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Review article

Cheese fortification through the incorporation of UFA-rich sources: A review of recent (2010-2020) evidence

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ABSTRACT

Cheese is a widely consumed dairy product with high saturated fatty acids (SFA) content, and with other high nutritional quality components. Due to the link of SFA and different diseases, many studies have replaced the cheese fat content with unsaturated fatty acids (UFA) rich sources to improve its nutritional quality. The fat replacement has physicochemical, textural, and sensory effects on dairy matrix. To the food science is mandatory to know which technological strategies of milk processing improve the quality of the end products. The most relevant results reveal that fish oil (FO) and flaxseed oil (FSO) have been the most researched UFA-rich sources, microencapsulation has been the most studied incorporation technology because it allows the oil entrapment with minimal effects on the cheese quality, and non-thermal technologies allow greater UFA fortification in cheese, improving its nutritional quality. Finally, the development of fortified cheeses with UFA-rich sources has been found as an innovative strategy to obtain high quality products with functional potential.

1. Introduction

Nowadays, there is an increased interest in the relationship between nutrition and non-communicable diseases, such as cardiovascular disease (CVD), which are the leading cause of death worldwide (World Health Organization, n.d.). Inadequate eating habits, with high consumption of food rich in SFA and sodium, is a modifiable risk factor for the development of these diseases (Billingsley et al., 2018). Therefore, food industry has been using food fortification in order to improve consumer health (El Sohaimy, 2012).

Fortification is the incorporation of bioactive compounds within a food matrix to prevent specific nutrient deficiencies and promote population health (Dwyer et al., 2015), the most used compounds are folic acid, calcium, iron, vitamin A, fiber, antioxidants and UFA (Feizollahi et al., 2018; Mudgil et al., 2016; Rasaie et al., 2014).

UFA have been used to replace SFA in different products, since the high intake of the latter affects health negatively (Briggs et al., 2017; Sakata and Shimokawa, 2013). Omega-3 fatty acids, mainly eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and alpha-linolenic acid (ALA), provided through FO and FSO, are the most commonly used UFA in food fortification (Ganesan et al., 2014).

Different food matrices, such as meat, poultry, eggs, and dairy products, have been fortified with UFA, due to their potential health benefits (Abdelhamid et al., 2018). The incorporation of these fatty acids into dairy matrices has been a topic of wide interest for the food industry, because they are high consumption products, which have great potential to be nutrient vehicles that contribute to health promotion and prevention (Ganesan et al., 2014). Widely consumed products, likely cheese is one of the most studied for fortification with UFA. However, it has been reported that the addition of these bioactive compounds has an effect on the physicochemical, textural, microbiological and sensory characteristics of cheese (Bermúdez-Aguirre & Barbosa-Cánovas Gustavo V., 2011; Farbod et al., 2015). Due to this reason, this article aims to describe the current trend of scientific literature showing the impact of UFA-rich sources incorporation on the technological properties of cheeses.

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2. Methods: search strategy

A search was made in databases indexed in SCOPUS and in ISI WEB OF SCIENCE. Articles were selected on studies focused on technologies used in the fortification of cheeses to improve the profile of fatty acids by modifying fats; this modification had to consist of the total or partial substitution of the milk fat by edible oils and/or lipophilic compounds. The searches included the period from 2010 to 2020 and were limited to original research articles. Review articles, meta-analyses, book chapters, conference papers, short communications, letters to editors, conference articles, and misprints were excluded. Furthermore, we filtered only studies that addressed physicochemical, texture and/or sensory analysis. The keywords and concepts to formulate the search equations in the different databases were: 1. ("functional food*" OR "food fortification" OR "fortification") AND ("dairy product*" OR "cheese*" OR "cheese* analog*" OR "imitation cheese*") AND ("omega-3 fatty acids" OR "omega 3″ OR "essential fatty acids" OR "omega 6″ OR "omega 9″ OR "PUFA*" OR "MUFA*"). 2. ("functional food*" OR "food fortification" OR "fortification") AND ("cheese*" OR "cheese* analog*" OR "imitation cheese*") AND ("low fat*" OR "partial replacement") AND ("functional food*" or "lipid*" or "fatty acid profile"). 3 ("cheese fortification" OR "cheese enrichment") AND ("cheese*") AND ("design" OR "development" OR "manufacture" OR "containing" OR "enrichment") AND ("omega-3 fatty acids" OR "omega 3″ OR "essential fatty acids" OR "omega 6″ OR "omega 9″). A screening was performed to discard articles that did not meet the criteria. After the search was conducted, duplicates were removed. Then titles and abstracts were reviewed. The remaining documents were selected for full-text reviewing.

3. UFA and its potential nutritional benefits, importance of its use in food fortification

Currently, the food industry is looking for solutions to contribute to different public health problems such as the increase of chronic diseases in the population. One of the encountered alternatives is the fortification of foods with bioactive compounds to develop functional products with the aim of preventing the appearance of such diseases.

Fatty acids are biomolecules chemically formed by a carbon chain with a carboxyl group at the end of the molecule. These compounds are classified according to the number of unsaturated bonds present in their carbon chain, dividing it into SFA (without unsaturation) and UFA (with unsaturation). The latter, in turn, are subdivided into monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) (Sokoła-Wysoczańska et al., 2018). Essential fatty acids, such α-linolenic acid (ALA, C18: 3 omega-3), eicosapentaenoic acid (EPA, omega-3), docosahexaenoic acid (DHA, omega-3), and linoleic acid (LA, C18: 2, omega-6), cannot be synthesized by human body; therefore, they must be obtained from the diet (Sąsiadek et al., 2018; Spector and Kim, 2015). While the main EPA and DHA food sources are tuna and salmon (Tur et al., 2012), for ALA are plant sources such as dark green leafy vegetables, FSO, among others (Orsavova et al., 2015). Recent studies have shown that the intake of FSO could contribute to the atherosclerosis prevention (the main cause of CVD), this related to a decrease in oxidative stress and systemic inflammation (Han et al., 2015). Evidence shows that ant intake greater than 2g of EPA and DHA/day has an effect in the reduction of arterial hypertension (Miller et al., 2014), triglycerides profile, and improvement of vascular function (Casanova et al., 2017; Preston Mason, 2019; Skulas-Ray et al., 2011). In other hang, an excessive consumption of LA increases the production of eicosanoids proinflammatory which increase the risk of thrombus and atheroma formation, the development of allergic and inflammatory disorders and the adipocytes proliferation, increasing the risk of obesity (Simopoulos, 2010). To prevent the development of chronic diseases, such as CVD, it is recommended to consume foods that provide omega-6 and omega-3 in an ideal ratio of 2:1 (Simopoulos, 2008, 2016).

Oleic acid, present in plant sources such as olive oil, avocado, and legumes, has been related with the reduction of CVD risk. It not only improves the endothelial function and the serum lipoprotein profile in patients with hypercholesterolemia, but also modulates inflammation and oxidative stress (Sales-Campos et al., 2013).

It can be clearly seen that the high mortality rate from cardiovascular diseases worldwide, and the great importance that its prevention has for public health, the European Food Safety Authority (EFSA) has established nutritional and health claims that allow a food to be classified based on its UFA content in order to make conscious choices that promote cardiovascular health (Turck et al., 2018). Main health claims related to UFA stablished by the EFSA are focused on ALA, and the proposed health benefit for this nutrient is the blood cholesterol regulation, according to the Article 13 of Regulation (1924)/2006 (European Parliament and Council, 2006). They propose three health claims related to this fatty acid: "Alpha-linolenic acid (omega 3) contributes to a healthy level of cholesterol in the blood", "Alpha-linolenic acid (omega 3) helps maintain a healthy cholesterol level in blood "," Alpha-linolenic acid (omega 3) helps to maintain the normal level of cholesterol in the blood ", and they establish specifications to be able to use this health claims, as shown below: The product must contain a significant amount of ALA (2–4 g, 1–2% of energy), the total fat content of the product must be at least 10%, the amount of UFA must be at least 70% of the total fat, the product must contain at least 0.3% ALA (w/w), and 0.3 g of ALA per 100 kcal (Panel and Nda, 2009).

4. Cheese as a food matrix for the UFA inclusion

The inclusion of unsaturated fatty acids sources, such as vegetables oils, in commonly consumed foods has become a good opportunity to increase the UFA intake and thus obtain the benefits they bring to human health. The use of dairy products as a means of transporting active compounds provides greater added value to its already recognized high nutritional quality (Lacroix et al., 2013). For example, several studies have been carried out fortifying different types of cheese by including vegetable oils in order to improve their nutritional quality by modifying their lipid profile (Achachlouei et al., 2013; Bermúdez-Aguirre & Barbosa-Cánovas Gustavo V., 2011; Ullah et al., 2018). Through these fortified products, the consumption of UFA can increase preventing different diseases in the population such as CVD (Han et al., 2015). Cheese is the product obtained from the precipitation of mammal milk casein, through an acid, enzymatic or mixed coagulation, which leads to whey separation and curd formation (Hill and Kethireddipalli, 2013). Therefore, this product concentrates the protein, fat and minerals of milk approximately ten times (Tunick, 2015). Cheese generally contains more than 20% fat, mainly composed of SFA (more than 60%), followed by UFA (MUFA and PUFA) (Manuelian et al., 2017). The main trans fatty acid present in cheese and dairy products is C18:2, cis-9, trans-11, an isomer of rumenic acid, a type of conjugated linolenic acid (CLA) produced through the microbial bio-hydrogenation of linoleic acid and in the rumen of cows, which has potential health benefits (Yang et al., 2015). Therefore, the fortification of cheeses with unsaturated fatty acids makes them an interesting alternative for healthy eating. The most studied for UFA fortification are fresh, cheddar and mozzarella cheeses (Bermúdez-Aguirre and Barbosa-Cánovas, 2014). Cheese fat has technological implications in the product. It contributes to the sensory quality because most of the volatile compounds that allow its characteristic flavor are fat-soluble. Also, the rheological and textural properties of cheese are influenced by the casein network, in which fat globules are important structural components along with minerals, bacteria and solutes such us lactose, lactic acid, soluble salts and peptides. Hence, the importance of the fat content (Lamichhane et al., 2018).

As can be seen, including UFA in a mass consumption food such cheese can be an effective strategy to achieve the dietary allowance of UFA, mainly those that are essential and promote health. Namely in western culture, in where the intake of fish and vegetable unrefined oils is not part of the lifestyle, hence functional dairy food market have risen in the last decade (Bimbo et al., 2017). With this panorama, because cheese has an interesting nutritional profile regarding fatty acid profile, and is widely well accepted by consumers, cheese seems to be an interesting system delivery of bioactive lipids.

5. Technological strategies of UFA fortification in cheeses

The inclusion of different UFA-rich vegetable and animal sources has been researched in fortified cheese processing. The most studied sources are FO, seed oils and legumes, with FSO and peanuts as the most researched, and other studies have used different oils such as olive, canola, soy, chia, palm, and corn oil.

In food fortification, the nature and form of the compounds used to enrich the matrix must be considered. It is also important to ensure the stability of the bioactive compounds even during storage, reduce the effects on the physicochemical, textural and sensory properties of the cheese and that the delivery of the active ingredients takes place in the gastrointestinal tract. Therefore, the development of techniques to increase the retention of bioactive ingredients in the cheese matrix is a challenge for the cheese industry (Lacroix et al., 2013). Several factors can affect UFA retention; for example, the oil incorporation strategy, microencapsulation being the technique with which the best retention of UFA in the cheese is obtained. The type of cheese and the stage of inclusion of UFA during cheese making also influence the retention of UFA and the sensory properties of the product (Bermúdez-Aguirre & Barbosa-Cánovas Gustavo V., 2011; Bermúdez-Aguirre and Barbosa-Cánovas, 2012).

Different incorporation strategies of UFA-rich sources have been studied in fortified cheeses production to improve the final fatty acid profile of the product. The most researched strategies for incorporating UFA-rich sources in cheeses are addition through cow feeding, direct incorporation of oils, and oil emulsions encapsulation. Table 1 summarizes the technological approach in cheese fortification with UFA in the last decade.

5.1. Fortified cheese obtained from the milk of cows fed with improved raw material: strategy of feeding the cows

The dairy industry is interested in improving the nutritional quality of their products using different milk fortification strategies. The inclusion of ALA-rich seeds or the addition of FO in cows feeding has been researched to improve the nutritional quality of milk and dairy products (Gebreyowhans et al., 2019). Different studies have evaluated the addition of extruded seeds in cattle feed, to fortify the milk used in cheese processing.

For example, Oeffner et al. (2013) supplemented the cows feeding with extruded flaxseed, to obtain fortified milk and process mozzarella cheese. The authors found that a supplementation up to 2.72 kg/day of extruded flaxseed increases ALA content in mozzarella cheese and promotes the textural characteristics of the product. Cattani et al. (2014) also used extruded flaxseed to supplement animal feed to improve the nutritional composition of milk for ripened cheese production. They evidenced an improvement in the fatty acid profile and an increase in the omega-3 fatty acids proportion of the cheese, with an inclusion of 500 g/day of extruded flaxseed in cows feeding.

Olive oil have also been used to supplement cows feeding. Vargas-Bello-Pérez et al. (2018) supplemented animal feed with unrefined olive oil and hydrogenated vegetable oil to obtain fresh milk for a chanco-type cheese processing. The researchers found that the cow's feed supplementation improved the fatty acid profile of the cheese, reducing the total SFA and increasing total MUFAs and total PUFAs in cheeses, however, negative effects on the sensory characteristics of the product were found.

According to the consulted databases, one study of cow's milk supplemented with FO for cheddar cheese production was found. Mohan et al. (2013) supplemented the cows feeding with FO (0,99 g de CLA/100 g de fatty acids) to manufacture cheddar cheese, the outcomes revealed a cheese with up to 2.6 times greater CLA content compared to control sample (2.61 g of CLA nonproducing starter culture/100 g of FA), showing an enhancement of the cheese nutritional quality. However, the age of the cheese affected the sensory properties.

The previous findings reported indicate that the feeding of dairy cows with diets supplemented with fish oil, extruded flaxseed and olive oil residues can be used to improve the fatty acid profile of dairy products. Nevertheless, studies are needed to improve the adverse effects on the sensory characteristics of cheeses.

5.2. Cheese fortification by direct incorporation of oils and oils emulsions

Several oil types, of vegetable and animal origin, have been applied to cheeses to improve the quality of final products. The most used UFA-rich animal source in fortified cheeses is FO. Also, fresh cheese is the most researched type of cheese fortified with FO, followed by cheddar and mozzarella (Bermúdez-Aguirre & Barbosa-Cánovas Gustavo V., 2011; Bermúdez-Aguirre and Barbosa-Cánovas, 2012; Calligaris, Gulotta, Ignat, Bermúdez-Aguirre, et al., 2013; Hejazian et al., 2016). The main benefit of FO inclusion in cheeses is the improvement in their EPA and DHA content, nutrients not available in a normal cheese. However, Ye et al. (2009) found that the addition of 5% of FO in the formulation off a processed cheese increased lipid oxidation and the presence of fishy flavors in the product. Whereas when MFO was incorporated, there have been reported an upward trend in sensory acceptance of cheese (Hejazian et al., 2016; Martini et al., 2009).

On the other hand, Achachlouei et al. (2013), fortified white cheese brine with olive and canola oil, using a 50% and a 100% level of milk fat replacement. They found an increase in moisture content and a decrease in fat content at the 80th day of storage. The increase in moisture content could be attributed to the high protein content, since this favors the water-holding capacity, while the high moisture content increases the enzymatic activity and microbial growth, which promotes lipolysis and consequent fat reduction. In this study, an adequate sensory acceptance of cheeses with a 100% milk fat replacement was verified. These results agree with those found by Felfoul (2016), regarding fat and moisture content, and lipolysis level, whom added an emulsion composed by olive oil and stabilizers to white cheese. unfortunately, the sensory acceptance was fewer compared to the unfortified cheese.

However, to increase the oil retention, the inclusion of surfactants agents such as soy protein has been studied. Totosaus et al. (2017), incorporated an emulsion of soybean oil, soy protein, and different types of carrageenan in an Oaxaca-type cheese (white and soft cheese of Mexican origin). The authors found a higher moisture and protein content and a lower fat content with a milk fat replacement greater than 75%. In addition, the emulsion incorporation increased the cheese hardness, especially with a milk fat replacement between 25 – 50%. Nonetheless, the authors found that, a 75% milk fat replacement using λ-carrageenan, improved the composition and textural characteristics of the cheese. Elseways, Arslan et al. (2010) found similar results regarding the moisture, fat, and protein content, and in texture properties of a Turkish white cheese fortified with a blend of interesterified vegetable oils. The oil blend contained palm oil, palm kernel Oil and soybean oil. The authors found an increase in the hardness of cheeses fortified with different oil inclusion s, being hardness an undesired characteristic in these types of cheeses.

Table 1. Physicochemical, textural, and sensory effects of the inclusion of different sources of unsaturated fatty acids into cheeses.

UFA target	Type of cheese	UFA source	Fortification Doses	Incorporation strategy	Effects on cheese matrix	References
PUFA	Chanco-style cheese	Olive oil and hydrogenated vegetable oil	OO or HVO: 30 g kg^{-1} DM	Cow feeding	*OO supplementation:* ↓ fat content and SFAs ↑ PUFAs and MUFAs ↓ AI and TI ↓ Holes, overall odor, and acidity of cheeses. *HVO supplementation:* ↑ Cow milk odor, bitterness, and acidity *OO and HVO* ↑ Salty flavor	(Vargas-Bello-Pérez et al., 2018)
CLA and omega-3	Ripened cheese	Extruded flaxseed	500 and 1000 g per day	Cow feeding	↓ C16:0, ↑ C8:0 and C18:0 The MUFA concentration was not affected. ↑ C18:3 and of total omega-3. ↑ C18:3n-6 ↓omega-6: omega-3 ratio.	(Cattani et al., 2014)
CLA	Cheddar cheese	FO	0.75% of the diet DM	Cow feeding	↑ Total CLA, C18:1, Trans-10, and trans-11 ↓ SCFAs and ↑ LCFAs ↑ UFA and ↓ SFA ↑ 18:3n-3 No variation was observed in fat, protein, fat in DM, and pH based on the type of milk used for the cheeses production. ↑ 2.1 times total CLA in treatment cheese compared after 1 month of ripening.	(Mohan et al., 2013)
Omega-3	Mozzarella	Flaxseed	Extruded Flaxseed: 0.91, 1.81, and 2.72 kg per day Ground Flaxseed: 1.81 kg per day	Cow feeding	↓ SFA and ↑ MUFA and PUFA ↓ SFA and atherogenic FA ↑ PUFA and MUFA Processing of flaxseed did not significantly affect cheese FA composition.	(Oeffner et al., 2013)
Omega-3	Cheddar cheese	Chia oil	2.5, 5, 7.5, and 10% (w/w)	Direct incorporation	Moisture, fat, and protein contents of all the treatments and control were not different from each other. ↓ SCFAs and MCFAs ↑ UFA and Phenolic content. ↓ Sensory score in 10% of chia oil incorporation.	(Ullah et al., 2018)
Omega-3	White cheese	FSO	1.27 % (w/w)	Direct incorporation	The best stage for fortification was during homogenization ↓ Moisture content. ↑ TBARS at the end of storage time.	(Gurdian et al., 2017)
Omega-9	White Soft Cheese	Peanut oil	4% (w/w)	Direct incorporation	↑ Oleic acid. ↓ Oil loss when stabilizer was added. ↑ Antioxidant activity of cheeses. Sensory quality of cheese fortified improved when a stabilizer was added.	(Khalifa et al., 2017)
MUFAs	Caciocavallo-like-cheese	Peanut sprout	0,5% (w/w)	Direct incorporation	↑ Moisture, total phenol content SCFAs content were not significantly different. ↓ Hardness, gumminess, and chewiness	(Ko et al., 2017)

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Table 1 (*continued*)

UFA target	Type of cheese	UFA source	Fortification Doses	Incorporation strategy	Effects on cheese matrix	References
					↑ Peanut sprout aroma and peanut sprout ↑ Sensory hardness	
Omega-3	Oaxaca-type cheese	SBO	25, 50 and 75% (w/w)	Direct incorporation	↑ Moisture and yield content ↑ Hardness, and ↓ cohesiveness ↑ Melt area, and adhesiveness 75% inclusion enhance nutritional profile.	(Totosaus et al., 2017)
MUFAs	White brined cheeses	Olive oil	3% (w/w)	Direct incorporation	No significant differences between cheeses pH ↓ Total solids, and cheese yield ↑ Protein content, and lipolysis index ↓ Sensory acceptation	(Felfoul, 2016)
Omega-3	Fresh cheese	FO FSO	1% (w/w)	Direct incorporation	↑ Cheese yield and fatty acid profile. ↓ Oil loss and ↑ emulsion stability with the use of saturated MG. Fortified cheese with saturated MG: preserves the texture and ↑ the viscosity.	(Calligaris et al., 2015; Calligaris, Gulotta, Ignat, Bermúdez, et al., 2013)
PUFA	Turkish white cheese	Corn oil	1, 1.5% (w/w) with or without 1% of milk fat.	Direct incorporation	↑ Protein content and salt matter The ripening period had an important effect on cheese texture regardless of the treatment. ↑ Hardness in 1% and 1.5% (100% milk fat replacement) compared to the other treatments. ↑ PUFAs and total cis fatty acid; ↓ SFAs and trans fatty acid content, compared to control. ↓ Cholesterol 1% and 1.5% (100% milk fat replacement) compared to the other treatments. Corn oil addition can solve the milk fat reduction sensory problems.	(Arslan et al., 2012)
Omega-3	Functional Iranian white brined cheese	Olive oil Canola oil	50 and 100 % (w/w)	Direct incorporation	↑ Moisture content and lipolysis. ↓ Fat content during ripening ↑ PUFAs ↓SFAs ↑ Acceptability, better taste, texture, flavor, and appearance.	(Achachlouei et al., 2013)
PUFA	Turkish white cheese	Interesterified fat of palm, palm kernel, and soybean oil	1, 1.5% (w/w) with or without 1% of milk fat.	Direct incorporation	↑ Moisture and salt content compared to control. ↑ PUFAs to SFAs ratios due to the presence of interesterified fat. ↓ Cholesterol ↑ Hardness, chewiness, and gumminess ↓ Sensory acceptation.	(Arslan et al., 2010)
EPA/DHA	Reduced-fat UF-Feta cheese	FO MFO	FO: 0.4% (w/w) FOP: 1.5% (w/w)	Direct incorporation and microencapsulation	↓ pH during 60 days of storage. ↑ PV during storage. ↑ hardness with FO ↓ the number of pores with FOP samples ↑EPA and DHA The FOP led to have a more	(Farbod et al., 2015)

(*continued on next page*)

Table 1 (*continued*)

UFA target	Type of cheese	UFA source	Fortification Doses	Incorporation strategy	Effects on cheese matrix	References
					compact texture of cheese. The sensory panel scores of FO fortified cheese were significantly higher than FOP fortified sample.	
Omega-3	Fresh cheese, cheddar, and mozzarella	FO MFO FSO FSP	1% (w/w)	Direct incorporation and microencapsulation	The best stage for fortification in fresh cheese was after pasteurization, while for cheddar cheese was during salting and for mozzarella was during curdling. Allowing ↑ omega-3 retention. Fortification with FO lengthens the shelf life using novel non-thermal technologies With FSO ↓ omega-3 retention, ↓ moisture, ↑ hardness, and ↓ in chewiness and fracturability. Aroma and flavor were preferred in the control sample and the cheese fortified with FSO compared to the cheese fortified with FO and MFO.	(Bermúdez-Aguirre & Barbosa-Cánovas Gustavo V., 2011; Bermúdez-Aguirre and Barbosa-Cánovas, 2012)
EPA/DHA	Fresh cheese	FO	5 % (w/w)	Microencapsulation	Stable pH, solid matter, protein, and fat content. ↑EPA and DHA Masking of the odor and taste attributes of FO.	(Hejazian et al., 2016)

Abbreviations: AI: Atherogenic index; CLA: conjugated linoleic acid; DM: Dry matter; DMI: Dry matter intake; FA: fatty acids; FO: Fish oil; FSO: Flaxseed oil; FSP: flaxseed powder; HVO: hydrogenated vegetable oil; LCFA: long-chain fatty acids; MCFAs: medium-chain fatty acids; MFO: Microencapsulated fish oil; MG: Monoglyceride; MUFA: monounsaturated fatty acids; OO: olive oil; PUFA: polyunsaturated fatty acids; PV: peroxide value; SBO: Soya bean oil; SCC: somatic cell count; SCFA: short-chain fatty acids; SFA: saturated fatty acids; TBARS: Thiobarbituric acid reactive substances; TI: thrombogenic index; UFA: unsaturated fatty acids.

Milk fat replacement with vegetable oils has aimed to improve the fatty acid profile of cheese. Ullah et al. (2018) fortified cheddar cheese with chia oil, finding a decrease in cholesterol content and an increase in ALA fatty acid. Regarding sensory quality, the authors found that there is an adequate acceptance of the fortified cheese compared to the unfortified product regarding odor and flavor attributes, when total cheese fat content is composed by 7.5% of chia oil and 92.5% of milk fat. On the other hand, Arslan et al. (2012) also found a fatty acid profile improvement on a Turkish white cheese fortified with corn oil compared to a control cheese, evidencing an increase in the ratio of PUFA/SFA, and a decrease in cholesterol content. In addition, a reduction in fat content was evidenced, with a rocket behavior of moisture content. In sensory analysis, it was found that ripened white cheeses fortified with corn oil have similar acceptance to a control cheese on the 60th ripening day, except the cheese fortified with 1% corn oil, representing an advantage over traditional cheeses.

Legumes are UFA-rich sources with great potential to be included in the cheese matrix, due to their MUFA content. Cheeses with addition of peanuts have been developed through nanoencapsulation. For example, Ko et al. (2017) used nanopowdered peanut sprout to fortify Caciocavallo cheese. The powder particles had a diameter between 73 and 640 nm with an average particle size of 300–350 nm. The authors found physicochemical changes in the fortified cheese, including an increase in the moisture content. This effect was attributed to the water-holding capacity of the nanopowdered peanut sprout, which is related to its particle size, allowing greater exposure to hydrophilic components. The textural characteristics of the fortified product were slightly affected with the inclusion of the nano-powder, evidenced in a decrease in cohesiveness and elasticity. Regarding sensory quality, the authors found that acceptance is achieved without off-flavors perception with an inclusion of less than 0.5% m/v of nanopowdered peanut sprout.

On the other hand, direct addition of the peanut oil has also been studied. Khalifa et al. (2017), incorporated peanut oil with different emulsifying agents (a blend of mono and diglycerides of fatty acids with whey protein powder and a blend of mono and diglycerides of fatty acids with guar gum, sodium carboxymethyl cellulose and xanthan gum) in a soft white cheese. The authors evidenced that the addition of 4% of peanut oil together with 1% of blend of mono and diglycerides, guar gum, sodium carboxymethyl cellulose and xanthan gum as stabilizers, resulted in less fat loss in whey and greater fat retention in the cheese. When fortified with the same proportion of peanut oil, but using the blend of mono and diglycerides and whey protein powder as stabilizers, there was a decrease in the peroxidation value and an increase in sensory acceptance, showing that the use of stabilizers blends promotes the sensory quality of the product.

5.3. UFA-rich oils encapsulation for cheese fortification

Encapsulation is an oil incorporation technology used in food fortification, it is based on the entrapment of an active compound (solid, liquid, or gas) inside an encapsulating agent (Nedovic et al., 2011), in order to form a capsule with a particle size determined, allowing a greater retention of the microencapsulated compound and its controlled release into the medium, along with a reduction of the interactions between flavor compounds that negatively affect the quality of the product (Gupta et al., 2016). This technology allows a better handling of the bioactive compound, promoting the system stability, improving the textural and sensory characteristics of the product (masking the off flavors), controlling the release of the active agent to the medium, delaying lipid oxidation, among other technological advantages (Kaushik et al., 2015; Zuidam et al., 2010).

Omega-3 fatty acids are susceptible to oxidation, which produces off-flavors in foods. Therefore, it is necessary to encapsulate them before their incorporation into the dairy matrix to avoid degradation and minimize interactions with other components present in food during processing and storage (Lacroix et al., 2013). For the microencapsulation of the bioactive molecules, simple emulsions, multiple emulsions multilayer emulsions and coacervates and gel particles have been used; emulsions being the most studied for their ability to stabilize the bioactivity of hydrophilic or hydrophobic molecules (Lacroix et al., 2013).

Gurdian et al. (2017) evaluated the quality of the cheese by incorporating flaxseed oil (FSO) to the white cheese in different stages of cheese making (homogenization, coagulation, and salting). After storage at 8 °C to 30 days, it was found that the best results were obtained in the homogenization stage, although a greater lipid oxidation was observed, this increase did not exceed the limit allowed for good quality food. The lowest yeast and mold counts were also obtained, excessive dehydration was avoided, and a significantly higher lipid content than the control white cheese. This indicates that in the homogenization stage the emulsion is more stable. Calligaris et al., 2013 made *queso fresco*, a soft and fresh Hispanic cheese, enriched with omega-3 fatty acids of animal (FO) and vegetable origin (FSO). The addition of fatty acids was carried out in the milk homogenization stage but applying high pressure (20–100 MPa). It was found that at pressures above 50 MPa, omega-3 fatty acids are efficiently incorporated into cheese and the amount of oil lost in the whey is reduced, higher humidity and yield and lower fat content were obtained. The decrease in the sensory attributes of the cheeses was attributed to the high pressure and not to the source of fatty acids. By applying high pressure during the homogenization stage, micro- and nano-scale droplet-containing emulsions are produced. Consequently, this is one of the most effective technologies for obtaining stable emulsions. Therefore, the addition of UFA in the homogenization stage, applying high pressures, is an interesting option for the fortification of cheeses, paying special attention to the sensory properties of the dairy product. This and other new non-thermal technologies such as the application of pulsed electric fields and ultrasound, have shown important results in the production of new ingredients, and the dairy industry, such as reducing microbial loads and increased shelf life of milk and dairy products. A change in casein micelles or fat globules has been observed during milk processing when using these technologies (Bermúdez-Aguirre and Barbosa-Cánovas, 2012). Calligaris et al., (2013) also added 18% of emulsions composed by saturated monoglycerides and FO to milk before fresh cheddar cheese processing, finding a decrease in the fat loss in whey, an increase in the viscosity and stability of the system, and textural characteristics of the product similar to those of a traditional cheese, constituting an advantage for a fortified product.

As is presented, seems to be necessary to apply a technology that allows oil entrapping, or the addition of antioxidant compounds that decrease the oxidation of UFA fatty acids. The immobilization of active compounds by using materials to coat small oil droplets, forming polymeric complexes, prevents the oxidation of fatty acids because of light, oxygen, humidity, and other environmental conditions. It also protects the bioactivity of the oil and ensures high availability in the food product during processing, distribution, and storage. The most studied polymeric materials are pectin, alginate and whey protein (Bermúdez-Aguirre and Barbosa-Cánovas, 2012; Lacroix et al., 2013).

Bermúdez et al. (2011) found that 1 g of microencapsulated FO (MFO) in 100 g of cheese allowed a better retention of EPA and DHA compared to the direct oil addition, since a better emulsion stability was obtained. In other research, the same authors determined that the retention of EPA and DHA could be affected depending on the step at which MFO is incorporated during cheese manufacturing. When MFO is added after pasteurization in fresh cheese making, it achieved higher EPA and DHA retention; whereas in cheddar cheese, the best moment for its addition during processing is at the salting stage and, for mozzarella cheese, the best moment is at curdling (Bermúdez-Aguirre and Barbosa-Cánovas, 2012). Despite the advantages of microencapsulation, other authors have reported the need to apply additional strategies for masking unwanted flavors, such as adding other ingredients to the product. For example, Farbod et al. (2015) evaluated the fortification with 15g of MFO powder and 4g of liquid FO per kg of milk to produce feta cheese, both with cumin powder, evidencing a greater sensory acceptance by consumers.

6. Conclusions

Cheese fortification with UFA-rich sources promotes the nutritional quality of the product by upgrading its fatty acid profile. The principal health claims related are focused on cardiovascular health care. Animal and vegetables oils are the novel sources of these compounds; however, its incorporation represents a challenge for their effects on the physicochemical, texture and sensory properties of cheeses. Therefore, according with the cheese type the inclusion stage its crucial to allow more oil retention in the final product. Special attention must be given to the fact that omegas-3 are susceptible to oxidation, which has negative effects on the sensory properties; mainly fish oil producing undesirable effects on cheese flavor quality, being the sensory acceptation by consumer a critical point.

The fortification of the feeding of the cows lets to an improvement of the fatty acid profile of the raw material, the most investigated source is flaxseed, because it provides ALA to the milk. This strategy may perhaps be more advantageous, since the less raw material manipulation the few cheese contamination. Nonetheless must studies be carried out to describe sensory quality and feasibility in an industrial scale.

Direct incorporation of oils and oils emulsions are the most studied fortification strategy, though the increasing of fat losses is one of the issues, meanwhile oil retention is affected by the fatty acid profile, the ripening and the storage time. Many factors must be monitored to prevent the main undesirable effect: the increase in lipid oxidation. Hence microencapsulation is an alternative to protect the oil from oxidation. For vehicles such, fresh cheese, cheddar and mozzarella, the microencapsulation seems to be the option to avoid lipid oxidation, mainly when fish oil is added. Moreover, non-thermal milk processing technologies, must be more explored. High-pressure homogenization is promising since has shown to increase omega-3 retention in fresh cheese and cheddar cheese fortified with flaxseed oil.

The cheese fortification process represents a challenge for the dairy industry and public health. Even So, it is essential to investigate the benefits of these cheeses on the health of the population, since to date there have been not clinical studies that support the functional potential of UFA-fortified cheeses.

Declarations

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