Influence of Temperature and Salt on Viscosity Property of Guar Gum

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Received 30 April 2007; accepted 4 July 2007

Abstract

The viscosity of guar gum is one of the factors that may reduce nutrient (i.e. glucose, lipid) absorption in the intestinal lumen. Some studies have shown that viscous guar gum did not decrease nutrient absorption. Those studies, however, did not report the effect of temperature or Krebs solution on viscosity of guar gum used. Therefore, the present study determined the viscosity behavior of guar gum at different temperatures (4 ^{o}C, 25 ^{o}C, 37 ^{o}C) and different solvents (water vs Krebs bicarbonate). When the 0.5% (w/w) guar gum was heated from either 4 ^{o}C or 25 ^{o}C to physiological temperature (37 ^{o}C) and held for 2 h, the viscosity measured at 37 ^{o}C of both solutions was similar. This result was similarly observed with 1% (w/w) guar gum. Krebs bicarbonate decreased the viscosity of 0.25% (w/w) guar gum at 37 ^{o}C, but it increased the viscosity of 0.5% (w/w) guar gum at 37 ^{o}C. The results of this study may help to better understand the viscosity behavior of guar gum under processing and physiological conditions.

Keywords: Guar; Gum; Viscosity; Salt; Temperature

Introduction

Guar gum is a hydrocolloid obtained from the endosperm of the *Cyanmopsis tetragonolobus* belonging to the family Leguminosae. The structure of guar gum consists of a linear backbone of β(1,4)-linked D-mannose units with various amounts of α(1,6)-linked D-galactose side chains. The ratio of mannose to galactose is 2:1. Guar gum is an economical thickener and stabilizer. It easily hydrates in cold water to give highly viscous solution. The very high viscosity attained at low concentrations makes guar gum an excellent thickener in the food industry, such as in soups, desserts, pie fillings (Dierckx & Dewettinck, 2002).

It has been reported that guar gum can reduce nutrient (i.e. glucose, lipids) absorption in humans, whether taken as a large dose in solution or in a solid food (Jenkins et al., 1980; Jenkins et al., 2000). The proposed mechanism of a reduction in the rate of glucose absorption is due to the presence of viscous gum dispersion in the gastrointestinal tract to form viscous solution, which reduces the rate of transport of solute across the intestinal epithelium. However, the studies of the effect of guar gum on absorption are contradictory. Some studies have shown that viscous gum did not delay nutrient absorption across intestinal epithelium (Elsenhans et al., 1980; Forster & Hoos, 1977; Schwartz & Levine, 1980). Leclere et al. (1994) indicated that the viscosity of guar gum did not reduce the accessibility of luminal contents toward the absorptive mucosal surface. One of the reasons for these controversies may lie in the study design, for example, the concentrations of guar gum used or conditions of the test solution, which may give different viscosities in the intestinal lumen.

Guar is a non-ionic gum which is not affected by ionic strength or pH. However, strong acid and alkali at high concentration tend to reduce the viscosity. Studies showed the changes in the rheological and thermal properties of gum when salts were added in the solution (Doyle et al., 2006; Richardson & Norton, 1998). Whistler & BeMiller (1997) reported that the viscosity of guar gum was markedly reduced by the presence of NaCl.

Although it has been reported that salts reduced the viscosity of guar solution, it has never been demonstrated whether the Krebs bicarbonate, a physiological buffer, affects the viscosity of guar solution. Generally, the alkali condition in the lumen is a combination of many salts e.g. NaCl, KCl, $NaHCO_3$, KH_2PO_4, $MgSO_4$. It is interesting to investigate the effect of physiological buffer solution (Krebs bicarbonate) on viscosity compared to that of the water. This may expand our knowledge on the controversy whether guar gum reduces glucose absorption in the gastrointestinal tract.

Many viscous food products are kept in either refrigerator (4 ^{o}C) or room temperature (25 ^{o}C) before consumption. Generally, increased temperature reduces the viscosity of gum (Burkus & Temelli, 2005). Since food is digested in gastrointestinal tract approximately 2-4 hours, the physiological temperature (37 ^{o}C) for such period may affect viscosity of guar gum in the intestinal lumen. No previous studies reported such the effect. It is interesting to study the viscosity property of guar gum when the solution is heated from the storage temperature of food products to the physiological temperature for over 2 h e.g. from 4 ^{o}C to 37 ^{o}C or from 25 ^{o}C to 37 ^{o}C

When using guar gum for reducing sugars and lipids absorption in the intestinal lumen, there are at least two factors to be concerned with: the physiological temperature and buffer solution. The objectives of the present study were (a) to investigate the effect of temperatures, based on storage temperature (4 ^{o}C and 25 ^{o}C) and physiological condition (37 ^{o}C), on the viscosity of guar gum, and (b) to investigate the effect of Krebs bicarbonate solution on the viscosity of guar gum.

Materials and Methods

Guar gum (100 mesh) was obtained from Danisco (Vernon, Texas). All chemicals (e.g. NaCl, $MgSO_4$, KH_2PO_4, KCl, $NaHCO_3$) used in this study were of analytical grade and procured from Sigma Chemical (St. Louise, MO).

Preparation of Krebs solution

Krebs bicarbonate solution was prepared by mixing of 0.3 g $MgSO_4$, 0.15g KH_2PO_4, 0.35g KCl, 2.1 g $NaHCO_3$, 6.5 g NaCl in 2 litres of water, and then the solution was adjusted to pH 7.4. The buffer solutions were prepared at two fold of the final concentrations in order to be combined with guar solutions at the ratio of 1:1.

Preparation of guar solutions for the ordering temperature test

Aqueous guar solutions were prepared on a weight-to-weight basis using reverse osmosis water in a boiling water bath for 30 min, with gentle stirring to ensure homogeneity. The solutions were cooled and held at 4 ^{o}C or 25 ^{o}C for 2 h, with gentle stirring to ensure homogeneity. A correction was later made for any loss of water due to evaporation prior to determining the viscosity. Those solutions were then heated to 37 ^{o}C and were held at 37 ^{o}C for 2 h in water bath, with gentle stirring to ensure homogeneity. A correction was made for any loss of water due to evaporation prior to measuring the viscosity.

Preparation of guar solutions for the effect of Krebs bicarbonate test

Since the Krebs bicarbonate solution should not be heated for 30 min, guar solutions were prepared at two fold of the final concentration in order to be combined with Krebs solution at the ratio of 1:1. The preliminary study showed that the maximum concentration of guar gum that completely dissolved in boiling water without clusters of gel-like was at 1% (w/w). Therefore, two doses of guar gum, 0.5% and 1% (w/w), were prepared as two fold of the final concentration in the present study.

Guar gum at 0.5%, and 1% (w/w) were dissolved in a boiling water bath for 30 min. After cooling, the solutions were corrected for any loss of water due to evaporation. These solutions were diluted with either water or Krebs bicarbonate solution to a ratio of 1:1, with gentle stirring to ensure homogeneity for 2 h at 37 ^{o}C. The final concentrations of guar gum in the test solutions were 0.25%, and 0.5% (w/w), respectively. Prior to measuring the viscosity, these solutions were corrected for any loss of water due to evaporation.

Determination of viscosity

Viscosity measurements were recorded at consecutive fixed shear rates of 1.29-129 s^{-1} using a Parr Physica UDS 200 rheometer (Glenn, VA). The viscometer was equipped with a Peltier heating system that controlled the sample temperature. Viscosity measurements were recorded at 4 ^{o}C, 25 ^{o}C, and 37 ^{o}C using DG 27 cup and bob geometry with a sample size of 7 $\pm$ 0.005 g. All analyses were performed in duplicate. Samples were put in the cup of viscometer until the desired temperatures were stable for 3 min before analyses. The same sample was used in the test of ordering-temperature measurements. The shear rate was reported in s^{-1} after multiplying the rpm value by a conversion factor of 1.29 s^{-1} provided by the manufacturer.

Statistical analyses

Data of the viscosity of solutions were reported as the mean $\pm$ SEM. The viscosity of guar solutions in either water or Krebs solution was statistically analyzed by one way ANOVA, followed by Student-Newman-Keuls (SNK) as a post-hoc test. Statistical analyses of viscosity of solutions in ordering temperature test were calculated by repeated measurement analysis ANOVA, followed by SNK. The p level of < 0.05 was considered to be statistically significant.

Results

Effect of ordering temperatures on viscosity of guar gum

The viscosities of 0.5% and 1% (w/w) guar solutions at 4 ^{o}C, 25 ^{o}C, and 37 ^{o}C were obviously reduced when the shear rates were increased at all shear rates (Table 1 to 4). The viscosity of 0.5% (w/w) guar solution at 4 ^{o}C was significantly higher than that of solution at 37 ^{o}C ($p<0.05$, Table 1). The viscosity of 0.5% (w/w) guar solution at 25 ^{o}C was significantly higher than that of 37 ^{o}C ($p<0.05$, Table 2). When compared the viscosity at 37 ^{o}C between Table 1 and 2, the viscosities were not different by greater than 10 milli pascal second (mPa•s) at the shear rates of 12.9, 25.8, 64.6, and 129 s^{-1}.

The viscosity of 1% (w/w) guar solution at 4 ^{o}C was significantly higher than that of solution at 37 ^{o}C ($p<0.05$, Table 3). The viscosity of 1% (w/w) guar solution at 25 ^{o}C was not significantly different compared to that of solution at 37 ^{o}C at all shear rates ($p>0.05$, Table 4). When the viscosity at 37 ^{o}C between Table 3 and 4 was compared, the viscosities were not significantly different at the shear rate of 6.46 to 129 s^{-1}($p>0.05$). However, at very low shear rate of 1.29 s^{-1}, the viscosity of guar solution with the beginning temperature at 4 ^{o}C was significantly lower than that of guar solution with the beginning temperature at 25 ^{o}C ($p<0.05$).

Table 1. Viscosity of 0.5% (w/w) guar solution at 4 °C and 37 °C

Shear rate (s^{-1})	Viscosity at 4 °C (mPa·s)	Viscosity at 37 °C (mPa·s)
1.29	292 ± 7.5	118 ± 6.1*
6.46	199 ± 5.7	88 ± 3.9*
12.9	158 ± 4.8	76 ± 3.3*
25.8	120 ± 2.5	62 ± 3.6*
64.6	79 ± 4.2	45 ± 2.3*
129	56 ± 3.0	34 ± 2.1*

Value is mean ± SEM; n=2

*indicates a significant difference ($p<0.05$) of the viscosity between 4 °C vs. 37 °C at the same shear rate.

Table 2. Viscosity of 0.5% (w/w) guar solution at 25 °C and 37 °C

Shear rate (s^{-1})	Viscosity at 25 °C (mPa·s)	Viscosity at 37 °C (mPa·s)
1.29	192 ± 5.5	141 ± 5.1*
6.46	137 ± 2.9	104 ± 2.2*
12.9	113 ± 2.4	87 ± 1.6*
25.8	89 ± 1.5	72 ± 1.1*
64.6	61 ± 0.8	51 ± 0.4*
129	44 ± 0.3	37 ± 0.2*

Value is mean ± SEM; n=2

*indicates a significant difference ($p<0.05$) of the viscosity between 25 °C vs. 37 °C at the same shear rate.

Table 3. Viscosity of 1% (w/w) guar solution at 4 °C and 37 °C

Shear rate (s^{-1})	Viscosity at 4 °C (mPa·s)	Viscosity at 37 °C (mPa·s)
1.29	4670 ± 197	2940 ± 131*
6.46	1880 ± 97	1260 ± 89*
12.9	1180 ± 86	842 ± 70*
25.8	722 ± 35	45 ± 26*
64.6	372 ± 21	290 ± 12*
129	226 ± 14	176 ± 10*

Value is mean ± SEM; n=2

*indicates a significant difference ($p<0.05$) of the viscosity between 4 °C vs. 37 °C at the same shear rate.

Table 4. Viscosity of 1% (w/w) guar solution at 25 °C and 37 °C

Shear rate (s^{-1})	Viscosity at 25°C (mPa·s)	Viscosity at 37°C (mPa·s)
1.29	3550 ± 185	3550 ± 181
6.46	1590 ± 87	1420 ± 83
12.9	1040 ± 61	937 ± 44
25.8	659 ± 55	602 ± 56
64.6	344 ± 36	319 ± 32
129	207 ± 21	194 ± 18

Value is mean ± SEM; n=2

Effect of Krebs bicarbonate solution on viscosity

The viscosity of 0.25% (w/w) guar solution dissolved in Krebs solution markedly decreased at all shear rates compared to that of guar dissolved in water at 37 °C ($p<0.05$, Table 5). On the contrary, the viscosity of 0.5% (w/w) guar solution dissolved in Krebs solution significantly increased at all shear rates when compared to that of guar dissolved in water at 37 °C ($p<0.05$, Table 6).

Table 5. Viscosity of 0.25% (w/w) guar solution mixed with either water or Krebs bicarbonate solution at 37 °C

Shear rate (s^{-1})	Viscosity (mPa·s)	
	Water	Krebs solution
1.29	32.8 ± 2.5	6.7 ± 0.3*
6.46	27.5 ± 2.7	3.3 ± 0.2*
12.9	25.3 ± 2.1	2.8 ± 0.2*
25.8	22.9 ± 2.0	2.6 ± 0.2*
64.6	19.2 ± 1.6	2.3 ± 0.2*
129	16.2 ± 1.0	2.2 ± 0.2*

Value is mean ± SEM; n=2

*indicates a significant difference (p<0.05) of the viscosity of guar solution mixed with water vs. Krebs solution at the same shear rate.

Table 6. Viscosity of 0.5% (w/w) guar solution mixed with either water or Krebs bicarbonate solution at 37 °C

Shear rate (s^{-1})	Viscosity (mPa·s)	
	Water	Krebs solution
1.29	145 ± 4.5	191 ± 4.8*
6.46	113 ± 2.2	145 ± 4.2*
12.9	96.2 ± 1.5	123 ± 2.6*
25.8	78.8 ± 1.4	101 ± 2.1*
64.6	56.4 ± 0.4	71.5 ± 0.6*
129	41.6 ± 0.2	52.5 ± 0.4*

Value is mean ± SEM; n=2

*indicates a significant difference (p<0.05) of the viscosity of guar solution mixed with water vs. Krebs solution at the same shear rate.

Discussion

Guar gum attained at low concentration in water provides high viscous solution. When guar gum is dispersed in water, the galactose side chain of the molecule interacts with water molecule, leading to inter-molecular chain entanglement of the guar gum in aqueous solutions, and causing the viscosity of the solution. With the increase in concentration of guar gum, the degree of inter-molecular chain interaction or entanglement would be enhanced, which results in increased viscosity (Zhang et al., 2005). The viscosity of 1% (w/w) guar solution in the present study was significantly higher than that of 0.5% (w/w) guar solution when compared at the same determining temperature (Table 1 vs. 3; Table 2 vs. 4). Guar solution in the present study showed the decreased viscosity with increasing shear rates (Table 1 to 4), thus this material has shear-thinning behavior and non-Newtonian flow, particularly in pseudoplastic sub-class (Bourne, 2002).

Temperature causes the water molecules to loose their ordering around the guar molecules, thus affecting the conformation and resulting in reduced-viscosity behavior (Finney & Soper, 1994). Results of this study showed that the viscosity of 0.5% (w/w) guar solutions was decreased when the gaur solutions were heated and held in the physiological-temperature for 2 h e.g. from 4 °C to 37 °C and 25 °C to 37 °C (Table 1 & 2). This may be due to elevated temperature increasing the energy dissipation movement of the molecule, or decreasing the inter-molecular interactions, which in turn decrease the interference of the hydrodynamic domain (Chen & Chen, 2001). Interestingly, the result showed that the viscosity of 1% (w/w) guar solution at 37 °C was similar to that of solution at the beginning temperature of 25 °C (Table 4). This indicates that the viscosity of 1% (w/w) guar solution was not influenced by the small-increased temperature. It is possible that the inter-molecular interactions may not be decrease when the temperature was not much different at high concentration of guar gum. However, 1% (w/w) guar solution used in this study was prepared as qualitative analyses. Thus, it requires further investigation in higher volume of water.

The preliminary study showed that the viscosity was decreased when the solution was heated. When such solution was recooled, the viscosity returned to the similar value at its beginning temperature (data not shown). This indicates that temperature caused reversible change in the viscosity of guar gum. Interestingly, results in the present study showed that heating 1% (w/w) guar solution from either 4 ^{o}C or 25 ^{o}C to 37 ^{o}C, the viscosity of both solutions at 37 ^{o}C was not significantly different ($p>0.05$, Table 3 & 4). This result was consistent with 0.5% (w/w) guar solution but only at the shear rate of 12.9 to 129 s^{-1} (Table 1 & 2). Although no information is available on shear rates within the intestine, it is perhaps relevant to note that the values of 50 to a few hundreds per second have been suggested for the mouth during mastication (Sherman, 1976). Results of viscosity at 37 ^{o}C in the present study are useful for physiological application. For example, if it is desired to use guar-containing products which kept in different storage temperature e.g., ice cream, beverages, jelly, by expecting the similar value of viscosity at physiological temperature, the amount of guar gum used in food products could be at either 0.5% or 1% (w/w).

The presence of Krebs bicarbonate solution markedly decreased the viscosity of 0.25% (w/w) guar solution compared to that of guar in water alone (Table 5). This reduced viscosity may be due to a decrease of the effective volume fraction, or a less entangled state of guar solution upon the addition of salts. The possible mechanism is based on the hypothesis that salts are hydrophilic molecules that strongly interact with water (Cybulska & Doe, 2002). Results in the present study suggest that high concentrations of salts reduce the availability of water in the solution preventing the expansion of the guar networks, thereby decreasing the viscosity. Consistent with this hypothesis, it was reported that added salts restricted the hydration of guar gum in the solution (Doyle et al., 2006).

Contrarily, results in this study showed that the viscosity of the 0.5% (w/w) guar solution significantly increased when the salts were added (Table 6). This suggests that the inter-molecular networks of guar and water were not disturbed. The possible mechanism to explain the result is that the presence of salts can facilitate the formation of intermolecular aggregates due to the alteration of the charge density and conformation of gum (Gittings et al., 2001). Zhang reported that the improved viscosity of the solution with increased salt concentration was due to the addition of salt disrupting the intra- and intermolecular associations, resulting in the expansion of the chain conformation. (Zhang et al., 2005). However, it is too early to conclude the mechanism at this point. It requires further investigation for structure and functional relationship of guar gum in Krebs solution.

Guar gum had been used to reduce the glucose absorption from the intestinal lumen. Many researchers found that the higher concentration of guar gum was more effective than the lower concentration (Jenkins et al., 2001). This may be attributed to the high viscosity property of the higher concentration of guar gum in the intestinal lumen. In the present study, the increased viscosity of 0.5% (w/w) guar solution in Krebs bicarbonate, but decreased viscosity of 0.25% (w/w) guar solution in Krebs bicarbonate, suggests that 0.5%(w/w) guar gum may be able to decrease the rate of glucose absorption more than 0.25% (w/w) guar gum.

Conclusion

The viscosity of 0.5% (w/w) guar gum at 4 °C was significantly higher than that of solution at 25 °C ($p<0.05$). When these two solutions were heated and held at 37 °C for 2 h, their viscosities at 37 °C were similar. This result was consistent with 1% (w/w) guar gum. These results suggest that if it is desired to use guar-containing products which kept in different storage temperature e.g., ice cream, beverages, jelly, by expecting the similar value of viscosity at physiological temperature, the amount of guar gum used in food products could be at either 0.5% or 1% (w/w).

The viscosity of 0.25% (w/w) guar gum mixed with Krebs bicarbonate buffer was markedly decreased when compared to that of guar gum in water. In contrast, the viscosity of 0.5% (w/w) guar gum mixed with Krebs bicarbonate buffer was significantly increased when compared to that of guar gum in water. These contrary results suggest that two different mechanisms might be applied for different concentrations of guar gum mixed with Krebs solution. If 0.25% (w/w) guar gum is used, Krebs bicarbonate may impede the entanglement formation of guar gum, thereby decreasing the viscosity. However, if 0.5% (w/w) guar gum is used, Krebs bicarbonate may facilitate the formation of intermolecular aggregates or alter the charge density of the solution thereby increasing the viscosity. Nevertheless, these proposed mechanisms require further investigation.

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