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Evaluation of Gum Arabic from *Acacia senegal* var *kerensis* and *Acacia senegal* var *senegal* as a Stabilizer in Low-fat Yoghurt

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Abstract

Gum arabic is a dried, gummy exudate obtained from the stems and branches of *Acacia senegal* and *Acacia seyal*. In Kenya, gum arabic comes from *Acacia senegal* var *kerensis* although its exploitation for commercial and industrial application is marginal. Therefore, the aim of this study was to characterize and determine the effect of the gum from *A. senegal* var *kerensis* on the quality characteristics of set low-fat yoghurt compared to gum arabic from *A. senegal* var *senegal*, with a view to increasing its utilization locally. Yoghurt was prepared containing gum arabic at four concentrations (0.2%, 0.4%, 0.6%, 0.8% gum w/v). Results showed that *A. senegal* var *kerensis* gum had higher molecular weight and gelling properties compared to *A. senegal* var *senegal* gum. In addition, *A. senegal* var *kerensis* gum was less susceptible to syneresis and showed a higher absolute viscosity compared to *A. senegal* var *senegal* gum at all concentration levels. Sensory evaluation revealed that addition of gum arabic significantly improved the body and the texture of the yoghurt. Therefore, *A. senegal* var *kerensis* gum is a better yoghurt stabilizer than gum arabic from *A. senegal* var *senegal*. An optimal gum concentration of 0.6% of *A. senegal* var *kerensis* gum in low-fat yoghurt is recommended from the results of this study.

Keywords: Gum arabic; Low-Fat Yoghurt; Stabilizer; Syneresis; Gum exudate

1 Introduction

Many health organizations consider the level of fat consumption to be too high. A recent World Health Organization (WHO) report recommended that the level of total fat intake should be between 15% and 30% of energy, of which saturated fatty acids should account for less than 10% since fat has been associated with an increased risk of obesity, arteriosclerosis, coronary heart disease, elevated blood pressure, tissue injury diseases associated with lipid oxidation and certain forms of cancer (Kaminarides, Stamou & Massouras, 2007). Thus, the goal of the food industry is to respond to consumer demand and to offer an increasing variety of low-fat choices, in which the attributes that consumers desire are not impaired. A reduction in fat content can be achieved by replacing it with several ingredients that provide the functionality of the missing fat. Hydrocolloids and carbohydrate-based fat replacers have been used safely as thickeners and stabilizers especially in dairy products, sauces and dressing formulations. Gum arabic (GA, E-Number 414) is an edible, dried, gummy

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exudate from the stem and branches of *A. senegal* and *Acacia seyal* that is rich in non-viscous soluble fiber (Williams & Phillips, 2009). It is defined by the Joint FAO/WHO Expert Committee for Food Additives (JECFA) as a dried exudate obtained from the stems and branches of *A. senegal* (L.) Willdenow or *Acacia seyal* (fam. *Leguminosae*) (FAO, 1999). Physically, it is a pale white to orange–brown solid which breaks with a glassy fracture. Chemically, gum arabic (GA) consists mainly of high molecular weight polysaccharide and their calcium, magnesium and potassium salts, which on hydrolysis yield arabinose, galactose, rhamnose and glucuronic acid (FAO, 1999). The backbone is composed of 1, 3-linked β-D-galactopyranosyl units. The side chains are composed of two to five 1, 3-linked β-D-galactopyranosyl units, joined to the main chain by 1, 6-linkages (FAO, 1999). Gum arabic has wide industrial uses as an emulsifier, stabilizer and thickening agent mainly in the food industry. These properties have been exploited for their functionality in food systems including textural attributes and mouth feel. There are two forms available commercially, namely *A. senegal* var *senegal* and *A. senegal* var *kerensis*. Both are acceptable as food additives and conform to the specification now approved by the FAO Joint Expert Committee on Food Additives and the Codex Alimenarius Commission (FAO Food and Nutrition Paper 52 Add.7 1999). *A. senegal* var *senegal* gum (standard type), produced in Sudan and other gum-producing regions of Africa, for example Nigeria and Niger, is significantly different from *A. senegal* var karensis gum that is produced in Kenya. The *A. senegal* var *kerensis* gum has high specific rotation, high nitrogen content and a high molecular weight compared to the *A. senegal* var *senegal* gum (Al-Assaf, Phillips & Williams, 2005). There are few reports on the research that assessed the qualities of *A. senegal* var *kerensis* gum for its commercial and industrial application in yoghurt processing.

Yoghurt producers are motivated to market low-fat products with natural ingredients in order to capture a niche market that continues to grow. In addition, producers have added gum arabic as a prebiotic in yoghurt production (Niamah, Al-sahlany & Al-Manhel, 2016). However, research has shown that reduced fat yoghurt exhibits lower tension and firmness than full fat yoghurt. The partial or total removal of fat from yoghurt decreases the overall quality perceived by the consumer (Folkenberg & Martens, 2003). This is for two main reasons: a change in the texture of the product and a change in the retention of flavor compounds (Nongonierma, Springett, Le Quéré, Cayot & Voilley, 2006). The change in texture perception results from a modification of the structure of the gels (Kilcast & Clegg, 2002). Fat globules of homogenized milk are part of the gel network. To modify texture perception, fat substitutes or bodying agents are commonly added (Sandoval-Castilla, Lobato-Calleros, Aguirre-Mandujano & Vernon-Carter, 2004). Some of the additives that have been used include starch and skimmed milk powder. The need to consume low-fat foods has created increased consumer awareness and a dramatic increase in the supply of, and demand for, low-fat foods containing fibers. Gum arabic which is known to possess special emulsifying and stabilizing properties has not been evaluated vis-à-vis low-fat yoghurt stabilization. Thus, the aim of the present study was to determine its effect on the rheological properties of set low-fat yoghurt (EAS, 2006) with a view to increasing its utilization in Kenya.

2 Materials and Methods

2.1 Materials

Gum arabic from *A. senegal* var *kerensis* and *A. senegal* var *senegal* were obtained from Kenya Forestry Research Institute Laboratories (KEFRI) and used without further purification. Unpasteurized skimmed milk was obtained from a local supplier and used to make low-fat yoghurt the same day.

2.2 Yoghurt preparation

The skimmed milk (0.5% Fat) was heated to 85 ^{o}C for 20 min, stabilizer (0.2%, 0.4%, 0.6%, 0.8% gum w/v) was added and the mixture heated for a further 10 min at 85 ^{o}C. Yoghurt manufacture was adapted from the standard technique (Kosikowski, 2019). The mixture of milk and added stabilizer was cooled to 45 ^{o}C and a *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (direct vat set culture (1 x 10^{10} cfu per gram)) (YF-L811, Chr. Hansen, Hamilton, New Zealand) was mixed into the milk and allowed to ferment for 3h at 42 ^{o}C in autoclaved glass jars. The warm yoghurt was then kept at 4 ^{o}C for cooling before the various analyses of physicochemical properties of yoghurt were performed after one day. Control yoghurt sample was manufactured following the same standard technique (Kosikowski, 2019) without the addition of a gum arabic.

2.3 Determination of the physicochemical and molecular characteristics of gum arabic

The physicochemical properties were obtained and molecular parameters of gum arabic measured using gel permeation chromatography online coupled with multi-angle laser light scattering system (GPC-MALLS). A Superose 6 10/300GL GPC column and a DAWN EOS multi-angle light scattering detector (Wyatt Technology Corporation, USA) were employed in the GPC-MALLS measurements at 25 ^{o}C. Aqueous sodium chloride solutions (0.2 M) were used both as a solvent and eluent. This technique is used to determine the molecular distribution of a polymeric system such as hydrogel of hydrocolloids including gum arabic (Al-Assaf et al., 2005; Montoro, de Fátima Medeiros & Alves, 2014). All chemicals used were of analytical grade and were obtained from BDH Chemicals (BDH Ltd, Poole, England) or Sigma Chemical Co. (St. Louis, Mo, USA) unless specified otherwise.

2.4 Analysis of physicochemical characteristics of yoghurt containing gum arabic

Chemical characterization

The following chemical analyses were carried out on the yoghurt, according to AOAC (2005): moisture (g/100 g w/w), ash (g/100 g w/w), total solids (g/100 g w/w), and fat (g/100 g w/w). All analyses were performed in triplicate.

Syneresis of yoghurt

The susceptibility of yoghurt to syneresis was determined using the method by Keogh and O'kennedy (1998). Centrifuge tubes containing 40 g of yoghurt were centrifuged at 222000 g for 10 min at 4 ^{o}C. The clear supernatant was poured off, weighed and expressed as percent weight relative to original weight of yoghurt.

pH value

The pH value of the yoghurt samples was measured at the end of the incubation time. Samples were vigorously stirred to break the formed gel and the pH was obtained using a pH meter (Orion 4 Star pH. ISE Benchtop, Thermo electric cooperation).

Acidity

Titratable acidity, expressed as percentage of lactic acid, was determined following FAO (1996) by mixing 10 g of yogurt with 20 mL of distilled water and titrating with 0.1N NaOH using phenolphthalein as indicator. Titratable acidity was then calculated as shown in equation 1:

$$TA = \frac{\frac{V_T}{1000} \cdot N_{NaOH} \cdot 90}{W_s} \cdot 100 \qquad (1)$$

Where TA is the tritatable acidity, V_T is the titer volume, N_{NaOH} is the normality of NaOH and W_s the weight of the sample.

Viscosity determination

Yoghurts were mixed with a hand blender at low speed for 15 s. This was to break the gel and to mimic the shaking or stirring by the consumer of the packed yoghurt. The apparent viscosity of the stirred yoghurt was measured with a Brookfield digital rotational viscometer (model DV-II+, Brookfield Engineering Laboratories Inc., Middleboro, MA) using a spindle 5 at 100 rpm in 150 mL of yogurt (Damian, 2013). The spindle rotated in the sample for 1 minute at 10 ^{o}C, the indicator stabilized, then the readings were taken.

Gel strength

The cylinder penetration test was performed using a Universal Testing Machine (Zwick Z2.5/TN1S, Zwick, Ulm, Germany) equipped with a 500 N force sensor (Guggisberg, Cuthbert-Steven, Piccinah, Buetikofer & Eberhard, 2009). An acrylic glass cylinder (h¼ 35 mm, Ø¼ 25.4 mm) was introduced vertically into the 150 g yoghurt cup with a constant speed of 30 mm min^{-1} for 40 mm. The software TESTXPERT (V10.1) was used to calculate the modulus of deformability (E modulus) using the secant of the values between 0.5 and 1.0 mm and the force at 35 mm (F (35 mm)). The penetration force was read directly from the machine. All yoghurts were measured at 10 ± 1 ^{o}C. The mean of two yoghurts from the same batch was calculated.

Rheological determination (Oscillatory test) of yoghurt

Rheological properties of yoghurt samples were investigated using a controlled stress rheometer (AR-550 TA Instruments, USA) as described by Karazhiyan et al. (2011). About 3.8 mL of sample were carefully placed in the measuring system and left to rest for about 10 minutes at 5 ^{o}C. Measurements were carried out on shear mode at 5 ^{o}C, using a cone and plate geometry. A shear rate sweep test was used with the shear rate ranging from 10^{-2} to 20^{-1} s. A frequency sweep test was also performed (with the frequency ranging from 1 to 10 Hz at a maximum strain of 4.06E-03, and amplitude of 1.42E-04). Because gels are viscoelastic materials, dynamic rheological tests to evaluate properties of gel systems are well suited for studying the characteristics of gels as well as gelation and melting (Walstra, Walstra, Wouters & Geurts, 2005). From dynamic rheological tests in the linear viscoelastic range, the storage modulus, G', and the loss modulus G", can be obtained. The G' value is a measure of the deformation energy stored in the sample during the shear process, representing the elastic behavior of a sample. In contrast, the G" value is a measure of the deformation energy used up in the sample during the shear and lost to the sample afterwards, representing the viscous behavior of a sample (Mezger, 2002). If the value G' is much greater than the G" value, the material will behave more like a solid; that is, the deformations will be essentially elastic to recoverable. However, if G" is much greater than G', the energy used to deform the material is dissipated viscously and the material behavior is liquid-like. These parameters represent the mouth feel from a consumer perspective.

Sensory evaluation of yoghurt containing gum arabic

Descriptive sensory analysis was performed following Meilgaard, Carr and Civille (1999) under normal light. The samples were placed in clear plastic cups. A panel consisting of seven semi-trained panelists was used for the evaluation. Three training sessions were held prior to testing using low-fat and full-fat yoghurt. In these sessions, the panelists were trained in the products and descriptors were chosen based on consensus among panelists, using low-fat products available on the market to cover a range of consistencies. A total of seven descriptors were used for the assessment of product appearance, texture, taste and overall acceptability. Test samples, identified by a three-digit code, were presented to the panelists in a randomized order immediately after being removed from the fridge (4 ^{o}C). Testing was conducted on duplicate samples, and each panelist was asked to assess them for each attribute on a nine-point scale.

2.5 Statistical analysis

The experiment was repeated twice (Trial 1 and Trial 2) in triplicate each time. Statistical analysis was performed using JMP Software. One-way analysis of variance (ANOVA) was done and mean comparison achieved using the Duncan's multiple range test at 95% confidence interval

(Sall, Stephens, Lehman & Loring, 2017).

3 Results and Discussions

3.1 Physicochemical and molecular characteristics of gum arabic

The results of the physicochemical and molecular testing of gum arabic are shown in table 1. The moisture content was 14.5% and 13.0% while the ash content was 3.6 % and 3.2 % for *A. senegal* var *kerensis* and *A. senegal* var *senegal* gum, respectively. The protein content of gum arabic from variety *kerensis* was higher than that of variety *Senegal*. In addition, both intrinsic and absolute viscosities were higher in the gum arabic from variety *kerensis*. This may be explained by the high molecular weight reported for variety *kerensis* compared to variety senegal. These results agree with Al-Assaf et al. (2005). According to these researchers, one of the major differences of the *A. senegal* var *kerensis* gum from Kenya is that it has high specific rotation, high nitrogen content and a high molecular weight compared to the *A. senegal* var *senegal* gum.

3.2 Moisture loss

The results of moisture loss in yoghurt containing gum arabic are shown in Tables 2 and 3. Moisture content was significantly reduced with addition of gum arabic from both varieties. Similar results were reported when gum arabic was added in *kobe*, a traditional fermented milk from Sudan (Hamad, Sulieman & Salih, 2013). In addition, Niamah et al. (2016) reported a slight decrease in moisture content of yoghurt when gum arabic was added up to a level of 1%. The moisture loss of the yoghurt stabilized with *A. senegal* var *kerensis* gum was significantly different ($P < 0.05$) compared to the yoghurt stabilized with *A. senegal* var *senegal* gum at all levels of gum concentration. Gum arabic from *A. senegal* var *kerensis* has been shown to retain higher moisture content in food products (Mwove, A. Gogo, N. Chikamai, Omwamba & M. Mahungu, 2016, 2018). This can be explained by the high protein content of *A. senegal* var *kerensis* gum which is much higher than that of *A. senegal* var *senegal* gum. Senthil, Ravi, Bhat and Seethalakshmi (2002), reported that protein has a high water-binding capacity.

The analysis of variance results of the physicochemical analysis of all the experimental yoghurts (1 day after preparation) are shown in Tables 2 and 3. The low-fat yoghurt stabilized with 0.8% *A. senegal* var *kerensis* gum had the highest total solids content while the control low-fat yoghurt had the lowest. Total solid increased as the level of gum arabic concentration increased. Mehanna, Ibrahim and El-Nawasany (2013), Obodoechi (2015) and Mahjoub (2016) reported an increase in total solids when gum arabic was added as a stabilizer in low-fat yoghurt. The ash content between yoghurt stabilized and the control was significantly different ($P < 0.05$). Similar results were observed when gum arabic was used in making Robe, a traditionally fermented milk product in Sudan (Hamad et al., 2013). In this research, addition of gum arabic at 5%, 7.5% and 10% significantly increased the ash content of the resulting product. It is evident that gum arabic did not affect the fat content. However, research involving higher levels of gum arabic, 1 – 4% have been found to reduce the fat content of yoghurt (Meso et al., 2013).

3.3 pH value and acidity

As shown in Tables 2 and 3, the pH and acidity values for the entire yoghurt samples did not show any significant difference from the control. The pH ranged from 4.32 to 4.41 and titratable acidity ranged from 1.12 to 1.38% lactic acid. No significant differences were noted between samples at different levels of both stabilizers. Results from this study indicate that the addition of gum arabic at different concentrations does not affect the pH or the titratable acidity of the low-fat yoghurts. Similar observations were reported when inulin, a plant extract was used (Guven, Yasar, Karaca & Hayaloglu, 2005) as a fat replacer. Other studies also reported that the pH of plain set yoghurt was not influenced by the incorporation of six different dietary fibers (Bayarri, Chulia & Costell, 2010).

Table 1: Physico-chemical characteristics of *A. senegal* var *kerensis* gum and *A. senegal* var *senegal* gum

Characteristic	*A. senegal var kerensis*	*A. senegal var senegal*	JECFA standards
Moisture content	14.5 %	13.0%	<15%
Ash content	3.6 %	3.2 %	<4%
Nitrogen content	0.68	0.38	-
Protein content (N x 6.63)	3.42	2.01	-
pH -1%	4.54	4.31	-
Viscosity- Intrinsic viscosity	27 ml/g	17.5 ml/g	-
Viscosity – Absolute viscosity	170 mPas	71.6 mPas	-
Optical rotation	-34.5	-28	-26 to -34
Gel determination	Moderate gel	Light gel	
Tannin Content	-	-	-
Equivalent weight	906	1150	-
Molecular weight	$1.19X10^6$	$5.99X10^5$	

Table 2: Physico-chemical properties of yoghurt stabilized with *A. senegal* var *kerensis* gum

	Trial 1*					Trial 2*				
	Control	0.2	0.4	0.6	0.8	Control	0.2	0.4	0.6	0.8
Moisture loss (%)	88.2a	84.6b	84.7b	84.0b	84.5b	87.6a	82.7b	82.4b	84.8ab	82.5b
Ash content (g/100g)	0.89d	2.14c	2.22bc	2.30b	2.41a	0.82e	2.14d	2.23c	2.34b	2.43a
Fat content (g/100g)	0.50b	0.53a	0.51ab	0.50b	0.51ab	0.51a	0.50a	0.54a	0.53a	0.53a
Total Solid (g/100g)	10.30e	11.68d	12.48c	14.87b	18.21a	10.50e	11.35d	12.56c	14.69b	17.67a
pH value	4.37a	4.33a	4.36a	4.37a	4.34a	4.38a	4.35a	4.33a	4.34a	4.35a
Acidity	1.16b	1.22a	1.22a	1.70b	1.23a	1.16a	1.12a	1.15a	1.14a	1.15a
Syneresis	68.0a	54.0b	50.0c	45.2d	42.0e	70.0a	54.7b	51.2c	48.2d	44.1e
Viscosity	870.0e	1351.6d	1381.7c	1455b	1526.7a	890.0e	1288.3d	1337.7c	1394.3b	1476.7a
Gel strength	125.5e	144.8d	154.1c	167.1b	187.7a	120.0e	131.9d	139.3c	145.2b	153.4a

a – e Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$
*Means separation carried out separately for each trial.

Table 3: Physico-chemical properties of yoghurt stabilized with *A. senegal* var *kerensis* gum

	Trial 1*					Trial 2*				
	Control	0.2	0.4	0.6	0.8	Control	0.2	0.4	0.6	0.8
Moisture loss (% MC)	88.20a	87.60b	86.32b	87.45b	87.02b	87.45a	86.68b	85.42b	85.45b	85.67b
Ash content (g/100g)	0.89e	2.15d	2.24c	2.29b	2.38a	0.82d	1.18c	1.28b	1.32b	1.43a
Fat content (g/100g)	0.50a	0.54a	0.54a	0.50a	0.50a	0.50a	0.52a	0.55a	0.52a	0.52a
Total Solid (g/100g)	10.3d	10.2d	11.7c	13.5b	16.4a	10.5d	10.4d	12.0c	13.9b	17.6a
pH value	4.37a	4.32ab	4.32ab	4.33ab	4.30b	4.35a	4.39a	4.41a	4.37a	4.40a
Acidity	1.16a	1.15a	1.14a	1.17a	1.38a	1.12a	1.16a	1.16a	1.17a	1.34a
Syneresis	68.0a	56.3b	52.3c	49.7cd	47.0d	70.0a	56.3b	52.3bc	49.0cd	45.3d
Viscosity	870.0e	1176.7d	1208.3c	1231.7b	1258.3a	890.0d	1175.0c	1210.0b	1228.3ab	1251.7a
Gel strength	125.5e	127.1d	129.6c	133.2b	135.7a	120.0e	126.1d	129.0c	131.5b	135.0a

a – e Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$
*Means separation carried out separately for each trial.

3.4 Syneresis index

The amount of syneresis in the control was significantly greater ($P < 0.05$) than the amount of syneresis in the treatments with both gum stabilizers used, as shown in Tables 2 and 3. The most important causes for syneresis in fermented products include the use of high temperatures for incubation, low solids content or inadequate storage temperatures (Lucey, 2001). Syneresis is for the most part due to a rearrangement of the network, leading to an increase in the number of particle-particle junctions. The network then tends to shrink, leading to whey separation (appearance of whey on the gel surface of set yoghurt). Although total solids were kept constant for both stabilizers, the yoghurt made from *A. senegal* var *kerensis* gum was less susceptible to syneresis and showed a significantly ($P < 0.05$) lower syneresis index compared to *A. senegal* var *senegal* gum at all concentration levels. The syneresis index for the gum-stabilized yoghurt decreased as the concentration level of the gum increased. This low syneresis in the *A. senegal* var *kerensis* gum-stabilized yoghurt can be attributed to the improved water holding capacity by the *A. senegal* var *kerensis* gum (Mwove et al., 2016, 2018). Enrichment of dry matter and / or of protein content are common means of avoiding whey separation in yoghurt (Tamime & Robinson, 1999). It has been shown that there is a relationship between the microstructure of yoghurt and firmness and susceptibility to syneresis. Yoghurts which have a denser structure and lower porosity exhibit more water retention capacity (Puvanenthiran, Williams & Augustin, 2002). It was reported (Staff, 1998) that low-fat yoghurts tend to have a higher degree of syneresis than high-fat yoghurts and this is the reason why stabilizers are added to low-fat yoghurt. The current work shows that the gum arabic from *A. senegal* var *kerensis* forms a better firm microstructure due to its high molecular weight than *A. senegal* var *senegal* gum as shown in reduction of syneresis. The stabilizers make the yoghurt less susceptible to rearrangements within its network, and consequently less susceptible to shrinkage and serum (whey) expulsion (Oh, Anema, Wong, Pinder & Hemar, 2007). Yoghurt is usually prepared from homogenized milk to improve stability. This process coats the increased surface of fat globules with casein, enabling the fat globules to participate as a copolymer with casein to strengthen the gel network and reduce syneresis (Keogh & O'kennedy, 1998). Therefore, it can be concluded that the gum arabic helped in forming protein-coated gum arabic spheres, which reinforced the gel structure by their association with casein micelles of the protein network.

3.5 Viscosity

The current result shows that there was a significant difference ($P < 0.05$) between the control and the yoghurt with added gum arabic (Tables 2 and 3). Significant differences ($P < 0.05$) were noted between samples from gum arabic *A. senegal* var *kerensis* at different levels of the gum concentration with viscosity increasing with increase in gum amounts for both. The higher absolute viscosity reported for low-fat yoghurt stabilized with *A. senegal* var *kerensis* gum than *A. senegal* var *senegal* gum is attributed to the higher molecular weight and gelling properties of the *A. senegal* var *kerensis* gum as compared to *A. senegal* var *senegal* gum. While studying the effect of guar gum and arabic gum on the physicochemical, sensory and flow behavior characteristics of frozen yoghurt, Rezaei, Khomeiri, Kashaninejad and Aalami (2011) found that increasing gum arabic in yoghurt increased the viscosity of resulting product. In addition, similar results were reported by Obodoechi (2015). Since yoghurt is usually prepared from homogenized milk to improve stability, this process coats the increased surface of fat globules with casein, enabling the fat globules to participate as a copolymer with casein to strengthen the gel network (Keogh & O'kennedy, 1998), hence increased viscosity. It has been previously reported that the protein network of low-fat yoghurt was less dense, more open, and with more void spaces than that of full-fat yoghurt. This is due to the smaller, fused casein micelle aggregates, probably due to lower number of fat globules acting as linking protein agents (Sandoval-Castilla et al., 2004). In the present study, the increase in viscosity suggests that the gum arabic participates as copolymer with casein. The *A. senegal* var *kerensis* gum is better at enhancing viscosity compared to *A. senegal* var *senegal* gum. The casein micelles in the low-fat yoghurt containing fat replacers form networks with differing structures depending on the chemical nature and functional properties of the fat replacers (Lucey, 2001).

3.6 Gel strength/ Firmness

The gel strength of gum arabic stabilized low-fat yoghurt was evaluated following a back-extrusion test performed on a universal testing machine (Houze, Cases, Colas & Cayot, 2005). The results for the samples containing gum arabic from *A. senegal* var *kerensis* and *A. senegal* var *senegal* gum are presented in Tables 2 and 3. The yoghurt samples stabilized with *A. senegal* var *kerensis* gum and *A. senegal* var *senegal* gum were significantly different ($P < 0.05$) from each other in terms of their gel firmness and also at different concentration level of the stabilizer. The gel strength of the yoghurt increased as the gum amount increased with the highest value record at the highest stabilizer concentration of 0.8% for both gums. This may be due to the increased levels of total solids, high molecular weight and gelling properties of gum arabic from Acacia senagal var *kerensis*, and also potential thermodynamic compatibility between casein and the gum arabic from *A. senegal* var *kerensis*. A high intrinsic viscosity or hydrodynamic molecular volume of the polysaccharide leads to smaller occupied volumes, which contribute to less exclusion of the polysaccharide in mixtures (Keogh & O'kennedy, 1998). This explains the difference in gel strength between *A. senegal* var *kerensis* gum and *A. senegal* var *senegal* gum. Thus, the aggregation of milk proteins, especially casein micelles decreases and consequently, phase separation is reduced. The potential electrostatic bonding between the hydroxyl groups of gum arabic and the positively charged regions on k-casein could have played a role in increasing the gel strength of the yoghurt (Guven et al., 2005). Similar results were reported on incorporation of either beta-glucan or inulin in yoghurt (Guven et al., 2005). The formulation resulted in an increase in product firmness and consistency in comparison with the control samples. The highest firmness and consistency of beta-glucan products was obtained from formulations containing a 2.5% addition level. The texture and the rheological results are in agreement with trends observed for yoghurt syneresis and increased gel strength (G' and firmness).

3.7 Rheological properties (Oscillatory test) of low-fat yoghurt

In the present study, storage (G') and loss (G") modulus values were determined and were found to be dependent on frequency at all concentrations studied (Figures 1- 4). Increasing the gum arabic concentration for both stabilizers up to 0.8% increased the value of both G" and G'. This is due to the increase in carboxylic cross-linking between the stabilizer and the casein micelles which play a dominant role in increasing the G' value of acid gels made from heated milk (Guven et al., 2005). Yoghurt enriched with *A. senegal* var *kerensis* gum at different gum arabic concentrations showed higher G' and G" values than control yoghurt. The same results were recorded for the *A. senegal* var *senegal* gum (Table 4). These values increased as the level of the stabilizer increased. Research has shown that heating milk to above 70 ^{o}C at natural pH predominantly promotes the unfolding of whey proteins and their complex formation with casein micelles involving β-casein (Guven et al., 2005). Gum arabic associates with casein micelles via the formation of intermolecular carboxylic bonds found in the AGP fraction. The binding of gum arabic to the micelle surface induces the formation of bridges between the casein particles and induces a network dominated by casein–AGP fraction interaction at pH 4.6. Gum arabic-arabinogalactan (AGP) fraction aggregates that associate with casein micelles help to crosslink casein particles and increase the number and strength of bonds between protein particles. This explains the rise of both G' and G" as the concentration of the gum is increased as shown in Table 4. The high G' and G" recorded for *A. senegal* var *kerensis* compared to *A. senegal* var *senegal* is due to the high molecular weight associated to the

Table 4: Physico-chemical properties of yoghurt stabilized with *A. senegal* var *kerensis* gum

		Control	0.2%	0.4%	0.6%	0.8%
A. senegal var kerensis	G'	99.92e	145.92d	191.92c	232.92b	262.92a
	G"	25.27e	26.27d	27.57c	28.57b	29.57a
A. senegal var senegal	G'	99.92e	139.79d	179.87c	221.80b	250.90a
	G"	25.27e	24.65cd	25.87bc	26.98ab	28.24a

a – e Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test at P $\leq$ 0.05
*Means separation carried out separately for each trial.

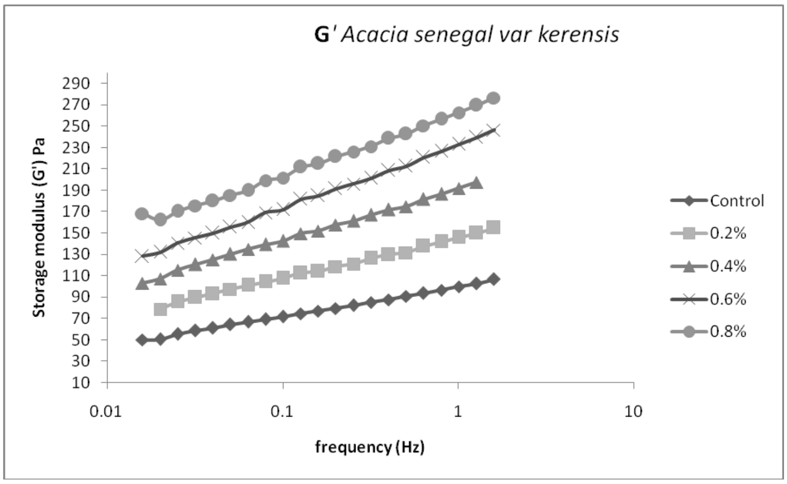

Figure 1: G' *A. senegal* var *kerensis* stabilized for low-fat yoghurt

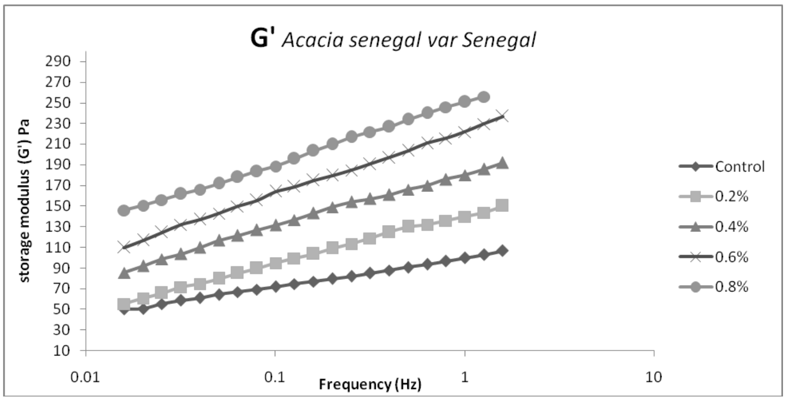

Figure 2: G' *A. senegal* var *senegal* stabilized for low-fat yoghurt

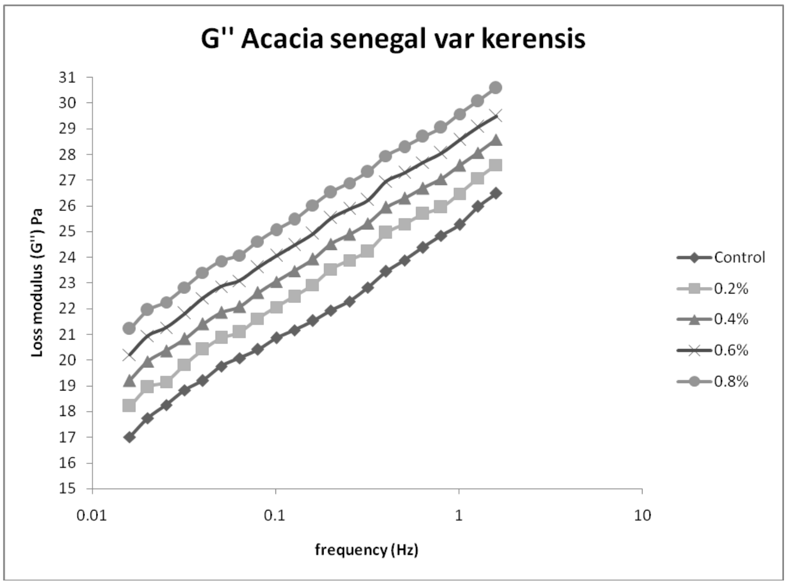

Figure 3: G” *A. senegal* var *kerensis* stabilized for low-fat yoghurt

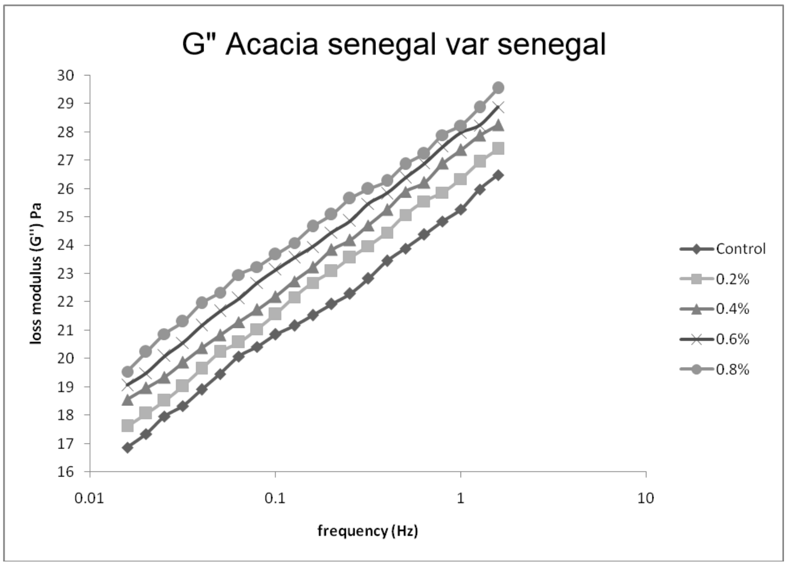

Figure 4: G” *A. senegal* var *senegal* stabilized for low-fat yoghurt

AGP content and the gelling property of the *A. senegal* var *kerensis* gum. High levels of hydrocolloids have been reported to increase whey protein self-aggregation (Mezger, 2002) and formation of a protein matrix with dominant whey protein aggregates. Most hydrocolloids are generally carboxylated or sulphated. Gum arabic carries carboxylic groups (Mezger, 2002) and is also an anionic polysaccharide, which can adsorb onto casein micelles during acidification. An adsorbing polymer, depending on its concentration, can lead to a colloidal system through the whole series of no influence – bridging – polymeric stabilization – depletion – destabilization (Syrbe, Bauer & Klostermeyer, 1998). If the amount of polymer is not large enough to completely cover the protein, a polysaccharide may be adsorbed onto more than one protein surface, thereby bridging two or more protein particles. However, flocculation becomes more and more effective up to about half of the saturation surface coverage (Mezger, 2002).

3.8 Sensory evaluation

Texture properties can often be assessed with instruments, but this is insufficient in characterizing the product. Many consumers use the sensory properties of foods to judge freshness and quality of a product (Kealy, 2006). Sensory properties including flavor, mouth feel and color can be evaluated by trained or untrained panelists (Kuenzel, Zandstra, El Deredy, Blanchette & Thomas, 2011). Consumer testing could provide the most meaningful and reliable information on the textural quality and acceptability of yoghurt (Jaworska, Szulinska, Wilk & Anuszewska, 2005). In the present study, panel testing procedures were carried out. Sensory analyses on appearance, texture, taste, body and overall acceptance of the *A. senegal* gum stabilized low- fat yoghurt as well as control samples were evaluated by 7 trained panelists using a 9-point hedonic scale (Kuenzel et al., 2011). Panelists were asked to score sample attributes from extremely like (9) to extremely dislike (1). Thus the highest numbers represented more desirable, and the lowest less desirable traits. The analysis of variance results are presented in Table 5 for *A. senegal* var *kerensis* and *A. senegal* var senegal. The control skim milk yoghurt had the lowest scores in all aspects except in appearance and taste. Both gum arabic from *A. senegal* var *kerensis* and *A. senegal* var *senegal* had no effect on the appearance/ color of the low-fat yoghurt as the gum content was increased. Gum arabic from the initial characterization was found to be tasteless and odorless thus it did not cause significant difference in the low-fat yoghurt. Similar results were reported by Akhtar and Dickinson (2007) and Yadav, Igartuburu, Yan and Nothnagel (2007) where gum arabic did not have any effect on taste and appearance of the beverage prepared.

Addition of gum arabic to skim milk yoghurt improved the texture and body of the yoghurt and the acceptability rating changed significantly ($P < 0.05$). Similar results were found when gum arabic was added to frozen yoghurt showing an increase in acceptability with increase in gum level up to a level of 0.5% (Rezaei et al., 2011). In addition, Moeenfard and Tehrani (2008) and Rezaei et al. (2011) reported an improvement in texture when stabilizers are used. However, Mahjoub (2016) reported a decrease in color, flavor, taste and overall acceptability when gum arabic and baobab were added up to 0.3% in yoghurt. The texture of the low-fat yoghurt increased as the level of concentration of gum arabic (both gums) increased. The results show that the panel preferred the yoghurt stabilized with *A. senegal* var *kerensis* gum to *A. senegal* var *senegal* gum. This was due to the high molecular weight and gelling property of *A. senegal* var *kerensis* gum leading to a better mouth feel. These results suggest that gel strength correlated with consumer acceptance. These findings are similar to earlier results suggesting a positive correlation between acceptance and gel strength of yoghurt (Frost & Janhoj, 2007).

The body of the yoghurt increased as the concentration of the gum arabic was increased (Table 5). These results correlate with the results from gel strength and rheological properties which showed that the G', and G" was highest in the 0.8% concentration level of gum arabic. Samples containing 0.4 and 0.6 % *A. senegal* var *kerensis* were also regarded as smooth. The low-fat yogurt containing 0.8% of *A. senegal* var *keren-*

Table 5: Sensory analysis results for low- fat yoghurt stabilized with *A. senegal* var *kerensis* and *A. senegal* var *senegal* gum

		Trial 1 Control	0.2	0.4	0.6	0.8	Trial 2 Control	0.2	0.4	0.6	0.8
A. senegal	Appearance	7.5b	7.2b	7.2b	8.4a	8.4a	7.4b	7.2b	7.3b	8.3a	8.1a
	Texture	3.8d	5.5c	7.0b	8.0ab	8.8a	3.8d	5.5c	6.7b	8.2a	8.7a
	Taste	8.9a	7.0b	6.0c	7.0b	5.8d	8.9a	7.0b	6.0c	7.0b	5.8a
var kerensis	Body	3.8d	5.5c	6.6b	8.2a	8.6a	3.8d	5.5c	7.0b	8.0ab	8.8a
	Overall acceptance	4.8c	6.0bc	6.6b	8.3a	6.6b	4.7c	5.8bc	6.8b	8.0a	6.5b
A. senegal	Appearance	7.5b	6.6b	7.2b	8.4a	8.4a	7.4b	7.2b	7.3b	8.3a	8.1a
	Texture	3.8d	5.0c	6.5b	7.0ab	7.4a	3.8d	4.8c	5.2b	6.8a	7.5a
	Taste	8.9a	6.8b	6.0c	7.0b	5.6d	8.9a	7.0b	6.2c	6.8b	5.6a
var senegal	Body	3.8d	4.0c	5.5b	6.0a	7.0a	3.8d	3.8c	5.6b	6.4ab	7.2a
	Overall acceptance	4.8c	5.0bc	6.0b	7.0a	6.0b	4.7c	5.2bc	5.8b	6.5a	6.0b

a – e Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$

*Means separation carried out separately for each trial.

sis was said to have a slimy texture and some panelist described it as too smooth, which was not profound. Some authors have indicated that smoothness is a highly desirable sensory characteristic in food emulsions such as dairy products (Bayarri, Carbonell, Barrios & Costell, 2011). Smoothness of dairy products decreases due to increased average size of the fat globules by decreasing the average distance between them and increasing the variation in their size for full-fat yoghurt. Additionally, smoothness can be related to creaminess and thickness (which depends on the viscosity). Both proteins and polysaccharides contribute to the structural and textural properties of yoghurt. The expert panel indicated a preference for yoghurts containing 0.6 % *A. senegal* var *kerensis* after one day of storage.

4 Conclusion

Gum arabic from *A. senegal* var *kerensis* can be used as a stabilizer in low-fat yoghurt formulations and this increases consumer acceptability. The present study demonstrates that stabilization of low-fat yoghurt with *A. senegal* var *kerensis* improves the textural quality of set-style yoghurts. The study showed that *A. senegal* var *kerensis* gum imparts better rheological properties to low-fat yoghurt when used as a stabilizer compared to *A. senegal* var senegal. Gum arabic from *A. senegal* var *kerensis* can be used in low-fat yoghurt to prevent serum separation and to adjust the viscosity. When used at a sufficient level, stabilizers reduced serum separation and increased apparent viscosity. *A. senegal* var *kerensis* gum addition was found to be a better yoghurt stabilizer than gum arabic from *A. senegal* var senegal. The optimal gum concentration in low-fat yoghurt recommended from the results of this study is 0.6% of *A. senegal* var *kerensis* gum.

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