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Simultaneous Effects of Total Solids Content, Milk Base, Heat Treatment Temperature and Sample Temperature on the Rheological Properties of Plain Stirred Yogurt

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Summary

Response surface methodology was used to establish a relationship between total solids content, milk base, heat treatment temperature, and sample temperature, and consistency index, flow behaviour index, and apparent viscosity of plain stirred yogurts. Statistical treatments resulted in developments of mathematical models. All samples presented shear thinning fluid behaviour. The increase of the content of total solids (9.3–22.7 %) and milk base heat treatment temperature (81.6–98.4 °C) resulted in a significant increase in consistency index and a decrease in flow behaviour index. Increase in the sample temperature (1.6–18.4 °C) caused a decrease in consistency index and increase in flow behaviour index. Apparent viscosity was directly related to the content of total solids. Rheological properties of yogurt were highly dependent on the content of total solids in milk.

Key words: yogurt, rheology, apparent viscosity, consistency, flow behaviour

Introduction

Yogurt is a fermented product made from milk fortified with milk solids using *Lactobacillus delbrueckii* ssp. *bulgaricus* and *Streptococcus thermophilus* (*1*) as starter cultures. It is considered the most popular fermented milk and it is characterized by a soft, viscous gel consistency and a delicate flavour (*2*). In many countries, yogurt is classified according to the fat content (whole, semi-skimmed or skimmed), but the most used classification refers to the physical structure of the gel, being set, stirred or fluid. Set yogurt should have a firm enough body to be spooned, texture should be fine and smooth, without clots or granules and no fissures, and it should have a typical acid taste (*3,4*). Consumer acceptance of stirred yogurt depends on acidity and aroma perceptions and on the textural properties of the product (*5*). Milk components and their concentrations are also important, especially fat and non-fat solids (*6*). Shelf life of yogurt should be around twenty days, under refrigeration and the product should maintain its own characteristics during storage (*3*). Beyond that time, the number of starter culture bacteria may drop, acidity increase, syneresis often occurs, off-flavours are likely to appear, and texture can change.

Different technological factors influence the rheological properties of yogurt, such as: (*i*) factors involved in the preparation of the milk base and its heat treatment, (*ii*) temperature of incubation and the type of culture

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employed, and (*iii*) the cooling process (*7,8*). In the industrial production of yogurt, the use of certain equipment can affect yogurt consistency. Structural losses in stirred yogurt can occur at several places from the incubation tank to the packaging machine. The fermentation tank must have an agitator to mix the starter culture into the milk and, optionally, to break the curd after fermentation. The agitation speed is critical. Low agitation speeds are used to optimize the mixture efficiency and to decrease losses of yogurt consistency (*6*). During the cooling stage, the yogurt is subjected to both shear and time effects. The breakdown of the structure is directly related to the geometry of the equipment used and the process conditions, especially temperature and flow rate (*8*).

Based on these considerations, the purpose of this research was to study how much the content of total solids, milk base heat treatment temperature and sample temperature influence the composition and the rheological properties of plain stirred yogurts. No data are available in the literature on the mathematical modeling of the simultaneous effects of these variables on the rheological properties of plain stirred yogurt.

Material and Methods

Yogurt production and control

A volume of 1500 mL of pasteurized whole milk (Paulista, São Paulo, Brazil) was used in each trial. The content of total solids of the milk was determined with an Ackermann calculator (*9*). Skim milk powder (Molico, Nestlé, Brazil) was used to standardize the pasteurized whole milk, to reach the desirable total solids (9.3–22.7 %). The milk base was heat treated in a continuous, indirect, helically-coiled tube up to 81.6, 85, 90, 95 or 98.4 °C, and held at that temperature for 3 min in an oil bath. Then it was cooled at 43 °C and inoculated with 0.1 % normal viscous freeze-dried mixed-starter culture of *Lactobacillus delbrueckii* ssp. *bulgaricus* and *Streptococcus thermophilus* (Chr. Hansen's, Horsholm, Denmark) direct vat set type. The inoculated milk was mixed and incubated at 42 °C. Fermentation was stopped until pH=(4.3±0.3). Afterwards, the curd was manually stirred by up and down movements for almost 3 min with a stainless spoon, according to a standardized protocol, cooled in an ice water bath, and packed into 150-mL plastic cups. The yogurt was stored for 16 h at 5–8 °C before evaluation.

Rheological measurements

Measurements were carried out at temperatures ranging from 1.6–18.4 °C (according to the trial), using a rotational rheometer (Rheotest 2.1 model, Freital, Lebkestrabe, Germany) with coaxial cylinder geometry (gap 0.275 mm). Shear rates ranging from 0.21–1851.81 Pa/s, under upward curves, and the corresponding shear stress data were obtained. The data were acquired *via* a personal computer using Microcal Origin software, 5.0 version (Northampton, MA, USA). A controlled-temperature bath circulated water through the jacket surrounding the rotor and cup assembly to maintain the specified temperature used in each trial. The flow curves were described by the Ostwald-de Waele and Herschel-Bulkley models as used by Penna *et al.* (*10*). Apparent viscosity was calculated at shear rate 100 s^{-1}.

Experimental design

The trials were made according to an orthogonal second-order design described by Barros Neto *et al.* (*11*). This was composed of 18 trials, 14 axial points and 4 central points. The independent variables were the content of total solids (TS, 9.3, 12, 16, 20 and 22.7 %), milk base heat treatment temperature (TT, 81.6, 85, 90, 95 and 98.4 °C), and sample temperature (ST, 1.6, 5, 10, 15, and 18.4 °C) (Table 1). The effect of these variables on yogurt rheological properties (consistency index, flow behaviour index and apparent viscosity) was studied. The significance of the model was tested by analysis of variance (ANOVA) and the influence of the variables was shown by a three-dimensional representation of the response. In all analyses a significance level of 5 % was considered.

Table 1. Coded and actual levels of three variables

Variables	Symbol[a]		Coded level of variables[a]				
			–1.68	–1	0	+1	+1.68
Total solids	TS/%	X_1	9.3	12	16	20	22.7
Treatment temperature	TT/°C	X_2	81.6	85	90	95	98.4
Sample temperature	ST/°C	X_3	1.6	5	10	15	18.4

[a]The passage from coded variable level to the origin level is given by the following equations: X_1= (TS-16)/4, X_2=(TT-90)/5, and X_3=(ST-10)/5

Results and Discussion

Rheological parameters for yogurt samples measured by the Ostwald-de Waele and the Herschel-Bulkley models showed adequate fit of the flow curves by both models (data not shown).

All yogurts could be characterized as non-Newtonian fluid (shear thinning), regardless of the variables used in the study, and indicated the presence of yield stresses ranging from 0.21–3.01 Pa. The increase of shear rate due to handling the curd lowered the yogurt viscosity and, according to Tamime and Robinson (*6*), low viscosity is one of the most common defects of yogurt. An increase of both the content of total solids (9.3–22.7 %) and milk base heat treatment (81.6–98.4 °C) promoted an increase in the consistency index K and decrease in the flow behaviour index n. Sample temperature (1.6–18.4 °C) also influenced the rheological properties; when the sample temperature was increased, there was a decrease in the consistency index and an increase in the flow behaviour index. Similar effect was reported by Ramaswamy and Basak (*12*).

In our study, through second-order design it was possible to obtain quadratic polynomial models describing the three rheological responses: yogurt consistency index ($\hat{Y}_1$), flow behaviour index ($\hat{Y}_2$) and apparent viscosity ($\hat{Y}_3$).

Values of consistency index ranged from 0.06–10.31 Pa·s^n, using the Ostwald-de Waele model. The second degree equations for the effect of the content of total solids (X_1), milk base heat treatment temperature (X_2), and sample temperature (X_3) on the consistency index ($\hat{Y}_1$), adjusted by multiple regression of the 18 trials are presented in Table 2.

The result of the fitted model for yogurt consistency showed the dependency of the variable X_1 (total solids) and it was independent of the variables X_2 (milk base heat temperature) and X_3 (sample temperature) (Eq. 1, Table 2). The quadratic coefficient of X_1, X_2, X_3 and their interactions showed no statistical significance. Thus, with the increase in the content of total solids of the yogurt, there is an increase in the consistency index.

Hess *et al.* (*13*), while studying the rheological properties of nonfat yogurt stabilized using *Lactobacillus delbrueckii* ssp. *bulgaricus* that produces exopolysaccharide or using a commercial stabilizer, noted that the consistency index (*K*) increased significantly with each incremental increase in nonfat solids (SNF). *K* for yogurts fermented with strains that produce exopolysaccharide (Eps) was significantly lower than for non-ropy yogurts. Consistency of yogurts formulated to contain 10 and 12 % SNF was not significantly different; however, consistency was significantly higher for yogurts containing 14 % SNF. According to Tamime and Robinson (*6*), consistency improves when the content of milk total solids increases from 12–20 %, and a small difference in consistency is achieved when the content of total solids varies from 16–20 %. Thus, there is little interest in the use of concentrations above 16 %.

The Eq. 2 (Table 2) was obtained to describe the simultaneous effects of the content of total solids and milk base heat treatment temperature on flow behaviour index ($\hat{Y}_2$). A smaller flow behaviour index was found when the content of total solids ranged from 16.8–22.2 %, and sample temperature varied between 4.5–16 °C (Fig. 1).

The apparent viscosity model (Eq. 3) is shown in Table 2. It was shown that the content of total solids directly affected apparent viscosity ($\hat{Y}_3$). With an increase in the content of total solids (9.3–22.7 %), there was an increase in yogurt apparent viscosity. There was a significant dependency of total solids on acid milk gel formation that could be attributed to differences in casein micelle composition (*14*). Apparent viscosity is also a function of aggregate size (*15*). Remeuf *et al.* (*16*) observed a relationship between micelle solvation and yogurt microstructure, as well as micelle size in milk base and yogurt graininess.

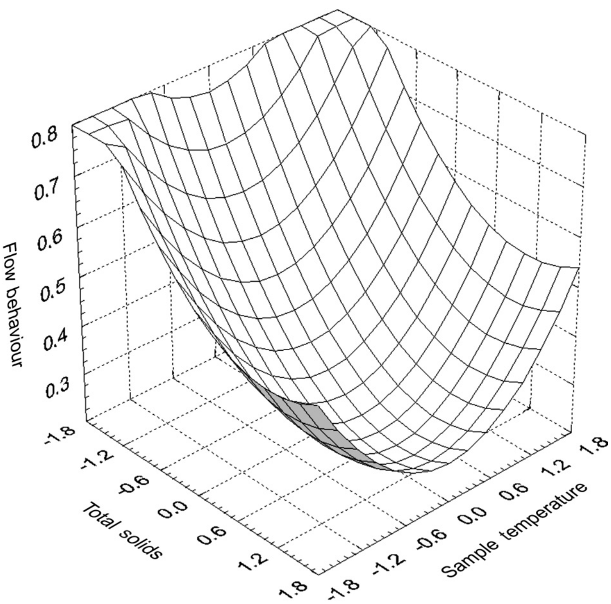

Fig. 1. Effect of the content of total solids, milk base, heat treatment and sample temperature on the flow behaviour index of yogurt

Commercial yogurts evaluated by Ramaswamy and Basak (*12*) showed apparent viscosity between 68.7–109 mPa, smaller than that obtained in this study, which varied from 22–425 mPa. This could be explained by the structural breakdown during storage and distribution. Besides this, Labropoulos *et al.* (*17*) showed that gel strength and apparent viscosity were the highest for yogurt made from milk preheated at 82 °C/30 min, followed by milk preheated at 63 °C/30 min, while milk preheated by a UHT process (149 °C/3.3 s) produced yogurt with the lowest gel strength and apparent viscosity. Parnell-Clunies *et al.* (*18*) studied the effect of preheating milk by different methods on the physical properties of yogurt. They found the following order of the effect of heat treatment on yogurt firmness and apparent viscosity: vat-heated (85 °C/10–40 min)>HTST (98 °C/ 0.5–1.87 min)>UHT (140 °C/2–8 s)>unheated milk, while water-holding capacity, and protein hydration indices of yogurts were the highest when manufactured from HTST or UHT-treated milk, and the lowest from unheated milk; intermediate values were obtained for yogurts manufactured using vat-heated (85 °C/10–40 min) milk. They found that apparent viscosity and curd firmness were highly correlated with whey protein denaturation, with apparent viscosity showing higher correlation coefficient.

Table 2. Adjusted models describing the simultaneous effect of the content of total solids, milk base heat treatment temperature and sample temperature on the consistency index, flow behaviour index, and apparent viscosity (at 100 s^{-1}) of yogurt

Response	Adjusted model	Significance level/%	Standard error	R^2
Consistency index	$\hat{Y}_1 = 3.85 + 3.25 X_1$ /1/	96	2.27	0.802
Flow behaviour index	$\hat{Y}_2 = 0.32 - 0.13 X_1 + 0.06 X_1^2 + 0.08 X_3^2$ /2/	99	0.08	0.859
Apparent viscosity (at 100 s^{-1})	$\hat{Y}_3 = 160.14 + 126.84 X_1$ /3/	97	82.20	0.612

X_1: total solids (TS/%), X_2: milk base heat treatment temperature (TT/°C), X_3: sample temperature (ST/°C), R^2: determination coefficient

Conclusions

All yogurt samples investigated in this work showed non-Newtonian fluid behaviour (shear thinning). With increase in the content of total solids (9.3–22.7 %) the consistency index and apparent viscosity increased and flow behaviour index decreased. Increasing the temperature of heat treatment (81.6–98.4 °C), an increase in consistency index (*K*) and decrease in flow behaviour index (*n*) were observed. Higher sample temperatures (1.6–18.4 °C) promoted a decrease in consistency index, and increased the flow behaviour index. Apparent viscosity was strongly affected by the content of total solids of yogurt; with an increase in the total solids there was an increase in apparent viscosity. Rheological properties of yogurt were highly dependent on the content of total solids of milk. Thus, the choice of type and quantity of dry matter fortification of milk should be considered in improving rheological properties of yogurt.

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