Austin Journal of Nutrition and Food Sciences

Open Access

Austin Publishing Group

Review Article

Rheological Properties of Yoghurt Manufactured by using Different Types of Hydrocolloids

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Received: August 22, 2016; **Accepted:** October 05, 2016; **Published:** October 13, 2016

Abstract

Several ingredients are added to many food systems in order to deliver a wide selection of products for the consumer. Food hydrocolloids or food gums are added to food systems for many reasons, principally adjusting the texture, improving the stability, or reducing the fat or calories of a product. The influences of different types of hydrocolloids and stabilizers on the rheological properties of yoghurt were studied. It was found that the yoghurt containing hydrocolloids and stabilizers had a stable color and water activity, and the syneresis did not prevail during storage. Hydrocolloids might be considered as a suitable food constituent in the production of fermented milk products particularly in yoghurt, in order to overcome the problem of syneresis especially during storage at relatively high temperatures that might occur during transportation, and to enhance the water holding capacity. This review gave a brief summary about yoghurt manufacturing using hydrocolloids and stabilizers such as carboxyl methyl cellulose, microcrystalline cellulose, xanthan and carrageen an gums, modified starch, cross- linked acetylated starch and inulin, and how to determine some of the rheological characteristics of yoghurt.

Keywords: Yoghurt; Hydrocolloids; Rheological properties

Introduction

Yoghurt is the most common fermented milk product worldwide and originates from countries around the Eastern Mediterranean Sea and the Balkans [1]. It considered a healthy food because of the beneficial characteristics of its high contents of protein and calcium [2]. The fundamental procedure in the conversion of milk to yoghurt is accumulation of casein micelles into athree-dimensional network structure. Casein represents about 80% of the total content of bovine milk protein and includes four main fractions: α_{s1}, α_{s2}, β and k [3]. Yoghurt may have two initial defects: the difference in viscosity and/or the serum expulsion (syneresis). Dairy constituents and hydrocolloids have been occasionally utilizedin order to overcome these defects [4].

Various milk components (for example, non-fat dry milk, milk protein concentrate and whey protein concentrate) and/or stabilizers (for example, pectin, gelatin and starch) were applied in yoghurt products to ensure appropriate texture through increasing the content of milk total solids [5]. Numerous studies have been reported on the utilization of gums to improve some characteristics of yoghurt [6]. The texture and syneresis characteristics of many dairy products are controlled by the addition of hydrocolloids that act as fat replacers. These polysaccharides interact with the casein network and contribute to the formation of gels in two-phase (liquid–solid) systems: a continuous, solid, three dimensional network structures forming the gel matrix holding a finely dispersed liquid phase [7,8]. The precise choice of the type and the content of hydrocolloid which will be used considered one of the most important issues in the manufacturing of fermented dairy products [9].

Hydrocolloids have been extensively applied to stabilize the body and texture of fermented dairy products. Hydrocolloids leaded to a reduction of syneresis in yoghurt and increased the water holding capacity in two ways; physical and chemical. Free water is physically trapped and confined within the increased network density, and chemically, the hydrophilic nature of hydrocolloids facilitates a link with the water molecules as, thus increasing gel water-binding capacity [10].

Yoghurt Manufacturing

Yoghurt is manufactured with different methods according to the international standards. Some modifications were carried out by adding different additives of stabilizers or hydrocolloids. So, for each application of the several additives, yoghurt was manufactured in different steps from author to another. But the manufacturing methods were based on the same principle of acid coagulation using lactic acid bacteria starters; *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. Usually, yoghurt is manufactured from the preheated milk, with fat and dry matter content varying with respect to region and regulations, either in the plain form or with added material such as fruits or fruit premixes, cereals, sugar, or additives such as gelling agents, colorants or flavorings. Regulation and codex principles differ widely around the world; in some countries, the use of additives is forbidden, or the existence of a certain number of viable starter bacteria in yoghurt is required (for example, 10^7 bacteria per gram in the USA; [11]).

Hydrocolloids and Stabilizers

Food hydrocolloids are non-digestible carbohydrates that have the ability of forming gels or viscous solutions. They could be considered a component of dietary fiber and thus if added to foods should increase the amount of fiber and potentially improve the health effects of the diet. Hydrocolloids are hydrophilic polymers which

Citation: Abdelmoneim AH, Sherif AM and Sameh KA. Rheological Properties of Yoghurt Manufactured by using Different Types of Hydrocolloids. Austin J Nutri Food Sci. 2016; 4(2): 1082.

usually have many hydroxyl groups and may be polyelectrolytes. They are derived from vegetables, animals, microbial, or synthetic origins and are naturally present in foodstuffs or added to regulate the functional properties of such materials [12]. Hydrocolloids are sometimes utilized in the manufacturing of milk products in order to overcome the unfavorable syneresis [13,14].

Hydrocolloids are compounds that can improve the consistency of yoghurt. These compounds include long and branched molecules, which are able to establish links with each other or with other molecules present in the environment in the form of an emulsion. Additions of hydrocolloids to yoghurt are effective in absorbing water, increasing viscosity, strengthening and improving the texture of yoghurt. Hydrocolloids also maintain the morphological features of yoghurt during transportation and storage [13,15]

Carboxyl methyl cellulose

In dairy products like yoghurt, it is very important that the hydrocolloids do not cover the natural flavor of the product and that they are effective at the typical pH range 4.0- 4.6 of the product. Bearing in mind these requirements, commonly used hydrocolloids often include Carboxyl Methyl Cellulose (CMC), pectin, alginate, and gelatin [16]. CMC, also recognized as cellulose gum, is actually an abbreviated form of sodium carboxyl methyl cellulose, a cellulose derivative with sodium carboxyl methyl groups bound to several hydroxyl groups of glucose monomers. CMC stabilizes the dispersions of protein, particularly close to their isoelectric point of pH value. Consequently, milk and dairy products are given better stability towards the precipitation of casein [17].

Andiç, Boran [5] studied the influence of Carboxyl Methyl Cellulose (CMC) and Edible Cow Gelatin (ECG) on the textural, physico-chemical, and sensory characteristics of yoghurt. Yoghurt was manufactured from the fullfat bovine milk with addition of CMC and ECG in mixture or solely, at two concentrations; 0.25 and 0.50% (w/w). Sole CMC addition at a concentration of 0.25% participated in higher viscosity (7175 cPcomparing to the control sample being 4526 cP on day 1) and firmness (561 g compared to the control yoghurt being 294 g on day 1), but resulted in lower water holding capacity and higher syneresis compared to the control. Though, sole ECG addition at concentration of 0.50% resulted in higher water holding capacity (69.29% in comparison with the control being 48.41%) and lower syneresis (0.22 compared to the control being 2.64, in mL per 100 mL initial sample), while also contributing to viscosity (5551 cP on day 1) and firmness (369 g on day 1). The results recommended that ECG was appropriate for yoghurt manufacturing compared with CMC, giving abetter gel network structure with lower syneresis and higher water holding capacity along with higher viscosity and firmness, while resulted in insignificant defects on the sensory characteristics.

Microcrystalline cellulose

Microcrystalline cellulose is an insoluble hydrocolloid derived from cellulose typically existed in vegetables and fruits. Microcrystalline cellulose has numerous uses and applications in pharmaceuticals and in foods preparations. It considered a naturally derived stabilizer, texturizing agent and fat substitute. It was used broadly in reduced fat salad dressing, various dairy products including cheese, frozen desserts and whipped topping and bakery products [18] .

According to **Hassan, Nawar** [18] microcrystalline cellulose was prepared from rice straw and was applied in yoghurt manufacturing. Different concentrations of Microcrstal line cellulose were used and compared with yoghurt (control) without addition. The obtained results showed that the addition of Microcrstal line cellulose in yoghurt manufacturing had no significant influence on the viability of the total bacteria count, *Lactobacillus delbrueckii supsp bulgaricus, Streptococcus thermophiles,* and the different samples were free from yeast, mould and coliform when fresh and during storage (5^{o}C ± 1^{o}C). Sensory evaluation revealed that, 0.1 % of Microcrstal line cellulose was the best concentration that gained high scores for the appearance, the body and texture and the flavor when fresh and during storage. Results also concluded that the samples of yoghurt manufactured by using 0.1% of Microcrstal line cellulose had higher acidity, acetaldehyde, diacetyl and total volatile fatty acids than the control. As well, the treated samples had higher viscosity and lower syneresis compared to the control.

Xanthan and carrageen an gums

In order to increase the firmness, prevent the syneresis and improve the texture of yoghurt, xanthan gum has been utilized [6]. Carrageen an, synergistic with some additional gums, could increase the gel strength and the water binding capabilities in addition to adapting the gel texture [19]. Anionic hydrocolloids, such as carrageen an, interact directly with the positively charged amino acids on the surface of casein micelles, through divalent cations, to strengthen the casein network and reduce syneresis [20]; they have slight influence on the taste and the aroma of nonfat set yoghurt [21]. Conversely, neutral hydrocolloids, such as xanthan gum, act by increasing the viscosity of the continuous phase, thus improving texture and preventing whey separation [21,22] Xanthan gum can be used within a wide concentration range [21], who reported that this hydrocolloid developed low gumminess, it also had the ability to prevent whey drainage due to its stabilizing property.

Hematyar, Samarin [4] studied the influences of carrageen an gums and xanthan at different levels on the chemical, microbiological, rheological and organoleptic properties of yoghurt. The viscosity of yoghurt samples containing xanthan and carrageen an increased compared with the control. Yoghurt samples containing 0.01% of xanthan gum had the highest viscosity throughout10 days of storage period. Syneresis of yoghurt samples was measured at 4°C and 25°C. The obtained results revealed that samples with xanthan and carrageen an reported less syneresis through the storage period. Samples containing 0.01% of xanthan gum showed high resistance towards whey syneresis during all days. The pH values and total solids of yoghurt samples did not affected by the incorporation of these gums during the storage period. Furthermore, mould, yeasts and coli form bacteria were not observed in samples at the end of storage period. Samples manufactured with 0.005% of xanthan gum had the highest sensory scores compared to the other samples.

Lunardello, Yamashita [23] examined the influence of carrageen an (0.10% and 0.30%), xanthan gum (0.15% and 0.35%) and alginate (0.05% and 0.15%) on nonfat set yoghurt characteristics, regarding instrumental texture profile and Water-Holding Capacity (WHC) of the yoghurt. The samples which exhibited the similar behavior of commercial yoghurt in terms of WHC, firmness and consistency, low adhesiveness and gumminess were analyzed by difference-from-control sensory test. The addition of carrageen an resulted in increasing the firmness, adhesiveness, gumminess and WHC at the highest concentration examined. The sensory evaluation did not show any significant variance between the formulations examined.

Modified starch

Schmidt, Herald [24] reported that the application of wheat starches as stabilizers in yoghurt manufacturing produced many positive effects to varying degrees. A wide variety of physical consistencies in order to achieve the expectations of consumers could be attained in yoghurt by using diverse wheat starches. The results showed that the properties of yoghurt produced with native wheat starch were comparable to those of gelatin-stabilized yoghurt; therefore, native wheat starch can be applied as a substitute in the production of set yoghurt. Moreover, the modified wheat starches can be considered in stirred-style yoghurt preparations.

Starch considered the most extensively used additive in food industry for this purpose [25]. It was used in yoghurt to increase its viscosity, enhance its mouth-feel, and overcome whey syneresis. It also help keeping the fruit uniformity mixed in the yoghurt where applicable. Starch granules absorb water and swell to many times their original size, resulting in increasing the viscosity of the solution [26]. Non-dairy ingredients like polysaccharides such as starches can be utilized in the production of yoghurt combined with dairy constituents or on their own in order to adjust the rheological properties. Yoghurts produced from different starches display different rates of viscosity e.g. wheat starch showed highest shear consistency compared to other varieties [27]. The modified starch was wholly soluble in the milk, thus giving smooth, viscous yoghurt. Samples containing starch gave the similar visual appearance of consistency as those that had milk powder [28].

The supplementation of corn starch as a stabilizer did not affect the fermentation process both in fermentation time and final pH attained. This is a very important criterion since an increase in processing times means an increase in the production cost [29].

Cross- linked acetylated starch

Cross-linked acetylated starch considered a possible stabilizer of yoghurt; nevertheless, its utilization in the production of set yoghurt has not been given much consideration. Cross-linked acetylated starch had been used because of its stability and resistance to retro gradation [30]. The cross-linked acetylated starch system will act as a viscous fluid [31,32].

The results of Cui, Lu [33] demonstrated that the steady-state rheological behavior of the set yoghurt system, which consistent with the Herschele-Bulkley model. Meanwhile, introduction of acetyl and cross-linking group had improved properties (such as swelling capacity and viscosity) over its native form. The rheological properties and microstructure characteristics of the set yoghurt system were affected by the modified starch. The network, which is the basic structural unit of system, gets stronger by adding the cross-linked acetylated starch. The viscoelasticity of the set yoghurt samples increased significantly because of the swelling and thermal mechanical properties of cross-linked acetylated starches. The elastic modulus (G′), viscous modulus (G″), conductivity and particle size revealed the aggrandizement trend, as the concentrations of cross-linked acetylated starch increased. Furthermore, the structure feature of cross-linked acetylated starch moreover contributed to the set yoghurt stability.

However, the study also found that the mouth feel of the set yoghurt became coarse as the concentration of modified starch exceeded 2% (w/w). On the other hand, the optimum content of modified starch for the production of set yoghurt was 0.5-1.5% (w/w). Owning to the cross-linked acetylated starch, the electrostatic adhesion, steric stabilization and osmotic effect might coexist in the set yoghurt system. It could be concluded that all those interactions together maintained the set yoghurt stability. As a possible stabilizer, the cross-linked acetylated starch has shown potential for the set yoghurt system.

Inulin

Inulin is a natural constituent produced from several vegetables and fruits [34]. Numerous studies have discussed the improving of physical, textural, flavor and rheological characteristics of low-fat yoghurtthrough incorporating the stabilizers into the milk [6,35-37]. Brennan and Tudorica [38] used the inulin as a fat replacer. The amounts of stabilizer had a significant impact on the evaluations for texture and syneresis of low-fat fermented skim milk. Similar results were stated for fermented cow's milk with an inulin addition [39].

Staffolo, Bertola [40] concluded that yoghurt samples containing inulin had a stable color and water activity, and their syneresis did not prevail during the storage period, being similar to the other dietary-fiber containing yoghurts. Debon, Prudêncio [41] concluded that the increase in inulin and oligofructose supplementations increased thetotal solids content of the fermented milk.

Guven, Yasar [42] reported that the low-fat yoghurt containing 2g inulin/100 g of milk stored at 4ºC for 1 day had the highest consistency compared to the 1 and 3 g-samples. Yoghurt samples containing 1g inulin/100 mL milk and the control yoghurt had the highest firmness values of 1.90 and 1.72 N, respectively. De Castro, Cunha [43] observed that the addition of 2% or 5% of oligofructose in whole fat fermented milk decreased the time dependency, the pseudoplastic behavior and the consistency index value. No significant variances were observed in the flow behavior of the fermented milks containing 2% or 5% of oligofructose. They suggested that the results may be related to a possible plasticizing effect of oligofructose which results in less moisturizing and reduction of the hydrodynamic volume of the protein, thus decreasing viscosity.

Modzelewska-Kapituła and Kłębukowska [44] concluded that the use of inulin as fat replacer in yoghurt manufacturing resulted in low-fat products with acceptable sensory characteristics. Inulin HPX did not affect the pH values and yoghurt bacteria counts. Inulin and fat content influenced the apparent viscosity values, although the observed differences could be easily removed by adjusting the total solids in all samples. Using 2.7% of inulin provided low-fat products with desirable sensory properties and apparent viscosity comparable to high-fat yoghurt. The amount of prebiotic should thus be taken into consideration in scheming low-fat yoghurts with inulin HPX as a fat replacer.

Isik, Boyacioglu [45] produced frozen yoghurt with low fat content and no added sugar. Yoghurt samples containing 5% polydextrose, 0.065% aspartame and acesulfame-K mixture, and different concentrations of inulin and isomalt (5.0, 6.5, and 8.0%) were produced at pilot scale and examined for their chemical composition and physical properties including proximate composition, viscosity, acidity, overrun, melting rate, heat shock stability, in addition to the organoleptic properties, and the viability of lactic acid bacteria. The obtained data showed that the incorporation of inulin and isomalt resulted in increasing the viscosity by 19 to 52% compared with that of reduced-fat control. The average calorie values of yoghurt samples replaced by sweeteners were about 43% lower than that of the original yoghurt sample. Low-calorie frozen yoghurt samples melted about 33 to 48% slower than the reduced-fat control sample at 45 min. Based on quantitative adjectival profile test results, statistically significant variances among products were detected for hardness, whey separation, iciness, foamy melting and sweetness properties. The results of principal component analysis showed that the sensory characteristics of the yoghurt sample containing 6.5% of inulin and 6.5% of isomalt were comparable to those of the control. The counts of lactic acid bacteria of frozen yoghurt samples were found to be between 8.12 and 8.49 log values, 3 months after yoghurt manufacturing. The overall obtained results concluded that it was possible to manufacture agood-looking frozen yoghurt product with the combination of inulin and isomalt with no added sugar and reduced fat.

Rheological Measurements

Syneresis and water holding capacity (WHC)

Syneresis can be determined by using a technique adopted from Riener, Noci [46]. Nevertheless, the syneresis was reported as the grams of the whey separated out of the total weight (100 g) of the yoghurt. Unset yoghurt mix (25g) was weighed in a centrifuge tube and the samples were then incubated together and the set gels were then stored at 4ºC for 24 h. Yoghurt samples were weighed and centrifuged for 10 min at 3500 xg and 4ºC. The whey separated from yoghurt sample was decaned off and the other remaining yoghurt in the tube was reweighed. The WHC was defined as weight (g) of the remaining (or drained) yoghurt out of the total weight (100 g) of the yoghurt (before centrifugation).

The water-holding capacity can be determined using several different measuring procedures, which are based on different measuring principles and conditions. Most of these procedures are devastating and the microstructure of yoghurt is mostly ignored. The water-holding capacity of yoghurt can be determined according to the procedure reported by Guzmán-González, Morais [47]. A sample of about 20g of yoghurt (Y) was centrifuged at 1250 x g for 10 min at 4 °C. The whey expelled (W) was removed and weighed. The water-holding capacity (WHC, $g.kg^{-1}$) was calculated as: WHC = (Y – W) /Y x 1000.

Gel firmness

Gel firmness measurements of set yoghurt are usually performed by means of constant speed penetration on universal testing machines or similar instruments, using cylindrical plungers [15 mm < d < 40 mm] and crosshead speed values ranging between 10 mm/min and 100 mm/min, commonly below the room temperature. With up-to-date equipment the force response, which is affected by plunger size and penetration speed, is monitored as a function of penetration depth. A number of researchers [48-53] used force values (or force values related to plunger diameter) at a predefined penetration depth to express gel firmness.

Gel firmness of yoghurt was also determined at 4-6 ºC by penetration measurements (Texture Analyzer, LFRA-4500, Brookfield, Inc., USA) equipped with a 4.5 kg load cell. The apparatus was adjusted to the following conditions: cylindrical probe (38 mm in diameter); penetration speed, 1 mm/s; penetration distance, 30 mm into surface. The peak force was measured in grams [54, 55].

Yoghurt viscosity

Yoghurt viscosity was measured by using Brookfield viscometer model BM type [27]. Three readings from every sample were taken and an average was reported. The readings were taken at 10ºC, the temperature at which the yoghurt is consumed. The spindle speed was adjusted according to the thickness of yoghurt sample. In this case, the specification combination used was speed 12 (revolutions/second) and spindle number 4. Tocalculate the final viscosity in centipoises, a factor of 500 was used to multiply the obtained figure.

According to Modzelewska-Kapituła and Kłębukowska [44], the apparent viscosity of yoghurts was also measured at 10°C using Rheotest 2, RV 21976 (VEB MLW Prufgerate-Werk Medingen, Ottendorf-Okrilla, Germany) equipped with N/N measurement vessels. After manual stirring of the yoghurt, 11 mL were subjected to measurements. The results were calculated according to the manufacturer's instructions and expressed in (mPa s). Apparent viscosity η was calculated according to the equation:

$$\eta = \frac{z \cdot \alpha \cdot 100}{Dr} \text{ (mPa s)}$$

Where z, constant characterizing measurement vessel, z = 34.6; α, angular coefficient read during measurement; and Dr, shearing rate (per second), Dr = 1312/s.

Brookfield viscometer model BM type was used to determine the viscosity of yoghurt [27]**.** Based on the results obtained by Okoth, Kinyanjui [28], it was observed that it was possible to make yoghurt of acceptable viscosity incorporating modified starch only at the rate of 0.5% without adding any skim milk powder. It was also established that it was possible to make yoghurt with as reduced skim milk powder content for instance 1% instead of 3%, while substituting the milk powder with 0.5% of modified starch.

Flow characteristics

Flow of set yoghurt system was measured by recording the shear stress values when shearing the samples at linear increasing shear rates from 1 to 100 s^{-1} through 100 s. Numerous rheological models have been employed to fit the viscosity data on the fermented dairy products [56]. Data from the descending segment of the shear cycle were fitted to Herschele Bulkley model,

$$\tau = \tau_0 + K\gamma^n$$

Where τ (Pa) is the shear stress, τ_0 (Pa) is the yield stress, K (Pa s^n) is the consistency index, γis the shear rate and n is the flow index.

Viscoelastic properties

Small deformation dynamic shear rheological tests were performed to obtain valuable information on the viscoelastic characteristics of set yoghurt system. To measure the linear viscoelastic region, stress sweeps were set at 1 Hz, from 0.1 to 100 Pa. The frequency sweeps were performed over the range *f*= 0.1- 100 Hz. The values of the elastic modulus [G′] , the viscous modulus (G″) and the loss tangent angle (tan δ) were calculated using the Rheo Win Pro software.

Determination of the apparent particle size and zeta potential

The apparent particle size and zeta potential of yoghurt were measured by using dynamic light scattering (DLS) and Zetasizer Nano Series (Malvern, UK) and Pals Zeta Potential Analyzer (Brook Hansen, UK).The scattered light signal was collected with the right angle detectors at a 90^0 (right angle) scattering angle. It was based on the principle of Fraunhofer [57]**.**Yoghurt samples were diluted 100-fold before the measurement. The samples were measured three times, taking the average measurement value and the zeta potential of the set yoghurt system was calculated by the relevant equation. The relationship of electro-osmotic flow (EM) and zeta potential (ξ) can be expressed as:

$$\mathrm{EM} = \frac{2\varepsilon\,\xi}{3\mu} f(\kappa\,\alpha)$$

Where EM is the electro-osmotic flow; ξ is the zeta potential; ε is the permittivity of the liquid; μ is the viscosity coefficient of liquid; α is the particle radius; k the Debyee-Huckel parameters; *f* (ka) is correction factor.

Conclusion

Currently, hydrocolloids are worldwide spread in various applications of the food processing industry. The most important feature of hydrocolloids in food industry applications is the manner they modify the rheological behavior. Hydrocolloids can be used in yoghurt production to overcome serum separation and to adjust the viscosity especially during storage at relatively high temperatures that might occur during transportation, and to enhance the water holding capacity. When used at adequate concentration, hydrocolloids reduced the serum separation to negligible levels and increase the apparent viscosity. However, the quantities of the hydrocolloids that can be utilized were found to be limited by their influences on the flavor of the final product.

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Austin J Nutri Food Sci - Volume 4 Issue 2 - 2016
ISSN : 2381-8980 | www.austinpublishinggroup.com

Citation: Abdelmoneim AH, Sherif AM and Sameh KA. Rheological Properties of Yoghurt Manufactured by using Different Types of Hydrocolloids. Austin J Nutri Food Sci. 2016; 4(2): 1082.