
[e] Universidade Estadual de Ponta Grossa (UEPG), Departamento de Engenharia de Alimentos, Av. Carlos Cavalcanti, 4748, 84030-900 Ponta Grossa, Brazil
[f] Universidade Federal do Rio de Janeiro, Instituto de Química (IQ), Laboratório de Apoio ao Desenvolvimento Tecnológico (LADETEC), 21949-900, Rio de Janeiro, Brazil
[g] Instituto de Tecnologia de Alimentos (ITAL), Centro de Pesquisa e Desenvolvimento de Laticínios (TECNOLAT), Avenida Brasil, 2880, Jardim Chapadão, 13070-178 Campinas, SP, Brazil

ARTICLE INFO

Article history:
Received 10 January 2016
Received in revised form 24 April 2016
Accepted 25 April 2016
Available online 30 April 2016

Keywords:
Food development
Processed cheese
Sodium
Fat
Prebiotics

ABSTRACT

Dairy industry has sought strategies for obtaining products that meet new market demands, focusing on foods of higher nutritional quality to be better options for consumers. In this competitive scenario, dairy foods have been developed to provide functional components and/or meet specific dietary needs, such as those observed in the setting of obesity and hypertension. Processed cheese, which originally has high-sodium and fat contents in its formulation, may also undergo a reformulation. In addition, nowadays, the addition of prebiotic ingredients into dairy products is a common technological practice to not only enhance their beneficial health effects but also to improve the final texture, replace fat components, and increase the fiber content. In the present review, we provide the state-of-the-art of the effects of fat and salt reduction and the positive impacts of adding prebiotics on the functional properties and sensory acceptance of processed cheeses.

Contents

1. Introduction

Recently, the use of different cheese types as food ingredients has increased due to the growth demands for ready meals (Guinee, Carić, & Kalab, 2004; Guinee & O'Callaghan, 2013). Processed cheese (PC) may be considered stable oil-in-water emulsions that are obtained from natural cheeses/dairy proteins and edible oils/fats with the addition of emulsifying agents and other dairy and non-dairy ingredients, which are subjected to heating and continuous mixing processes to homogenize and improve the texture of the final product (Hosseini-Parvar, Matia-Merino, & Golding, 2015; Tsujii &

* Corresponding author.
E-mail address: food@globo.com (A.G. Cruz).

http://dx.doi.org/10.1016/j.foodres.2016.04.034
0963-9969/

Shirotani, 2015). Processed cheese differs from conventional cheese since it is not obtained from traditional processes, which involve lactic fermentation of milk or direct acidification of milk using food grade organic acids. Besides the ingredients in the formulation, the physico-chemical, technological, and microbiological aspects can directly affect the properties of processed cheese (Davison et al., 1993; Merrill & Singh, 2014).

Regarding the U.S. Food and Drug Administration standards, only the products prepared using natural cheese and salts (≤3% w/w) with a certain level of moisture (<43% w/w) and fat contents (more than 47% w/w) can be categorized as processed cheese (Chang, 1979; Gliguem et al., 2009; Lee, Anema, & Klostermeyer, 2004). Processed cheese products not included in this categorization can be classified as processed cheese foods, processed cheese spreads or processed cheese analogs (Hanaei, Cuvelier, & Sieffermann, 2015; Sołowiej, Cheung, & Li-Chan, 2014). Processed cheese is available at the market under different technological forms, such as slices, cream and whole pieces (Guinee et al., 2004).

Different cheeses are foods with a high nutritive value which are suitable sources of calcium, phosphorus, and proteins, and their regular intake together with a balanced diet allied to healthy life habits confer some benefits, such as decreasing the lactose intolerance signs, protection against intestinal infections, lower risk of colon cancers, better bowel movements, among others (Davis, Blayney, & Guthrie, 2013; Gupta & Reuter, 1992). Processed cheeses are mainly applied as ingredients in prepared foods, namely pizzas, cheese burgers and sauces (Tamime, 2011). On the other hand, it is generally accepted that most of cheeses provide high levels of fats and sodium to the diet (Fouladkhah, Berlin, & Bruntz, 2015; Guinee & O'Callaghan, 2013). The equilibrium between maintaining the mentioned benefits in the food matrix and the necessities of the consumer market is an object that must be considered by the food industry, mainly when these products are consumed as ingredients in many types of processed cheeses.

Currently, the increased prevalence of non-communicable chronic diseases, especially obesity and hypertension has been recognized as a serious public health problem (Reeve & Magnusson, 2015; Robert-McComb, Bustamante-Ara, & Marroquin, 2014). Because of this, there is a trend that consumers are beginning to purchase products with reduced salt and fat, both for weight loss as for caring health.

Foods with low-fat content have been available to consumers for decades and constantly new products with similar properties are introduced into the market, making it possible that fat intake can be maintained within the recommended healthy limits (Lobato-Calleros et al., 2007; Nagao et al., 2003). The mechanical properties, textural aspect and the sensory acceptance by the consumers are the main factors that must be considered during the manufacture of reduced-fat products.

Salt (sodium chloride) has been considered as a food additive which enhances the human health either via killing or limiting the growth of food-borne pathogens and spoilage organisms (Ross, Morgan, & Hill, 2002). It is now recognized that the consumption of high levels of sodium may be a potential health hazard, so its reduction is gaining an extreme international attention (Cruz et al., 2011; Doyle & Glass, 2010). However, salt and sodium-containing ingredients are mainly added to processed cheese as emulsifying agents. Obviously, sodium salts are also added to enhance the flavor, decrease the water activity, thus avoiding the multiplication of microorganisms that can cause spoilage of the product, as illustrated in Fig. 1. When there is a decrease of the sodium salt levels in food, other food additives need to be added. These substances are intended to ensure food safety, flavor, overall quality and texture of the food (Taormina, 2010).

In order to reduce the intake of sodium and fat, different technological stages must be observed, including: data collection, finding standards and food types, increasing public consciousness in addition to monitoring and assessment. Promoting the food reformulation in the food industry is a challenge of this frame (Barr, 2010; Pérez-Cueto, et al., 2012). The food reformulation represents an alternative that food companies can perform to create a healthier product (Golan & Unnevehr, 2008; Uauy et al., 2009). These modifications include: limiting the addition of some ingredients, such as sodium salts, *trans*-fatty acids (TFA), saturated fatty acids (SFA) and sucrose, which are connected with negative health effects (when consumed at high doses) including obesity, diabetes, CHD and stroke (Kloss, Meyer, Graeve, & Vetter, 2015; Mozaffarian, Katan, Ascherio, Stampfer, & Willett, 2006; Walther, Schmid, Sieber, & Wehrmuller, 2008).

Another alternative for food companies is the use of prebiotic ingredients in the manufacture of dairy products, including cheeses. Prebiotics are short-chain carbohydrates with a degree of polymerization between two and about sixty that cannot be metabolized (enzymatically) by humans (Al-Sheraji et al., 2013). The development of functional foods, mainly those in the prebiotic category, plays an important role in modern food industry, especially in the dairy industry (Alves et al., 2013; Cruz et al., 2013; Morais, Morais, Cruz, & Bolini, 2014). In the GI tract, prebiotics selectively stimulate indigenous beneficial bacteria, such as bifidobacteria and lactobacilli. By changing the composition and functionality of the microbiota, prebiotics play a role not only by facilitating competitive exclusion of potential pathogens, but also in modulating the immune system and enhancing host defenses (Saulnier, Spinler, Gibson, & Versalovic, 2009).

Finally, taking into account by one hand the high demand for processed cheese and the consumers' awareness about the effects of salt and fat consumption and by the other hand the popularity and efficacy of adding prebiotic compounds to food products, this review article is addressed to give an overview on the effects of fat and salt reduction with prebiotic addition on consumers' acceptability of processed cheese.

2. Current guidelines to reduce fat and sodium in processed cheese

2.1. Insights of effects of sodium intake and obesity

Processed foods that are widely consumed by the population in many countries are potential sources of high levels of sodium (Buzzo et al., 2014; Capuano et al., 2013). In adults, the a high-sodium diet increase the blood pressure (hypertension), vascular and cardiac damage independent of high blood pressure, there may happen detrimental effects on calcium and bone metabolism, increased risk of stomach cancer, severity of asthma. In children, there might occur development of hypertension later in life and a tendency for children to prefer foods with high salt content due to suppressed salt taste receptors (Strazzullo, D'Elia, Kandala & Cappuccio, 2009). Herein, governmental and health agencies worldwide have set the maximum limit of sodium intake for children and adults. Table 1 contains the upper limits of sodium intake for adults in different countries.

According to the Obesity Society (2015), Latin America has experienced epidemiologic and nutritional transitions that have contributed to the high rates of overweight and obesity, in which estimates reach up to 60% and 70% (in adults) in some countries (Costa Rica and Argentina, respectively) and about 37% in children (5–11 yo) and adolescents (12–19 yo). One big problem related to obesity is the interlinked factor with type II diabetes: almost 90% of type II diabetic individuals are overweight or have diabetes. For instance, according to the WHO definition (WHO, 2015), an overweight individual has a body mass index greater of equal to 25, while obese people have a body mass index greater of equal to 30. The World Health Organization (WHO, 2015) stated that in 2014 there were 1.9 million adults (≥18 yo) who were overweight, and 600 million of this number were obese. In children (5–11 years old), 42 million individuals were overweight or obese in 2013. Allied to the increase in physical inactivity (sedentary life style), the consumption of energy-dense foods and beverages, especially high-fat ones, are the fundamental causes of obesity and overweight worldwide. As cheese is a rich source of fats (higher energy

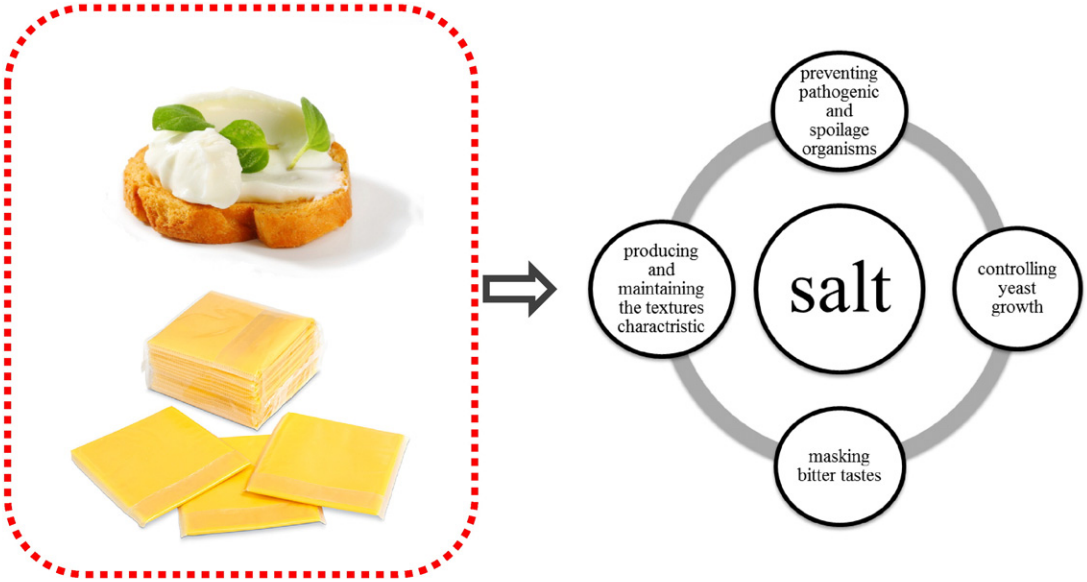

Fig. 1. The original purposes of salt in processed cheeses.

value), the manufacture of low-fat cheese that has similar sensory properties compared to the conventional counterpart, is a suitable technological strategy.

In this aspect, foods that are stated as "reduced-sodium" or "reduced-fat" must have at least a 25% reduction in their sodium or fat levels, respectively, compared to their conventional forms. If a food is labeled as "low-fat," it is critical to have a maximum fat content of 3 g per reference quantity, ensuring that the reference amount is not less than 50 g (Felicio et al., 2013). Products that have a reference amount of less than 50 g, such as cheese, must meet the fat requirement of 3 g fat in 50 g (Miller, Jarvis, Jarvis, & McBean, 2006). For foods labeled as low sodium, the product must include less than 140 mg sodium per 50 g (FDA, Food and Drug Administration, 2008), which is equivalent to 0.7% salt.

Normal sodium amounts of processed cheese establishing concentration ranges between 325 to 798 mg/50 g cheese (USDA, 2014). A reduced-sodium processed cheese should have approximately a maximum of 244 to 600 mg/50 g of sodium and a low-sodium processed cheese need to contain ≤140 mg/50 g of sodium. According to the FDA maximum permitted fat contents in PC, processed cheese food, and processed cheese spread are 30%, 23%, and 20%, respectively (Johnson Kapoor, McMahon, McCoy, & Narasimmon, 2009). Therefore, the maximum fat content for a reduced-fat PC will be 22.5%. Similarly, the maximum fat content for reduced-fat PCF must be 17.25% and for reduced-fat PC will be 15% (FDA, 2008).

Table 1
Upper limit (maximum level) of sodium intake for adults in different countries.

Region	Maximum daily intake — sodium (g/day)	Reference
United States	<2.3 g	CDC (2015)
Canada	<2.3 g (maximum limit) and <1.5 g (ideal maximum limit)	Health Canada (2012)
European Union	<5 g salt	WHO (2012)
Mercosul (Argentina, Brazil, Paraguay, Uruguay, Venezuela, Chile, Bolivia)	<2.4 g	Mercosul (2015)

3. Reduced-fat processed cheese

3.1. The role of fat and the effect of its reduction in processed cheese

Recently reduced-/low-fat processed cheese products have been launched in the market. The fat content can be replaced by water, protein or other compounds not normally found in cheese (Banks, 2004), such as gums and stabilizers (Tamime, 2011), resulting in a considerably different composition compared to their standard counterparts. As an example, a reduced-fat processed cheese may present a moisture content as high as 73% and a fat level between 10 and 24% (Lee et al., 2004), whereas the full-fat product may have a moisture level between 44 and 60% and a fat content higher than 20% (Cheese, 1991; Guinee, Mulholland, Kelly, & Callaghan, 2007).

The fat present in processed cheese is mainly resulted from the natural cheese which is used as its main ingredient (around 90%) (Bachmann, 2001; Carić & Kaláb, 1999). However, some other minor sources of other dairy ingredients, such as dried cream and anhydrous milk fat also contribute to the total fat content of the final product (Tamime, Muir, Shenana, Kalab, & Dawood, 1999). Therefore, using a lower-fat containing natural cheese as an ingredient for processed cheese production is one of the best ways to manufacture a reduced-fat processed cheese (Hauerlandová et al., 2014). The estimated fat content of various components of a processed cheese formulation is presented in Table 2.

Table 2
Contribution of fat components of various food ingredients that are used in the manufacture of processed cheese.

Ingredient	Contribution of fat (% w/w)
Natural cheese	26.5
Dried cream	2.3
Non-fat dried milk	–
Whey powder	–
Butter oil (anhydrous)	1.9
Whey protein concentrate	–
Emulsifying salt	–
Salt	–
Acidifying agent	–
Mold inhibitor	–
Water	–
Total	30.7

In order to reduce the fat content in processed cheese to a value not higher than 25%, a reasonably easier solution is to remove fat from other fat-rich dairy ingredients and interchange them with a proper fat substitute. It is worthy to note that manufacturing a processed cheese with a highly reduced-fat content needs the successful manufacture of a lower-fat natural cheese base with acceptable textural and sensory characteristic (Johnson et al., 2009; Kumar, 2012). Previous studies also indicated that the flavor and texture of natural cheese will also be affected during the fat reduction that must be considered for its usage as an ingredient for reduced-fat processed cheese (Doyle & Glass, 2010; Green & Manning, 1982). Despite the numerous studies attempting to develop lower-fat containing processed cheese, currently very limited reduced-fat, low-fat, or fat-free processed cheeses are sold all over the world (Mistry, 2001).

3.2. Sensory attributes of fat-reduced processed cheese

Muir, Williams, Tamime, and Shenana (1997) studied the sensory characteristics of 16 commercial processed cheese samples (PC) selected on the basis to comprise different brands as well as the full-fat, reduced-fat, and/or low-fat versions within each brand. Considering the results of this study which evaluated full-fat PC (58% moisture, 21% fat) reduced-fat PC (60% fat reduction, 63% moisture, and 8.4% fat) and low-fat PC (63% moisture, 3% fat) from the same manufacturer, it was observed that reducing the fat amount resulted in a decreased creaminess with increasing the acid and bitter properties of the PC (Johnson et al., 2009). Furthermore, this reduction resulted in increased graininess, stickiness, and decreased spread ability and the overall sensory acceptability of the PC. Thus, the studies were mainly focusing on the manufacture of a reduced-fat, low-fat, and/or fat-free based on reduced natural cheese up to now (Finnocchiaro, 1997; Johnson et al., 2009; Moran et al., 2006). These modifications, however, resulted in the production of processed cheese that had a lower-fat content, but the texture, flavor and functional properties were not improved (Banks, 2004; Johnson & Lucey, 2006; Kapoor & Metzger, 2008; Mistry, 2001). Recently, research has also concerned the use of a lower-fat cheese base, with the inclusion of different fat replacers at various levels in a processed cheese formula in order to successfully obtain a product with acceptable texture, flavor, and functional properties.

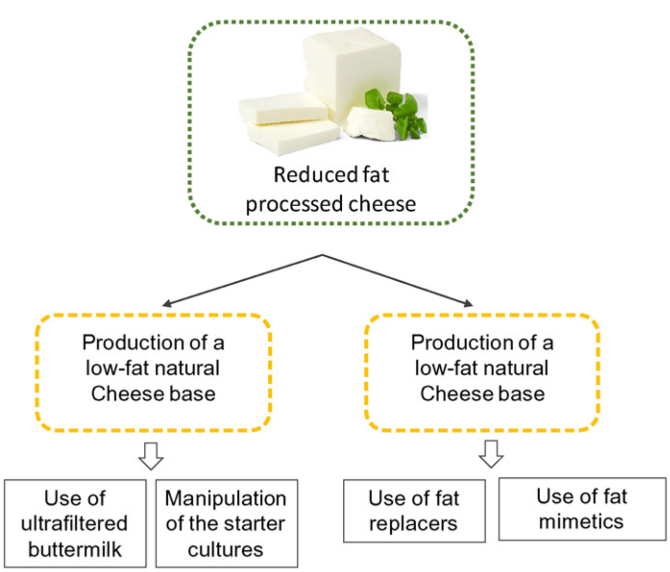

Fig. 2. Different techniques to reduce fat content in processed cheese.

3.3. Production aspects of reduced-fat processed cheese

The study conducted by Roller and Jones (2010) showed that the production of low/reduced-fat processed cheese can be classified into two major categories, with or without fat replacer, as illustrated in Fig. 2. Fat replacers can be categorized as fat substitutes and as fat mimetics (Roller & Jones, 2010). Fat substitutes are mainly lipid-based macromolecules that are similar to fats and oils both physically and/or chemically such as: sucrose fatty acid esters and polyesters, carbohydrate fatty acid esters, various emulsifiers (such as mono- and diglycerides, lecithin), and structured lipids (such as medium-chain triacylglycerols) (Miele, 2013).

Fat mimetics are normally carbohydrate-based compounds (modified starches and hydrocolloids) or protein macromolecules that are considered to imitate the organoleptic and physical properties of fats mainly by water binding (Gaonkar & McPherson, 2014). Fat mimetics are generally carbohydrates or proteins exhibiting polar and water-soluble properties, which create a creaminess and lubricity state similar to full-fat products. Fat mimetics are not able to replace the non-polar functional properties of fat, like the flavor carrying ability (Guinee & Kilcawley, 2004; Kumar, 2012). Different hydrocolloids are used as fat mimetic agents (Table 2).

The development of low-fat processed cheese is conditioned by the rheological parameters, as the product is heavily judged by sensory attributes, such as appearance and texture, which are related to the microstructure of the product. Processing parameters capable of affecting cheese microstructure, which represent the physicochemical balance of chemical molecules present in milk constituents, play a key role on the characteristics of the final product (Pereira, Gomes, & Malcata, 2009).

It could be desirable to obtain a processed cheese that meets specific functional properties according to its intended use. It is worth emphasizing that processed cheeses have different applications, which should also be considered during the development of a formulation with functional appeal. Thus, other desirable characteristics, such as cohesiveness, adherence, and melting rate, should be compatible with the final application of the cheese. A cheese used for melting in the preparation of hot sandwiches, for example, must be elastic enough after heating (Kapoor & Metzger, 2008).

3.3.1. Low-fat processed cheese

Processing parameters capable of affecting cheese microstructure, which represent the coexistence of the milk constituents, play a key role on the characteristics of the final product. The quality of processed cheese, like any food, is directly linked to sensory attributes such as appearance, texture, and flavor, which should be in harmony so that the product is well-accepted (Foegeding, Çakir, & Koç, 2010). One of the main problems arising from fat reduction in cheese is the development of a firmer, less unctuous texture, compromising chewing. The opposite behavior is observed for high-fat cheeses (Rogers, McMahon, Daubert, Berry, & Foegeding, 2010).

To date, no raw material is able to replace all the fat properties, since its presence is closely related to both palatability and sensory characteristics such as body, taste, and texture. On the other hand, these substitutes are alternatives to produce foods to meet the needs of individuals with low-calorie or hypolipidic diets (Pinheiro & Penna, 2004). Various ingredients such as protein compounds (milk and eggs), carbohydrates (gums, dextrins, maltodextrins, cellulose, polydextrose, inulin, and starches), and synthetic fats (dialkyl dihexadecyl malonate and sucrose polyester) may be used alone or in combination to produce low-fat cheeses (Diamantino & Penna, 2011). Among these, starch is one of the main fat substitutes used in the food industry to provide desirable characteristics to the final products. In contrast, Ferreira, Souza, Santos, Collares-Queiroz, and Steel (2012) pointed out that the production of these substitutes may be a difficult task, and sometimes their addition does not promote a significant reduction in

Table 3
Studies on fat replacement in processed cheese.

Fat replacer	Technique of study	Conclusion and remarks	Reference
Resistant starch	• Texture profile analysis and flow • Rheology • Sensory analysis	• A good, firm cheese • Good meltability • Starches containing higher amylose contents (such as corn, potato, and wheat starch) are capable of increasing strength and reducing melting of processed cheeses.	Noronha, O'Riordan, and O'Sullivan (2008)
Pectin gel	• Scanning electron microscopy • Rheological analysis • Texture profile analysis • Thermal analysis	• Lower-fat globules with weaker structure • Higher texture and mouthfeel scores • It decreases the melt enthalpy of the samples. • The hardness, gumminess, chewiness and adhesiveness and low-fat samples with pectin gel addition were more similar to the full-fat cheese analogs.	Liu, Xu, and Guo (2008)
Lecithin	• Sensory analysis	• Its texture attributes were more similar to full-fat control cheeses. • Its texture acceptance scores were higher than scores for reduced-fat cheeses. • Lecithin improved processed cheese texture without negatively affecting acceptance	Drake, Truong, and Daubert (1999)
Inulin	• Meltability and hardness • Scanning electron microscopy • Dynamic rheology	• Similar hardness • Values of G' and G'' decreased with increasing temperature but at temperatures >55 °C increased for cheeses containing the higher level of inulin. • Lower level of honeycomb structures evident in the protein matrix relative to the control • Meltability, density, cohesiveness and viscosity increase	Hennelly, Dunne, O`Sullivan, and O` Riordan (2006), Karimi et al. (2015), Sołowiej et al. (2015)

the total energy value of the final product, due to the need for keeping its sensory properties (Table 3).

Starch is not only an important carbohydrate for plants; it is also a source of energy for the subsequent levels of the food chain. In view of such relevance, many organisms have acquired the ability to produce enzymes that degrade this homopolysaccharide for subsequent release of glucose, a monomer that will serve as an energy substrate in catabolic pathways that occur intracellularly (Amaral, Gaspar, Costa, Aidar, & Buckeridge, 2007). In addition to the energetic contribution, starch has been used as an ingredient for processing of low-fat cheeses, which may represent benefits from the functional and economical points of view, because it is a raw material of vegetable origin and available in large quantity, with lower economic value when compared to dairy raw materials.

This polysaccharide can be obtained from various vegetables, being used for human consumption and in chemical, pharmaceutical, and textile industries. It is a semi-crystalline polymer having a fraction of amylose (linear chain with up to 3000 glucose units linked primarily by α-1,4 bonds) and amylopectin (branched polymer with a fraction formed by α-1,4 bonds and in branch points by α-1,6 bonds. Starch can have different amylose and amylopectin contents in proportions that usually vary around 1:3 and 1:4, depending on the type of vegetable (Amaral et al., 2007; Beninca et al., 2013).

Starch undergoes gelatinization (breaking of hydrogen bonds present in amylose and amylopectin with binding of water molecules) when heated in aqueous solution, which alters its chemical structure and increases the size of its granules, a condition which also increases paste viscosity. The viscosity, which varies according to its botanical origin, is a determining factor for the application of this carbohydrate in food products to obtain desirable rheological characteristics (Sarker et al., 2013).

The addition of starch to processed cheeses requires preliminary tests utilizing a wide range of operating parameters such as curd homogenization rate and heat treatment time and temperature. The measurement of rheological (firmness, adherence, rigidity modulus and storage) and functional (melting, browning, oil retention) properties in the final product as well as the conduction of affective sensory tests with potential consumers are also fundamental and required tasks.

Thus, it becomes imperative to know the interactions between milk proteins and starch (or amylose and amylopectin fractions), and their effects on dairy products have been researched. The association between these two components can lead to many interactions that affect the physicochemical characteristics of the products, including the effects of nutrients such as lactose and minerals on skim milk, even at low concentrations. Nevertheless, some interactions have not been elucidated, such as those between milk proteins and the surface of starch granule. Understanding these phenomena allows obtaining dairy products with higher sensory quality, especially with regard to consistency (Considini et al., 2011).

In addition to the technological benefits of starches, a portion of these nutrients can remain intact through the enzymatic action occurring during the digestive process. These fractions of complex carbohydrates that cannot be digested, and therefore are not used as energy sources by man, are also fermented by lactic acid-forming bacteria, such as resistant starch (Yang et al., 2006). Thus, these compounds also allow the proliferation and intestinal colonization by these microorganisms, called bacteroids and bifidobacteria, similar to that observed for other prebiotic compounds (Lerayer et al., 2013).

The ratio between amylose and amylopectin fractions affects the rheological aspects of low-fat cheeses. Starches containing higher amylose contents (such as corn, potato, and wheat starch) are capable of increasing strength and reducing melting of processed cheeses (Mounsey & O'Riordan, 2008a), which are undesirable characteristics. In addition to the amylase/amylopectin ratio, the presence of proteins in the alimentary system may also affect the characteristics of the gel formed. Proteins increase gel strength due to the interactions with this carbohydrate, promoting increased density of proteins in the matrix and formation of elastic starch globules (Jamilah et al., 2009).

Native or unmodified starches have some limitations of use such as insolubility in cold water, viscosity, and thickness reduction after cooking, tendency to retrogradation and loss of ordered structure after gelatinization (causing syneresis). These disadvantages have led industry to develop modified starches, which are starches subjected to one or more physical or chemical changes. The physical changes may be achieved without using additives or biological agents, and involve techniques such as overheating, osmotic pressure, and pulsed electric fields. In contrast, the chemical changes involve derivatization mechanisms such as esterification, crosslinking, cationization and acidification (Ashogbon & Akintayo, 2014; Heertje, 2014). Enzymatic changes are also employed by using catalysts such as fungal α-amylase, which was used in the formulation of casein-reduced processed cheese made with addition of waxy starch partially degraded by this enzyme

(Kiziloz, Cumhur, & Kilic, 2009). In processed cheeses, like Feta cheese, the effects of starch of tapioca and lecithin have already been investigated. In general, modified starches can be used as fat substitutes, texture enhancers, stabilizers, emulsifiers and thickeners (Abbas, Khalil, & Hussin, 2010). Pregelatinized starches of corn, waxy corn, wheat, potato, and rice can also be used in the manufacturing of processed cheeses, providing a reduction of melting and cohesion in different levels. In addition, it was observed that both starches and renin compete for water (Mounsey & O'Riordan, 2008b), which may lead to undesirable changes in food.

In fact, starches from different dietary sources are used more often to increase viscosity and firmness of processed cheeses. Positive effects have been reported due to the addition of various types of starches, including starch with high content of amylose (Gampala & Brennan, 2008), potato starch with 21% amylose (Ye & Hewitt, 2009) and corn, rice and potato starch (Trivedi et al., 2008a,b) in processed cheeses, thus the starch–dairy protein interactions have been investigated (Mounsey & O'Riordan, 2008a,b).

4. Low-sodium processed cheese

Currently, there is a great concern on the excessive dietary sodium consumption, since this mineral has been associated to some coronary chronic diseases, such as systemic arterial hypertension (Cruz et al., 2011). Reducing sodium intake is the main focus of public health policies worldwide aimed to prevent and control hypertension (Felicio et al., 2013), which is characterized by systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg in adults. It accounts for 62% of strokes and 49% of coronary heart disease. For instance, the prevalence of hypertension in many countries exceeds 25%, i.e., prevalence of 40% in Czech Republic, Slovenia, and Hungary (Kloss et al., 2015).

Hypertension represents a significant burden throughout the world with respect to quality of life and health care system resources, contributing directly to increased mortality and risk of cardiovascular diseases such as myocardial infarction, angina pectoris, heart failure, and stroke (Lollo et al., 2015). As a result of this global scenario, the World Health Organization issued a recommendation of a maximum intake of 5 g of salt per day for adults, corresponding to 2 g of sodium (WHO, 2012). However, several studies have shown that sodium intake in general population surpasses the maximum limit recommended and, therefore, many government programs and incentives are being deployed in different countries in order to minimize such practice. For example, in the USA, the FDA recommends a maximum amount of 2.4 g of sodium/day. Therefore, to execute an intervention that can be implemented on a large scale production is necessary to an understanding of the possible impediments for this kind of change (Newson et al., 2013).

Among dairy products, cheese makes a decisive contribution in daily sodium intake, thus changes in processes are required to meet the global recommendations of the Health Agencies (Felicio et al., 2013). In Brazil, a recent agreement between the Ministry of Health and the industrial sector aims to reduce sodium levels in many processed foods, including dairy products. The current estimate of sodium consumption exceeds 4 g/day (>10 g salt/day). The national goal is to remove 28,000 tons of sodium from foods by 2020 and, among dairy products, the goal is a reduction of 63% (Brasil, 2014) for *requeijao cremoso*, a typical Brazilian processed cheese, which illustrates the challenges to be overcome by the industrial sector.

Processed cheese is obtained from a mixture of cheeses at different ripening stages, salt, water, and emulsifying salts, such as citrate, sodium phosphate, or polyphosphate. During processing, the emulsifying salts play an important role ensuring homogeneous products with the desired consistency (Chen & Liu, 2012). The real effect of emulsifying salts is the cation exchange of calcium from insoluble calcium paracaseinate to sodium ions, which leads to the formation of more soluble sodium paracaseinate (Salek, Cernikova, Maderova, Lapcik, & Bunka, 2016). Their application is related to the chain peptization, dispersion, hydration, and swelling of the proteins, in addition to emulsification and stabilization of fat (Hoffmann, Gärtner, Lück, Johannsen, & Maurer, 2012). Indeed, salt reduction in processed cheese represents a factor of concern about the aspects related to its functional properties such as firmness and melting (Felicio et al., 2013).

The sodium content in processed cheese is conditioned mainly by the emulsifying salts that mostly contain sodium, together with the sodium chlorine added to the curd, with percentages of 1.5–2.0% w/w (Johnson et al., 2009). Therefore, efforts to reduce sodium in processed cheese must involve the modification of one or two ingredients during the formulation and manufacture (Johnson et al., 2009). A usual technology alternative is the replacement of NaCl by potassium chloride (KCl), once the latter helps to maintain the salty taste, and allows reducing the salt content in food by up to 25% without no loss of palatability (Gomes et al., 2011). A recent study using response surface methodology reported 27% reduction in overall sodium content of processed Mozzarella cheese through partial replacement of sodium chloride by potassium chloride (KCl) and also by using potassium-based emulsifying salts, i.e., potassium citrate and di-potassium phosphate. The final formulation of processed cheese included 30.96% of KCl and 2% of emulsifying as optimum, for obtaining a product with the maximum sensory scores (Chavhan, Kanawjia, Khetra, & Puri, 2015).

In fact, emulsifying salts containing potassium as a replacement for sodium are commercially available and have been successfully used in processed cheese formulation. However, some changes were observed in some characteristics of the processed cheese, such as an increased fracture, higher firmness, lower melting capacity and protein solubility (Guinee & O'Kennedy, 2012). Furthermore, these compounds present surface activity, probably due to protein with amino acid residues and capacity to decrease surface tension at low concentrations, resulting in an increase in viscosity of the continuous phase and thereby reducing the time required for coalescence of fat droplets. In general, positive changes in the compaction and rearrangement in the protein matrix of processed cheese elaborated with potassium emulsifying salts were observed (Salek et al., 2016).

Generally, the replacement of sodium chloride by other salts or its simple reduction leads to multifactorial problems in the manufacturing process of processed cheese, resulting in changes in physicochemical, rheological, functional, and sensory qualities of the product (Felicio et al., 2016).

5. Prebiotic-enriched processed cheese

Prebiotic ingredients promote intestinal health by selectively stimulating the proliferation of beneficial microorganisms, what in turn contributes to defeat potential pathogens. Besides this they promote the intestinal transit, having a similar function to insoluble fiber (Rolim, 2015). According to recent study, prebiotics influence proliferation of colonic bacteria in organic metabolism, by regulating the immune response, intestinal absorption of glucose and lipid metabolism (Yang et al., 2015). Prebiotic demand was US$ 2.3 billion in 2012 and is estimated to reach US$ 4.5 billion in 2018, growing at 11.4% between 2012 and 2018; Europe is the global leader in prebiotics and dominates the demand for these products since inulin was available as ingredient, accounting for over 40% of the overall market in 2011 (Before it's new, 2013).

Prebiotics as non-digestible carbohydrates, change the composition and/or the activity of the gastrointestinal microbiota in a way that improves the host health (Gibson, Probert, Loo, Rastall, & Roberfroid, 2004). They can bring about large (specific) shifts in the populations of bacterial groups in the gut ecosystem and direct carbon flux from carbohydrate substrates to metabolic end products, such as organic acids, which are thought to improve local and systemic health (Rastall & Gibson, 2014). Different prebiotics are used in foods that are

Table 4
Prebiotic factors used in the manufacture of processed food products.

Prebiotic factor
Oligosaccharide
Fructo-oligosaccharides (oligofructose, inulin)
Fructan
Human kappa casein and derived glycomacropeptide
Stachyose and raffinose
Casein macropeptide
Lactitol (4-O-B-D-galactopyranosyl)/D-glucitol
Lactulose (4-O-B-D-galactopyranosyl)/D-fructose

summarized in Table 4. Among these ingredients inulin, which behaves both like a soluble and fermentable fiber, is one of the best known (Akalın & Erişir, 2008; Cardarelli, Buriti, Castro, & Saad, 2008; Meyer, Bayarri, Tárrega, & Costell, 2011). Inulin creates a defensive effect toward *Lactobacillus acidophilus* (Roller, Rechkemmer, & Watzl, 2004), *Lactobacillus casei* (Aryana & McGrew, 2007; Donkor, Nilmini, Stolic, Vasiljevic, & Shah, 2007), *Lactobacillus paracasei* (Makras, Van Acker, & De Vuyst, 2005), *Lactobacillus rhamnosus* (Femia et al., 2002), *Lactobacillus plantarum* (Altieri, Bevilacqua, & Sinigaglia, 2011) and *Bifidobacterium* spp. (Roberfroid, Van Loo, & Gibson, 1998), to improve their endurance and activity throughout the storage of foods that contain these microorganisms. Among the studied oligosaccharides, inulin has more efficient prebiotic characteristics when compared to oligofructose, regarding aspects related to: fermentation activity and the bacterial community composition as similar as the human bacterial flora (Van de Wiele, Boon, Possemiers, Jacobs, & Verstraete, 2007).

Inulin is colorless and odorless, with a pleasant sweet taste, and can be dissolved in water (Chawla & Patil, 2010). Inulin is a reserve carbohydrate in different plants, consists of fructose molecules bound by links β-(2 → 1) fructosyl fructose being the term "fructan" used to describe such compounds (Delzenne, Cani, Daubioul, & Neyrinck, 2005; Ritsema & Smeekens, 2003; Tungland & Meyer, 2002). Inulin is able to create a stable foam and emulsion when it is used in a gel form, and it has similar properties to fat (Akalın & Erişir, 2008; Franck, 2002; Guven, Yasar, et al., 2005). Inulin and oligrofructose confer a rich taste in the product they are added by creating a good mouthfeel and textual characteristics similar to what is observed when fat is used in different products (Karimi, Azizi, Ghasemlou, & Vaziri, 2015).

The physicochemical and functional properties of inulin are linked to degree of polymerization (DP) as well as the presence of branches. The short-chain fraction, oligofructose, is much more soluble and sweeter than native and long-chain inulin, and contributes to improve mouthfeel (Apolinário et al., 2014). It has also been demonstrated that only the longer chains inulin which has DP higher than 10 take part in gel formation, whereas the smaller ones are still dissolved (Mensink, Frijlink, Maarschalk, & Hinrichs, 2015). Different parameters determine the gel formation ability of inulin including: the inulin structure type, inulin concentration, temperature, pH, the existence of ions (e.g. Ca^{2+}), and the presence of other rheology modifier components in the food system (Tungland & Meyer, 2002). The interaction of inulin compounds with water described differently, as hydration, adsorption, absorption, binding, or holding (Greg Kelly, 2008).

The sweetness of inulin is about 10% of that of sucrose. By removing the smaller inulin molecules, the sweetness is eliminated and the gel-forming capabilities are enhanced (Schaafsma & Slavin, 2015). In addition, gel formation by inulin in water solution depends on the presence of crystal seeds, in which the minimal crystal seed concentration necessary to form stable gel structure after previous complete inulin dissolution was established as 0.02% which results in a weak gel structure while a crystal seed concentration of about 0.4% was related to formation of strong stable gels, without significant change in the hardness (Glibowski, Pikus, Jurek, & Kotowoda, 2014). The product structure and the presence of other ingredients especially hydrocolloids, can modify the rate and the extent of inulin crystallization and thus influence its functionality as fat replacer (Meyer et al., 2011). Spite of the inulin source determines its physicochemical characteristic like its length and particle size, it does not directly affect the WBC.

In processed cheese, the best results are provided in oil–water spreads with a fat content varied between 20 and 60%, and water-continuous formulations containing 15% fat or less (Franck, 2002). The rheological and textural properties of processed cheese spread with lower fat in the presence of inulin as a fat replacer (Dave, 2012).

Authors concluded that the yield-stress values of low-fat cheese spreads prepared in the presence of 7–8% inulin is significantly higher compared to those full-fat (20% fat with no inulin added) or low-fat spreads containing low inulin content ones. The spread ability of low-fat spreads is also positively affected by inulin. The results revealed that the low-fat processed cheese spreads with 7–8% inulin had yield-stress amount and spread ability like the full-fat one.

It is valuable to be mentioned that co-addition of prebiotic and probiotic enhances the therapeutic value of dairy products. Although almost all dairy products are the usually studied food matrices for probiotic and prebiotic ingredient addition (Auty et al., 2001; Cruz, Faria, & Van Dender, 2007; Granato, Branco, et al., 2010; Huang and Adams, 2004; Tamime et al., 2005; Vinderola, Mocchiutti, & Reinheimer, 2002) cheeses are more preferred especially from the probiotic point of view (Karimi, Mortazavian, & Cruz, 2011; Karimi, Sohrabvandi, & Mortazavian, 2012; Lollo et al., 2012; Miller et al., 2006). The main good potential characteristic which could be mentioned are: its higher pH value and lower titratable acidity, higher buffering capacity, more fat content, more nutrient availability, lower oxygen content, and denser texture matrix (Karimi et al., 2011, 2012). It is clear that for probiotic processed cheese, in order to maintain the concept of functional food, production of reduced-fat probiotic processed cheeses is preferred.

Ideally, taking into consideration all the concepts explained in this review, it seems obvious that the development of processed cheeses with a low content of sodium and fat, added or not with prebiotics, should have sensory rating, functional properties, physicochemical characteristics, and shelf life time comparable to the conventional counterpart, as shown in Fig. 3.

6. Perspectives

The development of food products with a health appeal is an irreversible tendency for dairy industry, which is obliged to act toward the reformulation of many conventional and well-established products. In the particular case of processed cheese, the reduction of fat and sodium contents is a trend and demanding task because of high incidence of obesity/overweight and hypertension. In the first case, the addition of different types of starch (native and modified) and prebiotic ingredients is a potential alternative, while in the second case the use of blends of emulsifying salts with normal and reduced-sodium contents, as well as lower salt in the curd comprise practical and easy-to-implement alternatives.

The reformulation of processed cheese necessarily involves the assessment of functional properties and sensory acceptance of the reformulated products, without affecting their technological attributes, which could limit the use of reformulated processed cheeses in both direct consumption and food service.

Thus, these products can be incorporated into diets of people who avoid eating conventional cheeses, but who routinely consume cheese as an ingredient in sandwiches and pastes. Besides contributing to the maintenance of health, these products allow for a more diverse diet for patients with non-communicable chronic diseases, facilitating to adherence of the patients to the nutritional treatments and leading to healthier food choices.

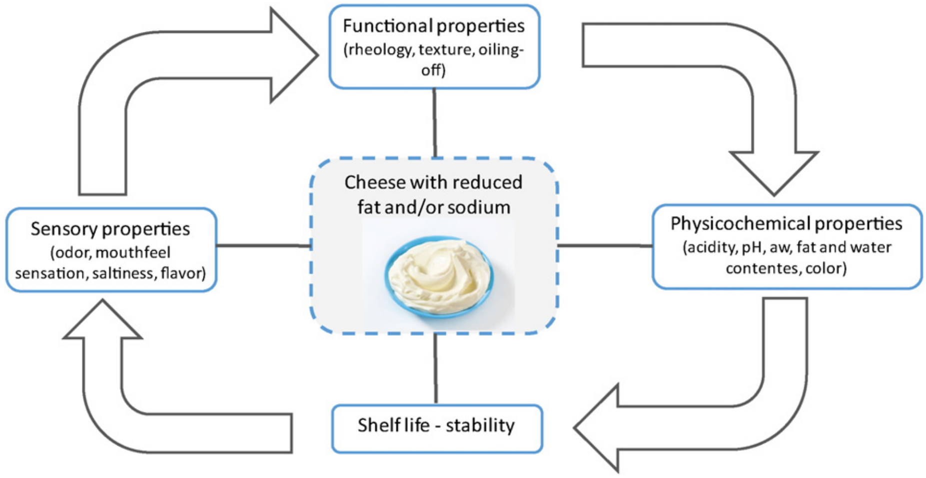

Fig. 3. Concepts and factors involving the manufacture of low-fat and/or low-sodium processed cheeses.

References

Abbas, K. A., Khalil, S. K., & Hussin, A. S. M. (2010). Modified starches and their usages in selected food products: A review study. *Journal of Agricultural Science*, *2*, 90–100.

Akalın, A., & Erişir, D. (2008). Effects of inulin and oligofructose on the rheological characteristics and probiotic culture survival in low fat probiotic ice cream. *Journal of Food Science*, *73*, 184–188.

Al-Sheraji, S. H., Ismail, A., Manap, M. Y., Mustafa, S., Yusof, R. M., & Hassan, F. A. (2013). Prebiotics as functional foods: A review. *Journal of Functional Foods*, *5*, 1542–1553.

Altieri, C., Bevilacqua, A., & Sinigaglia, M. (2011). Prolonging the viability of *Lactobacillus plantarum* through the addition of prebiotics into the medium. *Journal of Food Science*, *76*, 336–345.

Alves, L. L., Richards, N. S. P. S., Mattanna, P., Andrade, D. F., Rezer, A. P. S., Milani, L. I. G., ... Faria, J. A. F. (2013). Cream cheese as a symbiotic food carrier using *Bifidobacterium animalis* Bb-12 and *Lactobacillus acidophilus* La-5 and inulin. *International Journal of Dairy Technology*, *66*, 63–69.

Amaral, L. I. V., Gaspar, M., Costa, P. M. F., Aidar, M. P. M., & Buckeridge, M. (2007). Novo método enzimático rápido e sensível de extração e dosagem de amido em materiais vegetais. *Hoehnea*, *34*, 425–431.

Apolinário, A. C., Damasceno, B. P. G. L., Beltrão, N. E. M., Pessoa, A., Converti, A., & Silva, J. A. (2014). Inulin-type fructans: A review on different aspects of biochemical and pharmaceutical technology. *Carbohydrate Polymers*, *101*, 368–378.

Aryana, K. J., & McGrew, P. (2007). Quality attributes of yogurt with *Lactobacillus casei* and various prebiotics. *Food Science and Technology*, *40*, 1808–1814.

Ashogbon, A. O., & Akintayo, T. E. T. (2014). Recent trend in the physical and chemical modification of starches from different botanical sources: A review. *Starch*, *66*, 41–57.

Auty, M., Gardiner, G., McBrearty, S. J., O'Sullivan, E. O., Mulvihill, D. M., Collins, J. K., ... Ross, R. P. (2001). Direct in situ viability assessment of bacteria in probiotic dairy products using viability staining in conjunction with confocal scanning laser microscopy. *Applied and Environmental Microbiology*, *67*, 420–425.

Bachmann, H. P. (2001). Cheese analogues: A review. *International Dairy Journal*, *11*, 505–515.

Banks, J. M. (2004). The technology of low-fat cheese manufacture. *International Journal of Dairy Technology*, *57*, 199–207.

Barr, S. I. (2010). Reducing dietary sodium intake: The Canadian context. *Applied Physiology, Nutrition, and Metabolism*, *35*, 1–8.

Before it's new (2013). *What Exactly Is Cheese Powder, Anyway*. Available in http://beforeitsnews.com/alternative/2013/11/what-exactly-is-cheese-powder-anyway-2823064.html Acessed in 18/04/2016.

Beninca, C., Colman, T. A. D., Lacerda, L. G., Carvalho Filho, M. A. S., Bannach, G., & Schnitzler, E. (2013). The thermal, rheological and structural properties of cassava starch granules modified with hydrochloric acid at different temperatures. *Thermochimica Acta*, *552*, 65–69.

Brasil (2014). *Acordo entre governo e indústria retira toneladas de sodio de alimentos*. Available in http://www.brasil.gov.br/saude/2014/08/acordo entre-governo-e-industria-retira-toneladas-de-sodio-de-alimentos.

Buzzo, M. L., Carvalho, M. F. H., Arakaki, E. E. K., Matsuzaki, R., Granato, D., & Kira, C. S. (2014). Elevados teores de sódio em alimentos industrializados consumidos pela população Brasileira. *Revista do Instituto Adolfo Lutz*, *73*, 32–39.

Capuano, E., van der Veer, G., Verheijen, P. J. J., Heenan, S. P., van de Laak, L. F. J., Koopmans, H. B. M., & Van Ruth, S. M. (2013). Comparison of a sodium-based and a chloride-based approach for the determination of sodium chloride content of processed foods in the Netherlands. *Journal of Food Composition and Analysis*, *31*(1), 129–136.

Cardarelli, H. R., Buriti, F. C., Castro, I. A., & Saad, S. M. I. (2008). Inulin and oligofructose improve sensory quality and increase the probiotic viable count in potentially synbiotic petit-suisse cheese. *Food Science and Technology*, *41*, 1037–1046.

Carić, M., & Kaláb, M. (1999). Processed cheese products. *Cheese: Chemistry, physics and microbiology* (pp. 467–505). Springer.

CDC. Center for Disease Control and Prevention (2015). *Dietary guidelines for Americans 2015–2020* (8th ed.) (Available at: http://health.gov/dietaryguidelines/2015/guidelines/. Access: 18/4/2016).

Chang, P. K. (1979). *Process cheese containing a modified whey solids*. (Google Patents).

Chavhan, G. B., Kanawjia, S. K., Khetra, Y., & Puri, R. (2015). Effect of potassium-based emulsifying salts on sensory, textural, and functional attributes of low-sodium processed mozzarella cheese. *Dairy Science and Technology*, *95*, 265–278.

Chawla, R., & Patil, G. (2010). Soluble dietary fiber. *Comprehensive Reviews in Food Science and Food Safety*, *9*, 178–196.

Cheese, M. O. D. (1991). Manufacture of Egyptian, soft and pickled cheeses. *Feta and Related Cheeses*, *160*.

Chen, L., & Liu, H. (2012). Effect of emulsifying salts on the physicochemical properties of processed cheese made from mozzarella. *Journal of Dairy Science*, *95*, 4823–4830.

Considini, T., Noisuwan, A., Hemar, Y., Wilkinson, B., Bronlund, J., & Kasapis, S. (2011). Rheological investigations of the interactions between starch and milk proteins in model dairy systems: A review. *Food Hydrocolloids*, *25*, 2008–2017.

Cruz, A. G., Cavalcanti, R. N., Guerreiro, L. M. R., Sant'Ana, A. S., Nogueira, L. C., Oliveira, C. A. F., ... Bolini, H. M. A. (2013). Developing a prebiotic yogurt: Rheological, physico-chemical and microbiological aspects and adequacy of survival analysis. *Journal of Food Engineering*, *114*, 323–330.

Cruz, A. G., Faria, J. A., & Van Dender, A. G. F. (2007). Packaging system and probiotic dairy foods. *Food Research International*, *40*, 951–956.

Cruz, A. G., Faria, J. A. F., Pollonio, M. A. R., Bolini, H. M. A., Celeghni, R. M. S., Granato, D., & Shah, N. P. (2011). Cheeses with reduced sodium content: Effects on functionality, public health benefits and sensory properties. *Trends in Food Science & Technology*, *22*, 276–291.

Data Source, USDA, Nass; Graph USDA, AMS, DMN (2014). *USDA/AMS/Dairy Market News, Madison, Wisconsin*, *Vol. 608*. (pp. 278–4150), 278–4150 (Available from http://www.ams.usda.gov/mnreports/dymcheese_prod_tot.pdf).

Dave, P. Graduate Degree/Major: MS Food and Nutritional Sciences Research Adviser: Karunanithy Chinnadurai, Ph. D. Submission Term/Year: Fall, 2012 Style Manual Used: American Psychological Association. (53 pp.)

Davis, C., Blayney, D., & Guthrie, J. (2013). *The consumption of cheese in relation to dairy foods: A USA perspective*.

Davison, B. C., Schwimmer, W. H., Prostko, L. J., Hamann, A. C., Buliga, G. S., Helth, A. A., ... Smith, G. F. (1993). *Low fat processed cheese product having fat-mimetic properties and method of making same*. (Google Patents).

Delzenne, N. M., Cani, P. D., Daubioul, C., & Neyrinck, A. M. (2005). Impact of inulin and oligofructose on gastrointestinal peptides. *British Journal of Nutrition*, *93*, 157–161.

Diamantino, I. M., & Penna, A. L. B. (2011). Efeito da utilização de substitutos de gordura em queijos light. *Revista do Instituto Adolfo Lutz*, *70*, 258–267.

Drake, M. A., Truong, V. D., & Daubert, C. R. (1999). Rheological and sensory properties of reduced fat processed cheeses containing lecithin. *Journal of Food Science*, *64*, 744–747.

Donkor, O. N., Nilmini, S., Stolic, P., Vasiljevic, T., & Shah, N. P. (2007). Survival and activity of selected probiotic organisms in set-type yoghurt during cold storage. *International Dairy Journal*, *17*, 657–665.

Doyle, M. E., & Glass, K. A. (2010). Sodium reduction and its effect on food safety, food quality, and human health. *Comprehensive Reviews in Food Science and Food Safety*, *9*, 44–56.

FDA. Food and Drug Administration (2008). *21 CFR, part 133.169 to 133.180. Cheese and related cheese products*. Washington, DC: Food and Drug Administration, Department of Health and Human Services.

Felicio, T. L., Esmerino, E. A., Cruz, A. G., Nogueira, L. C., Raices, R. S. L., Deliza, R., ... Pollonio, M. A. R. (2013). Cheese. What is its contribution to the sodium intake of Brazilians? *Appetite*, *66*, 84–88.

Felicio, T. L., Esmerino, E. A., Vidal, V. A. S., Cappato, L. P., Garcia, R. K. A., Cavalcanti, R. N., ... Cruz, A. G. (2016). Physico-chemical changes during storage and sensory acceptance of low sodium probiotic Minas cheese added with arginine. *Food Chemistry*, *196*, 628–637.

Femia, A. P., Luceri, C., Giannini, A., Biggeri, A., Salvadori, M., Clune, Y., ... Caderni, G. (2002). Antitumorigenic activity of the prebiotic inulin enriched with oligofructose in combination with the probiotics *Lactobacillus rhamnosus* and *Bifidobacterium lactis* on azoxymethane-induced colon carcinogenesis in rats. *Carcinogenesis*, *23*, 1953–1960.

Ferreira, R. E., Souza, A. B., Santos, J. R. U., Collares-Queiroz, F. P., & Steel, C. J. (2012). Legumes starches and application of residues. *Alimentação e Nutrição Araraquara*, *23*, 171–178.

Finnocchiaro, E. T. (1997). *Non-fat, reduced fat and low fat cheeses and method of making.* (Google Patents).

Foegeding, E. A., Çakir, E., & Koç, H. (2010). Using dairy ingredients to alter texture of foods: Implications based on oral processing considerations. *International Dairy Journal*, *20*, 562–570.

Fouladkhah, A., Berlin, D., & Bruntz, D. (2015). High-sodium processed foods: Public health burden and sodium reduction strategies for industry practitioners. *Food Reviews International*, *31*(4), 341–354.

Franck, A. (2002). Technological functionality of inulin and oligofructose. *British Journal of Nutrition*, *87*, 287–291.

Gampala, P., & Brennan, C. (2008). Potential starch utilization in a model processed cheese system. *Starch*, *60*, 685–689.

Gaonkar, A. G., & McPherson, A. (2014). *Ingredient interactions: Effects on food quality.* CRC Press.

Gibson, G. R., Probert, H. M., Loo, J. V., Rastall, R. A., & Roberfroid, M. B. (2004). Dietary modulation of the human colonic microbiota: Updating the concept of prebiotics. *Nutrition Research Reviews*, *17*, 259–275.

Glibowski, P., Pikus, S., Jurek, J., & Kotowoda, M. (2014). Factors affecting inulin crystallization after its complete dissolution. *Carbohydrate Polymers*, *110*, 107–112.

Gliguem, H., Ghorbel, D., Cécile Grabielle-Madelmont, C., Goldschmidt, B., Lesieur, S., Arrita, H., ... Lesieur, P. (2009). Water behaviour in processed cheese spreads. *Journal of Thermal Analysis and Calorimetry*, *98*, 73–82.

Golan, E., & Unnevehr, L. (2008). Food product composition, consumer health, and public policy: Introduction and overview of special section. *Food Policy*, *33*, 465–469.

Gomes, A. P., Cruz, A. G., Cadena, R. S., Celeghini, R. M. S., Faria, J. A. F., Bolini, H. M. A., ... Granato, D. (2011). Manufacture of low-sodium Minas fresh cheese: Effect of the partial replacement of sodium chloride with potassium chloride. *Journal of Dairy Science*, *94*, 2701–2706.

Granato, D., Branco, G. F., et al. (2010). Probiotic dairy products as functional foods. *Comprehensive Reviews in Food Science and Food Safety*, *9*, 455–470.

Green, M. L., & Manning, D. J. (1982). Development of texture and flavour in cheese and other fermented products. *Journal of Dairy Research*, *49*, 737–748.

Greg Kelly, N. D. (2008). Inulin-type prebiotics — A review: Part 1. *Alternative Medicine Review*, *13*, 315–329.

Guinee, T., Carić, M., & Kalab, M. (2004). Pasteurized processed cheese and substitute/imitation cheese products. *Cheese: Chemistry, Physics and Microbiology*, *2*, 349–394.

Guinee, T., & Kilcawley, K. (2004). Cheese as an ingredient. *Cheese: Chemistry, Physics and Microbiology*, *2*, 395–428.

Guinee, T., Mulholland, E., Kelly, J., & Callaghan, D. J. (2007). Effect of protein-to-fat ratio of milk on the composition, manufacturing efficiency, and yield of cheddar cheese. *Journal of Dairy Science*, *90*, 110–123.

Guinee, T., & O'Callaghan, D. (2013). Effect of increasing the protein-to-fat ratio and reducing fat content on the chemical and physical properties of processed cheese product. *Journal of Dairy Science*, *96*, 6830–6839.

Guinee, T. P., & O'Kennedy, B. T. (2012). Reducing the level of added disodium phosphate alters the chemical and physical properties of processed cheese. *Dairy Science & Technology*, *92*, 469–486.

Gupta, V., & Reuter, H. (1992). Processed cheese foods with added whey protein concentrates. *Le Lait*, *72*, 201–212.

Guven, M., Yasar, K., et al. (2005). The effect of inulin as a fat replacer on the quality of set-type low-fat yogurt manufacture. *International Journal of Dairy Technology*, *58*, 180–184.

Hanaei, F., Cuvelier, G., & Sieffermann, J. M. (2015). Consumer texture descriptions of a set of processed cheese. *Food Quality and Preference*, *40*, 316–325.

Hauerlandová, I., Lorencová, E., Buňka, F., Navrátil, J., Janečková, K., & Buňková, L. (2014). The influence of fat and monoacylglycerols on growth of spore-forming bacteria in processed cheese. *International Journal of Food Microbiology*, *37–43*, 182–183.

Health Canada (2012). Sodium in Canada. (Available at:) http://www.hc-sc.gc.ca/fn-an/nutrition/sodium/index-eng.php (Access: 18/4/2016)

Heertje, I. (2014). Structure and function of food products: A review. *Food Structure*, *1*, 3–23.

Hennelly, P. J., Dunne, P. G., O`Sullivan, M., & O`Riordan, E. D. O. (2006). Textural rheological, and microstructural properties of imitation cheese containing inulin. *Journal of Food Engineering*, *75*(3), 388–395.

Hoffmann, W., Gärtner, J., Lück, K., Johannsen, N., & Maurer, A. (2012). Effect of emulsifying salts containing potassium on the quality of block-type processed cheese. *International Dairy Journal*, *25*, 66–72.

Hosseini-Parvar, S. H., Matia-Merino, L., & Golding, M. (2015). Effect of basil seed gum (BSG) on textural, rheological and microstructural properties of model processed cheese. *Food Hydrocolloids*, *43*, 557–567.

Huang, Y., & Adams, M. C. (2004). In vitro assessment of the upper gastrointestinal tolerance of potential probiotic dairy propionibacteria. *International Journal of Food Microbiology*, *91*, 253–260.

Jamilah, B., Mohamed, A., Abbas, K. A., Abdul Rahman, R., Karim, R., & Hashim, D. M. (2009). Protein-starch interaction and their effect on thermal and rheological characteristics of a food system: A review. *Journal of Food, Agriculture and Environment*, *7*, 169–174.

Johnson, M., & Lucey, J. (2006). Major technological advances and trends in cheese. *Journal of Dairy Science*, *89*, 1174–1178.

Johnson, M. E., Kapoor, R., McMahon, D. J., McCoy, D. R., & Narasimmon, R. G. (2009). Reduction of sodium and fat levels in natural and processed cheeses: Scientific and technological aspects. *Comprehensive Reviews in Food Science and Food Safety*, *8*, 252–268.

Kapoor, R., & Metzger, L. E. (2008). Process cheese: Scientific and technological aspects — A review. *Comprehensive Reviews in Food Science and Food Safety*, *7*, 194–214.

Karimi, R., Azizi, M. H., Ghasemlou, M., & Vaziri, M. (2015). Application of inulin in cheese as prebiotic, fat replacer and texturizer: A review. *Carbohydrate Polymers*, *119*, 85–100.

Karimi, R., Mortazavian, A. M., & Cruz, A. G. (2011). Viability of probiotic microorganisms in cheese during production and storage: A review. *Dairy Science & Technology*, *91*, 283–308.

Karimi, R., Sohrabvandi, S., & Mortazavian, A. M. (2012). Review article: Sensory characteristics of probiotic cheese. *Comprehensive Reviews in Food Science and Food Safety*, *11*, 437–452.

Kiziloz, M. B., Cumhur, O., & Kilic, M. (2009). Development of the structure of an imitation cheese with low protein content. *Food Hydrocolloids*, *23*, 1596–1601.

Kloss, L., Meyer, J. D., Graeve, L., & Vetter, W. (2015). Sodium intake and its reduction by food reformulation in the European Union — A review. *NFS Journal*, *1*, 9–19.

Kumar, R. (2012). *An investigation into improvement of low fat cheddar cheese by the addition of hydrocolloids.* University Of Minnesota.

Lee, S. K., Anema, S., & Klostermeyer, H. (2004). The influence of moisture content on the rheological properties of processed cheese spreads. *International Journal of Food Science and Technology*, *39*, 763–771.

Lerayer, A., Barreto, B. A. P., Waitzberg, D. L., Bacarat, E. C., Grompone, G., Vannucchi, H., et al. (2013). *In gut we trust.* (272 pp.).

Liu, H., Xu, X. M., & Guo, S. H. (2008). Comparison of full-fat and low-fat cheese analogues with or without pectin gel through microstructure, texture, rheology, thermal and sensory analysis. *International Journal of Food Science and Technology*, *43*, 1581–1592.

Lobato-Calleros, C., Reyes-Hernández, J., Beristain, C. I., Hornelas-Uribe, Y., Sánchez-García, J. E., & Vermon-Carter, E. (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 Research International*, *40*, 529–537.

Lollo, P., Cruz, A. G., Moura, C. S., Carvalho-Silva, L. B., Oliveira, C. A., Faria, J. A. F., & Amaya-Farfan, J. (2012). Probiotic cheese attenuates exercise-induced immune suppression in Wistar rats. *Journal of Dairy Science*, *95*, 3549–3558.

Lollo, P. C. B., Morato, P. N., Moura, C. S., Almada, C., Felicio, T. L., Esmerino, E. A., ... Cruz, A. G. (2015). Hypertension parameters are attenuated by the continuous consumption of probiotic Minas cheese. Food Research International, 76. *Part*, *3*, 611–617.

Makras, L., Van Acker, G., & De Vuyst, L. (2005). *Lactobacillus paracasei* subsp. Paracasei 8700: 2 degrades inulin-type fructans exhibiting different degrees of polymerization. *Applied and Environmental Microbiology*, *71*, 6531–6537.

Mensink, M. A., Frijlink, H. W., Maarschalk, K. V. D. V., & Hinrichs, W. L. J. (2015). Inulin, a flexible oligosaccharide I: Review of its physicochemical characteristics. *Carbohydrate Polymers*, *130*, 405–419.

Mercosul (2015). *Acordo n. 02/15 — Recomendações de políticas e medidas regulatórias para a redução do consumo de sódio.*

Merrill, R. K., & Singh, M. (2014). *Blended cheeses and methods for making such cheeses.* (Google Patents).

Meyer, D., Bayarri, S., Tárrega, A., & Costell, E. (2011). Inulin as texture modifier in dairy products. *Food Hydrocolloids*, *25*, 1881–1890.

Miele, N. A. (2013). *Calorie reduction in food: Sensory performance of a new sweetener and fat replacer optimization.*

Miller, G. D., Jarvis, J. K., Jarvis, J. K., & McBean, L. D. (2006). *Handbook of dairy foods and nutrition.* CRC Press.

Mistry, V. V. (2001). Low fat cheese technology. *International Dairy Journal*, *11*, 413–422.

Morais, E. C., Morais, A. R., Cruz, A. G., & Bolini, H. M. A. (2014). Development of chocolate dairy dessert with addition of prebiotics and replacement of sucrose with different high-intensity sweeteners. *Journal of Dairy Science*, *97*, 2600–2609.

Moran, J., Mehnert, D., Galer, J., Reeve, J., Jackson, T., Baldwin, C., & Smith., G. (2006). *Reduced-fat flavor components.* (Google Patents).

Mounsey, J. S., & O'Riordan, E. D. (2008a). Characteristics of imitation cheese containing native or modified rice starches. *Food Hydrocolloids*, *22*, 1160–1169.

Mounsey, J. S., & O'Riordan, E. D. (2008b). Modification of imitation cheese structure and rheology using pre-gelatinised starches. *European Journal of Food Technology*, *226*, 1039–1046.

Mozaffarian, D., Katan, M. B., Ascherio, A., Stampfer, M. J., & Willett, W. C. (2006). Trans fatty acids and cardiovascular disease. *New England Journal of Medicine*, *354*, 1601–1613.

Muir, D. D., Williams, S. A. R., Tamime, A. Y., & Shenana, M. E. (1997). Comparison of the sensory profiles of regular and reduced-fat commercial processed cheese spreads. *International Journal of Food Science and Technology*, *32*, 279–287.

Nagao, K., Wang, Y. -M., Inoue, N., Han, S. Y., Buang, Y., Noda, T., ... Yanagita, T. (2003). The 10trans, 12cis isomer of conjugated linoleic acid promotes energy metabolism in OLETF rats. *Nutrition*, *19*, 652–656.

Newson, R. S., Elmadfa, I., Biro, G., Cheng, Y., Prakash, V., Rust, P., ... Feunekes, G. I. J. (2013). Barriers for progress in salt reduction in the general population. An international study. *Appetite*, *71*, 22–31.

Noronha, N., O'Riordan, E. D., & O'Sullivan, M. (2008). Influence of processing parameters on the texture and microstructure of imitation cheese. *European Food Research and Technology*, *226*, 385–393.

Obesity Society (2015). Obesity in Latin America. (Available at:) http://www.obesity.org/resources/facts-about-obesity/obesity-latin-america (Access: 19/4/2016)

Pereira, C. I., Gomes, A. M. P., & Malcata, F. X. (2009). Microstructure of cheese: Processing, technological and microbiological considerations. *Trends in Food Science & Technology*, *20*, 213–219.

Pérez-Cueto, F. J., Aschemann-Witzel, J., Shankar, B., Brambila-Macias, J., Bech-Larsen, T., Mazzocchi, M., ... Verbeke, W. (2012). Assessment of evaluations made to healthy eating policies in Europe: A review within the EATWELL Project. *Public Health Nutrition*, *15*, 1489–1496.

Pinheiro, M. V. S., & Penna, A. L. B. (2004). Substitutos de gordura: Tipos e aplicações em produtos lácteos. *Alimentos e Nutrição*, *15*, 175–186.

Rastall, R. A., & Gibson, G. R. (2014). Recent developments in prebiotics to selectively impact beneficial microbes and promote intestinal health. *Current Opinion in Biotechnology*, *32*, 42–46.

Reeve, B., & Magnusson, R. (2015). Food reformulation and the (neo)-liberal state: New strategies for strengthening voluntary salt reduction programs in the UK and USA. *Public Health*, *129*, 351–363.

Ritsema, T., & Smeekens, S. (2003). Fructans: Beneficial for plants and humans. *Current Opinion in Plant Biology*, *6*, 223–230.

Roberfroid, M. B., Van Loo, J. A., & Gibson, G. R. (1998). The bifidogenic nature of chicory inulin and its hydrolysis products. *The Journal of Nutrition*, *128*, 11–19.

Robert-McComb, J. J., Bustamante-Ara, N. E., & Marroquin, J. E. A. (2014). Nutritional guidelines, energy balance, and weight control: Issues for the aging active female. *The active female* (pp. 535–554). Springer.

Rogers, N. R., McMahon, D. J., Daubert, C. R., Berry, T. K., & Foegeding, E. A. (2010). Rheological properties and microstructure of cheddar cheese made with different fat contents. *Journal of Dairy Science*, *93*, 4565–4576.

Rolim, P. M. (2015). Development of prebiotic food products and health benefits. *Food Science and Technology (Campinas)*, *35*, 3–10.

Roller, M., Rechkemmer, G., & Watzl, B. (2004). Prebiotic inulin enriched with oligofructose in combination with the probiotics *Lactobacillus rhamnosus* and *Bifidobacterium lactis* modulates intestinal immune functions in rats. *The Journal of Nutrition*, *134*, 153–156.

Roller, S., & Jones, S. A. (2010). *Handbook of fat replacers*. CRC Press.

Ross, R. P., Morgan, S., & Hill, C. (2002). Preservation and fermentation: Past, present and future. *International Journal of Food Microbiology*, *79*, 3–16.

Salek, R. N., Cernikova, M., Maderova, S., Lapcik, L., & Bunka, F. (2016). The effect of different composition of ternary mixtures of emulsifying salts on the consistency of processed cheese spreads manufactured from Swiss-type cheese with different degrees of maturity. *Journal of Dairy Science*, *99*, 3274–3287.

Sarker, M. Z. I., Elgadir, M. E., Ferdosh, S., Akanda, M. J. H., Pingkan Aditiawati, P., & Takahiro, N. (2013). Rheological behavior of starch-based biopolymer mixtures in selected processed foods. *Starch*, *65*, 73–81.

Saulnier, D. M. A., Spinler, J. K., Gibson, G. R., & Versalovic, J. (2009). Mechanisms of probiosis and prebiosis: Considerations for enhanced functional foods. *Current Opinion in Biotechnology*, *20*, 135–141.

Schaafsma, G., & Slavin, J. L. (2015). Significance of inulin fructans in the human diet. *Comprehensive Reviews in Food Science and Food Safety*, *14*, 37–47.

Sołowiej, B., Cheung, I. W., & Li-Chan, E. C. Y. (2014). Texture, rheology and meltability of processed cheese analogues prepared using rennet or acid casein with or without added whey proteins. *International Dairy Journal*, *37*, 87–94.

Sołowiej, B., Glibowski, P., Muszyński, S., Wydrych, J., Gawron, A., & Jeliński, T. (2015). The effect of fat replacement by inulin on the physicochemical properties and microstructure of acid casein processed cheese analogues with added whey protein polymers. *Food Hydrocolloids*, *44*, 1–11.

Strazzullo, P., D'Elia, L., Kandala, N. B., & Cappuccio, F. P. (2009). Salt intake, stroke, and cardiovascular disease: Meta-analysis of prospective studies. *British Medical Journal*, *339*, b4567.

Tamime, A., Saarela, M., Søndergaard, A. K., Korslund, A., Mistry, V. V., & Shah, N. P. (2005). Production and maintenance of viability of probiotic microorganisms in dairy products. *Probiotic Dairy Products*, 39–72.

Tamime, A. Y. (2011). *Processed cheese and analogues*. John Wiley & Sons.

Tamime, A. Y., Muir, D. D., Shenana, M. E., Kalab, M., & Dawood, A. H. (1999). Processed cheese analogues incorporating fat substitutes: Rheology, sensory perception of texture and microstructure. *LWT- Food Science and Technology*, *32*, 50–59.

Taormina, P. J. (2010). Implications of salt and sodium reduction on microbial food safety. *Critical Reviews in Food Science and Nutrition*, *50*, 209–227.

Trivedi, D., Bennett, R. J., Hemar, Y., Reid, D. C. W., Lee, S. K., & Illingworth, D. (2008a). Effect of different starches on rheological and microstructural properties of (I) model processed cheese. *International Journal of Food Science and Technology*, *43*, 2191–2196.

Trivedi, D., Bennett, R. J., Hemar, Y., Reid, D. C. W., Lee, S. K., & Illingworth, D. (2008b). Effect of different starches on rheological and microstructural properties of (II) commercial processed cheese. *International Journal of Food Science and Technology*, 2197–2203.

Tsujii, S., & Shirotani, N. (2015). Cheese-like food article, US Patent 20,150,010,688.

Tungland, B., & Meyer, D. (2002). Nondigestible oligo-and polysaccharides (dietary fiber): Their physiology and role in human health and food. *Comprehensive Reviews in Food Science and Food Safety*, *1*, 90–109.

Uauy, R., Aro, A., Clarke, R., Ghafoorunissa L'Abbé, L. R., Skeaff, C. M., Stender, S., & Tavella, M. (2009). WHO scientific update on trans fatty acids: Summary and conclusions. *European Journal of Clinical Nutrition*, *63*, 68–75.

Van de Wiele, T., Boon, N., Possemiers, S., Jacobs, H., & Verstraete, W. (2007). Inulin-type fructans of longer degree of polymerization exert more pronounced in vitro prebiotic effects. *Journal of Applied Microbiology*, *102*, 452–460.

Vinderola, C., Mocchiutti, P., & Reinheimer, J. A. (2002). Interactions among lactic acid starter and probiotic bacteria used for fermented dairy products. *Journal of Dairy Science*, *85*, 721–729.

Walther, B., Schmid, A., Sieber, R., & Wehrmuller, K. (2008). Cheese in nutrition and health. *Dairy Science and Technology*, *88*, 389–405.

World Health Organization (WHO) (2012). *Guideline: Sodium intake for adults and children*. Geneva: World Health Organization (WHO).

World Health Organization (WHO) (2015). Food and health in Europe: A new basis for action. (Available at:) http://www.euro.who.int/__data/assets/pdf_file/0005/74417/E82161.pdf (Access: 18/4/2016)

Yang, C. Z., Shu, X. L., Zhang, L. L., Wang, X. Y., Zhao, H. J., Ma, C. X., et al. (2006). Starch properties of mutant rice high in resistant starch. *Journal of Agricultural and Food Chemistry*, *54*, 523–528.

Yang, J., Summanen, P. H., Henning, S. M., Hsu, M., Lam, H., Huang, J., & Li, Z. (2015). Xylooligosaccharide supplementation alters gut bacteria in both healthy and prediabetic adults: A pilot study. *Frontiers in Physiology*, *6*, 216.

Ye, A., & Hewitt, S. (2009). Phase structures impact the rheological properties of rennet-casein-based imitation cheese containing starch. *Food Hydrocolloids*, *23*, 867–873.