Available online at www.sciencedirect.com
ScienceDirect
International Dairy Journal 17 (2007) 776–781
INTERNATIONAL DAIRY JOURNAL
www.elsevier.com/locate/idairyj

# Flow behaviour of inulin–milk beverages. Influence of inulin average chain length and of milk fat content

B. Villegas, E. Costell*

*Physical and Sensory Properties Laboratory, Instituto de Agroquímica y Tecnología de Alimentos, CSIC. P.O. Box 73, 46100 Burjassot (Valencia), Spain*

Received 17 January 2006; accepted 26 September 2006

**Abstract**

The effects of the addition of different types of inulin (oligofructose, native and long chain) at different concentrations (2%, 4%, 6%, 8% and 10%, w/w) on the flow behaviour of milk beverages model systems were studied. The flow of the inulin–milk solutions was Newtonian, except for whole milk samples with higher long chain inulin concentrations (8% and 10%), which were shear thinning. All inulin-$\kappa$-carrageenan–milk samples were shear thinning. The viscosity of 3.1% fat whole milk could be approximated by skim milk with 4–10% short chain inulin, or with 6–8% native inulin or with 4–6% long chain inulin. In $\kappa$-carrageenan–milk samples the addition of inulin could not replace the effect of milk fat on the viscosity of these systems.


*Keywords:* Milk beverages; Flow behaviour; Inulin; $\kappa$-carrageenan; Milk fat content

## 1. Introduction

Inulin is a natural component of several fruits and vegetables. It is mainly obtained from chicory roots by an extraction process with hot water, followed by purification and crystallisation. 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. The degree of polymerisation of the chains ranges from 2 to 60 units and is commonly characterised by the average degree of polymerisation, which in native inulin is approximately 12. By partial enzymatic hydrolysis of the native inulin with endo-inulinase, oligofructose, with a polymerisation degree between 2 and 7, with an average value of 4, can be obtained. Alternatively, the oligomers with a polymerisation degree below 10 can be separated from native inulin by physical methods (ultrafiltration, crystallisation, etc), and a long-chain inulin with an average degree of polymerisation between 22 and 25 is thus obtained (Franck, 2002; Moerman, Van Leeuwen, & Delcour, 2004).

In addition to its beneficial effects on health, as a dietetic fibre and as a prebiotic ingredient (Flamm, Glinsmann, Kritchevsky, Prosky, & Roberfroid, 2001; Roberfroid & Slavin, 2000), inulin shows interesting technological properties, as a low-calorie sweetener, as a fat substitute, or it can be used to modify texture (Tungland & Meyer, 2002). These properties are linked to the degree of chain polymerisation. The short-chain fraction, oligofructose, is much more soluble and sweeter than native inulin, with a sweetness profile similar to that of sucrose, lower sweetening power (30–35%) and a low caloric content (1–2 kcal$g^{-1}$). Long-chain inulin is more thermally stable, less soluble and more viscous than the native product (Wada, Sugatani, Terada, Ohguchi & Miwa, 2005), and can be used as a fat substitute, with an efficiency that is practically double than that of native inulin (Coussement, 1999; Voragen, 1998). Its properties as a fat substitute are attributed to its capacity to form microcrystals that interact with each other forming small aggregates, which occlude a great amount of water, creating a fine and creamy texture that provides a mouth sensation similar to that of fat (Bot, Erle, Vreeker & Agterof, 2004; Franck, 2002; Kaur & Gupta, 2002).

The combined consideration of its nutritional and technological characteristics makes inulin a very attractive ingredient. In most cases, its addition to different foods has

*Corresponding author. Tel.: +34 96 3900022; fax: +34 96 3636301.
*E-mail address:* ecostell@iata.csic.es (E. Costell).

0958-6946/$ - see front matter 
doi:10.1016/j.idairyj.2006.09.007

been done in order to increase fibre ingestion, in amounts that ranges from 3 to 6 g per portion, or to assure its bifidogenic nature, by adding 3–8 g per portion (Coussement, 1999). Despite the great number of commercial products including it in their formulation, there is still little information available referring to its physical properties and to the effects produced by its incorporation on the physical characteristics of different types of foods. Some authors have analysed the effect of adding inulin on the rheological and sensorial characteristics of several dairy products, like ice-creams (El-Nagar, Glowers, Tudorica, & Kuri, 2002; Schaller-Povolny, & Smith, 1999, 2001) yoghurts (Dello Stafollo, Bertola, Martino, & Bevilacqua, 2004; El-Nagar et al., 2002; Guven, Yasar, Karaca, & Hayaloglu, 2005), fresh cheese (Koca & Metin, 2004; Hennelly, Dunne, O'Sullivan, & O'Riordan, 2006) and dairy desserts (Tárrega & Costell, 2006). In most of these studies the objective was to use inulin, generally one with a high degree of polymerisation, in low-fat food formulations. There is little information on the rheological behaviour of inulin and the effect on the same of the possible interactions with other ingredients, like different types of hydrocolloids or starch (Bishay, 1998; Giannouli, Richardson, & Morris, 2004; Zimeri & Kokini, 2003a). Likewise, some information exists on the differences in the physico-chemical properties of oligofructose and inulins with different degrees of polymerisation (Blecker et al., 2003; de Gennaro, Birch, Parke, & Stancher, 2000; Schaller-Povolny, Smith, & Labuza, 2000). The latter studies have been carried out in aqueous systems and no data have been found regarding the physical properties of inulin in other media like, for example, dairy systems.

The aims of this work were: (1) to study the effect of the addition of different types of inulin (oligofructose, native and of long chain) on the flow behaviour of milk beverage model systems with or without milk fat and/or $\kappa$-carrageenan and (2) to compare the viscosity of the whole milk samples with that of skimmed milk samples with different concentrations of the three types of inulin added.

## 2. Materials and methods

### 2.1. Materials and sample preparation

Three types of inulin: long chain length ($\geqslant$23 monomers) (Frutafit TEX!), native (9–12 monomers) (Frutafit IQ) and with a high level of short chain molecules or oligofructose (2–10 monomers) (Frutafit CLR) from Sensus (Brenntag Química, Spain), $\kappa$-carrageenan (Satiagel ABN 26, SKW Biosystems, France) and skimmed and whole milk powders (Central Lechera Asturiana, Spain) were used.

Two lots of 32 samples each were prepared: without and with $\kappa$-carrageenan (0.02%, w/w). Each lot was divided into two sublots: one with whole milk (3.12% fat content) and another one with skimmed milk (0.1% fat content). For each sublot, a sample without inulin added and samples with different concentrations (2%, 4%, 6%, 8% and 10%, w/w) of each of the three types of inulin were prepared. Two preparations for each composition were done.

Inulin–milk beverages were prepared by dispersing 12% (w/w) milk powder and the corresponding inulin concentration in deionised water, at 250 rpm and 70 °C for 15 min, with the help of a magnetic stirrer and a hot plate (Ared, Velp Scientifica). Samples were stored in refrigeration (4 ± 1 °C) during 24 h before measurement.

Kappa-carrageenan was dissolved in deionised water at room temperature for 5 min and then at 70 °C for 10 min, agitating with a magnetic stirrer at 250 rpm. These solutions were kept refrigerated (4 ± 1 °C) for 24 h before mixing with inulin–milk dispersions. Mixing was performed at 250 rpm and 70 °C for 5 min. Samples were then kept at 4 ± 1 °C for 4 h before measurement.

### 2.2. Flow measurement

Flow measurements were carried out in a concentric cylinders viscometer Haake model VT 550, using a double gap sensor NV (radii ratio = 1.02, length = 60 mm) and controlled by the Rheowin Pro software (version 2.93, Haake). Shear stress ($\sigma$) was registered at shear rates ($\dot{\gamma}$) from 1 to 600 $s^{-1}$ with a ramp of 120 s. For each sample, measurements were done in triplicate at a controlled temperature of 5 ± 1 °C using a Phoenix P1 Circulator device (Thermo Haake). A fresh sample was loaded for each measurement.

Experimental data were fitted to the Newton model

$$\sigma = \eta\dot{\gamma}, \quad (1)$$

or to the Ostwald-de Waele model

$$\sigma = K\dot{\gamma}^{n}, \quad (2)$$

using the Rheowin Pro software (version 2.93, Haake). Where $\eta$ (mPas) is the Newtonian viscosity, $K$ (mPas$^n$) the consistency index and $n$ the flow index. For samples showing Newtonian flow, viscosity values were used for the characterisation and comparison of samples. For samples with shear thinning flow, since parameter $K$ units depend on $n$ values, apparent viscosity values at 1 $s^{-1}$ ($\eta_1$) were used to compare samples viscosity.

### 2.3. Experimental design and data analysis

For each of the four sublots of samples, the influence of the inulin type and of the inulin concentration and their interactions on the flow parameters values were studied using a factorial design with two factors: inulin type (3 levels) and inulin concentration (6 levels). Analyses of variance of two factors with interactions were applied to the different sets of data. Least significant differences (LSD) were calculated by the Fisher's test ($\alpha \leqslant 0.05$). These analyses were performed with the Statgraphics Plus 4.1 software.