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Effect of dairy powders fortification on yogurt textural and sensorial properties: a review

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Yogurts are important dairy products that have known a rapid market growth over the past few decades. Industrial yogurt manufacture involves different processing steps. Among them, protein fortification of the milk base is elemental. It greatly enhances yogurt nutritional and functional properties and prevents syneresis, an undesirable yogurt textural defect. Protein enrichment can be achieved by either concentration process (evaporation under vacuum and membrane processing: reverse osmosis and/or ultrafiltration) or by addition of dairy ingredients. Traditionally, skim milk powder (SMP) is used to enrich the milk base before fermentation. However, increased quality and availability of other dairy ingredients such as milk protein isolates (MPI), milk protein concentrates (MPC) whey protein isolates (WPI) and concentrates (WPC), micellar casein (MC) and caseinates have promoted their use as alternatives to SMP. Substituting different dry ingredients for skim milk powder in yogurt making affects the yogurt mix protein composition and subsequent textural and sensorial properties. This review focuses on various type of milk protein used for fortification purposes and their influence on these properties.

Keywords: Yogurt, dairy powder addition, fermentation, textural, sensorial properties.

Abbreviations: MPC, Milk Protein Concentrate; SMP, Skim Milk Powder; WP, Whey Powder; WPC, Whey Protein concentrate; WPI, Whey Protein Isolate; MC, Micellar Casein; NaCn, Sodium Caseinates; CaCn, Calcium Caseinate.

Yogurt is a very popular fermented dairy product widely consumed all over the world (Lucey & Singh, 1998; Verman & Sutherland, 2004; Peng et al. 2009). Three major types are found: drinking, set and stirred yogurt. The typical yogurt manufacturing process changes milk properties in an irreversible way and consists of different processing steps (Fig. 1). First, the milk base fat content is standardised to the desired level by mixing cream and skim milk powder (Sodini & Béal, 2003; Lee & Lucey, 2010). Afterward, the non-fat total solid content is traditionally increased to achieve a protein concentration between 40–50 g/kg (Sodini et al. 2005). Fortification of the milk base is one of the most important steps that enhances functional and nutritional properties and prevents textural defects such as poor gel firmness and syneresis as assessed by sensory evaluations and instrumental measurements (Dave & Shah, 1998; Schkoda et al. 2001; Sodini & Béal, 2003; Séverin & Wenshui, 2005; Marafon et al. 2011). Dry matter fortification can be achieved by either concentration process (evaporation under vacuum) followed by membrane processing (ultrafiltration or reverses osmosis) or by the addition of dairy ingredients including skim milk powder (SMP), whey proteins, caseins and caseinates (Tamime & Robinson, 2000; Sodini & Béal, 2003; Damin et al. 2009; Peng et al. 2009). The fortified milk is then homogenised at 10–20 and 5 MPa at first and second stage respectively with a temperature ranging between 55 and 65 °C (Lee & Lucey, 2010). This processing step generates fat globules with new surface layer formed by the caseins and whey proteins thus increasing the number of possible structure-binding components in yogurt products (Lee & Lucey, 2010). The milk base is subsequently submitted to a drastic heat treatment. In fact, it is usually heated at 85 °C for 30 min, at 90–95 °C for 5–10 min or at 115 °C for 3 s (Sodini & Béal, 2003). Heat treatment causes

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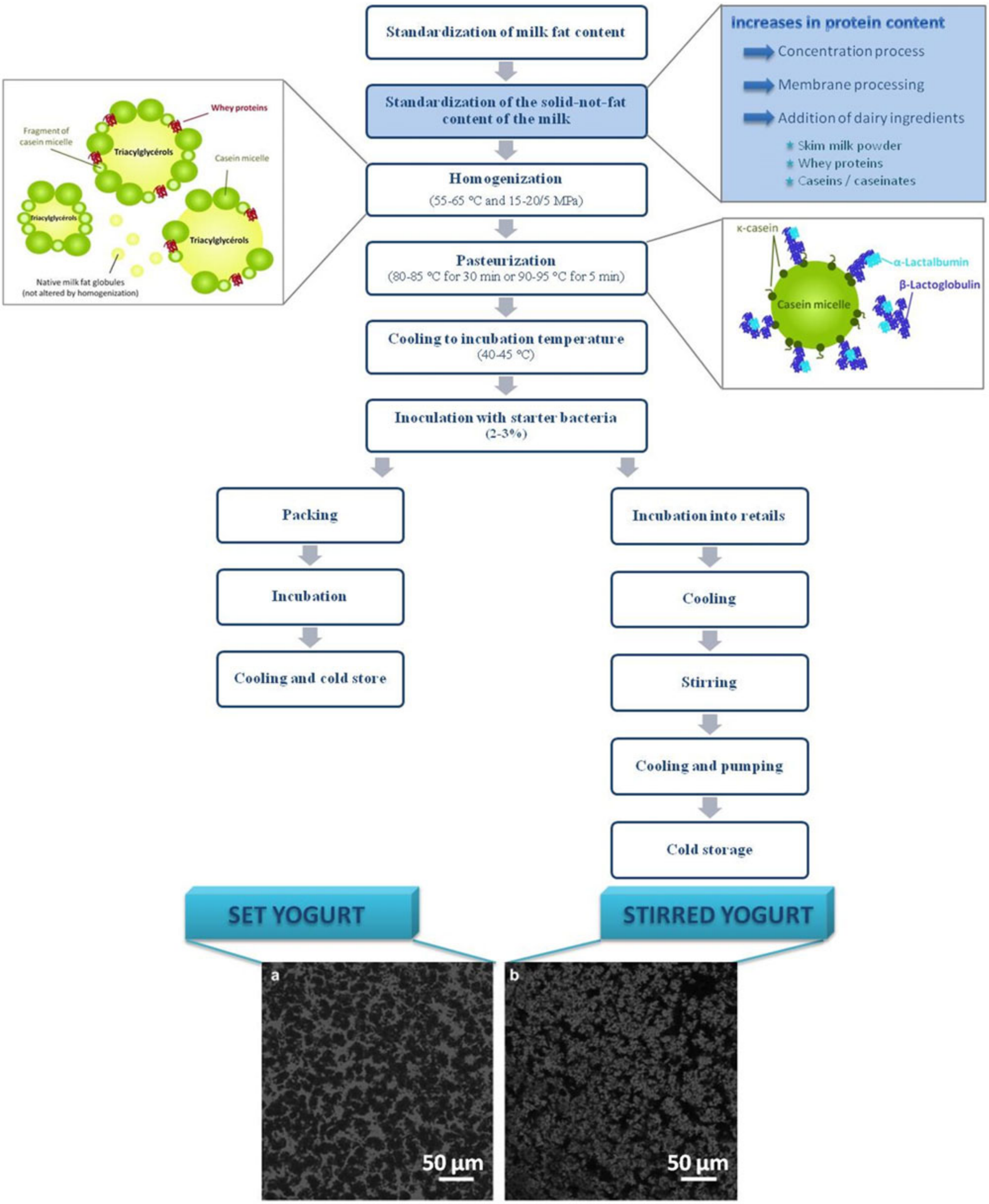

Fig. 1. Main processing steps of the two majors yogurt types: set and stirred yogurt (adapted from Sodini & Béal, 2003; Lee & Lucey, 2010; Pesic et al. 2012; Berton-Carabin et al. 2013). Confocal scanning electron microscopy images are taken from Corredig et al. (2011).

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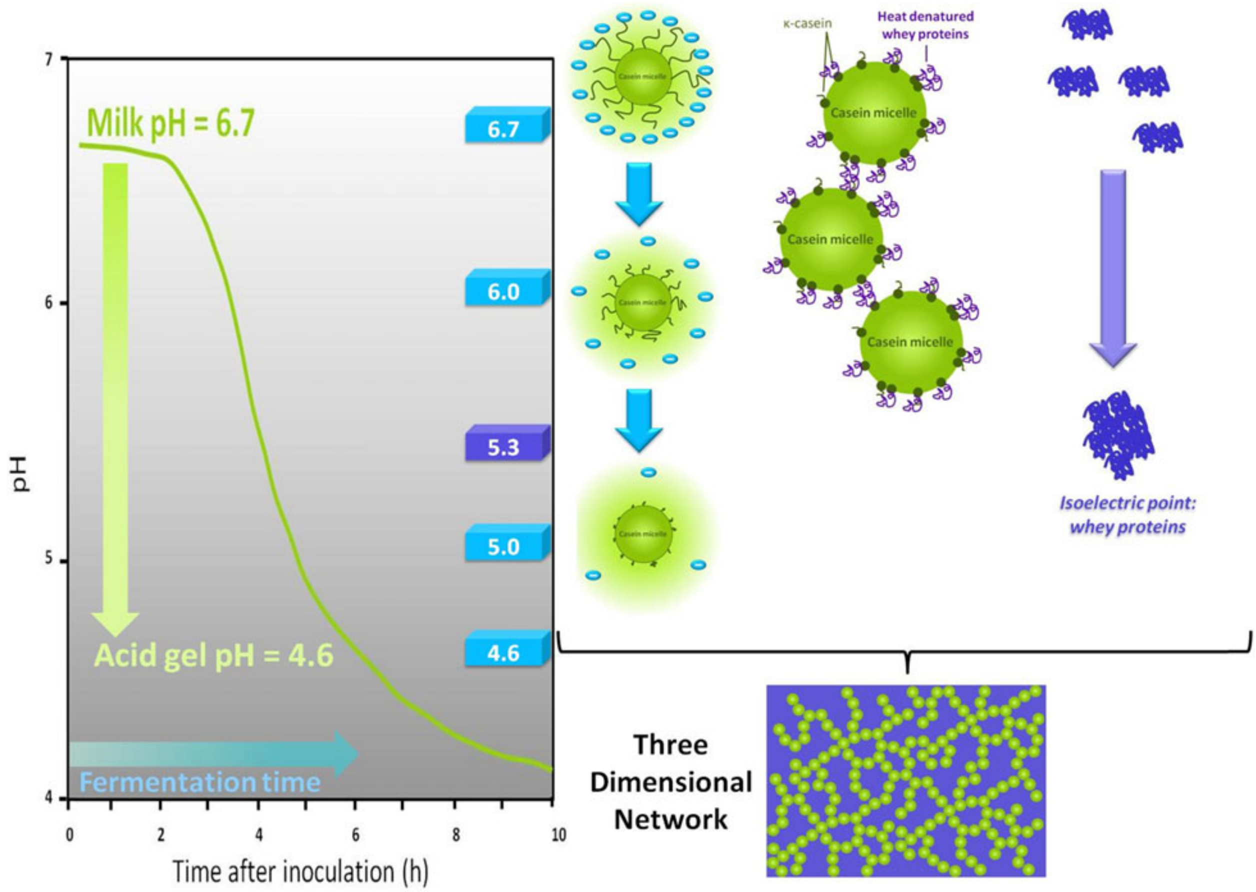

Fig. 2. Typical pH profiles during the fermentation process of yogurt (adapted from De Brandere & De Baerdemader, 1999).

whey protein denaturation and complex formation (whey protein–whey protein or whey protein–casein micelles) through disulphide bonding, which initiates gelation (Ozer et al. 1998; Vasbinder et al. 2001; 2004; Lakemonda & van Vliet, 2007; Lee & Lucey, 2010; Matumoto-Pintro et al. 2011). Subsequently, the milk base is cooled to the incubation temperature (40–45 °C) (Sodini & Béal, 2003) prior to inoculation with a mixture of two homofermentative bacterial cultures: *Streptococcus thermophilus and Lactobacillus delbrueckii* subs. *bulgaricus* (Tamime et al. 1984; Tamime & Robinson, 2000; Damin et al. 2009; Peng et al. 2009) which convert lactose to lactic acid. The AFNOR standards define for yogurt 'appellation' a minimum level of 10 million living microorganism per gram of product at the time of consumption. Throughout fermentation growth of *Strep. thermophilus* is stimulated by Lactobacilli proteolytic activity, *Lb. bulgaricus* releases formic acid and CO_2. In the final count *Strep. thermophilus* is dominant over *Lb. bulgaricus* (Birollo et al. 2000; Oliviera et al. 2001; Sodini & Béal, 2003; Damin et al. 2009). As the pH of the milk base drops (from 6·7 to 4·6, which usually takes 2 to 6 h) the net negative charge on the casein micelles decreases, the rate of solubilised colloidal calcium phosphate increases leading to the removal of the 'hairy' layer of *k*-casein (De Brandere & De Baerdemader, 1999; Vasbinder & de Kruif, 2003; Lee & Lucey, 2010). This results in decreases in electrostatic repulsion and steric stabilisation and increases in casein–casein interactions leading to the formation of a three-dimensional network consisting of casein clusters, chains and strands (Fig. 2) (Ozer et al. 1998; Lee & Lucey, 2010; Marafon et al. 2011; Patel, 2011). Finally, fruits, flavouring ingredients, thickeners and stabilisers (where regulations permit) are added before blast chilling and cold storage. The primary aim of stabiliser addition is their ability to form linkage with protein particles resulting in viscosity and texture enhancement as well as mouth feel improvement (Everett & McLeod, 2005; Ares et al. 2007). It is important to note that set and stirred yogurt are formed during incubation in retail pots and large fermentation tanks respectively. The latter being usually disrupted by agitation (stirring) and pumped through a screen (Sodini & Béal, 2003; Lee & Lucey, 2010). It is obvious from the previous description that yogurt manufacture and properties are primary dependant on the level, nature and relative proportion of milk proteins. Indeed, methods of milk enrichment affect yogurt mix composition and impart the buffering capacity, the extent of protein interactions, the length of fermentation as well as the microstructure and hence the resulting textural and sensorial properties of the coagulum. These latter attributes are determinant features, defining yogurt quality and consumer acceptability (Kristo et al. 2003; Soukoulis et al. 2007; Lee & Lucey, 2010). In this review, the effects of milk fortification with various dairy ingredients on gel formation as well on physical and sensorial properties of yogurt products are described and discussed.

Textural properties of yogurt gels

Yogurt is organised as a concentrated dispersion of protein particles, aggregates, chains and clusters (Tamime et al. 1984; Sodini et al. 2004; Lee & Lucey, 2010). Yogurt texture defines the disposition of the different part of the system and represents the rheological, microstructural and sensorial properties assigned by mechanical, visual and instrumental attributes (Sodini et al. 2004). Yogurt textural characteristics are affected by several parameters such as temperature and time of heat treatment, type and amount of starter bacteria, temperature of fermentation, storage conditions and more particularly protein composition of the milk base (Lucey et al. 1998; Kristo et al. 2003; Marafon et al. 2011). Indeed, protein bonds formation and rearrangements as well as protein interactions with other compounds (i.e. flavour compounds) by reversible and irreversible bindings define the gel network and determine the yogurt aroma (characterised by the presence of specific carbonyl compounds) and consumer acceptance (Tamime & Robinson, 2000; Guichard, 2002; Lucey, 2004; Isleten & Karagul-Yuceer, 2006; Saint-Eve et al. 2006).

Yogurt gel network can be assessed by a wide range of non-Newtonian effect such as shear-thinning, yield stress and thixotropic flow behaviours, visual observation of microstructure, physical (water holding capacity and syneresis) and sensorial attributes (thickness, smoothness or lumpiness, graininess, and flavour) (Tamime et al. 1984; Gastaldi et al. 1997; Lucey et al. 1997; Remeuf et al. 2003; Sodini et al. 2004; Damin et al. 2009; Lee & Lucey, 2010).

Effect of dairy powders addition on yogurt textural properties

Addition of milk powder

The use of SMP to fortify yogurt is preferable to whole milk powder, the latter being involved in oxidised flavour (Tamime & Robinson, 2007). The addition of SMP for fortification purposes appears to be by far the most common practice in yogurt industry (Lucey & Singh, 1998; Sodini & Béal, 2003; Soukoulis et al. 2007; Damin et al. 2009; Peng et al. 2009) and is considered as the standard process for yogurt preparation (Remeuf et al. 2003; Damin et al. 2009). Addition rates of SMP in the yogurt mix ranges from as slight as 1% to as high as 6% with a recommended level of 3–4% (Tamime & Robinson, 2007). In general, addition of 2% of SMP is considered appropriate for improving yogurt textural quality (Tamime & Robinson, 2007; Soukoulis et al. 2007). The addition of important amounts of SMP exceeding 6% w/w engenders a powdery taste in yogurt products (Tamime & Robinson, 2000). Addition of SMP has produced good quality yogurt and assisted in increasing yogurt viscosity and gel strength when compared with yogurt produced without fortification (Tamime & Robinson, 2000; Peng et al. 2009; Patel, 2011). Indeed, addition of 1, 2 and 3% of SMP has increased yogurt viscosity by 22, 43 and 70% respectively (Patel, 2011). Furthermore the use of SMP for dry matter fortification seems to not affect the pH profile and development during yogurt fermentation (the sigmoidal pH decrease has occurred from the beginning of the fermentation) despite the remarkable increase in buffering capacity near the pH vicinity of 5·8 to 4·1 (De Brabandere & De Baerdemaecher, 1999; Peng et al. 2009). Enrichment of yogurt mix with SMP has led to a very low graininess, lumpiness and important water holding capacity in yogurts (Remeuf et al. 2003; Isleten & Karagul-Yuceer, 2006). Further, SMP fortified yogurts display an irregular gel organisation with short and individualised casein filaments in addition to marked micelles fusion and numerous pores heterogeneous in size with a considerable amount (up to 50%) of small pores (Fig. 3) (Modler & Kalab, 1983; Guzmán-González et al. 1999; Remeuf et al. 2003; Damin et al. 2009). Finally, yogurts prepared from SMP have been characterised as having a marked fermented, cereal-type flavour and astringency as assessed by sensory evaluations (Isleten & Karagul-Yuceer, 2006). SMP-fortified products have also been distinguished by their rich mineral composition (in calcium, magnesium, copper, zinc, potassium and manganese) as well as their tyrosine content (Isleten & Karagul-Yuceer, 2008).

In conclusion, standardisation of the total solid content of the milk base with SMP and the specifications of the SMP used seem to be insufficient to produce yogurt of consistent physical attributes over the season. Moreover, the potential development of excess acidity of the final product, a consequent of the high lactose content of the powder, remains the limiting factor for the use of SMP (Tamime & Robinson, 2007; Patel, 2011). Excessive acidification below the pH of 4 might enhance whey separation and gel defects in the final products (Jaros & Rohm, 2003).

Addition of whey powder

Whey proteins are the class of milk proteins that remains soluble after rennet or acid precipitation (Considine et al. 2011). They are a by-product from cheese industry, processed generally by ultrafiltration and spray drying (González-Martínez et al. 2002; Sodini et al. 2005). These globular structured proteins are of many types: whey protein concentrates (WPC), whey protein isolates (WPI) and whey protein hydrolysates (WPH). Their characteristics differ regarding the processing conditions practiced before drying such as demineralisation, lactose removal, whey protein concentration or straightforward drying

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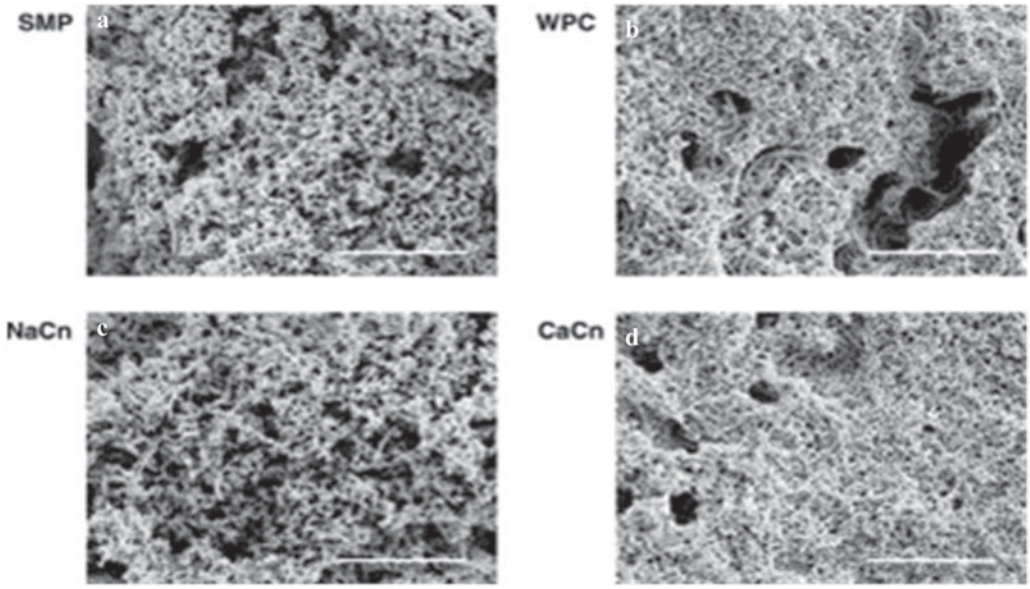

Fig. 3. Microstructure of yogurt prepared with milk fortified with skim milk powder (a), sodium caseinates (b), whey protein concentrates (c) and calcium caseinates (d) by Remeuf et al. (2003).

(Boudier & Schuck, 2010). The addition of whey proteins to fortify yogurt mixes has gained interest because of their nutritional and functional attributes (Séverin & Wenshui, 2005; Sodini et al. 2005; Isleten & Karagul-Yuceer, 2006). Indeed, whey proteins are valuable dairy ingredients with their high protein (branched amino-acids), mineral (calcium, potassium) content (Ha & Zemel, 2003; Séverin & Wenshui, 2005; Sodini et al. 2005), functional properties of emulsification, water-holding, foaming, thickening and gelling characteristics (González-Martínez et al. 2002). Moreover, whey protein may form a tightly-packed viscoelastic structure at their interfaces, hence favouring long term stability (Tamime & Robinson, 2000).

Whey protein powder was used to fortify yogurt mixes at levels ranging between 0·6 to 4% w/w (considered as an upper limit) (Tamime & Robinson, 2007; Lee & Lucey, 2010). However the recommended level of whey protein addition to dairy products is around 1 to 2% w/w since higher levels may impart an undesirable whey flavour as well as under some conditions a grainy texture (González-Martínez et al. 2002; Lucey & Singh, 1998; Tamime & Robinson, 2000). Addition of WPC to milk bases seems to be a more popular practice than WPI addition even though these latter powders contain higher whey protein content and branched-amino acids (>90 *vs.* 60–85%) and relatively lower concentration of lactose and minerals (Considine et al. 2011). The effect of replacement of SMP by whey proteins on physical and textural properties of yogurts have been studied by many authors (Modler & Kalab, 1983; Lucey et al. 1999; Guzmán-González et al. 1999; González-Martínez et al. 2002; Puvanenthiran et al. 2002; Remeuf et al. 2003; Sodini et al. 2005; Amatayakul et al. 2006; Herrero & Requena, 2006; Aziznia et al. 2008; Damin et al. 2009) and a range of inconsistent effects have been reported. First, according to González-Martínez et al. (2002). yogurt samples fortified with WP showed a slower decrease in pH values in the first fermentation stage. This behaviour can be attributed to the lower lactose concentration in WP fortified yogurts (Penna et al. 1997). While Penna et al. (1997), Lee & Lucey (2010), Lucey et al. (1997), Soukoulis et al. (2007), found a reduction in acidification/gelation time for yogurt mix supplemented with WPC, an opposite effect was reported by Puvanenthiran et al. (2002) and Damin et al. (2009). For their part, Isleten & Karagul-Yuceer (2006) reported that milk fortification with WP isolates did not affect fermentation time ($t_{pH4·7}$). A similar tendency was observed by Marafon et al. (2011) in WPC fortified probiotic yogurt. The observed decrease in fermentation in yogurt mix fortified with WPC can be explained by WPC susceptibility to heat coagulation (Thomopoulos et al. 1993; Shaker et al. 2001) related to their high calcium content, making the solution unstable (Lee & Lucey, 2010). In contrast, the observed increase in fermentation time has been explained by an increase in buffering capacity of the mix when the casein to whey ratio is altered (Puvanenthiran et al. 2002). To continue, addition of WPC to yogurt mix seems to sustain a constant cell count of the typical starter culture (*Strep. thermophilus* and *Lb. bulgaricus*) in the inoculum with the dominance of *Strep. thermophilus* strain over *Lb. bulgaricus* (Lucey et al. 1998; Birollo et al. 2000; Oliveira et al. 2001; Isleten & Karagul-Yuceer, 2008; Damin et al. 2009). Nevertheless, and according to McComas & Gilliland (2003) and Tamime & Robinson (2007), an enhanced growth of some probiotic species (*Lb. acidophilus* and *Bifidobacterium longum*) was observed in yogurt with mix supplemented with WPC. Whereas in some studies WP addition favoured yogurt viscosity, firmness and gel strength (*G*′) and reduced syneresis (Lucey et al. 1999; Bhullar et al. 2002; Haque & Ji, 2003; Remeuf et al. 2003; Isleten & Karagul-Yuceer, 2006; Tamime & Robinson, 2007; Lee & Lucey, 2010, it seems in others insufficient to improve yogurt quality profile (Guzmán-González et al. 1999; González-Martínez et al. 2002; Sodini et al. 2005). Many mechanisms may be put forward to explain these inconsistencies. Heat treatment of yogurt mix fortified with WP leads to a high level of cross-linking within the gel network, explaining the observed increase in yogurt viscosity and water holding capacity (Remeuf et al. 2003). As the casein to whey ratio decreases, the gel network becomes finer, the cross-link denser and pores smaller resulting in a decreased amount of syneresis (Puvanenthiran et al. 2002). On the other hand, some authors have reported that interactions between serum proteins and *k*-caseins, make micelles less sensitive to the pH decrease enhancing their solvatation rather than their aggregation and contributing to weaker gels (Oldifield et al. 2000; González-Martínez et al. 2002). Some researchers believe that the more open gel structure formed with low casein content will make the aggregate network more sensitive to syneresis (González-Martínez et al. 2002).

Besides, the replacement of SMP by WPC imparted yogurt's microstructure (Fig. 3). Some studies describe a WPC-enriched matrix as a very fine network containing a lot of very small pores (Remeuf et al. 2003; Saint-Eve et al. 2006) and where casein micelles appear as individual (not fused) entities and casein micelle chains are less apparent (Tamime & Robinson, 2000; Remeuf et al. 2003). Others described it as a more compact flocculated protein matrix with more obvious micelle chains (Modler & Kalab 1983) and larger pore and whey protein aggregates (Krzeminski et al. 2011). These different microstructure observations can be explained with respect to WPC isolation method: ultrafiltration and ion exchange (representing an individual micelle structure delimited by flocculated proteins) or electrodialyses (compact flocculated matrix with apparent micelle chains) (Modler & Kalab, 1983).

Finally, WPC-fortified yogurts are characterised by limited acetaldehyde content according to Isleten & Karagul-Yuceer, (2008) and important acetaldehyde content according to Tamime & Robinson (2007), a subtle fermented and creamy flavour, a pronounced whey flavour and an appreciable sweetness (Isleten & karagul-Yuceer, 2006). In addition, WPC-enriched yogurts are distinguished by a homogeneous fluid, a soft gel exempt of lumps and a yellowish aspect (González-Martínez et al. 2002). In terms of consumer acceptance, the data is also conflicting: WPC fortified products were preferred by panellist in some studies and rejected in others (González-Martínez et al. 2002; Isleten & Karagul-Yuceer, 2006).

Two main conclusions can be drawn from what was previously reported. These apparent contradictions in the literature are primary due to the different methods used to determine the physical and rheological properties of yogurts in these studies and to the variation in functional properties of WPC. For instance, the increase and decrease in fermentation time may be explained by the demineralised whey fraction; fermentation time being reduced in line with increases in demineralised whey (González-Martínez et al. 2002). The degree of whey protein denaturation, the level of non-protein nitrogen in WPC (Sodini et al. 2005) as well as the casein to whey ratio (Puvanenthiran et al. 2002) can explain some inconsistencies between studies. As a final point, WPC fortification of the milk base appears very suitable for drinking yogurt production (Ozen & Kilic, 2009).

Addition of casein powder

Caseins are the most important class of proteins in bovine milk (Walstra et al. 1999; Hussain et al. 2012). They are recognised for their binding, foaming, gel forming, thickening and emulsifying capacities (Walstra et al. 1999). This later property is mainly due to its high proline content (Chen, 2002; Khwaldia et al. 2004). Micellar caseins (or native phosphocaseins) are prepared by microfiltration (to reduce whey protein concentration) and have undergone extensive diafiltration (Peng et al. 2009). For their part, caseinates are obtained by skim milk acidification to pH 4·6 (leading thus to casein precipitation) followed by water washing (to remove the soluble components) and final pH neutralisation (Fabra et al. 2010). Regarding the alkali used to adjust the pH, the recovered caseinate fraction is termed sodium (NaCn), calcium (CaCn), magnesium (MgCn) or potassium caseinate (KCn) when NaOH, CaOH, MgOH or KOH are respectively used (Fabra et al. 2010). Among these, NaCn and CaCn are the most commonly used in dairy industries. Nevertheless, due to variations in their aggregates state, CaCn have less emulsifying abilities than NaCn, ultimately limiting their use in dairy applications (Fabra et al. 2010). Addition rate of MC and caseinate in yogurt mix is between 1 to 2% w/w. Higher amounts of caseinate addition impart uncontrolled thickening (Tamime & Robinson, 2000). The addition of MC to yogurt mix greatly increases the buffering capacity around pH 5 during acidification consistent with high concentration of total calcium and insoluble calcium content (Peng et al. 2009). In contrast, addition of sodium caseinates considerably decreased the buffering capacity in the vicinity of pH 5 during acidification. Addition of NaCn might have solubilised some of the colloidal calcium phosphate from the casein micelles in milk. Indeed, it has been reported that NaCl addition to milk can lead to exchange of colloidal calcium by sodium (Peng et al. 2009). The increased buffering capacity in MC fortified yogurt justifies the different observed pH profiles and the slow rate of decrease in pH close to 5. This is probably accountable for the longer fermentation time (Peng et al. 2009). Fermentation time ($t_{pH4·5}$) was decreased in yogurt mix enriched with NaCn according to Damin et al. (2009). However, Isleten & Karagul-Yuceer (2006) and Peng et al. (2009) reported a constant fermentation time for yogurt supplemented with different dairy powders (SMP, WPC and NaCn). Furthermore, yogurt fortification with NaCn does not

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Table 1 Summary of the three most common dairy powders added in yogurt formulation and their main influences on products textural properties from Guzman-Gonzalez et al. 1999; Gonzalez-Martinez et al. 2002; Remeuf et al. 2003; Isleten & Karagul-Yuceer, 2006; Tamime & Robinson, 2007; Isleten & Karagul-Yuceer, 2008; Damin et al. 2009; Peng et al. 2009)

Powder type added	Recommended addition rates	Effect on pH profile	Physical properties	Microstructure	Sensorial properties	Specifications	Conclusion
Skim milk powder	3–4%	An increase in buffering capacity near the vicinity of 5.8 to 4.1	A good viscosity and a poor rate of graininess and lumpiness	An irregular gel organization with short casein filaments and numerous pores heterogeneous in size	A marked fermented and astringent taste	Yogurt products rich in mineral composition (particularly, in calcium); and rich in lactose	The control method but insufficient to produce a yogurt of consistent textural characteristics all over the season
Whey proteins concentrates	1–2%	A slow decrease in pH values in the first fermentation stage	An opposite tendency of increased and decreased firmness and viscosity	A very fine gel network with very small pores with less or more obvious casein micelles chains	A marked fermented, creamy and whey flavor and an appreciable sweetness	Yogurt products poor in lactose content	Resulting properties primary rely on powder characteristics Their use is appropriate for drinking yogurt
Sodium caseinates	1–2%	A decrease in the buffering capacity near the vicinity of 5	A remarkable increase in yogurt firmness and viscosity	A coarse and loose gel network with few pores and large casein micelles and extensive caseins clusters	A marked aftertaste and astringency	Yogurt products with a poor mineral content	The best fortification method in means of increasing yogurt physical attributes

seem to affect the ultimate bacterial counts of yogurt cultures (Damin et al. 2009; Marafon et al. 2011). In terms of rheology, MC fortified yogurt displayed the lowest G' and yield stress values (Peng et al. 2009). Contrarily, acid-induced gels made from NaCn had the maximal loss tangent, yield stress and G' values (Damin et al. 2009; Peng et al. 2009). In fact, many authors reported that yogurt fortification with NaCn resulted in higher viscosity, firmness and stronger networks and less syneresis than yogurt fortified with different types of milk protein ingredients (Rohm, 1993; Guzmán-González et al. 2000; Remeuf et al. 2003; Isleten & Karagul-Yuceer, 2006; Damin et al. 2009; Peng et al. 2009). The slow solubilisation during fermentation process of high amounts of CCP, may have contributed to the decrease in G'' values. Tamime et al. (1984) have concluded that NaCn fortification of the milk base is the most effective means of increasing yogurt firmness. This latter finding is believed to be caused by the partial removal of CCP (subsequent to NaCn addition) affecting the internal structure of caseins micelle, increasing their mobility, contact area and thus the elastic modulus (Peng et al. 2009). The structure of yogurt enriched with casein-based ingredients differs from that fortified with other milk proteins ingredients (Fig. 3). To our knowledge, the microstructure of yogurt made with MC has not been assessed. Nonetheless, Peng et al. (2009) reported the highest permeability values for yogurt supplemented with MC. Once again, this could be related to the extended time at pH values near 5 which allowed particle rearrangement after gelation. High permeability value reflects inhomogenities in gel network and implies a coarse gel with larger pores (Lucey et al. 1997; Peng et al. 2009). The milk supplementation with NaCn seems to impact severely on yogurt microstructure (Modler & Kalab, 1983). NaCn fortified yogurts have fewer pores and exhibit a relatively coarse and loose structure with the largest casein micelles and extensive micelle clusters (Tamime et al. 1984; Tamime & Robinson, 2000; Remeuf et al. 2003; Damin et al. 2009). Some authors reported that CaCn fortified yogurts showed a dense, more compact and finely performed microstructure comparable with that of yogurt prepared with WPC (Remeuf et al. 2003; Akalain et al. 2008).

Finally, NaCn fortified yogurts are characterised by a poor content of some minerals such as copper, magnesium, potassium and iron. However, they present a considerable content of calcium, sodium and zinc (Guzmán-González et al. 2000; Isleten & Karagul-Yuceer, 2006; Peng et al. 2009). They are also characterised by a flat lumpiness, an important acetaldehyde amount, a pronounced animal like, cereal and cardboard flavour, a marked aftertaste, an astringency taste and finally, a poor sweetness flavour (Lucey et al. 1998; Isleten & Karagul-Yuceer, 2006). In terms of consumer acceptance, while some panellist in some studies preferred NaCn fortified yogurts (Isleten & Karagul-Yuceer, 2008), others reject it and found it unacceptable (Tamime et al. 1984).

In conclusion, the difference effect on yogurt products between MC and NaCn could be explained by the very different physicochemical properties of both powders as well as the micellar state of casein in these powders and the non-micellar soluble form of caseins present in NaCn.

The Table 1 recapitulates the most common dairy powder listed above and used in yogurt formulation as well as their influence on product textural attributes.

Addition of other dairy ingredients and protein blends

The addition of other dairy ingredients (than WP, casein and caseinates) has been reported during yogurt manufacture in some instance. The addition of milk protein hydrolysates (in the range of 0·3–0·5 g/100 g) (casein and whey) reduced the fermentation time, increased yogurt viscosity, decreased yogurt graininess and syneresis and resulted in a more open gel microstructure with fewer branched proteins (Sodini & Beal, 2003; Zhao et al. 2006; Tamime & Robinson, 2007). The addition of casein hydrolysates stimulated the growth of *Strep. thermophilus* (Tamime & Robinson, 2007) and enhanced the cell counts of probiotic microorganisms in yogurt (Oliveira et al. 2002; Sodini et al. 2002; McComas & Gilliland, 2003; Lucas et al. 2004; Tamime & Robinson, 2007). Furthermore, milk protein concentrates and isolates have been added to increase the protein content of yogurt mix (Chandan & Shahani, 1995) and produced firm yogurts (Tamime & Robinson, 2007). Addition of MPC improved viscosity and gel strength up to 100 and 50% respectively when comparing with SMP-fortified yogurts (Patel, 2011). Fresh buttermilk powder was used up to 50% as a replacement of SMP in yogurt manufacture and produced an acceptable soft and smooth textured yogurt. The use of fresh buttermilk powder concentrated by ultrafiltration has also been reported in the literature. The yogurt products obtained present a denser matrix and a lower syneresis, but an impaired flavour and aroma (Sodini et al. 2006; Tamime & Robinson, 2007; Lee & Lucey, 2010).

Blends of different type of milk protein (such as SMP and sweet whey powder in a ratio of 75 : 25; whey and casein in a 1 : 1 ratio; CaCn and WP in a ratio of 1 : 1; SMP and WPC in a ratio of 1·5 : 0·5; and finally blends of NaCn and CaCn) have been used in yogurt manufacture and resulted in an overall good quality product in terms of sensory and texture profiles as well as extent of syneresis (González-Martínez et al. 2002; Augustin et al. 2003; Tamime & Robinson, 2007).

Conclusion

Miscellaneous dairy ingredients can be added to the yogurt milk bases for fortification purposes. These methods of milk protein enrichment will not have the same consequences on the protein and mineral composition of the milk base, the length of fermentation process, extent of proteins interactions and the microstructure of the coagulum. Fortification with SMP seems insufficient to produce yogurts of consistent physical properties over the entire season. Addition of WPC seems to be highly dependent on the specifications of the powders employed and appears definitely appropriate for drinking yogurt production. Addition of NaCn seems to be the most effective means of increasing yogurt textural characteristics. Lastly, using blends of different dairy ingredients in a proper ratio appears as a useful and interesting perspective for yogurt mix fortification.

References

Akalain AS, Unal G, Dinkci N & Hayaloglu AA 2008 Microstructural, textural, and sensory characteristics of probiotic yogurts fortified with sodium calcium caseinate or whey protein concentrate. *Journal of Dairy Science* **95** 3617–3628

Amatayakul T, Sherkat F & Shah NP 2006 Physical characteristics of set yoghurt made with altered casein to whey protein ratios and EPS-producing starter cultures at 9 and 14% total solids. *Food Hydrocolloids* **20** 314–324

Ares G, Gonçalvez D, Pérez C, Reolon G, Segura N, Lema P & Gambaro A 2007 Influence of gelatin and starch on the instrumental and sensory texture of stirred yogurt. *International Journal of Dairy Technology* **60** 263–269

Augustin MA, Cheng LJ, Glagovskaia O, Clarke PT & Lawrence A 2003 Use of blends of skim milk and sweet whey protein concentrates in reconstituted yogurt. *Australian Journal of Dairy Technology* **58** 30–35

Aziznia S, Khosrowshahi A, Madadlou A & Rahimi J 2008 Whey protein concentrate and Gum tragacanth as fat replacers in Nonfat Yogurt: chemical, physical, and microstructural properties. *Journal of Dairy Science* **91** 2545–2552

Berton-Carabin C, Elias RJ & Coupland JN 2013 Reactivity of a model lipophilic ingredient in surfactant-stabilized emulsions: effect of droplet surface charge and ingredient location. *Colloids and Sufaces A: Physicochemical and Engineering Aspects* **418** 68–75

Bhullar YS, Uddin MA & Shah NP 2002 Effects of ingredients supplementation on textural characteristics and microstructure of yoghurt. *Milchwissenschaft* **57** 329–332

Birollo GA, Reinheimer JA & Vinderola GC 2000 Viability of lactic acid microflora in different types of yoghurt. *Food Research International* **33** 799–805

Boudier JF & Schuck P 2010 Les laits en poudres. *Science des Aliments* **29** 51–60

Chandan RC & Shahani KM 1995 Other fermented dairy products. *Biotechnology: Enzymes, Biomass, Food and Feed* **9** 385–418

Chen H 2002 Formation and properties of casein films and coatings. In *Proteins-based Films and Coatings*, pp. 181–211 (Ed. A Gennadios). New York: CRC Press

Considine 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

Corredig M, Sharafbafi N & Kristo E 2011 Polysaccharide-protein interactions in dairy matrices, control and design of structures. *Food Hydrocolloids* **25** 1833–1841

Damin MR, Alcântara MR, Nunes AP & Oliveira MN 2009 Effects of milk supplementation with skim milk powder, whey protein concentrate and sodium caseinate on acidification kinetics, rheological properties and structure of nonfat stirred yogurt. *Food Science and Technology* **42** 1744–1750

Dave RI & Shah NP 1998 The influence of ingredient supplementation on the textural characteristics of yogurt. *Australien Journal of Dairy Technonolgy* **53** 180–184

De Brabandere AG & De Baerdemaeker JG 1999 Effects of process conditions on the pH development during yogurt fermentation. *Journal of Food Engineering* **41** 221–227

Everett DW & McLeod RE 2005 Interactions of polysaccharide stabilisers with casein aggregates in stirred skim-milk yoghurt. *International Dairy Journal* **15** 1175–1183

https://doi.org/10.1017/S0022029913000514 Published online by Cambridge University Press

Fabra MJ, Talens P & Chiralt A 2010 Influence of calcium on tensile, optical and water vapour permeability properties of sodium caseinate edible films. *Journal of Food Engineering* **96** 356–364

Gastaldi E, Lagaude A, Marchesseau S & Torodo De la Fuente B 1997 Acid milk gel formation as affected by total solids content. *Journal of Food Science* **62** 671–687

González-Martínez C, Becerra M, Cháfer M, Albors A, Carot JM & Chiralt A 2002 Influence of substituting milk powder for whey powder on yoghurt quality. *Trends in Food Science and Technology* **13** 334–340

Guichard E 2002 Interactions between flavour compounds and food ingredients and their influence on flavor perception. *Food Reviews International* **18** 49–70

Guzmán-González M, Morais F, Ramos M & Amigo L 1999 Influence of skimmed milk concentrate replacement by dry dairy products in a low fat set-type yoghurt model system. I: use of whey protein concentrates, milk protein concentrates and skimmed milk powder. *Journal of the Science of Food and Agriculture* **79** 1117–1122

Guzmán-González M, Morais F & Amigo L 2000 Influence of skimmed milk concentrate replacement by dry dairy products in a low-fat set-type yoghurt model system. Use of caseinates, co-precipitate and blended dairy powders. *Journal of the Science of Food and Agriculture* **80** 433–438

Ha E & Zemel MB 2003 Functional properties of whey, whey components, and essential amino acids: mechanisms underlying health benefits for active people (review). *Journal of Nutritional Biochemistry* **14** 251–258

Haque ZU & JI T 2003 Cheddar whey processing and source: II. Effects on non-fat ice cream and yogurt. *International Journal of Food Science and Technology* **38** 463–473

Herrero AN & Requena T 2006 The effect of supplementing goats milk with whey protein concentrate on textural properties of set-type yogurt. *International Journal of Food Science and Technology* **41** 87–92

Hussain R, Gaiani C & Scher J 2012 From high milk protein powders to the rehydrated dispersions in variable ionic environments: a review. *Journal of Food Engineering* **113** 486–503

Isleten M & Karagul-Yuceer Y 2006 Effects of dried dairy ingredients on physical and sensory properties of Nonfat Yogurt. *Journal of Dairy Science* **89** 2865–2872

Isleten M & Karagul-Yuceer Y 2008 Effects of functional dairy based proteins on nonfat yogurt quality. *Journal of Food Quality* **31** 265–280

Jaros D, Rohm H 2003 *The Rheology and Textural Properties of Yoghurt*. Cambridge, UK: CRC PressWoodhead

Khwaldia K, Banon S, Desobry S & Hardy J 2004 Mechanical and barrier properties of sodium caseinate-anhydrous milk fat edible films. *International Journal of Food Science and Technology* **39** 403–411

Kristo E, Biliaderis CG & Tzanetakis N 2003 Modelling of the acidification process and rheological properties of milk fermented with a yogurt starter culture using response surface methodology. *Food Chemistry* **83** 437–446

Krzeminski A, Groayhable K & Hinrichs Jr 2011 Structural properties of stirred yoghurt as influenced by whey proteins. *Food Science and Technology* **44** 2134–2140

Lakemonda Catriona MM & van Vliet T 2007 Acid skim milk gels: the gelation process as affected by preheating pH. *International Dairy Journal* **18** 574–584

Lee WJ & Lucey JA 2010 Formation and physical properties of Yogurt. *Asian – Australasian Journal of Animal Sciences* **23** 1127–1136

Lucas A, Sodini I, Monnet C, Jolivet P & Corrieu G 2004 Probiotic cell counts and acidification in fermented milks supplemented with milk protein hydrolysates. *International Dairy Journal* **14** 47–53

Lucey JA 2004 Formation, structural properties and rheology of acid-coagulated milk gels. In *Cheese: chemestry, Physics and Microbiology*, Vol. 1, 3rd edition, pp. 105–122. London: Elsevier Academic Press

Lucey JA & Singh H 1998 Formation and physical properties of acid milk gels: a review. *Food Research International* **30** 529–542

Lucey JA, Teo CT, Munro PA & Singh H 1997 Rheological properties at small (dynamic) and large (yield) deformations of acid gels made from heated milk. *Journal of Dairy Research* **64** 591–600

Lucey JA, Tamehana M, Singh H & Muuro PA 1998 a comparison of the formation, rheological properties and microstructure of acid skim milk gels made with a bacterial culture or glucono-δ-lactone. *Food Research International* **31** 147–155

Lucey JA, Munro PA & Singh H 1999 Effects of heat treatment and whey protein addition on the rheological properties and structure of acid skim milk gels. *International Dairy Journal* **9** 275–279

Marafon AP, Sumi A, Granato D, Alcantara MR, Tamine AY & Nogueira de Oliveira M 2011 Effects of partially replacing skimmed milk powder with dairy ingredients on rheology, sensory profiling, and microstructure of probiotic stirred-type yogurt during cold storage. *Journal of Dairy Science* **94** 5330–5340

Matumoto-Pintro PT, Rabiey L, Robitaille G & Britten M 2011 Use of modified whey protein in yoghurt formulations. *International Dairy Journal* **21** 21–26

McComas KA & Gilliland SE 2003 Growth of probiotic and traditional yogurt cultures in milk supplemented with whey protein hydrolysate. *Journal of Food Science* **68** 2090–2095

Modler HW & Kalab M 1983 Microstructure of yogurt stabilized with milk proteins. *Journal of Dairy Science* **66** 430–437

Oldfield DJ, Singh H, Taylor MW & Pearce KN 2000 Heat-induced interactions of ß-lactoglobulin and α-lactalbumin with the casein micelle in pH-adjusted skim milk. *International Dairy Journal* **10** 509–518

Oliveira MN, Sodini I, Remeuf F & Corrieu G 2001 Effect of milk supplementation and culture composition on acidification, textural properties and microbiological stability of fermented milks containing probiotic bacteria. *International Dairy Journal* **11** 935–942

Oliveira CAF, Fernandes AM, Neto OCC, Fonseca LFL, Silva EOT & Balian SC 2002 Composition and sensory evaluation of whole yogurt produced from milk with different somatic cell counts. *Australian Journal of Dairy Technology* **57** 192–196

Ozen AE & Kilic M 2009 Improvement of physical properties of nonfat fermented milk drink by using whey protein concentrate. *Journal of Texture Studies* **40** 288–299

Ozer BH, Robinson RK, Grandison AS & Bell AE 1998 Gelation properties of milk concentrated by different techniques. *International Dairy Journal* **8** 793–799

Patel S 2011 Evaluating the Effect of Milk Protein Concentrates (MPC) Fortification on Rheological Properties of Nonfat Set Yogurt Using Vane Rheometry Vol. Master of Science: The Graduate School University of Wisconsin-Stout

Peng Y, Serra M, Horne DS & Lucey JA 2009 Effect of fortification with various types of milk proteins on the rheological properties and permeability of nonfat set yogurt. *Journal of Food Science* **74** 666–673

Penna ALB, Baruffaldi R & Oliveira MN 1997 Optimization of yogurt production using demineralized whey. *Journal of Food Science* **62** 846–850

Pesic MB, Barac MB, Stanojevic SP, Ristic MN, Macej OD & Vrvic MM 2012 Heat induced casein-whey protein interactions at natural pH of milk: a comparison between caprine and bovine milk. *Small Rumin Research* **108** 77–86

Puvanenthiran A, Williams RPW & Augustin MA 2002 Structure and visco-elastic properties of set yoghurt with altered casein to whey protein ratios. *International Dairy Journal* **12** 383–391

Remeuf F, Mohammed S, Sodini I & Tissier JP 2003 Preliminary observations on the effects of milk fortification and heating on microstructure and physical properties of stirred yogurt. *International Dairy Journal* **13** 773–782

Rohm H 1993 Influence of dry matter fortification on flow properties of yogurt. 1. Evaluation of flow curves. *Milchwissenschaft* **48** 556–560

Saint-Eve A, Lévy C, Martin N & Souchon I 2006 Influence of proteins on the perception of flavored stirred yogurts. *Journal of Dairy Science* **89** 922–933

Schkoda P, Hechler A & Hinrichs J 2001 Influence of the protein content on structural characteristics of stirred fermented milk. *Milchwissenschaft-Milk Science International* **56** 19–22

Séverin S and Wenshui X 2005 Milk biologically active components as nutraceuticals: review. *Critical Reviews in Food Science and Nutrition* **45** 645–656

Shaker RR, Abu-Jdayil B, Jumah RY & Ibrahim SA 2001 Rheological properties of set yogurt during gelation process: II. Impact of incubation temperature. *Milchwissenschaft* **56** 622–625

Sodini I & Béal C 2003 Fabrication des yaourts et lait fermentés Technique de l'ingénieur

Sodini I, Lucas A, Oliveira MN, Remeuf F & Corrieu G 2002 Effect of milk base and starter culture on acidification, texture, and probiotic cell counts in fermented milk processing. *Journal of Dairy Science* **85** 2479–2488

Sodini I, Remeuf F, Haddad S & Corrieu G 2004 The relative effect of milk base, starter, and process on yogurt texture: a review. *Critical Reviews in Food Science and Nutrition* **44** 113–137

Sodini I, Montella J & Tong SP 2005 Physical properties of yogurt fortified with various commercial whey protein concentrates. *Journal of the Science of Food and Agriculture* **85** 853–859

Sodini I, Morin P, Olabi A & Jiménez-Flores R 2006 Compositional and functional properties of buttermilk: a comparison between sweet, sour, and whey buttermilk. *Journal of Dairy Science* **89** 525–536

Soukoulis C, Panagiotidis P, Koureli R & Tzia C 2007 Industrial yogurt manufacture: monitoring of fermentation process and improvement of final product quality. *Journal of Dairy Science* **90** 2641–2654

Tamime AY & Robinson RK 2000 *Yogurt Science and Technology*. Washington, DC: CRC Press Woodhead

Tamime AY & Robinson RK 2007 *Tamime and Robinson's Yoghurt Science and Technology*, 3rd edition. Cambridge, UK: CRC PressWoodhead

Tamime AY, Kalab M & Davies G 1984 Microstructure of set-style yoghurt manufactured from cow's milk fortified by various methods. *Food Microstructure* **3** 83–92

Thomopoulos C, Tzia C & Milkas D 1993 Influence of processing of solids-fortified milk on coagulation time and quality properties of yogurt. *Milchwissenschaft* **48** 426–430

Vasbinder AJ & de Kruif CG 2003 Casein-whey protein interactions in heated milk: the influence of pH. *International Dairy Journal* **13** 669–677

Vasbinder AJ, van Mil PJJM, Bot A & de Kruif CG 2001 Acid induced gelation of heat treated milk studied by diffusing wave spectroscopy. *Colloids and Surfaces B: Biointerfaces* **21** 245–250

Vasbinder AJ, van de Velde F & de Kruif CG 2004 Gelation of casein-whey protein mixtures. *Journal of Dairy Science* **87** 1167–1176

Verman AH & Sutherland JP 2004 Quality of yogurt. *Journal of Dairy Science* **2** 7–9

Walstra P, Geurts TJ, Noomem A, Jellema A & Van Boekel MAJS 1999 *Dairy Technology*. New York: Marcel Dekker, Inc.

Zhao QZ, Wang JS, Zhao MM, Jiang YM & Chun C 2006 Effect of casein hydrolysates on yogurt fermentation and texture properties during storage. *Food Technol Biotechnol* **44** 429–434