The effect of whey protein concentrate as a fat replacer on the rheological characteristics of yogurt

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ABSTRACT

The aim of present study was to evaluate the effect of adding whey protein concentrate (WPC) as a fat replacer in the rheological properties of yogurt. Whole yogurt and nonfat yogurt with 0 %, 1.5 %, 3.0 % and 4.5 % of WPC were developed and available. The steady and dynamic shear rheological properties were determined using a HAAKE MARS rheometer at 10 °C with a sensor stainless steel double gap cylinder system DG41 and a sensor cone-plate C60/1° (60 mm diameter), respectively. Results revealed that the yogurt exhibited non-Newtonian and shear thinning behavior. The Bingham model was fitted satisfactorily to the experimental data of curve flow. The addition of WPC resulted in an increase of the storage modulus, G', in the frequency range tested, indicating that the whey protein concentrate has contributed to the gel matrix. Yogurts containing 3.0 and 4.5 % of WPC and whole yogurt showed the same profile of dynamic modulli, presenting a more elastic than others with lower levels of WPC. This indicates that yogurts with 3.0 % and 4.5 % of WPC shown a rheological behavior similar to whole yogurt and these levels of WPC were effective as a milk fat replacer in yogurt.

Keywords: Viscoelasticity, Fat replacer, Whey proteins, Reduced-fat yogurts

INTRODUCTION

Recent marketing research indicates that the production of fermented dairy products is on the rise. Yogurt products have achieved considerable economic importance worldwide owing to their high nutritional image [1]. Yogurt has been attributed nutraceutical, therapeutic [2] and probiotic effects [3] uch as digestion enhancement, immune system boosting, anticarcinogenic activity and reduction in serum cholesterol [4].

Recently, the relationship between fat consumption and heart diseases has been accepted, and the reduction of dietary animal fat has been recommended by nutritionists [5]. Milk fat has an important role in the texture, flavour and colour development of dairy products [6]. Fat replacers have been used safely as thickeners and can be effective fat replacers in various foods [7]. At the same time the amounts required of skim milk powder, sodium caseinate, or whey protein concentrates to achieve the total solids content similar to that of the full-fat yogurt can lead to a powdery taste, excessive acid development from lactose fermentation, excessive firmness, higher whey expulsion, and grainy texture [8].

Several of the previous research on yogurt quality has focused on physical characteristic of yogurt as influenced by the addition of gelatin [9], inulin [10], k-carragenean [11] and calcium fortification[12]. The present investigation was carried out to examine the substitution of fat milk by whey protein concentrate in the rheological characteristics of yogurt with added whey protein concentrate.

MATERIALS & METHODS

Preparation of yogurts

Five yogurt were prepared, 3 produced with skim milk containing 1.5, 3.0 and 4.5% of whey protein concentrate (WPC), WPC1.5%, WPC3. % and WPC4.5%, respectively, and two controls prepared with skim milk without addition of WPC (WPC0%) and whole milk (WHOLE). All samples contained 10 % sugar and 0.02 % of starter culture. The WPC was homogenized with milk in OMNI Macro ES homogenizer (Omni International, Marietta, GA, USA) at 4000 rpm for 10 min and these were mixed with sugar. The homogenates were pasteurized at 83 ºC for 30 min, cooled to 42 ºC and then inoculated with the starter culture containing *Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp bulgaricus*. Inoculated mixtures were incubated at 42 ºC until the pH decreased to 4.2 (required about 4.5 h). After fermentation, the yogurts were cooled to room temperature and then were performed to break the mass. All processed yogurts were packaged and stored at 5 ºC.

Rheological determination

The rheological measurements were performed with a Modular Advanced Rheometer System (HAAKE MARS, Thermo Electron Corp., Germany) equipped with a water bath (Phoenix 2C30P, Thermo Electron Corp., Germany). All the measurements were carried out at (10 ± 0.15) ºC and the data were analyzed by Haake RheoWin Data Manager.
The steady shear measurements were made with a sensor stainless steel double gap cylinder system DG41 in duplicate. Flow curves of the yogurts were obtained by varying the shear rate in ramp from 0 to 500 s^{-1} (upward, downward, and upward with duration of 150 s each). The area between the first up and down curves was used to determination of thixotropic. The last up curve data was fitted to the Bingham model (eq. 1)

$$\tau = \tau_0 + \eta_{pl}\dot{\gamma} \qquad (1)$$

where τ is the shear stress (Pa), τ_0 is the yield stress (Pa), η_{pl} is the plastic viscosity (Pa.s), and $\dot{\gamma}$ is the shear rate (s^{-1}).
Steady stress rates sweep measurements were applied across a range of steady stress rates (1-100 Pa) at 120 s. The tangential method was used to obtain the yield stress values.
The viscoelastic properties were determined using the cone-plate system C60/1° (60 mm diameter). Initially, oscillatory stress sweeps between 1.0 to 10.0 Pa at a frequency of 0.1 Hz were applied to investigate the linear viscoelastic range. The results indicated that a shear stress chosen within the linear viscoelasticity range for the yogurts WPC0% and WPC1.5% was 3.0 Pa, and for WPC3.0%, WPC4.5% and WHOLE was 2.0 Pa. Then, frequency sweep measurements ranging from 0.01 to 10 Hz at the shear stress in viscoelastic range for each yogurt were carried out to determine the mechanical spectra of the yogurts.

Results and discussion

The Bingham model was fitted satisfactorily to the experimental data of curve flow ($R^2 > 0.99$). The values of Bingham equation rheological parameters of the yogurts are given in Table 1.The yogurts containing 4.5 % and 1.5 % of WPC were characterized by the highest and lowest average values of plastic viscosity (η_{pl}) respectively. The yogurts containing 0 % and 1.5 % of WPC showed lower η_{pl} value than the whole yogurt, whilst the yogurts containing 3.0 % and 4.5 % of WPC had higher η_{pl} value. The yield stress (τ_0) ranged from 0.386 to 1.086 Pa. Yogurts containing 0 %, 1.5 % and 3.0 % of WPC showed lower τ_0 while yogurt with 4.5 % of WPC showed higher τ_0, when compared to whole yogurt.

Table 1. Rheological parameters of WPC and whole yogurts measured during steady shear.

Yogurt	Parameters			
	τ_0 (Pa)*	η_{pl} (Pa.s)	R^2	ΔA ($Pa.s^{-1}$)
WPC 0%	0.476	0.043	0.995	2750.0
WPC 1.5%	0.386	0.053	0.999	3888.5
WPC 3.0%	0.790	0.076	0.996	7074.0
WPC 4.5%	1.086	0.090	0.996	9219.0
WHOLE	0.799	0.055	0.995	8439.0

It was noted the existence of the hysteresis area between the upward and downward curves indicating that the flow of all samples is time dependent. The hysteresis area is an index of the energy per unit time and unit volume needed to eliminate the influence of time in flow behavior [13]. The effect of WPC addition on the area of hysteresis loop (ΔA) is also shown in Table 1. The ΔA is an indication of yogurt structural breakdown and rebuilding (a degree of thixotropy) during shearing [14]. The yogurt containing 4.5 % of WPC showed the highest ΔA, indicating that more structural breakdown and better structural reversibility took place during shearing. The thixotropy of yogurt containing 4.5 % of WPC was closer to that of whole yogurt, which indicates that the structure of yogurt with WPC level of 4.5 % was more similar with the whole yogurt than other levels. The thixotropic nature of plain yogurt was observed by several other authors [15].
The dynamic testing provides useful information on the viscoelastic properties of yogurts, i.e., the storage modulus (G') and loss modulus (G"), which denote the degree of solid like (elastic) and liquid like (viscous) behavior, respectively. Figure 1 shows typical frequency sweep for whole yogurt and yogurts containing WPC. The G" was higher than G' throughout the frequency range examined, with crossover at high frequency for all samples. This crossover point represents the transition of the yogurt from a more viscous behavior (G" > G') at almost frequency to a more elastic behavior (G' > G") at higher frequency. Opposite behavior was observed by Damin et al [16], when the authors found G" values higher than G'

for nonfat yogurt supplemented with WPC (0.3, 0.6, 0.9 and 1.2 %), sodium caseinate (0.25, 0.50, 0.75 and 1.00 %) and skim milk powder (13, 13.5, 14, 14.5 %).

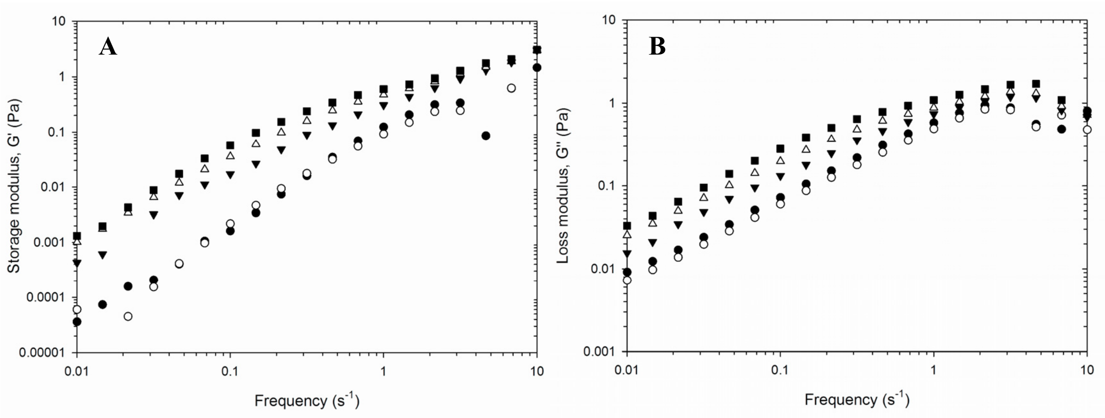

Figure 1. Storage modulus (G') and loss modulus (G") as a function of frequency at 10 °C for (■) whole yogurt and yogurts containing (●) 0 %, (○) 1.5 %, (▼) 3.0 % and (△) 4.5 % of WPC.

In general, the addition of WPC resulted in an increase in G' and G" values at tested frequency range. This result showed that WPC contributed to the gel matrix, since addition of WPC resulted in an increase in the G' value. According Singh & Creamer [17], when milk is heated to high temperatures (like 80 °C/30 min) whey proteins are almost completely denatured and some of denatured whey proteins associate with the casein micelles, involving κ-casein via thiol-disulphide interchange. During acidification, the denatured whey proteins (associated or not with the casein micelles) may aggregate as the isoeletric point of whey protein are approached [18]. This results in increased cross-linking or bridging within the gels, and is responsible for the increase observed in *G*' [19].

In general the dependency of G' on frequency was more marked than that of G" (Figure 1). The frequency dependence of the dynamic modulli allows these yogurts to be categorized as "physical gels". The network formed in physical gels is of linkages that are more susceptible to disruption when force is applied. The highest G' value of whole yogurt indicates the importance of milk fat in contributing to the elasticity component of yogurt. The G' profile for whole yogurt and yogurts containing 3.0 % and 4.5 % of WPC were similar, while a similar trend can be seen to yogurts containing 0 % and 1.5 % of WPC. This indicates that yogurts with 3.0 % and 4.5 % of WPC shown a rheological behavior similar to whole yogurt.

CONCLUSIONS

The developed yogurts exhibited non-Newtonian and shear thinning behavior. The Bingham model was fitted satisfactorily to the experimental data of curve flow. The addition of WPC resulted in an increase of G' in the frequency range tested. Yogurts containing 3.0 and 4.5 % of WPC and whole yogurt showed the same profile of dynamic modulli, presenting a more elastic than others with lower levels of WPC. This indicates that yogurts produced with 3.0 % and 4.5 % of WPC shown a rheological behavior similar to whole yogurt and these levels of WPC were effective as a milk fat replacer in yogurt.

ACKNOWLEDGEMENTS

The authors wish to thank the Brazilian agencies, CNPq and FAPEMIG, for financial support.

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