**Effects of hydrocolloids and processing conditions on acid whey production
with reference to Greek yogurt**

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ABSTRACT

Background: Greek yogurt is one of the most popular products in the overall yogurt category and has gained immense popularity due to its higher nutritional values compared to traditional yogurt. Greek yogurt is defined as a strained yogurt in which yogurt is concentrated by removing acidic whey from the solid part. This process creates large volumes of acid whey as by-product that cannot be readily utilized nor disposed of easily.

Scope and Approach: The dairy industry has been seeking a solution to the problem related to acid whey production. Here, we discuss several factors, especially hydrocolloids that have the potential to limit the quantity of acid whey in Greek yogurt production by playing a major role in the water retention capacity of yogurt products. In addition, the impact of yogurt processing conditions on acid whey production is discussed.

Key findings and conclusions: Hydrocolloids, though still largely unexplored, could have potential benefit of helping to minimize acid whey production if used as additives in Greek yogurt. Moreover, through the optimization of yogurt processing conditions, acid whey production could also be reduced.

Keywords: Greek yogurt; acid whey; water holding capacity; hydrocolloids; gums; proteins, processing conditions

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1. Introduction

Yogurt is the world's most common dairy product. Greek and Greek style yogurts (hereafter referred to as 'GY') are currently the fastest growing products in the dairy industry (Bong & Morau, 2014). GY, also known as strained yogurt, is obtained after draining whey. GY can be manufactured using addition of hydrocolloids or by straining the natural set yogurt in cloth bags. Recently, there are other straining methods available to manufacture GY for the industrial scale production (Fig. 1) (Özer, 2010; Bong & Moraru, 2014). As a result of the draining process, GY has higher total solids and lower lactose than regular yogurt. This has contributed to increased consumption of GY and is directly related to consumer awareness of the health benefits associated with this yogurt due to its higher nutritional value (Desai et al., 2013). Due to the higher production of GY and straining process, there is increased acid whey production. The production of large quantities of acid whey has brought about both economic and environmental challenges (Elliott, 2013; Bong & Morau, 2014; Smithers, 2015). Even though acid whey is a nutritious byproduct, it cannot be readily utilized by the food industry. The high biological oxygen demand and low pH (< 4.5) further restrict the use of acid whey. In addition, there are strict regulations against the dumping of acid whey and particular care must be taken with its disposal (Elliot, 2013). Moreover, the disposal of acid whey creates additional costs for the dairy industry. We should mention here that some of GY companies are actually paying milk suppliers to use acid whey in animal feed (Elliot, 2013). The dairy industry is therefore seeking a solution to the problems associated with acid whey. Thus, the reduction of acid whey during yogurt production could directly benefit the GY industry.

Water holding capacity (WHC) is the ability of food to hold its own or added water during the application of force, pressure, centrifugation, or heating. WHC is also the ability of food to retain

1 water against gravity and has shown to play a major role in the formation of food texture (Sahni
2 et al., 2014). In yogurt production, WHC is one of the most important physical properties that
3 contribute to curd stability. Hydrocolloids such as gums and proteins have been used as additives
4 to improve the texture and quality of yogurt. These hydrocolloids have the ability to hold water
5 and form a gel-like structure. The WHC of yogurt is an indicator of its ability to retain serum in
6 the yogurt's gel structure. This ability contributes to minimal whey separation which is a crucial
7 aspect of the overall quality of the yogurt (Lee & Lucey, 2010).

8 Several studies have indicated the importance of hydrocolloids in yogurt quality
9 (Soukoulis et al., 2007; Saha & Bhattacharya, 2010; Akalin et al., 2012; Tasneem et al., 2014);
10 however, a review of the literature revealed lack of detailed information on the factors
11 influencing WHC. Thus, we would like to discuss and summarize several factors that could
12 influence water holding properties. These factors include milk composition, hydrocolloids,
13 starter culture and probiotics, and processing conditions. We believe the present discussion could
14 contribute to a broader understanding of the minimization of acid whey production during GY
15 manufacture under the influence of several factors discussed. Although standard definitions of
16 terminology such as water holding capacity, water binding property, gelling property, whey
17 separation, serum separation, and syneresis may vary, we have used this terminology
18 interchangeably throughout the paper to simply explain water (acid whey) holding phenomena in
19 yogurt production.

Fig. 1. Processing steps in the manufacture of Greek yogurt

2. Milk composition

Milk composition varies due to breed, geographical location and feeding, and these variations strongly affect the manufacturing conditions, sensory quality, and nutritional properties of yogurts (Ozrenk & Inci, 2008). The composition of milk can vary depending on the season of the year. Different levels of fat and protein have been observed in milk harvested in different seasons. Ozrenk and Inci (2008), found higher milk fat, protein, and total solids in milk harvested in winter compared to summer. Such seasonal variations in milk have been reported to affect the viscosity, serum separation, and acidity in yogurt production (Sodini & Tong, 2006). For instance, low fat yogurt may be more prone to syneresis while yogurt made from full-fat milk retained a significantly higher percentage of serum within its structure that is shown to reduce syneresis (Brennan & Tudorica, 2008). Le et al. (2011) also reported that milk fat globule can help to increase the WHC of yogurt gel. The authors noted that that these milk fat globules increased the firmness of yogurt and produced denser microstructures compared to nonfat yogurt and thus enhanced WHC. Milk fat also stabilizes the contraction of protein gel formed after fermentation of the yogurt mix and hinders whey separation. As a result, in yogurt with few or no stabilizers, a low fat content in milk encourages whey separation, while a high fat content prevents separation because milk fat plays an important role as a stabilizer. During the preparation of low fat or nonfat yogurt, stabilizers are used to compensate for the loss of the stabilizing effect of milk fat (Chandan & O'Rell, 2006a). The size of casein micelles also varies according to feeding regimens and individual cows, and between seasons. Glantz et al. (2010) studied the importance of casein micelle size and milk composition on milk gelation. The structure of the casein micelle is essential in the processing of milk into a gelled product such as yogurt. Smaller sizes of casein micelles were observed in summer compared to winter. These

1 authors also reported that a smaller native micellar size may favor gelation characteristics in
2 milk.

3 Thus, a prior knowledge of milk composition based on seasonal variations could help
4 those in the dairy industry decide which products could be processed from milk samples received
5 in different seasons. For example, if the protein content in milk is high, the milk can be
6 processed to make cheese whereas if the fat content is higher, milk can be processed to produce
7 butter (Ozrenk & Inci, 2008). Moreover, when milk protein is higher, the milk can be processed
8 to manufacture GY, as GY is noted for its higher protein content. The study of the effect of
9 seasonal variation on the composition of milk is clearly important to the dairy industry as well as
10 to consumers who are looking for healthier food products.

11 **3. Hydrocolloids**

12 **Hydrocolloids** are widely used in many food products to improve quality and shelf life. They are
13 heterogeneous group of long chain polymers commonly used to describe a range of
14 polysaccharides and proteins (Williams & Philips, 2009) and are characterized by their ability to
15 form gels, viscous solutions, and thickeners when dispersed in water. The presence of a large
16 number of hydroxyl (–OH) groups markedly increases the affinity of hydrocolloids to bind water
17 molecules making these hydrocolloids hydrophilic compounds. Hydrocolloids produce a
18 dispersion that is intermediate between a true solution and a suspension and thus exhibit the
19 properties of a colloid. Polysaccharides and proteins are appropriately referred as ‘hydrocolloids’
20 or ‘hydrophilic colloids’ (Saha & Bhattacharya, 2010). The reasons for using hydrocolloids in
21 dairy products are twofold: **the binding of water and improvements in texture which otherwise**
22 **suffer from wheying-off** (Syrbe et al., 1998). In yogurt, particularly, variations in viscosity,

1 syneresis, and whey production during storage are considered to be major defects. Therefore,
2 hydrocolloids (gums and proteins) are often added to overcome such defects (Keogh &
3 O'kenedy, 1998).

4 Gums are complex hydrophilic carbohydrates that are composed primarily of long chain,
5 straight or branched polysaccharides that contain –OH groups and allow the large molecules to
6 bind water. Gums are mostly grouped together based on their sources and are classified both by
7 structure and function. The functionality of gums is based on their physical properties such as
8 thickening and gelling agents. These two properties modify or control the flow of aqueous
9 solutions. Gums are derived mainly from plants and plant products such as seeds and exudates.
10 Other sources include microorganisms, animals, seaweeds, and some gums are synthesized.
11 Gums can be neutral or anionic. Each gum displays different characteristics on the basis of the
12 type and number of monosaccharide, configuration, and number and location of the linked
13 groups. Due to their unique characteristics, gums can be added to control the functional
14 properties of yogurt. The most important functional properties include thickening, gelling,
15 emulsifying, stabilization, controlling the crystal growth of ice viscosity, and water binding
16 (Saha & Bhattacharya, 2010). Dried milk proteins are also considered to be excellent food
17 ingredients due to their high nutritional value. In food products, proteins are used to bind water
18 and emulsify fat. These properties of proteins contribute to the modification of textural and
19 rheological characteristics of several foods including yogurts.

20 Among several properties, WHC is considered to be an important factor (Kneifel &
21 Seiler, 1993; Kneifel et al., 1991) in food product development. The mode of action of
22 hydrocolloids has also attributed to the ability to retain large quantities of water and hold water
23 immobile thus increasing firmness and viscosity. These hydrocolloids react with milk

constituents (mainly proteins), and stabilize the protein network, preventing the free movement of water (Tamime & Robinson, 2007). This action could thus help reduce the production of whey during the processing of GY thereby create more solids in final product. Sometimes the use of certain hydrocolloids such as polysaccharides and dried protein ingredients could also bring undesirable characteristics and off flavors. However, such defects can be corrected by choosing right formulations and fermentations conditions (Williams et al., 2003).

Throughout the following sections, we will discuss several types of polysaccharides (gums) and proteins that have been used as stabilizers in yogurt. Table 1 presents the source, chemical composition, characteristics and applications of selected hydrocolloids. There are different types of gums on the market that are being used as food additives, but in this paper we have discussed only those that have the potential to be used in the production of GY. Typical usage level, interaction effects and regulatory status of hydrocolloids used in yogurts are presented in Table 2. Similarly, effects of selected hydrocolloids on WHC of yogurts that are reported in literature are presented in Tables 3 and 4.

3.1. Polysaccharides

3.1.1 Xanthan gum

Xanthan gum, an anionic polysaccharide, is the most important industrial polysaccharide produced through fermentation when the microorganism *Xanthomonas campestris* ferments glucose in the presence of some trace elements (El-Sayed et al., 2002). Due to its specific physical (viscosity, pseudo-plasticity) and chemical properties (water solubility, pH stability), xanthan gum has been widely used in different food products (Kobori et al., 2009). The primary structure of xanthan gum consists of a linear (1-4)- β -D glucose backbone with a charged

1 trisaccharide side chain on each second glucose residue (Jansson et al., 1975). In solution, the
2 secondary structure of xanthan gum undergoes a transition from a single helix to a double helix.
3 This process depends on several factors including physicochemical conditions such as pH,
4 salinity and temperature as well as the acetate and pyruvate content of the primary structure (Liu
5 et al., 2011).

6 Xanthan gum is a free flowing powder with white to cream color. It is approved for food
7 use and is being extensively used in the food industry as an emulsifier, a thickener for sauces, to
8 prevent ice crystal formation in ice cream, and as a fat replacer in food (Lii et al., 2002;
9 Sanderson, 1996). This is possible mainly because of a number of functional properties of
10 xanthan gum: solubility in cold and hot water, rapid hydration, the capacity to provide water
11 binding resulting in high viscosity at low concentrations, thermal stability, excellent solubility
12 and stability in an acid system, little variation in viscosity with changing temperature, unique
13 rheological properties that provide high viscosity under low shear and low viscosity under high
14 shear, and the ability to provide good freeze-thaw stability (El-Sayed et al., 2002). These authors
15 have shown that the addition of xanthan gum (0.005%) decreased the syneresis rate without
16 affecting pH values or the contents of total solids thereby indicating the efficacy of xanthan gum
17 as a stabilizer in the production of fermented dairy products. Similarly, Hematyar et al. (2012)
18 found that xanthan gum at a concentration of 0.01% exhibited high viscosity and less syneresis
19 during ten days storage of yogurt samples without any observable changes in pH or total solids.
20 This could be attributed to the interaction between the gum and milk protein. Xanthan gum
21 develops a weak structure in water that creates high viscosity solutions at low concentrations. In
22 general, xanthan gum had the best stabilizing effect, enhancing firmness and consistency without
23 developing brittleness or excessive gumminess. In addition to improving rheological

characteristics, xanthan also help improve bacterial survival. Probiotic bifidobacteria encapsulated with xanthan gum and skim milk in simulated gastric juice have been found to survive somewhat better than free cells (Rokka & Rantamäki, 2010). This would indicate that the viability of probiotic bacteria in acidic food products such as yogurt can be increased by using polysaccharides to help deliver viable bacteria to the host's gastrointestinal tract.

Xanthan gum has also been proven effective at improving the texture and firmness of yogurt as well as preventing wheying-off and syneresis. Soukoulis et al. (2007) noted improved texture and no wheying-off defects with 0.01% xanthan gum added to whole fat and skimmed yogurts. Sánchez et al. (1995) investigated the water binding capacity and hydration time of several gums and found xanthan was the best water binder (232 mL/g) compared to locust bean gum (11.6 mL/g), and sodium alginate (25 mL/g). These authors found that the hydration time for xanthan gum was 410 min which was also higher compared to locust bean gum and sodium alginate. Xanthan was the best water binder as it is completely soluble in cold or hot water and produces high viscosities. This efficient hydration property of xanthan gum is due to the side chains of anionic character consisting of units of α -D mannose, β -D glucuronic and pyruvate, occurring on a glucose backbone. Bahrami et al. (2013) investigated the effects of different types of hydrocolloids on WHC of yogurts and found that yogurts treated with 0.1% xanthan gum had the highest WHC and improved texture with the least syneresis compared to the control sample. This study further showed xanthan gum to be a suitable hydrocolloid for yogurt production. Most importantly, xanthan gum hydrates quickly once dispersed and provides water binding and prevents the wheying-off defect. This water holding property of xanthan gum would prove very beneficial during GY manufacturing by possibly resulting in less acid whey production and a higher total solid content. Xanthan gum also exhibits synergistic interaction with galactomannans

such as guar, locust bean, and tara gum (Phillips & Williams, 2009). If these gums were used together, their interaction could result in enhanced WHC and gelation which would make thicker yogurt.

3.1.2. Gellan gum

Gellan gum is an extracellular anionic gel-forming polysaccharide with a higher molecular weight produced by the bacterium *Sphingomonas elodea*, purified by recovery with isopropyl alcohol, dried, and milled (Rokka & Rantamäki, 2010). Gellan has a tetrasaccharide repeat unit consisting of four linked monosaccharides residues linked together to form 1,3- β -D-glucose, 1,4-D-glucuronic acid, 1,4-D-glucose and 1,4- α -L-rhamnose (Gibson, 1992).

Gellan is a food gum off-white powder that is primarily used as a gelling or thickening agent. It is approved as a food additive and widely used in confectioneries, jams, jellies, fabricated foods, hydrogels, pie fillings, puddings, ice cream and yogurt (Danalache et al., 2014). Gellan is water soluble and has an outstanding flavor release, high gel strength, an excellent stability over a wide pH range (3.5-8.0). It is thermally reversible, high temperature resistant, and sets quickly with minimal refrigeration (Chandrasekaran, 1991). Sun and Griffiths (2000) reported a higher survival of bifidobacteria in gellan-xanthan beads in low pH environments including yogurt. Utilization of gellan could be a useful way to deliver bifidobacteria to the large intestine using yogurt as a delivery vehicle. The thickening property of gellan can also be manipulated to positively impact texture by adding cations such as potassium, magnesium, calcium, and/or sodium salts (Karlton-Senaye & Ibrahim, 2013; Chandrasekaran, 1991). The use of gellan gums has been shown to increase the total yield of cheese and to reduce the loss of

solids (proteins) in whey due to the interactions of gellan with milk proteins, especially casein and whey lactoglobulins (Bajaj et al., 2007).

Mao et al. (2001) studied the WHC of gellan aqueous solution as affected by gel composition and microstructure. The study showed that only a 1-2% water loss was reported after four months storage at 4°C. The formation of different gel structures is most likely the reason for this functionality. It has been reported that the formation of small pores may be responsible for the WHC during storage as the formation of this thin web gel structure creates higher capillary forces that hold the water in gels. In addition, the formation of smaller pores reduces the rate of water diffusion thus contributing to WHC, whereas gels with bigger pores are mainly responsible for gel strength. Water retention during cheese making was enhanced following the addition of a small amount (250-750 ppm) of gellan to milk (Sanderson & Clark, 1983). This shows that gellan gum can be incorporated in yogurt production and help bind water thus reducing the amount of acid whey. Very limited studies have focused on the WHC of gellan gum as contributing to major functionality in dairy products. There is immense potential for this gum to be used as an alternative to other gums from plants and marine algae in different dairy products including yogurts. Gellan gum acts as a fluid gel and this property makes it suitable for pourable gel. Gellan gum is also a non-animal gel source which is suitable for vegetarians and other consumers with religious or other dietary restrictions (Halal/Kosher). Recently, gellan gum has been included in the national list of non-organic ingredients allowed for use in organic foods and beverages. As a result, this gum could offer unique benefits to the dairy industry to produce by contributing to the production of new organic GY brands.

3.1.3. Locust bean gum (LBG)

1 LBG, a plant galactomannan extracted from the seed endosperm of the carob tree (*Ceratonia*
2 *siliqua*), is a high molecular weight polymer. LBG is a neutral galactomannan consisting of a
3 linear backbone of (1–4)-linked β -D-mannose residues substituted with (1–6)-linked
4 monosaccharide sidechains of α -D -galactose. LBG has a mannose-to-galactose ratio of
5 approximately 4 (Wielinga, 2009). The galactose side units allow for hydration and hydrogen
6 bonding activity. The distribution of the side units greatly influences the physical behavior of
7 galactomannan.

8 LBG is a slightly off-white powder, partly soluble in cold water and less viscous forming
9 a weak gel. Since LBG exhibits low solubility at ambient temperature, heat is required to achieve
10 maximum solubilization and to reach the highest WHC (Arda et al., 2009). The highest viscosity
11 is obtained by dispersing the gum into 95°C water and then cooling it down (Dunstan et al.,
12 2001). Since LBG is a neutral hydrocolloid, it is stable over a wide pH range (pH 3-11). LBG is
13 widely used in food as a thickening agent due to its ability to yield high viscosity at low
14 concentrations (Arda et al., 2009). LBG is an excellent stabilizer for dairy products, such as ice
15 cream, due to its high swelling potential and its ability to bind free water. It also has good heat-
16 shock resistance and provides good body to the ice cream product (Lazaridou et al., 2001). LBG
17 has been used in soft cheeses to catalyze the coagulation step and to increase the yield of curd. It
18 also contributes body and texture to the final cheese product. Keogh and O’Kennedy (1998)
19 observed that LBG has the ability to interact with other hydrocolloids to influence gelling
20 properties.

21 Peker and Arslan (2013) studied the effects of LBG on the sensory, chemical, and
22 physical properties of low-fat yogurt. They found that LBG could be used to improve the
23 physical and sensory properties of set type low-fat yogurt. Similarly, LBG at 0.10% prevented

serum separation and increased apparent viscosity without affecting the taste and aroma of yogurt drink (Koksoy & Kilic, 2004). The WHC of yogurts made using different concentrations (0.013, 0.02 and 0.026% w/v) of LBG was investigated by Peker and Arslan (2013). Their results showed that the addition of LBG led to an increase in WHC compared to the control sample during 15 days of storage at 4°C. Ünal et al. (2003) studied the effects of LBG, dry matter concentrations of milk powder, and storage time (14 days, 4°C) on the physical properties of low-fat set yogurts that were prepared using two different manufacturing processes. They found an increase in WHC in the samples with increasing levels of dry solids. The ideal concentrations of dry matter and LBG were found to be 14 and 0.02 g/100 g, respectively. Increased WHC could be attributed to the pre-treatment method involved in the yogurt manufacturing process that allows for increased swelling and hydration of proteins and hydrocolloids. Since LBG does not form gels when used by itself, this gum needs to be heated for complete solubility. However LBG can form gels when combined with other polysaccharides such as xanthan and carrageenan gum leading to increased WHC. Keogh and O’Kennedy (1998) used LBG in combination with xanthan gum (50:50) in stirred yogurt and observed a reduction in serum separation. Due to the structural compatibility of LBG with xanthan and kappa-carrageenan, LBG can create a strong elastic gel with increased WHC and decreased tendency to water expulsion of yogurt during storage. This synergism of LBG can be of commercial value in GY manufacture.

3.1.4. Guar gum

Guar gum is derived from the seed bean plant *Cyamopsis tetragonolobus*. This long-chain, linear molecule of beta-1,4-D-galactomannans with alpha-1,6-linked D-galactose has a molecular weight of approximately 1,000,000. The galactose content of galactomannans has been studied to show that it strongly influences the behavior of each hydrocolloid. Low galactose content leads

1 to stronger synergistic interactions with other hydrocolloids as well as a stronger gelling capacity
2 independently based upon the interactions of smooth areas of the mannan backbone. The main
3 chain of this gum consists of D-mannose units and the side chains of α -D-galactose with the ratio
4 of D-galactose to D-mannose being 1:2 (Sanchez et al., 1995). Since guar gum has a higher
5 galactose content, it swells and disperses almost completely in both cold and hot water (Sahin &
6 Ozdemir, 2004). Its viscosity is mainly dependent upon factors such as time, temperature,
7 concentration, pH, ionic strength, and type of agitation. Maximum viscosity is reached between
8 25-40°C. Guar gum is also stable over a wide pH range with an optimal rate of hydration
9 between pH 7.5-9.0. However, if both temperature and pH are in extreme ranges, it could lead to
10 gum degradation and affect overall functionality (Deis, 2001).

11 Guar gum is used as a thickener and stabilizer in the food industry due to the ability of
12 this gum to hydrate and bind water usually in amounts less than 1% of food weight (Slavin &
13 Greenberg, 2003). Wang et al. (2000) studied the viscosity of guar gum solutions under various
14 conditions of pH and temperature. Results of the study showed that guar gum is hydrolyzed to its
15 monosaccharides at high temperatures and under acidic conditions. The lowest pH values at
16 which guar galactomannan remained stable were 2.0, 3.0 and 3.5 at 25, 37, and 50°C,
17 respectively. Based on the results, Wang et al. (2000) suggested that guar gum could be used in
18 mild acidic processing conditions, particularly where excessive heat treatment is not applied.
19 Guar gum is neutral in flavor and does not affect final product palatability.

20 Guar gum is uncharged and thus unaffected by any change in solution pH which results
21 in greater stability. This has been confirmed by a decrease in syneresis by 93%, at 0.2 g/100g
22 gum addition without affecting either the texture or flavor of yogurt drink (Kök, 2010). In an
23 acidic product like yogurt, guar gum exhibits highly viscous colloidal dispersion that increases

viscosity and reduces syneresis (Tasneem et al., 2014). Brennan and Tudorica (2008) also confirmed that guar gum decreased syneresis in yogurt. Contrary to these results, Bahrami et al. (2013) found larger syneresis values and minimum WHC in samples containing 0.1% of guar gum when compared to the control sample. This study also showed that with a higher concentration of gum (0.3%), there was an incremental reduction in WHC. This could be due to the optimal pH differences caused by the activity of guar gum (7.5-9.0) with yogurt pH (4.5-4.7). Sanchez et al. (1995) compared the WHC of several gums and suggested that guar gum had the highest water binding capacity (40 mL/g) and hydration time (3500 min). Milani and koocheki (2010) demonstrated that the incorporation of guar gum greatly enhanced the quality of frozen yogurt dessert. When gum concentration increased from 0% to 0.3%, viscosity also increased. The function of stabilizers such as guar gum in frozen yogurt is considered to be their water binding capacity by forming a three-dimensional network of hydrated molecules throughout the system. Moreover, water retention is associated with the limited mobility of free water molecules and with increased bulk viscosity. This correlation between hydrocolloid performance and viscosity could contribute to the fact that viscosity enhancement is affected by the reduction of water molecules mobility through steric hindrance and water-holding mechanisms (Milani & koocheki, 2010; Soukoulis et al., 2008). These observations strongly suggest that guar gum in GY should be considered as a way to reduce the amount of acid whey.

3.1.5. *Cassia gum*

Cassia gum is a naturally occurring galactomannan found in the endosperm of *Cassia tora* and *C. obtusifolia* seeds. Cassia gum consists mainly of high molecular weight ranging from 200,000-300,000 Da, providing high water binding capacity. This gum is composed of galactomannans with a linear chain of 1,4- β -D-mannopyranose units with 1,6-linked- α -D-galactopyranose units (Kaur

et al., 2008). Cassia gum is related to locust bean gum and guar gum in terms of structure and chemical properties (Hallagan et al., 1997).

Cassia gum is insoluble in ethanol but disperses well in cold water and forms colloidal solutions. At boiling, it forms high-viscosity aqueous dispersions, but in aqueous solution it forms a gel when used in combination with other hydrocolloids such as carrageenan or xanthan gum (Hallagan et al., 1997). Cassia gum is an effective thickener and stabilizer that is used for broad range of food applications including utilization as an additive in dry soups and seasoning, as a water retention agent in baked products, and for texture improvement in meat and poultry products. Cassia is also used as an emulsifier, foam stabilizer, and texturizing agent. However, cassia gum is less known and less utilized in the industrial applications as compared to other gums (Karlton-Senaye & Ibrahim, 2013).

Singh et al. (2009) studied the WHC of galactomannan gum isolated from *Cassia pleurocarpa* seeds. The results from this study showed the water and saline retention capacity of galactomannan to be 9.65 and 8.04 g/g, respectively. This could be due to the presence of –OH groups on the branched structure of galactomannan which could have resulted in higher WHC potency thus indicating the potential of cassia gum as a valuable additive for improving WHC in GY production.

3.1.6. Gum arabic

Gum arabic, also called acacia gum comes from exudate *Acacia Senegal* trees (Idris et al., 1998). It consists mainly of highly complex polysaccharides of a branched β -(1,3)-linked galactose backbone with branches through the 1,6 positions along with arabinose, rhamnose and uronic acids. It also contains small proportion of proteinaceous material (Williams & Phillips, 2009b; Idris et al., 1998).

Gum arabic has high water solubility and relatively low viscosity compared to other exudate gums. Such properties are attributed to the highly branched molecular structure and low molecular weight of this polymer (Williams & Phillips, 2009_b). It is widely used in the food industry for its functional properties as a stabilizer and emulsifier. It also provides desirable qualities because of its influence over viscosity, body and texture. Rokka and Rantamäki (2010) reported that the incorporation of soluble fiber from gum arabic in a milk-based medium during storage increases the viability of *Lactobacillus paracasei*. In addition, bifidobacteria population was found to survive better compared to free cells when encapsulated in gum arabic.

Gum arabic possesses a high WHC and can influence rheological properties such as the viscosity of food products. Razaei et al. (2011) found that the viscosity of samples containing arabic gums was higher than that of the control sample. Gum arabic that are rich in protein, are good stabilizers because they have sufficient hydrophobic groups to act as bonding points as well as hydrophilic groups that reduce surface tension in a liquid-liquid or liquid-gas interface (Segura-Campos et al., 2014). Yeh et al. (2005) reported a high water absorption capacity due to the presence of proteins in gums that have a large number of exposed hydrophilic sites interacting with water. Being highly soluble in water, fibers present in gum arabic and denatured proteins could increase the WHC of gums by enhancing the gums' swelling ability (Segura-Campos et al., 2014). Similarly, Hamad et al. (2013) studied the effect of gum arabic as a stabilizer in the production of Sudanese fermented milk product. The addition of gum powder at 10% produced 2.85 ml of whey as compared to 6.95 ml in the control sample during storage at 6 °C for 15 days. Gum arabic is extensively used as a food additive and has prebiotic properties. This means that it can stimulate the growth of beneficial gut micro flora. Thus, the inclusion of gum arabic in yogurt not only helps reduce acid whey but also provides therapeutic effects.

3.1.7. Carrageenan

Carrageenan is obtained from red seaweed (*Rhodophyceae*) and possesses linear galactan backbone with alternating disaccharide repeating sequences of 1,4-linked α -D-galactose and 1,3-linked- β -D-galactose. Carrageenan contain variables proportions of sulfate groups in different positions. Individual members of each series contain different amounts of each sulfate group which can be categorized into three major groups: kappa, iota and lambda (Arda et al., 2009). These variations allow carrageenan to produce different rheological properties (Hoefler, 2001).

Carrageenan is able to stabilize gels and act as a thickener due to the presence of a sulfated linear polysaccharide and a negative charge. Usually, kappa carrageenan is known to form thermally reversible gels especially in the presence of cations such as K^+ and Na^+ (Arda et al., 2009). In contrast, gels made with iota are weaker. While lambda carrageenan does not gel in water, they interact strongly with proteins to produce a pseudoplastic thickener. Carrageenan possesses its own unique water-holding and viscosity-increasing abilities, which mainly affect the textural and stabilizing properties of food. The ability of carrageenan to hold water has found many applications in the dairy, dessert, and confection industries (Rey & Labuza, 1981). The most common use for carrageenan gum in dairy products is in ice cream or ice milk. It is added to control ice crystallization as well as whey separation.

Lunardello et al. (2012) studied the effect of carrageenan (0.10%, 0.30%) on WHC in nonfat set yogurt. Carrageenan increased firmness, adhesiveness, gumminess and WHC at the highest concentrations tested. This could be explained by the fact that carrageenan is an anionic hydrocolloid which is capable of interacting with positive charges on the surface of proteins to build the protein network and reduce syneresis (Soukoulis et al., 2007). Carrageenan also shows

1 synergistic effects with other gums that could increase gel strength and WHC (Hematyar et al.,
2 2012). Kappa carrageenan has been shown to improve consistency, viscosity and the WHC of
3 yogurt. This is likely due to carrageenan's capacity to interact with milk products and proteins
4 (Perez-Mateos, 2001). Milani and Maleki (2007) reported that the functional properties of
5 carrageenan gels are also related to the degree of sulphation within the three carrageenan groups
6 (Imeson, 2009).

7 Kappa carrageenan and casein provide a strong stabilizing network for yogurts that can
8 promote water binding and prevent syneresis. However, their instability at low acidity and the
9 requirement of cations to induce gelling could be limiting factors (Imeson, 2009). To overcome
10 this, blends of a suitable combination of carrageenan and galactomannan (guar and locust bean
11 gum) can be used. Very low levels of carrageenan (100-200 ppm) have been used to stabilize and
12 prevent whey separation in dairy products (Imeson, 2009). In many GY products, carrageenan
13 has been used in combination with other gums such as pectin to maintain a smooth texture and
14 could also be applied to reduce acid whey. The presence of several valuable properties such as
15 the ability to gell, stabilize, and thicken makes carrageenan one of the most popular additives in
16 yogurt varieties including GY.

17 3.1.8. *Inulin*

18 Inulin is a storage carbohydrate found in many plants. It is mainly derived from plant
19 components by an extraction process that uses hot water, followed by purification and
20 crystallization. Inulin consists of β -2,1-linked fructosyl units with a terminal glucosyl unit.
21 Native inulin is a mixture of oligomers and longer polymer chains with a variable number of

fructose molecules, usually including a glucose molecule at the end of the chain (Kip et al., 2006).

Hydroxyl groups of inulin are more able to interact with water than other parts. This enables inulin to form stable gels and hold more water (Barclay et al., 2010). Inulin is a natural polysaccharide with unique physicochemical properties that give it a range of uses in several food applications. For example, inulin can be used to develop a low calorie foods, or used as an additive for bulking and to replace fat, sugar and flour in food products (Kip et al., 2006). The addition of inulin to foods has been shown to increase viscosity, improve overall texture, and support the viability of probiotic bacteria in several foods including yogurt (Aryana & Mc-Grew, 2007).

Chain lengths of inulin can have an effect on some characteristics of yogurts including gelling capacity. Aryana and McGrew (2007) determined the effect of chain length of inulins on the characteristics of fat-free plain yogurt incorporated at 1.5g/100g yogurt mix. The results showed that the yogurts made with the long chain lengths had significantly lower syneresis values compared to the control and yogurts with shorter chain lengths. This could be due to the better water binding capacity of longer chain lengths. These observations are consistent with those of Gonzalez-Tomas et al. (2008), who demonstrated that a long-chain inulin at a concentration of 7.5% had significantly improved values of viscosity in skimmed-milk samples.

The results of improved viscosity suggest that inulin may act as a stabilizer due to its ability to bind water. As a result, water molecules become immobilized and unable to move freely among other molecules present within the food matrix. These improved viscosity values could be attributed to the formation of aggregates containing inulin crystals which would retain a

high amount of liquid phase thus contributing to increased WHC. Brennan and Tudorica (2008) found that inulin above 2% reduces the syneresis of low fat yogurt. These findings are also in agreement with Rinaldoni et al. (2012), who demonstrated that with an increased concentration of inulin (2-7% w/v), there was a concomitant increase in the viscosity of soy yogurt. This could be due to the total solids and the inulin high WHC that behaves as a thickener. The thickener forms complexes through hydrogen bridges, with the yogurt proteins thus contributing to a lower syneresis. Similarly, Staffolo et al. (2004) reported improved texture and functional properties of low fat yogurt by using inulin. They found that yogurt containing inulin had no syneresis during storage. It is well established that inulin serves as a prebiotic and has been used to replace fat while conferring very similar sensorial properties (Akin et al., 2007). However, the use of inulin in GY is very limited. Our observational study in Table 4 showed only one non-fat plain yogurt (brand 'H') containing inulin. The fat substituting property of inulin makes it a very suitable additive to create an improved 'creaminess' mouthfeel in GY. Moreover, being highly hygroscopic, inulin can easily bind with water to form a gel-like network that reduces acid whey. These characteristics suggest that inulin deserves to be explored for its use in the production of more GY varieties with improved quality.

3.1.9. Pectin

Pectin is a polysaccharide derived from plant material, mainly citrus fruit peels, apple peels, or sugar beets and widely used a gelling agent and stabilizer in many food applications (Milani & Maleki, 2012). Pectin consists of two families of covalently linked polymers, galacturonans and rhamnogalacturonans that form linear chains. It is generally comprised of 1,4-linked -D-galacturonic acid with different degree of esterification (Tasneem et al., 2014). The degree of esterification has an important impact on the conformation and solution properties of these

1 polymers. Based on the degree of esterification, pectins are classified into two categories: low
2 methoxyl pectin (LMP) that contains less than 50% methyl esters, and high methoxyl pectin
3 (HMP) with greater than 50% methyl esters (Tasneem et al., 2014; Milani & Maleki, 2012).

4 Pectin can be applied as a stabilizer in several dairy products including GY particularly to
5 improve the yogurt's colloidal stability. Generally, a 0.2 – 0.3% concentration of pectin
6 improved quality attributes of yogurt such as appearance, body, texture, flavor, and reduced
7 whey separation, increased firmness, prevented syneresis, and extended shelf life (Tasneem et
8 al., 2014; Tamime & Robinson, 2007). Pectin has also been found to exert prebiotic effects that
9 help feed probiotics and stimulates their growth. Sendra et al. (2008) found that the addition of
10 pectin from citric fiber in fermented milks enhanced the growth and survival of probiotic
11 bacteria. This enhanced effect of probiotic could induced a more rapid transformation of lactose
12 into lactic acid.

13 Adding an anionic stabilizer such as pectin has also been shown to produce higher WHC.
14 Everett and McLeod (2005) found an increased WHC with higher LMP concentration (> 1g/L).
15 According to this study, with higher levels of LMP, proteins were increasingly covered by this
16 polysaccharide and the aggregates were partially sterically stabilized. As the casein network
17 began to lose structural integrity and expel serum phase, this stabilization mechanism led to
18 increasing WHC. Similar results were obtained in other studies as well. HMP did not prevent
19 serum separation in yogurt drink at a level of 0.25% but were effective at an increased
20 concentration of 0.50% (Koksoy & Kilic, 2004). Lucey et al. (1999) also found evidence to
21 support these results. In this study, pectin at concentrations higher than 0.3% prevented serum
22 separation in acidic milk beverages. The authors highlighted the mechanism involved in whey
23 separation when pectin was not sufficient in milk beverages. This was attributed to the formation

of large casein aggregates or an unstable, weak gel, which undergoes further rearrangements of the strands and clusters during storage resulting in a reduction in WHC. HMP is thus used as a stabilizer to produce the gelling effect in yogurt. This thermally irreversible hydrocolloid can be added to milk products at a higher pH, followed by immediate acidification resulting in a product's having gel strength that is maintained at low pH values. Thus, in addition to preventing syneresis, HMP is useful in the production of yogurt that exhibits good mouthfeel characteristics and higher viscosity (Tasneem et al., 2014). Ramirez-Santiago et al. (2010) evaluated the syneresis properties of stirred yogurt in the presence of soluble fiber (hemicellulose and pectin). The presence of fiber at 1g/100 was found to significantly reduce the syneresis (15.4 g/100g) compared to the control sample (23.3g/100g). This effect is due to the functionality of anionic hydrocolloid pectin that is capable of interacting with positive charges on the surface of proteins, strengthening the protein network and controlling syneresis through ionic and steric stabilization effects. Due to the high WHC, the role of pectin as a gelling agent is to form a network and to bind water. In addition, pectin is generally recognized as one of the safest and most acceptable food additives (May, 2000), making pectin an important hydrocolloid used in GY functionality.

3.2. Proteins

3.2.1. Milk powders

Milk powders are usually added to enrich the protein content of milk before fermentation and to increase the viscosity of yogurts. The level of the addition of milk powder determines the viscosity, gel strength, and ability to retain water of the yogurt (Sodini & Tong, 2006). Several studies have shown a relationship between the addition of different milk powders and improved yogurt quality such as higher gel firmness, reduced syneresis, increased WHC, and improved

mouth feel. Thus, the application of milk powders is of great interest not only to reduce acid whey in GY but also to enhance the level of protein in yogurt.

Skim milk powder (SMP) is obtained by spray drying concentrated milk from which the fat content has been removed (Singh et al., 1992). The addition of SMP has been shown to improve the textural quality and decrease the vulnerability of yogurts to syneresis. Soukoulis et al. (2007) reported that skim milk yogurts exhibited longer incubation times and higher viscosities resulting in enhanced firmness and consistency and less syneresis effect. Similarly, Becker and Puhon (1989) reported a 25% increase in gel strength and a 15% increase viscosity with the addition of 1% SMP compared to yogurt made without SMP. This study confirmed fewer syneresis effects with increased SMP. The higher WHC for yogurts fortified with SMP was also reported by Remeuf et al. (2003), and was attributed to the presence of high dry matter in SMP fortified milk. Imm et al. (2000) investigated a novel method of transglutaminase (TGase) treatment for skim milk yogurt with respect to water binding and gelation. The results of this study showed that TGase-treated SMP (TG-SMP) had improved WHC and gelation compared to the control SMP as TG-SMP formed dense gels due to Tgase-induced cross-linking. This reduction of syneresis is beneficial for the manufacture of low-fat yogurt.

Whole milk powder (WMP) is the product resulting from the removal of water from pasteurized milk. Unlike SMP, WMP is not commonly used as an additive for WHC. Salvador and Fiszman (2004) studied the effect of refrigerated storage on whole and skimmed flavored set-type yogurt. These authors reported that the firmness values of whole yogurt were lower than for skimmed yogurt under all the storage conditions studied. These results are also supported by Paseephol et al. (2008), who demonstrated a weak gel structure of full fat yogurt prepared from

16% WMP compared with nonfat yogurt due to low protein content (4.2%) compared to the higher protein (5.4%) in nonfat yogurt. This could be attributed to the interference of fat globules with the protein matrix formation. These processes are believed to be responsible for a weak WHC and softer yogurt gel formation.

Buttermilk powder (BMP) is obtained by removing water from liquid buttermilk derived from the churning of butter and has been successfully used to replace SMP for milk fortification in yogurt manufacture (Guinee et al., 1995). However, no significant differences were observed in the viscosity and WHC of low-fat stirred yogurt stabilized with SMP or BMP at a 5% protein content (Guinee et al., 1995). Romeih et al. (2014) investigated the influence of BMP addition and protein cross-linking by microbial transglutaminase (TG) on the functional characteristics of fat free set yogurt produced from buffalo skim milk. The authors indicated that the addition of BMP showed a marked impact on the gel network, resulting in a more complex and dense gel structure that improved WHC. This suggests that the addition of BMP could be a valuable additive in fat free yogurt production as well as a source of extra protein.

3.2.2. Milk proteins

Milk proteins primarily consist of two main categories: casein and whey, which can be separated on the basis of their solubility at pH 4.6. The primary groups of milk proteins which precipitate out under these conditions are caseins (75 – 80 %), while the proteins which remain soluble are whey proteins (20 – 25 %). Milk proteins are extensively being used in yogurt production to increase the protein content (Fox, 2001). Several studies have shown that the supplementation of various types of milk proteins in yogurt manufacture have improved WHC or prevent syneresis in yogurt production indicating that these proteins can also be added in GY production to reduce

the volume of acid whey. Therefore, high milk protein powders are finding application in low lactose, high protein products such as GY.

Milk protein concentrates (MPCs) are complete milk proteins that contain both casein and whey proteins in the similar ratio as in milk. MPC is essentially skim milk that contains fat levels of < 3% with various amounts of lactose and minerals remaining in the product. MPCs are produced by ultrafiltration or by blending nonfat dry milk with highly concentrated proteins such as casein (Mulvihill & Ennis, 2003). In general, MPCs have a protein content of 42 – 85 %. MPCs are multifunctional ingredients and provide benefits such as water binding, gelling, foaming, emulsification, and heat stability. The use of MPCs as an ingredient has been increasing at the expense of casein and caseinate due to MPCs improved flavor profile. Common applications include infant formulas, desserts, baked goods, toppings, low-fat spreads, dairy-based dry mixes, dairy-based beverages, sports and nutrition beverages/foods, geriatric nutritional products, weight loss beverages/foods and some processed cheese products. MPCs can be used as a replacer for WMP and SMP to formulate Greek style yogurts with higher protein and low lactose. In a recent paper on ‘Innovative uses of milk protein concentrates in product development’ the author highlighted the use of MPCs as one of the approaches to make high-protein Greek style yogurt without production of acid whey (Agarwal et al., 2015). These authors also indicated that the use of MPCs in yogurt production is well accepted.

3.2.3. Whey products

The applications of whey powder is limited in yogurt manufacture because it has been associated with some defects in texture, flavor, and appearance when added at high levels. Because whey powder is relatively less expensive than SMP, its use has been documented (Sodini & Tong,

2006). Whey proteins are those that remain soluble after rennet or acid precipitation. The main whey proteins are β -lactoglobulin, α -lactalbumin and bovine serum albumin.

Whey proteins contain intramolecular disulfide bonds that stabilize the proteins' structure. β -Lactoglobulin contains a sulfhydryl group that becomes active upon denaturation of protein by heat and can subsequently form sulfhydryl-disulfide interactions with itself and other proteins. With these properties, whey proteins affect the structure and rheological properties of coagulated milk gels including yogurt and cheese (Fox, 2001). In the food industry, Whey protein concentrate (WPC), and whey protein isolate (WPI) are used extensively due to their nutritional and functional properties and especially their gel-forming ability which produces viscoelastic gels after denaturation (López-Fandiño, 2006; Kinsella & Whitehead, 1989).

Whey protein concentrates (WPCs) are dairy products enriched in whey proteins (60-85%) and are derived from cheese whey by the removal of mineral and lactose. Production procedures for WPCs include ultrafiltration/diafiltration and spray drying of the ultrafiltration retentate. On a dry basis WPC generally contains 35 %, 50 % or 80 % protein. Compared to the caseins present in SMP, whey proteins lack opacity and white appearance. WPC can contribute to water binding properties, thereby reducing syneresis and resulting in a firmer product (Augustin et al., 2003; Cheng et al., 2000). Sodini et al. (2006) conducted a study to examine the effect of whey processing on WPC functionality in yogurt. The highest water holding capacities were obtained when yogurt was fortified using WPC from whey with low heat treatment. The results of this study indicate that the processing of protein also plays an important role in whey protein functionality.

The addition of WPC (1%, w/v) improved the texture of set-type nonfat yogurt and resulted in greater sizes in the gel network as well as lower syneresis and higher WHC capacity. During 2 weeks' storage at 4°C, the addition of whey protein increased WHC and decreased the syneresis of yogurts compared to the control samples (Delikali & Ozcan, 2014). According to Puvanenthiran et al. (2002), the fortification of yogurt with WPC caused a decrease in the casein whey protein ratio whereas the maximum gel strength of yogurt increased and whey drainage was reduced. The formation of aggregates by interaction with casein micelles created a more rigid gel structure in the yogurt. This gel-like structure increased in size when the proportion of whey protein increased which may be due to a higher cross-linkage of the network noticed in yogurts fortified with WPC (Aziznia et al., 2008; Remeuf et al., 2003). Remeuf et al. (2003) reported that when milk was enriched with WPC (34 to 80% wt/wt protein), heating led to a high level of cross-linking within the gel network, which increased both yogurt viscosity and WHC. When properly heated, yogurts fortified with WPC have higher viscosity and better water-holding properties. Morris et al. (1995) reported that syneresis is reduced by fifty percent when milk for yogurt is fortified with 4% WPC compared to 4% SMP. The WHC of yogurts enriched with WPCs was higher than that of the control yogurt. The WHC of WPC enriched yogurts was 601 to 636 g kg⁻¹, compared with 501 g kg⁻¹ for the control yogurt. This may be due to a higher cross-linkage of the network noticed in yogurts fortified with WPCs (Sodini et al., 2005). Similar results were also reported by Bhullar et al. (2002), who found that supplementation with 2% (w/v) of WPC increased viscosity and reduced syneresis. Usually, replacing SMP with WPC results in increased gel strength in set yogurt, increased viscosity in stirred yogurt and increased WHC in both types of yogurts. These properties make WPC an excellent whey ingredient for GY production.

3.2.4. Casein and derivatives

Acid casein react with a strong alkali to result in an almost neutral protein product known as caseinate. The type of alkali used to neutralize the acid casein curd determines what type of caseinate is produced. For example, sodium caseinates (NaCn) are prepared from coagulated casein micelles, which are subsequently washed and neutralized with NaOH, whereas reacting acid casein curd with calcium oxide or calcium hydroxide results in the formation of calcium caseinate. Sodium caseinate is a valuable food ingredient with high protein content and functional properties of emulsification, water binding, and texture improvement. Due to its excellent functional and nutritional properties, sodium caseinate has been widely used in the food industry. Sodium caseinate is also the most water soluble form of caseinate and has been shown to produce higher viscosities than calcium caseinate (O'Regan et al., 2009).

The fortification with casein based ingredients tended to increase firmness and reduce syneresis in set yogurts and increase viscosity in stirred yogurt compared to control yogurts (Guzmán-González et al., 2000). Peng et al. (2009) reported that fortification with NaCn resulted in yogurt products with less syneresis than yogurts enriched with SMP. Similarly, Modler et al. (1983) reported that yogurts made with additional casein-based ingredients were firmer and showed less syneresis than yogurts fortified at the same protein level with whey protein-based ingredients. Modler et al. (1983) further noted that yogurt containing 1.5% caseinate had a gel strength of approximately twice that of yogurt made with gelatin as a control sample. These results however, contradict with the findings of other authors who observed that yogurts fortified with caseinate had lower WHC than those enriched with WPC (Akalin et al., 2012; Guinee et al., 1995).

1 **Table 1.** Source, chemical composition, characteristics and applications of selected hydrocolloids

	Microbial	Monosaccharides	Main Chain	Characteristics	Applications
Polysaccharides	Xanthan gum	Glucose, mannose, glucuronate	(1-4)- β -D-glucose	Thickener; very soluble in hot and cold water; high viscosity; stable to heat, pH, and enzymes	Soups and gravies, ketchups, instant beverages, desserts, toppings and fillings
	Gellan gum	Straight chain based on repeating glucose, rhamnose, and glucuronic acid units	Tetrasaccharide repeating units	Strong gel; heat to dissolve; gels with cations upon cooling; stable to acid and heat	Icings, non-standardized jams and jellies
	Plant seeds				
	Locust bean gum	Mannose, Galactose	Mannan	Thickener; insoluble in cold water; viscous at 95°C.	Dairy products including ice cream, ketchup, fruit juices, pudding powder, cake batter
	Guar gum	Mannose, galactose	Mannan	Water soluble; thickener and non-gelling behavior; increase viscosity; water binding properties	
	Cassia gum	Mannose, galactose	Mannan		
	Plant of compositae family				
	Inulin	Fructose	β -(2-1) fructosyl-fructose linkages	Fat replacer; gives a fat like mouth feel and texture; gelling capacity with water	Dairy products, bread and other bakery products, confectionery & ice cream, beverages and spreads
	Plant cell wall				
	Pectin	Galacturonic acid, rhamnose	Galacturonan	Gelling agent; thermo reversible gels on cooling at acidic pH	Jams, jellies, glazes, milk based desserts
	Plant exudate				
	Gum arabic	Galactose, arabinose, rhamnose, glucuronic acid	Galactan	Low viscosity; dissolves in cold and hot water; readily soluble; emulsifying agent	Fruit juice based beverage, soft drinks

2

1

2 **Table 1**

3 (Cont'd)

	Seaweeds	Monosaccharides	Main Chain	Characteristics	Applications
Polysaccharides	Alginates (brown seaweeds)	Guluronic acid, mannuronic acid	Guluromannuronan	Gelling agent; irreversible gels with calcium ions in cold water	Restructured foods, cold prepared bakery creams
	Kappa-carrageenan (red seaweeds)	3,6-Anhydro-D-galactose, D-galactose-4-sulfate	Galactan	Gels with calcium or potassium salts; binds protein	Puddings, milk shakes, tofu
	Synthetic gum Carboxymethyl cellulose	Glucose	D-glucose residues linked by β -1,4-linkage	Thickener; high viscosity but is reduced by adding electrolytes and at low pH; water soluble	Salad dressings, gravies, fruit pie fillings, ketchup
Proteins	Animal Milk powders Milk proteins Whey products Caseinates	-	-	Water binding; gelation, emulsification; affect flavor, texture, and appearance	Yogurt, fruit yogurt, milk shakes, ice cream products, coffee creamer & whiteners

4 *Source:* Kapoor et al. (2013); Saha and Bhattacharya (2010); Williams and Phillips (2009a); Tomasik (2003)

1 **Table 2.** Typical usage level, interaction effects and regulatory status of commonly used hydrocolloids in yogurts

Hydrocolloids	Level (%)	Interaction effects	Regulatory status
Xanthan gum	0.05 - 0.3	A synergistic interaction occurs between xanthan gum and locust bean, guar, and cassia	Recognized as food additive under the provision of the US FDA regulations (CFR 21, § 172.695) for use as a stabilizer
Gellan gum	0.04 - 0.1	Synergies with gelatin and carrageenan have been reported in the literature. However, these synergies are likely based on ionic effects and volume exclusion rather than direct gum interactions. Gellan gum can be used in combination with other stabilizers such as starch.	Gellan gum is approved for food use in many countries including US, European Union, Canada, South Africa, Australia, Japan, most of South East Asia, and Latin America
Locust bean gum	0.05 - 0.1	Interact with agar-agar, carrageenans, and xanthan gum	The FDA recognizes locust bean gum as GRAS (Generally recognized as safe), as listed in the code of federal regulations (CFR 21,§ 184.1343) for its stabilizing, thickening and fat-replacing properties
Guar gum	0.05 - 0.1	Interact with agar-agar, carrageenans, and xanthan gum	Listed as GRAS in CFR 21,§ 184.1339
Gum Arabic	0.05 - 0.1	Synergistic effect with other hydrocolloids is rare. It interacts with sugar and sugar alcohols.	Gum Arabic is generally recognized as safe (GRAS) as listed in the CFR 21,172.780
Carrageenan	0.2 - 0.5	Hot solutions of kappa carrageenan and locust bean gum form strong, elastic gels with low syneresis when they are cooled below 50-60°C.	The FDA recognizes carrageenan as permitted for direct addition to food for human consumption in the Code of Federal Regulations (CFR 21, § 172.620)
Pectin	0.05 - 0.3	Pectin forms strong thermoreversible gels with alginates at low solid levels over a wide pH range. Most importantly, it is an anionic hydrocolloid capable of interacting with positive charges on the surface of the proteins, strengthening the protein network.	The FDA recognizes pectin as GRAS. Pectin can be used in all non-standardized foods and in accordance with the code of federal regulations (21CFR 184.1588)

2 *Source:* Valli and Miskiel (2001), Yaseen et al. (2005), Soukoulis et al. (2007), Phillips and Williams (2009), Milani and Maleki (2012), Tasneem
3 et al. (2014), Wüstenberg (2014)

4

1 **Table 3.** Impact of selected gums on water holding properties

Gums	Tested concentration (%)	Experimental treatments	References
Xanthan	0.005, 0.01, 0.1	Increased WHC and reduced syneresis in fermented dairy products, no wheying-off defect in whole fat and skimmed yogurts	El-Sayed et al. (2002); Soukoulis et al. (2007); Hematyar et al. (2012); Bahrami et al. (2013)
Locust bean	0.013, 0.02, 0.1	Prevented serum separation in yogurt drink, increased WHC in low fat yogurts	Koksoy & Kilic (2003); Ünal et al. (2003)
Guar	0.1, 0.25	The reduction in serum separation (control sample= 12mL/50 mL, 0.1%=2 mL/50 mL; 0.25%= 0 mL/50 mL) was observed in yogurt drink after 15 days of storage at 4 °C	Koksoy & Kilic (2004)
Gum arabic	10.0	Only 2.5 mL of whey was produced with the addition of gum powder compared to 6.95 mL in control sample during storage at 6°C for 15 days in fermented milk product Robe	Hamad et al. (2013)
Carrageenan	0.3	Increased WHC in nonfat set yogurts	Lunardello et al. (2012)
Inulin	>2.0	Reduced syneresis in low fat yogurt	Brennan & Tudorica (2008)
Pectin	0.2-0.3	Increased WHC, reduced whey separation and prevented syneresis in yogurt	Tamime & Robinson (2007); Everett & McLeod (2005); Tasneem et al. (2014)

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1 **Table 4.** Impact of selected proteins on water holding properties

Proteins	Tested concentration (%)	Experimental treatments	References
Skim milk powder (SMP)	1-3	Lowest syneresis was observed in non-fat yogurt compared to the control samples after 28 days of storage at 4°C	Zare et al. (2011)
	2.0	Decreased syneresis in skimmed milk yogurts stored at 7°C for 24 h	Soukoulis et al.(2007)
Whey protein concentrate (WPC 80%)	1.0	Decreased syneresis and increased WHC in non fat yogurt during 2 weeks of storage at 4°C	Delikanli & Ozcan (2014)
	2.0	A significant decrease in syneresis and increase in WHC was observed in whole milk yogurts fortified with WPC throughout the storage of 28 days at 4 °C	Akalin et al. (2012)
Whey protein isolate (WPI)	1.0	Nonfat-yogurt fortified with WPI had the lowest level of syneresis than control yogurt stored at 5°C for 12 days	Isleten & Karagul-Yuceer (2006)
Milk protein hydrolysates (MPH)	0.3 - 0.5	The addition of milk protein hydrolysates (casein and whey) decreased yogurt syneresis	Zhao et al. (2006); Karam et al. (2013)
Sodium caseinate (NaCn)	1.0 - 1.5	Yogurt fortified with NaCn displayed less syneresis than control yogurts	Modler et al. (1983); Isleten & Karagul-Yuceer (2006)

4. Current trend in hydrocolloids used in Greek yogurt sold in the U. S.

Table 5 shows the list of hydrocolloids used in popular Greek yogurts brands sold in the U.S. markets. We accessed the major brands' official websites and conducted an observational study in the local markets for available Greek yogurts that include hydrocolloids. Based on our observations, most of the yogurts contain carbohydrate based hydrocolloids, whereas very few yogurts contain protein based hydrocolloids. The use of hydrocolloids seems to be very common in flavored yogurts compared to plain ones. The most commonly used hydrocolloid is pectin followed by locust bean gum and carrageenan. We also noted the use of modified corn starch as thickening agents in most of the Greek yogurts. Previous studies conducted in our laboratory also suggested that gums could be added to milk to improve viability and enhance the β -galactosidase activity of *Lactobacillus* spp. (Karlton-Senaye et al., 2015; Karlton-Senaye & Ibrahim, 2013). This result suggests that supplementation of hydrocolloids not only improves physicochemical characteristics (eg., WHC, texture) but also enhance the microbiological quality of yogurt during refrigerated storage. It is also important to investigate the types of gums other than those that are currently being used in Greek yogurt manufacturing. There are still the largely unexplored potential benefits of hydrocolloids that can be used as additives in Greek yogurt production.

Table 5. Greek yogurts and hydrocolloids

Brands	Types	Hydrocolloids
A	Nonfat/flavored	Gelatin, modified corn starch
B	Nonfat/flavored	Carrageenan, guar gum, , pectin, locust bean gum, xanthan gum, sodium carboxymethyl cellulose, gelatin, modified corn starch
C	Nonfat/flavored	Pectin, carrageenan, locust bean gum, modified corn starch
D	Nonfat/flavored	Gellan gum, locust bean gum, pectin, modified corn starch
E	Nonfat/flavored	Pectin, locust bean gum, guar gum

F	Full fat/flavored	Pectin
G	Nonfat/flavored	Gelatin, pectin, modified corn starch
H	Nonfat/plain	Inulin, pectin
H	Full fat/flavored	Pectin, gum arabic, xanthan gum
I	Nonfat/plain	Carrageenan, pectin, modified corn starch
I	Low fat/plain	Whey protein concentrate, milk protein concentrate
I	Low fat/flavored	Whey protein concentrate, milk protein concentrate, modified corn starch, pectin

Source: Specifications obtained from the manufacturers official websites.

5. Starter culture and probiotics

Selection of yogurt starter culture is another factor that affects yogurt quality. Some strains of starter culture produces a ropy exopolysaccharide (EPS) substance which imparts a ropy texture to the yogurt. EPS are polymeric compounds that are considered to be natural biothickeners that contribute to the structure of fermented milk products (Mostefaoui et al., 2014). EPS-producing starter cultures are becoming increasingly popular due to their high water-binding and texture-promoting abilities in yogurts (Güler-akin et al., 2009). In addition, EPS-producing cultures have been successfully used to enhance the quality of yogurt by increasing viscosity, improving sensory characteristics including mouth-feel, taste perception, shininess and creaminess, and enhancing water binding capacity and storage stability of the final product (London et al., 2015). Table 5 shows the effect of some EPS- producing yogurt cultures on the WHC and syneresis. All types of yogurts made with EPS producing cultures had increased WHC or lower whey separation (syneresis) that could most likely be attributed to the fact that some of the free water in the coagulum had been bound by polysaccharides produced by ropy cultures.

Guzel-Seydim et al. (2005) investigated the effect of ropy and non-ropy producing strains of yogurt culture on the yogurt quality. Their study showed increased consistency and viscosity of yogurts made from milk inoculated with EPS producing culture. Similarly, whey separation decreased more with ropy cultures than in yogurt made with non-ropy producing culture under the same preparation conditions. In a recent study (London et al., 2015), the effect of EPS producing *Lactobacillus mucosae* DPC 6426 was evaluated as an adjunct culture during low-fat yogurt manufacture. The results of this study showed an approximately 10% reduction in syneresis after 28 days of storage, suggesting that *L. mucosae* DPC 6426 produced a ropy EPS that has a greater WHC.

Viscosity was also found to be comparatively high with the EPS-rich yogurt versus control yogurt during the same storage period. Improvement in viscosity and WHC is due to the free water in the coagulum being bound by polysaccharides produced by ropy cultures. EPS produced by yogurt culture also interacts with the free water in the gel-like structure thus improving yogurt texture. Moreover, EPS producing cultures contribute to a polymer-like behavior of the serum phase, this polymer like substance formation might have the ability to hold water and increase viscosity. In addition, the electrostatic attraction between charged polysaccharide and casein network provided three dimensional structures to the fermented milk resulting in a gel like structure. The use of EPS producing cultures could provide better texture, especially for low fat yogurts instead of using additives as fat replacers (Guzel-Seydim et al., 2005). The addition of probiotic bacteria also reduced acid development in yogurt during storage. Increased production of EPS was observed in yogurts with the addition of probiotic cultures compared to those without probiotics. Thus, formation of EPS by the starter and probiotic cultures could contribute to the prevention of syneresis and an increase in viscosity.

With the selection of such probiotic strains that are capable of EPS production and acid tolerance, the yogurt gel strength can be improved resulting in increased WHC of yogurt (Kailasapathy, 2006).

From the above mentioned studies, it is evident that yogurt made with EPS-producing cultures is less susceptible to syneresis, more viscous, and had more WHC than that made with EPS-non-producing cultures. Therefore, the selection of the right strains and optimum rate of inoculation could help produce GY with thick consistency as well as a decrease in susceptibility to syneresis during storage. Inoculation rate of starter culture and probiotics is another factor that can also affect whey separation. Lee & Lucey (2004) found that decrease in whey separation as inoculation rate was increased with decrease in incubation temperature.

Table 5. Effect of some EPS producing starter culture on water holding capacity (WHC) and syneresis of yogurts

Bacterial strains	Description of culture component	WHC/Syneresis	References
CHCC-10935	<i>L. bulgaricus</i> , EPS producing	Improved WHC in low fat yogurts	Zhang et al. (2016)
DPC 6426	<i>Lactobacillus mucosae</i> , EPS producing	EPS-containing yoghurt had a significantly lower level of syneresis compared with control yoghurt throughout storage at 4 °C for 28 days	London et al. (2015)
YO-MIX 601	<i>S. thermophilus</i> and <i>L. bulgaricus</i> , ropy-polysaccharide producing	The reduced fat stirred yogurts made with EPS strains showed a significantly lower level of whey separation than those made with non-EPS strains during 21 days of storage	Güler-akin et al. (2009)
B-3 filant type	Ropy polysaccharide producing yogurt culture	Higher WHC was observed in plain set type yogurts during 14 days of storage	Guzel-Seydim et al. (2005)
ST-ASCC 285, ST-ASCC 1275	<i>S.thermophilus</i> ,EPS producing	Reduced the level of syneresis in set yogurts	Amatayakul et al. (2006)

6. Processing conditions

This section describes the steps involved in the actual production of yogurt. Like traditional yogurts, GY quality also depends heavily on processing methods and conditions. Each individual step significantly affects the quality of the yogurt. Optimization and modification of these processing conditions often leads to higher quality yogurts. These processing steps can be manipulated either alone or in combinations to produce an acid milk gel with high gel strength, short gelation time, smooth texture and little or no syneresis that could lead to the minimization of acid whey production.

6.1. Pasteurization

During the manufacture of yogurt, heat treatment is applied to pasteurize milk and to change milk composition properties in order to improve yogurt quality. The thermal processing of milk plays a major role in the formation of solid-like yogurt gels by promoting *k*-casein-whey protein interactions leading to reduced casein micelle contact. This process develops an open structural protein matrix that can hold water (Trejo et al., 2014). Usually yogurt mix is pasteurized at 80-85°C for 30 min or 90-95°C for 10 min. During this process, whey proteins undergo physical changes due to the heat treatment affecting the yogurt viscosity (Chandan & O'Rell, 2006b). Yogurt made from mix pasteurized at 93°C showed a low syneresis effect compared to yogurt made from mix pasteurized at 72°C (Lee & Lucey, 2004a). Spontaneous whey separation is related to an unstable protein network, which could be due to an increase in rearrangements that result in loss of whey within the gel network (Lee & Lucey, 2004; Lee & Lucey, 2010). However, in yogurt pasteurized at >80°C, the casein network and denatured whey proteins form stronger bonds in the protein network. This reduces the likelihood of casein rearrangements and thus prevents whey separation. Denaturation of whey protein by 70-95% improves water

absorption capacity helping create smooth consistency, high viscosity and less whey separation. Heat treatment also affects yogurt textural quality. It is known that the holding time of milk at a temperature above 75°C causes 99% denaturation of β -lactoglobulin, thereby producing characteristic yogurt gel due to the aggregation of casein micelles. Thus, whey separation can be prevented by subjecting the milk to an intense heat treatment (Lucey, 2002).

Quian et al. (2010) investigated the physical properties of yogurt that had been pasteurized at different temperatures (85-95°C) for various amounts of time (1-35 min). These results showed that pasteurization treatment at 90°C for 5 min resulted in the highest WHC (80.17%) and higher viscosity. Mild heat treatment during whey processing was more favorable for the production of functional whey protein concentrates. In contrast, yogurt gels made from milk heated at higher temperatures and incubated at lower temperatures indicated that these gels had smaller pores and a more cross-linked network created by denatured protein, which has been shown to reduce whey separation and improve WHC (Lee & Lucey, 2003). Sodini et al. (2006) determined the effect of heat treatment of whey on the functional properties of WPC in yogurt. WPC with low denaturation levels produced yogurt with high WHC suggesting that the minimizing heat treatment (72°C for 15s at pH5.8) during whey processing could maximize the functional properties of WPC used in yogurt. Kucukcetin (2008) found that the syneresis of yogurt decreases progressively with an increase in the degree of whey protein denaturation; however with > 90% denaturation, this trend is less pronounced than in yogurt obtained from milk containing $\leq$ 90% of heat-denatured whey protein. These results differ with those reported by Sodini et al. (2006), who suggested that WPC with low denaturation levels produced yogurts with a high WHC.

Ultra-high pressure (UHP) in milk acid gel formation has also been shown to improve the texture and firmness, reduce syneresis and increase WHC when compared to yogurt prepared with conventional methods (Trujillo et al., 2002). Ferragut et al. (2000) evaluated ewe milk yogurt made from high pressure treated milk using different combinations of temperature and pressure and from pasteurized (70°C, 10 min) milk. This study showed an increase in yogurt firmness as pressure increased. With treatments of 350 MPa at 25°C and 500 MPa at 55°C there was no difference in whey syneresis compared to pasteurized milk. Water retention was maintained only in yogurts made from HP-treated milk during 20 days of storage at 4°C. The characteristics of yogurt prepared from thermosonicated and conventionally heated milks were previously compared by Riener et al. (2010). That study showed that yogurt from thermosonicated milk displayed higher WHC and lower syneresis than yogurt prepared from conventionally heated milk (90°C for 10 min). The authors also noted that the reduction in fat globule size achieved by thermosonication could have enhanced such effects. These results also show that milk can be treated using non thermal processing techniques to produce microbially safe, minimally processed yogurts without compromising quality.

6.2. Homogenization

The homogenization process involves reducing the size of fat globules into smaller pieces that are dispersed evenly throughout the milk. Homogenization of the milk is an important processing step for yogurts containing fat. In general, yogurt mix is homogenized at 15 MPa, and homogenization can be done before or after pasteurization at temperatures ranging between 55 and 65°C. Homogenization prevents fat separation (creaming) during fermentation and storage, reduces whey separation, increases water retention, increases whiteness, and enhances the consistency of yogurt (Lee & Lucey, 2010).

1 In addition, homogenization of milk reduces the size of fat globules and promotes the
2 interaction of homogenized fat with the protein matrix thus improving yogurt quality (Sodini et
3 al., 2004). This process affects the characteristics of yogurt such as water binding properties
4 (Sfakianakis & Tzia, 2014). Homogenization creates smaller milk fat globules that facilitate the
5 incorporation of fat into the protein network. The increased surface area of homogenized fat
6 globules favors the interactions between fat and milk proteins, casein and denatured whey,
7 during acidification which may lead gel formation thus contributing water binding ability
8 (Sfakianakis & Tzia, 2014; Cho et al., 1999). Serra et al. (2009) evaluated the effects of ultra-
9 high pressure homogenization (UHPH) on cow's milk and its suitability for yogurt
10 manufacturing. The authors concluded that the yogurts prepared from milk UHPH treated at 200
11 or 300 MPa at 40°C showed higher gel firmness in texture, less syneresis, and lower titrable
12 acidity compared with conventionally treated milk as well as that fortified with 3% SMP.
13 According to the authors, the gels from UHPH-treated milk had a higher WHC that was most
14 likely due to the higher degree of casein particles solvation and the high dispersion of the fat
15 fraction. In another study, Wu et al. (2000) evaluated the effect of ultrasound on milk
16 homogenization and yogurt fermentation. It was found that high amplitude ultrasound has a very
17 good homogenization effect compared to conventional homogenization. Their study showed that
18 at high amplitude levels, extremely small fat globules were produced. These globules increased
19 the total fat membrane surface area which included a significant amount of new bonded
20 hydrophilic casein. This resulted in increased WHC and reduced syneresis which was attributed
21 to the ability of the proteins to retain water within the yogurt structure. However,
22 homogenization has an adverse impact on low fat yogurt by increasing syneresis or reducing
23 WHC due to empty spaces between casein matrices as well as a lack of native milk fat globules

(Trachoo, 2003). On the other hand, in high fat yogurts, clusters of fat globules can fill up these spaces and reduce acid whey production.

6.3. Incubation temperature, time, and pH

Selection of incubation temperature affects overall yogurt quality. Usually, yogurts are prepared either with high (45.7°C) or low temperature (40°C) incubation. The use of lower incubation temperatures leads to longer incubation times but forms more viscous gels that are less prone to whey syneresis. At a lower incubation temperature, there is an increase in the size of the casein particles because of a reduction in hydrophobic interactions which, in turn, leads to an increased contact area between particles (Lee & Lucey, 2010). However, higher incubation temperatures make the gel network more prone to rearrangements during gelation, and these changes can lead to greater whey separation (Lee & Lucey, 2004; Lee & Lucey, 2010). As a result, Lee and Lucey (2004) suggested a low incubation temperature (< 40°C) with an optimum inoculation rate to achieve lower whey separation and less textural defects in yogurt (Lee & Lucey, 2004).

The effect of incubation temperature on the rheological nature of yogurt curd during gelation was investigated by Shaker et al. (2002). The authors found that incubation temperature affected yogurt viscosity during the gelation process. Increasing the incubation temperature decreased the flow behavior index and increased the consistency coefficient. These results indicated that the optimum incubation temperature for acid development was 45°C with minimum and maximum viscosity at 40 and 48°C, respectively.

Recently, Trejo et al. (2014) investigated the effect of a low temperature step during fermentation on the physico-chemical properties of fat-free yogurt. When pH reached 5.2, fermentation of milk was stopped by reducing the temperature to 4°C for 30-120 min. After this,

1 fermentation was continued at 40°C until milk pH reached 4.6. This study showed no significant
2 differences between control and the sample chilled for 30 min. However, samples that were held
3 at 4°C for 60-120 min showed higher WHC than the control sample. The results indicated that
4 the introduction of a cold step in the fermentation process at pH 5.0-5.2 would form a strong gel
5 yogurt with a high WHC or resistance to syneresis without the use of stabilizers or gums as
6 additives. The syneresis effect is also directly related to the pH of the system. Ramírez-Sucre
7 and Velez-Ruiz (2013) pointed out that higher syneresis usually occurs when there is higher pH.
8 In yogurt, when pH reaches < 4.0, syneresis becomes more visible due to curd contraction owing
9 to the reduction of hydration of water (Penna & Oliveira, 2003).

10 *6.4. Storage*

11 The rate of cooling is of critical importance in obtaining a product with the desired textural
12 quality. Cooling too quickly can cause a weak body and stimulate whey separation during cold
13 storage. Storing yogurt for 1-2 days improves viscosity. During the first 24–48 h of cold storage,
14 an improvement in the physical characteristics of the coagulum is observed, mainly due to
15 hydration and/or stabilization of casein micelles. Proper hydration is required to avoid syneresis.
16 Thus, it is important to delay the sale or distribution of yogurt for 24–48 h (Shah, 2003). After
17 the pH of yogurt reaches the desired value, the yogurt is cooled to around 5°C. Cooling of yogurt
18 can take place in one or two phases. One-phase cooling involves the rapid decrease of the
19 coagulum temperature to less than 10°C, where the fermentation process is inhibited leading to
20 yogurt with low viscosity. Two-phase cooling is initiated by rapidly decreasing the temperature
21 to less than 20°C and then gradually reaching the storage temperature of 5°C leading to yogurt
22 with an increased viscosity and limited syneresis (Tamime & Robinson, 2007).

As storage time increased, the instability of the resultant gel in yogurt increased and the ability to entrap the serum phase decreased (Lee & Lucey, 2004). As a result, high levels of syneresis were obtained after storing samples for 12 days. This observation agreed with Al-Kadamany et al. (2002) who reported that the level of free whey in concentrated yogurt produced by the traditional method increased upon storage. Salvador and Fiszman (2004) also reported that the level of syneresis in whole and skimmed set types of yogurt increased with storage time. High storage temperatures and acidity levels have been linked to higher degrees of wheying-off in acid milk gels. For example, at 15°C and 25°C, initially, samples exhibited increasing rates of wheying-off with the degree of syneresis decreasing sharply in the later stages of storage. The increased syneresis with storage time was usually associated with severe casein network rearrangements that promoted whey expulsion (Al-Kadamany et al., 2003; Lucey, 2002).

7. Limitations

Sometimes the use of hydrocolloids such as polysaccharides and dried protein ingredients in yogurt can result in undesirable characteristics such as off flavors. For instance, some milk proteins have a short shelf life compared to other dried ingredients and are prone to lipid oxidation which can increase the likelihood of off flavors. Desai et al. (2013) also observed some off flavors in fortified Greek yogurts that contained added dairy ingredients. Today's consumers demand natural functional yogurts with clean labels, and some yogurt producers are trying to eliminate added hydrocolloids. However, clean labels in yogurt could limit the hydrocolloids available to modify texture and taste. In addition, Greek yogurts that are manufactured with added hydrocolloids contain lower overall protein compared with strained Greek yogurts (Desai et al., 2013). Thus, yogurt manufacturers need to consider formulating the yogurt products that meets consumers' expectations.

8. Conclusion

Dairy products, including traditional yogurt, contain either a single hydrocolloid or a combination of several hydrocolloids to achieve desired characteristics. The addition of hydrocolloids as a stabilizer in the manufacture of yogurt is a common practice. In this paper, we have addressed the potential effects of such hydrocolloids to reduce the quantity of acid whey production in Greek yogurt. The presence of hydrocolloids (polysaccharides and milk proteins) could significantly reduce acid whey production in Greek yogurt. Based on our observational study of available Greek yogurt that includes hydrocolloids, further work is warranted in order to determine which appropriate hydrocolloids have not yet been exploited commercially in the manufacture of Greek yogurts. Greek yogurts traditionally achieve their texture through the straining process that concentrates solids, especially protein. However, from a commercial point of view, such a method could prove to be costly and time consuming. The use of hydrocolloids not only help hold the water but also modify the yogurt texture and also the palate breakdown and taste. Thus, the inclusion of hydrocolloids other than milk proteins in the manufacture of Greek yogurt becomes significant. Additional research is also needed to optimize the yogurt processing steps including homogenization, incubation time and temperature, and culture type that could minimize acid whey production. Therefore, in order to obtain a Greek yogurt with less acid whey production, it is very important to consider the formulation composition as well as processing conditions.

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