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CHANGES IN CREAM CHEESE RHEOLOGICAL PROPERTIES DURING MIXING WITH A FRUIT CONCENTRATE

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Key words: cottage cheese, fruit concentrate, fruit flavored cottage cheese, static mixer, rheological properties.

Abstract

A static mixer was used to mix a strawberry-vanilla concentrate with cream cheese produced with the centrifugal method and a cherry concentrate with cream cheese produced with the ultrafiltration method. Rheological properties of the components and the mixtures were examined at temperature 15°C with a rotational viscometer in a range of shear rate corresponding to processes of chewing and swallowing food products by man ranging from 1.5 to 121.5 s^{-1}. Their flow and viscosity curves were plotted. All the fluids examined were shown to display characteristics of shear thinning. Attempts were also made to describe the flow curves with Ostwald-de Waele, Herschel-Bulkley and Casson models. The values of correlation coefficients obtained in the study indicated that the Herschel-Bulkley model was the most suitable for the description of the curves, and that the curves exhibited the yield stress. In both cases an increase in the shear rate increased the internal tension difference and decreased the viscosity difference between the components and their mixture. In both cases of mixing cream cheese with a fruit concentrate, a flavored cream cheese, was obtained with a lower viscosity than its components.

ZMIANY WŁAŚCIWOŚCI REOLOGICZNYCH SERKA TWAROGOWEGO PODCZAS MIESZANIA Z KONCENTRATEM OWOCOWYM

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Słowa kluczowe: reologia serka homogenizowanego, reologia koncentratu owocowego, mieszanie serka homogenizowanego.

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Abstrakt

Za pomocą mieszadła statycznego mieszano koncentrat truskawkowo-waniliowy z serkiem homogenizowanym wyprodukowanym metodą wirówkową oraz koncentrat wiśniowy z serkiem wyprodukowanym metodą ultrafiltracyjną. Właściwości reologiczne komponentów i mieszanin zmierzono w temperaturze 15°C reometrem rotacyjnym. Badano szybkość ścinania odpowiadającą procesowi żucia i przełykania żywności przez człowieka. Stwierdzono, że komponenty i mieszaniny są płynami wykazującymi cechy rozrzedzania ścinaniem, do opisu których najlepiej pasuje model Herschela-Bulkleya. Na podstawie badań stwierdzono, że w zakresie szybkości ścinania od 1,5 do 121,5 s^{-1} lepkość uzyskanych mieszanin była mniejsza od lepkości komponentów.

Introduction

Fruit-flavored cream cheese is part of the basic human diet (GÓRSKA-WARSEWICZ 2007). According to unpublished data of the Central Office of Statistics, the market for fruit-flavored cream cheese, yoghurt and other fermented milk products in Poland in 2013 was estimated at ca. 348 thousand tons, with a value of ca. 1725 million zlotys and growing. The reason for the growing consumption of cream cheese can be seen in the increasing range of flavors, its consistency, texture and additives, as well as its pro-health benefits, such as boosting the immune system or restoring the microbiological balance of the body. The organoleptic properties of flavored cream cheese, including its consistency and flow properties, depend on such factors, as, for example, the type and content of fruit concentrate and the method of the cream cheese manufacture. One of the quantitative methods of estimating the changes of cream cheese properties during the process of mixing it with fruit concentrate are rheological tests of shear rate within the range responsible for a consumer's organoleptic sensations (MARZEC 2007, SURÓWKA 2002, SZCZEŚNIAK 2002).

The aim of this study was to determine the rheological properties of two types of fruit-flavored cream cheese, obtained by mixing white cream cheese with fruit concentrate and to compare it to the properties of the ingredients.

Materials and Experimental Methods

Cream cheese with a fat content of 5% produced by the centrifugal method at the Dairy Plant in Kalisz (PL) was mixed with strawberry-and-vanilla concentrate and cream cheese with a fat content of 5% produced by the ultrafiltration method at the Dairy Plant in Chełm (PL) was mixed with cherry concentrate. Both concentrates were produced by Zentis in Żelków near Siedlce (PL). The mixing process of components was conducted on a semi-technical scale in a vertical flow mixer using a static mixer constructed by the

author (LIMANOWSKI 2006). The mixing length was 1.76 m and the mixer diameter was 0.05 m. The ingredients were supplied separately with OnLine' lobe pumps manufactured by the Johnson Pump (UK) Ltd. company. The mass flow of the centrifugal cream cheese was 105 kg h^{-1}, the mass flow of the concentrate was 25.8 kg h^{-1} and the concentrate content in the mixture was 21.2%. The mixing process and the rheological measurements were conducted at 8°C (DRAKE et al. 2009). The mass flow of the ultrafiltration cream cheese was 1896.9 kg h^{-1}, the mass flow of the concentrate was 432 kg h^{-1} and the concentrate content in the mixture was 18.5%. The mixing process and the rheological measurements were conducted at 15°C. The rheological properties of the cream cheese were determined because of the surprising results of the tests of the centrifugal cream cheese, which had been conducted earlier. They showed that the flowability of the mixture of cream cheese and strawberry-vanilla concentrate was greater than that of the ingredients separately. Measurements conducted for the ultrafiltration cream cheese and cherry concentrate were an attempt at expanding the study scope; moreover, the tests were expected to confirm the previous findings (BRIGHENTI et al. 2008). To this end, measurements of the rheological properties were conducted at two different temperatures (slightly exceeding the process temperature), at different mass flows of the product flowing through the mixer and at different mass content levels of the concentrate (which is only a consequence of the difficulty of keeping them at the assumed level). The flow and viscosity curves of the components and mixtures were determined with a Rheotest-2 rotary rheometer with an S/S1 cylinder system, based on mean values of shear stress and viscosity, measured three times at an increasing and decreasing shear rate?, ranging from 1.5 to 121.5 s^{-1} (LIMANOWSKI, HAPONIUK 2003). This range was selected because it is associated with the processes of chewing and swallowing of food by humans (BARNES et al. 1989). The device readings were recorded after 60 seconds of the sample shearing. The dependence of shear stress on the shear rate was described using known mathematical models (BARNES et al. 1989, BASAK, RAMASWAMY 1994, CASTILLOA et al. 2006, WIŚNIOWSKI, SKRZYPASZEK 2006):

Ostwald de Waele $$\tau = K \cdot ?^{n} \quad (1)$$

Herschel-Bulkley $$\tau = \tau_0^{HB} + K \cdot ?^{n} \quad (2)$$

Casson $$\tau^{1/2} = (\tau_0^{C})^{1/2} + (\eta \cdot ?)^{1/2} \quad (3)$$

where:

τ – shear stress [Pa]

η – non-Newtonian viscosity [Pa · s]

? – shear rate [s^{-1}]

K – consistency coefficient [Pa · s^{n}]

n – flow behavior index [–]

η_C – Casson viscosity [Pa · s]

τ_0^{HB} – Herschel-Bulkley yield stress [Pa]

τ_0^{C} – Casson yield stress [Pa]

Results and Discussion

Mixing centrifugal cream cheese with strawberry-vanilla concentrate produced flavored cream cheese, whose shear stress and viscosity were lower than those measured for the separate components (Table 1, Figure 1, Figure 2). Calculations made with the Statistica software package showed that the highest flow curve correlation coefficients were obtained by describing them with the Herschel-Bulkley model (KUTCHMANN 1997). Calculations made with the use of Casson's model showed an uncertainty of estimation at the level of confidence of 95% despite using the maximum number of iterations and two independent methods of estimation: Gauss-Newton's and Levenberg-Marquardt's.

Table 1

Constants of equations of flow curves of a strawberry-vanilla cream cheese

Model	Constants, correlation coefficient R	Cream cheese	Strawberry-vanilla concentrate	Strawberry-vanilla cheese
Ostwald de Waele	K [Pa · s^n]	51.573 ± 6.786	39.513 ± 1.823	22.518 ± 2.506
	n [–]	0.296 ± 0.034	0.350 ± 0.012	0.450 ± 0.027
	R [–]	0.960	0.997	0.991
Herschel-Bulkley	τ_0^{HB} [Pa]	73.410 ± 5.434	30.575 ± 1.869	25.465 ± 6.671
	K [Pa · s^n]	3.517 ± 1.595	18.223 ± 1.144	8.543 ± 2.993
	n [–]	0.794 ± 0.092	0.484 ± 0.012	0.630 ± 0.069
	R [–]	0.994	0.999	0.997
Casson	τ_0^C [Pa]	insecure estimation	insecure estimation	27.837 ± 2.524
	η_C [Pa]			0.670 ± 0.053
	R [–]			0.995

The yield stress for a mixture of cream cheese and concentrate was lower than for the yield stress of the components, its consistency coefficient K was higher and the flow index n was lower than the initial values of K and n for the cream cheese. This means that addition of the concentrate reduced the inner stress, loosened the consistency of the cream cheese and made it more susceptible to flowing. In the range of shear rate which is most important in terms of organoleptic sensations, i.e. from 50 s^{-1} to 100 s^{-1}, the shear stress in fruit-flavored cream cheese was lower by 15.9% than the stress before mixing and was 8.9% lower than the stress in the concentrate. As the shear rate increased, the stress differences also increased, and the corresponding differences of viscosity decreased proportionally. The extent of the changes was estimated from the approximating curves.

Further studies showed that the direction of the changes of cream cheese, as described above, was consistent with the results of studies of a mixture

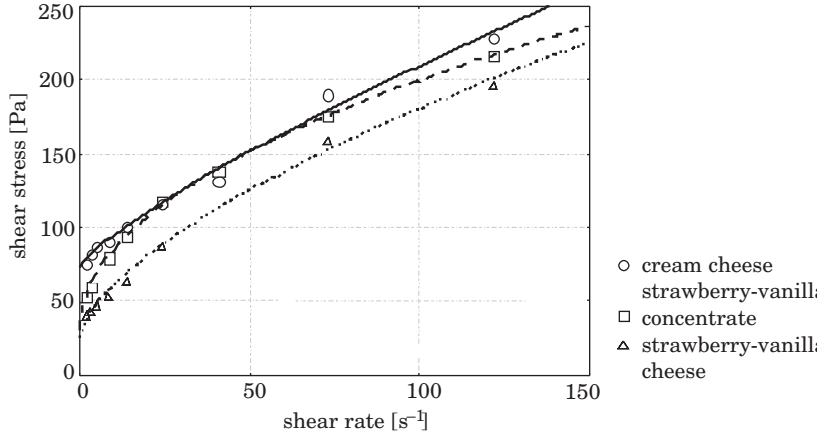

Fig. 1. Flow curves of a cream cheese produced with the centrifugal method, a strawberry-vanilla concentrate and their mixture

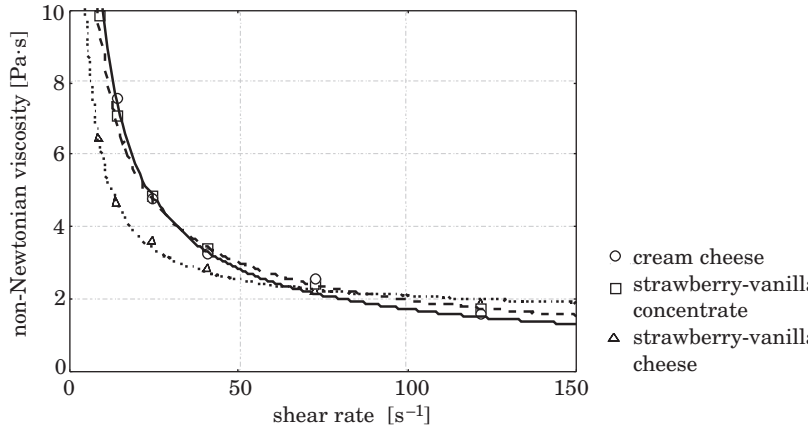

Fig. 2. Curves of changes in non-Newtonian viscosity of a cream cheese produced with the centrifugal method, a strawberry-vanilla concentrate and their mixture

of cream cheese manufactured by the ultrafiltration method and cherry concentrate (Figure 3). The most faithful mathematical reproduction of the measurement points which formed the flow curves for the components and the mixture was obtained again with the H-B model. The correlation coefficients for the curves described by the power-law model O-dW were smaller, and those calculated by the Casson model again showed uncertainty of estimation. A comparison of the constant values of the approximation equation H-B showed that adding the concentrate to the cream cheese slightly increased the yield stress of the mixture and reduced the consistency coefficient; it did not

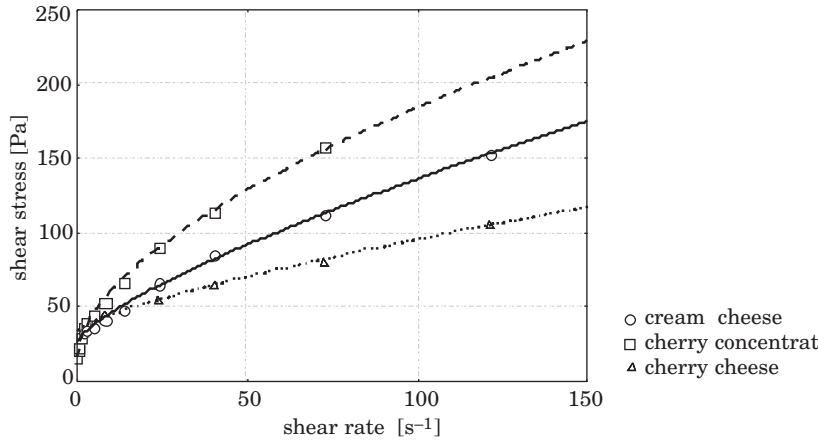

Fig. 3. Flow curves of a cream cheese produced with the ultrafiltration method, a cherry concentrate and their mixture

Table 2

Constants of equations of flow curves of a cherry concentrate

Model	Constants, correlation coefficient R	Cream cheese	Cherry cheese concentrate	Cherry
Ostwald de Waele	K [Pa · s^n] n [–] R [–]	17.025 + 2.308 0.449 + 0.033 0.986	24.459 + 0.821 0.304 + 0.015 0.993	24.809 + 2.680 0.285 + 0.028 0.970
Herschel-Bulkley	τ_0^{HB} [Pa] K [Pa · s^n] n [–] R [–]	26.336 + 1.727 3.527 + 0.577 0.747 + 0.033 0.999	16.313 + 2.093 11.624 + 1.549 0.580 + 0.030 0.998	33.706 + 0.895 1.976 + 0.298 0.748 + 0.030 0.999
Casson	τ_0^{C} [Pa] ηC [Pa] R [–]	21.122 + 0.825 0.499 + 0.017 0.999	insecure estimation	insecure estimation

change the flow capability (Table 2). In effect, the flow and viscosity curves for the mixture were below the corresponding curves of the components on the diagram. Based on the approximating curves, it was found that the tangent stress in the fruit-flavored cream cheese in the shear rate range from 50 s^{-1} to 100 s^{-1}, was about 27.9% lower than the stress in the cream cheese before mixing and by as much as 48.3% compared to the stress in the concentrate (Figure 3). An increase in the shear rate was accompanied by an increase in the differences between the shear stress of the components and the mixture and the tendency to equalize the viscosity (Figure 4). The results obtained for mixing the cream cheese with fruit concentrate found the same tendency for changes in the rheological properties of the cream cheese in both cases under

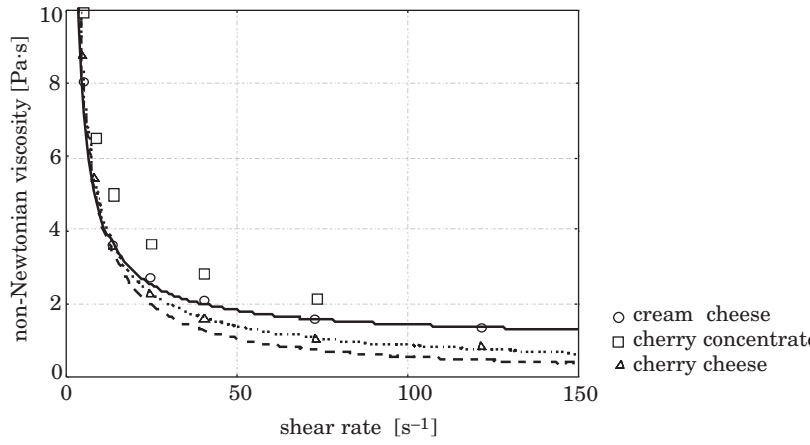

Fig. 4. Curves of changes in non-Newtonian viscosity of a cream cheese produced with the ultrafiltration method, a cherry concentrate and their mixture

study, despite the fact that the processes were conducted under different conditions. A rapid change in the mixture viscosity does not correspond to any known mathematical rules for its estimation. It can only be speculated that the observed changes may be caused by the content of dry matter and fat, the type and amount of used stabilizers, the methods of cold storage of milk and dairy products, the type of milk pre-processing (homogenization, pasteurization), process-related (type of starter cultures, conditions of incubation, temperature, pH) and technical factors (type of pumps used, method of mixing and type of mixer, diameter and length of the pipelines, type of the fixtures used, mass flow, methods of packaging and storage and others) (CHEN, CHENG 1998). Estimation of the effect of the factors and their interaction on the basic rheological properties of the product requires extensive methodological studies.

Conclusions

All of the products under study: cottage cheese, strawberry-vanilla concentrate, cherry concentrate, strawberry-vanilla cheese and cherry cheese have been found to be non-Newtonian, shear-thinned liquids, whose flow curves can be described most precisely by the Herschel-Bulkley model.

Increasing the shear rate increased the internal stress and decreased the difference in viscosity between the components and their mixture. The differencies between viscosity of strawberry-vanilla cheese and their components

were less than in the case of cheery cheese and their components in the middle area of shear rate (ca. 40–100 s^{-1}).

The mixing of cream cheese with fruit concentrate produced flavored cream cheese with higher flowability than those of its components.

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