FLOW BEHAVIOUR OF INULIN-MILK BEVERAGES. INFLUENCE OF INULIN CHAIN LENGTH AND OF MILK FAT CONTENT.

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Introduction

Inulin is used either as a macronutrient substitute or as a supplement added in foods mainly for its nutritional properties. Chemically, inulin consists of a long chain made up of fructose molecules and one glucose molecule at one end. The fructose molecules are connected by β -(2-1) bonds and the last fructose is linked with a glucose by an α -(1-2) bond as in sucrose [1, 2]. The average molecular weight and degree of polymerisation of inulin depend on the source of inulin, the time of harvest and the process of production. In native chicory inulin, the number of fructose units linked together ranges from 2 to more than 60, with an average degree of polymerisation of the order of 10 and the high performance forms of inulin have an average degree of polymerisation of 25 [3]. The rheological behaviour of inulin and inulin-hydrocolloids mixtures in water were characterised by Bishay [4] who found a synergistic effect between inulin and calcium alginate. The objective of this work was to study the influence of the addition of inulin of different chain lengths on the flow behaviour of dairy beverages model systems with different milk fat content and with and without κ -carrageenan added.

Materials and methods

Samples

Inulin of long average chain length (≥ 23 monomers) (Frutafit TEX!), native (9-12 monomers) (Frutafit IQ) and with a high level of short chain molecules (2-10 monomers) (Frutafit CLR) from Sensus (Brenntag Química, Spain), κ -carrageenan (Satiagel ABN 26, SKW Biosystems, France) and skim milk and

whole milk powders (Central Lechera Asturiana, Spain) were used. Two lots of 32 samples were prepared: with and without κ -carrageenan (0.02%). Each lot was divided in two sublots: one with whole milk (3.12% fat content) and another one with skim milk (0.1% fat content). Samples with each of the three types of inulin at different concentrations (0, 2, 4, 6, 8 and 10%) were prepared. Samples were prepared by dissolving the components in deionised water using a heating magnetic stirrer at 70°C. They were stored in refrigeration ($4\pm 1^\circ\text{C}$) for 24 hours before measurements. Two samples were prepared for each composition.

Flow measurements

Measurements were carried out in a concentric cylinders viscometer HAAKE model VT 550, using a double gap sensor NV and controlled by the Rheowin v. 2.5, Haake Software OS 550. Shear stress was determined at shear rates 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 $5\pm 1^\circ\text{C}$. Experimental data were fitted to Newton ($\sigma = \eta \dot{\gamma}$) and Ostwald- de Waele ($\sigma = K \dot{\gamma}^n$) models, using the Rheowin Data Manager V. 2.5 software. Since parameter K units depend on n values, in samples with shear thinning flow, apparent viscosity at 1 s^{-1} values were used to compare samples viscosity.

Experimental design and data analysis

For each of the two lots of samples (with and without κ -carrageenan), the influence of the milk fat content, the inulin type and the inulin concentration and their interactions on the flow parameter values were studied using a factorial design with three factors: fat content (2 levels), inulin type (3 levels) and inulin concentration (6 levels). Analyses of variance of three factors with interactions were applied to the different lots of data. Least significant differences (LSD) were calculated by the Fisher's test ($\alpha \leq 0.05$). These analyses were performed with the Statgraphics Plus 3.1 software.

Results

Flow behaviour of inulin-milk systems

The variation of shear stress (σ) values with shear rate ($\dot{\gamma}$) for both skim milk and whole milk samples fitted well to Newton model ($0.951 \leq R^2 \leq 0.994$) except for whole milk samples with higher concentrations (8 and 10%) of long average chain length inulin. The flow of the latter was slightly shear thinning and fitted well to Ostwald-de Waele model ($0.986 \leq R^2 \leq 0.992$), showing flow indices (n) in the range between 0.81 and 0.94. As an example, rheograms obtained for skim milk and whole milk, both without inulin and with 10% concentration of each inulin type, are shown in Figure 1. In this figure the flow differences, due to milk fat content and to inulin chain length, can be clearly observed. The flow of skim milk samples with 10% inulin, for both native and short chain inulin, was similar to that of the whole milk sample without inulin. A three-way ANOVA with interactions was used to study the combined effects of milk fat, inulin type and inulin concentration on viscosity values (Table 1). The effect of the interaction among the three factors was significant ($F=588.91$, $p=0.000$). As expected, the viscosity values increased with milk fat content (Table 1) although this increase depended on the concentration and on the type of inulin. No significant differences among viscosity of samples with inulin concentrations up to 6% concentrations were detected. Addition of higher inulin concentrations significantly increased viscosity, this effect being stronger in the long chain inulin systems (Figure 2). Differences between whole milk and skim milk samples viscosity was higher for both long chain and short chain inulin systems than for native inulin samples (Figure 3).

Flow behaviour of inulin- κ -carrageenan-milk systems

Experimental flow data for both skim milk and whole milk-inulin- κ -carrageenan samples showed shear thinning flow that fitted well to Ostwald-de Waele model

($0.932 \leq R^2 \leq 0.996$) with average consistency index (K) values that ranged from 6.13 mPasⁿ for the sample with skim milk and κ -carrageenan and without inulin to 200.71 mPasⁿ for the sample with whole milk, κ -carrageenan and 10% short chain inulin concentration. Average flow index (n) values ranged from 0.62 to 0.99. Rheograms obtained for skim milk and whole milk with κ -carrageenan samples, without inulin and with 10% concentration of each inulin type are shown in Figure 4. By comparing this Figure with Figure 1, it can be observed that also in this case, the flow of skim milk samples with 10% of inulin for both native and short chain inulin were similar to the flow of whole milk sample without inulin, although flow differences due to the milk fat content and to the inulin chain length showed different trends. The effect of interaction among milk fat content, concentration of inulin and type of inulin on the apparent viscosity values at 1s⁻¹ (η_i) (Table 2) and on the flow index (n) values were significant ($F=5.22$, $p=0.000$ and $F=11.90$, $p=0.000$, respectively). Samples prepared with whole milk were more viscous than those with skim milk (Table 2). For inulin concentrations up to 6%, significant differences on η_i values were detected for the three types of inulin. Viscosity values of short chain inulin samples were the highest and those of native inulin samples the lowest. For 8 and 10% inulin concentrations, viscosity of native inulin samples remained significantly lower and no significant differences in viscosity were detected between short and long chain inulin samples (Figure 5). In this case, the differences in viscosity between whole milk and skim milk samples was higher for short chain inulin systems than for both long chain and native inulin samples (Figure 6).

Conclusions

It can be concluded that the effect of inulin addition on rheological behaviour of milk beverages without and with κ -carrageenan is clearly dependent on milk fat content and on inulin chain length although flow differences of the two lots of samples showed different trends. Despite these differences, the flow of skim milk samples with 10% inulin for both native and short chain inulin were similar to the flow of whole milk sample without inulin for the two lots of samples.

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TABLE 1. Viscosity average values (mPas) (n = 6) of samples with skim milk and whole milk and different concentrations of short chain inulin (CLR), native inulin (IQ) and long chain inulin (TEX)^a.

MILK TYPE	INULIN TYPE	INULIN CONCENTRATION (%)					
		0	2	4	6	8	10
SKIM MILK	CLR		4.83 (0.21)	5.74 (0.08)	5.97 (0.62)	6.39 (0.09)	6.78 (0.19)
	IQ	4.90 (0.34)	5.17 (0.04)	5.41 (0.23)	5.93 (0.01)	6.38 (0.21)	6.88 (0.04)
	TEX		5.22 (0.03)	5.63 (0.21)	6.21 (0.51)	8.03 (0.45)	13.22 (0.04)
WHOLE MILK	CLR		7.70 (0.07)	7.99 (0.48)	8.74 (0.08)	10.18 (0.01)	10.65 (0.07)
	IQ	6.39 (0.35)	5.20 (0.27)	5.82 (0.20)	6.29 (0.23)	7.11 (0.01)	7.10 (0.30)
	TEX		5.53 (0.19)	6.41 (0.05)	7.82 (0.71)	18.86 ^b (2.02)	70.85 ^b (1.84)

^aStandard deviation between parentheses

^bSamples with pseudoplastic flow behaviour; apparent viscosity at 1s⁻¹ values.

TABLE 2. Apparent viscosity average values at 1s⁻¹ (mPas) (n = 6) of samples with skim milk and whole milk, k-carrageenan and different concentrations of short chain inulin (CLR), native inulin (IQ) and long chain inulin (TEX)^a.

MILK TYPE	INULIN TYPE	INULIN CONCENTRATION (%)					
		0	2	4	6	8	10
SKIM MILK	CLR		15.94 (0.07)	14.34 (0.43)	21.49 (2.25)	15.91 (0.00)	14.88 (4.35)
	IQ	6.13 (0.20)	12.65 (2.08)	11.01 (0.04)	11.58 (0.45)	17.71 (1.15)	14.88 (0.46)
	TEX		9.36 (0.05)	11.31 (1.25)	14.37 (0.57)	29.91 (2.13)	48.2 (2.49)
WHOLE MILK	CLR		167.65 (22.66)	152.14 (18.34)	135.4 (5.23)	159.82 (37.74)	200.71 (20.45)
	IQ	59.40 (3.99)	65.64 (5.73)	89.99 (4.92)	87.96 (4.13)	79.16 (4.68)	101.99 (0.81)
	TEX		111.86 (9.81)	117.83 (6.68)	111.93 (13.86)	174.05 (6.11)	174.26 (14.98)

^aStandard deviation between parentheses

FIGURE 1. Shear stress-shear rate plots for inulin-milk beverages. Samples without inulin (—), with 10% of short chain (CLR) (—), native (IQ) (—) and long chain (TEX) (—) inulins and with whole milk (filled circles) and skim milk (empty circles). Experimental points and model fitting curves. Measurements at $5\pm1^{\circ}\text{C}$.

FIGURE 2. Influence of inulin concentration on viscosity for samples with short chain (CLR) (■), native (IQ) (■) and long chain (TEX) (■) inulins.

FIGURE 3. Influence of type of inulin on viscosity of whole milk (■) and skim milk (■) samples.

FIGURE 4. Shear stress-shear rate plots for milk-k-carrageenan samples without inulin (—), with 10 % of short chain (CLR) (—), native (IQ) (—) and long chain (TEX) (—) inulins and with whole milk (filled circles) and skim milk (empty circles). Experimental points and model fitting curves. Measurements at $5 \pm 1^\circ\text{C}$.

FIGURE 5. Influence of inulin concentration on apparent viscosity for milk-k-carrageenan samples with short chain (CLR) (—), native (IQ) (—) and long chain (TEX) (—) inulins.

FIGURE 6. Influence of inulin type on apparent viscosity of milk-k-carrageenan samples with whole milk (—) and skim milk (—).