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Rheological and Thermophysical Properties of Model Ice Cream Mixtures

Reološka i termofizička svojstva modelnih sladolednih smjesa

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Summary

World production and consumption of ice cream is constantly increasing. At the same time the assortment is expanding and new ingredients as well additives are being used. As the quality of the ice cream is, primarily, characterized by certain organoleptic properties, it is necessary to investigate the influence of additives used in the production on these characteristics, especially consistency. Therefore, in this work the temperatures of phase transitions (freezing, thawing) as well as rheological properties of some model ice cream mixtures prepared by mixing of eggs, sucrose, sorbitol, glycerol, milk powder and water, were investigated.

Temperatures of phase transition were determined by differential thermal analysis, and rheological properties in rotational rheometer Rheotest 3. It was pointed out that glycerol addition decreases freezing as well as thawing temperatures of ice cream mixtures, while other ingredients did not exhibit such effect. However, some of the components, like egg yolk and glycerol, had much greater influence on the rheological properties of ice cream mixtures. Viscosity of mixtures increased with temperature decrease, especially below 0 °C.

Sažetak

Svjetska proizvodnja i potrošnja sladoleda je u stalnom usponu, uz istodobno proširenje asortimana, što znači i stalno uvođenje novih sirovina i dodataka u proizvodnju. Kako je kakvoća sladoleda određena u prvom redu njegovim pojedinim organoleptičkim svojstvima, potrebno je ispitati kakav će utjecaj na njih, posebno na konzistenciju, imati dodaci. Stoga su u ovom radu određivane temperature faznih promjena (zamrzavanja, odmrzavanja), te reološka svojstva nekoliko modelnih sladolednih smjesa pripremljenih miješanjem jaja, saharoze, sorbitola, glicerola, mlijeka u prahu i vode.

Temperature faznih promjena određivane su diferencijalnom termičkom analizom, a reološka svojstva u rotacijskom reometru Rheotest 3. Utvrđeno je da dodatak glicerola snizuje temperature zamrzavanja i odmrzavanja sladolednih smjesa dok ostali sastojci nisu davali taj učinak. Međutim, pojedini sastojci, kao žumance jajeta i glicerol, kudikamo su više utjecali na reološka svojstva tih smjesa. Viskoznost smjesa povećala se snizivanjem temperature, osobito ispod 0 °C.

Introduction

Freeezing is considered to be the most successful method of food preservation primarily because of very good organoleptic and nutritional characteristics of frozen food. However, some problems may occur during thawing because of relatively long time, as well as posibility of cell fluid losses (in fruits, vegetables or meat), phase separation (in creams, dressings etc.), and changes in some other physical properties *(1-3)*.

Recently, the investigations have been directed toward preparing such liquid and semiliquid foods that are inherent in products with the so called »freeze flow« properties. This means that they will be preserved by low temperatures but without the occurrence of water crystalization. Such products, like various dessert creams, ice creams, fruit purees etc. have appropriate consistency at low temperatures, excellent organoleptic properties and can be consumed immediatly after removing from freezer.

»Freeze flow« properties can be obtained by decreasing the product's freezing temperature. The simplest way to achieve it, is to increase mass fraction of solid matter. However, this also changes some other product characteristics and increases the product's price. »Freeze flow«

properties could be also obtained by changing product composition by adding low quantities of some ingredients which could exert certain influence on freezing point depression *(4-7)*.

As every change of solid mass fraction and composition has an influence on the rheological properties, it is necessary to monitor both, thermophysical and rheological properties, depending on the composition, freezing conditions and temperature *(8-13)*.

The most frequently consumed chilled or frozen products, whose rheological and thermophysical properties have a marked effect on their organoleptic characteristics, are ice creams. Therefore the aim of this work was to investigate the influence of several ingredients of ice cream mixtures on their thermophysical and rheological properties, and to prepare a product with »freeze flow« properties.

Materials and Methods

In this work, tests were carried out with model ice cream mixtures prepared by mixing several components chosen against our own recipes in amounts shown in Table 1.

The following ingredients were used:

- fresh eggs , class »S« (whole egg or egg yolk) from local market,
- sugar, »N« crystal,
- whole milk powder (»Zdenka« Veliki Zdenci),
- sorbitol (»Pilva« Zagreb),
- glycerol (»Kemika« Zagreb)

All ingredients were weighed against the recipes and mixed by hand for 5 minutes. In prepared mixtures (12 samples) mass fraction of solid matter by drying at 105 °C to constant mass was determined.

The temperatures of phase transitions (freezing and thawing) of samples were determined by differential thermal analysis (DTA) using apparatus type MP Δt Pt by continuously scanning the temperature as well as temperature difference between sample and reference material (quartz sand) *(14)*.

Rheological properties were determined by using a rotational rheometer Rheotest 3 (WEB MLW – Werk Medingen Sitz Freital, Germany) with concentric cylinders (fixtures type N, S1 and S2). For achieving the adequate as well as constant temperature Ultra Kryostat MK 70 was used. Shear stress against the increasing shear rates from 81 to 1312 s^{-1} (rising measurements) was measured. At the highest shear rate, shear stress lasted two minutes. After that rotational rate successively decreased to the initial value (recurrent measurements). Measurements were carried out at 4, 0 and –5 °C.

Results and Discussion

The results of phase transition temperatures determination have shown that freezing temperatures of investigated samples depend both on the mass fraction of solid matter and on their composition (Table 2).

The greater mass fraction of solid matter, the lower freezing temperatures were. Temperatures of the freezing curves peaks (temperatures of complete crystalization) were for the most samples lower (for about 4 °C) than the initial freezing temperatures. Sorbitol as well glycerol addition effected freezing point depression; glycerol (samples 1G, 2G, 3G) had somewhat greater influence than sorbitol. Whole egg or egg yolk addition had no significant influence on the changes of the freezing temperatures, while the existing differences between them (probably because of the small quantity of egg added) were primarily a consequence of various mass fractions of the product solid matter.

The thawing temperatures were lower than the corresponding freezing temperatures. They were less effected by the solid matter fraction, but much more by its composition. Sorbitol and glycerol presence exerted significant influence on the thawing temperatures (samples 1S, 1G, 2S, 2G). This influence was greater when whole egg

Table 1. Mass fraction of ingredients used in ice cream mixtures preparation
Tablica 1. Maseni udio sastojaka upotrijebljenih u pripremi sladolednih smjesa

Sample Uzorak	Whole egg or egg yolk* Melanž jaja ili žumance*	Sucrose Saharoza	Water Voda	Milk powder Mlijeko u prahu	Sorbitol Sorbitol	Glycerol Glicerol	Solid matter Suha tvar
				w/%			
1	15.0	20.0	65.0	–	–	–	24.0
1S	15.0	15.0	65.0	–	5.0	–	24.0
1G	15.0	15.0	65.0	–	–	5.0	24.0
1S-M	15.0	15.0	45.0	20.0	5.0	–	43.0
1G-M	15.0	15.0	45.0	20.0	–	5.0	43.0
2	15.0*	20.0	65.0	–	–	–	27.5
2S	15.0*	15.0	65.0	–	5.0	–	27.5
2G	15.0*	15.0	65.0	–	–	5.0	27.5
2S-M	15.0*	15.0	45.0	20.0	5.0	–	46.5
2G-M	15.0*	15.0	45.0	20.0	–	5.0	46.5
3S	5.0 10.0*	15.0	65.0	–	5.0	–	26.3
3G	5.0 10.0*	15.0	65.0	–	–	5.0	26.3

Table 2. Freezing and thawing temperatures of ice cream mixtures
Tablica 2. Temperature zamrzavanja i odmrzavanja sladolednih smjesa

Sample Uzorak	Freezing temperature Temperatura zamrzavanja / °C	Maximum of freezing curve Vrh krivulje zamrzavanja / °C	Thawing temperature Temperatura odmrzavanja / °C
1	–2.6	–6.5	–10.0
1S	–3.0	–6.8	–16.6
1G	–4.0	–7.6	–17.5
1S-M	–9.0	–10.5	–22.0
1G-M	–9.3	–12.5	–20.0
2	–3.0	–7.2	–13.4
2S	–3.5	–7.5	–13.5
2G	–4.3	–8.0	–15.0
2S-M	–7.5	–8.5	–21.0
2G-M	–9.0	–9.0	–22.0
3S	–2.5	–7.6	–20.0
3G	–5.0	–8.0	–21.0

was added, but lower in the samples with egg yolk. Therefore, thawing temperature of sample 1 (whole egg + sucrose + water) was –10 °C, of sample 1S (whole egg + + sucrose + sorbitol + water) –16.6 °C and of sample 1G (whole egg + sucrose + glycerol + water) –17.5 °C. This means that the products with glycerol or sorbitol addition will begin to thaw at lower temperatures and their total thawing time will be shorter.

Measured values of shear stress and shear rate of investigated ice cream mixtures were transformed by Ostwald Reiner model:

$$\tau = k \cdot \gamma^{n} \qquad /1/$$

to flow behaviour index *(n)* and consistency coefficient *(k)* that are shown in Table 3. Flow behaviour index values ranged for all samples and all measuring temperatures between 0.71 and 0.92. That means all the samples investigated had thixotropic non-Newtonian properties. Their consistency is expressed as consistency coefficient *k* and, as it could be seen from Table 3, it depends on the sample composition as well as on the measuring temperature. The lowest consistency was registered in samples with whole egg and sorbitol addition whilst the highest was found in those into which powdered milk was added. These samples had also the highest mass fraction of solid matter. The samples prepared with egg yolk had significantly higher consistency than those with whole egg, which is the consequence of the emulsifying effect of egg yolk.

Replacement of one part sucrose with sorbitol had no influence on the consistency, whilst glycerol addition resulted in increased consistency of all samples.

Samples 3S and 3G, which differed only in sorbitol or glycerol presence, had almost the same consistency at 4 and 0 °C whilst at –5 °C the sample with glycerol addition had significantly higher viscosity.

Temperature lowering caused viscosity increase, as a rule, by ca 45 %. The lowest temperature at which viscosity was measured was –5 °C and it was limited by sample's freezing temperature. Although at –5 °C some investigated ice cream mixture began to freeze (as it could be seen from their freezing temperature), there was no change in the consistency coefficient values.

According to the results obtained, in ice cream mixture preparations one part of sucrose can be replaced with glycerol. Besides, instead of whole egg it is better to use only egg yolk.

Conclusion

Freezing temperatures of ice cream mixtures depend both on the mass fraction of solid matter and on their composition. Sorbitol and glycerol addition resulted in lowering of the freezing temperatures, while egg addition showed no significant effect.

All samples belong to the tixotropic non-Newtonian systems which remained the same at all measuring temperatures. The lowest cosistency was found for mixtures with whole egg and sorbitol addition, whilst the highest was found in those into which powdered milk was

Table 3. Rheological parameters of investigated samples at some temperatures
Tablica 3. Reološki parametri ispitivanih uzoraka pri pojedinim temperaturama

Sample Uzorak	t_c/ °C	n	k/mPa s^n	Sample Uzorak	n	k/mPa s^n
	4	0.84	16.00		0.79	31.82
1	0	0.84	18.71	2	0.81	33.06
	–5	0.83	25.41		0.83	34.84
	4	0.86	15.62		0.79	31.22
1S	0	0.79	30.25	2S	0.81	33.50
	–5	0.77	40.19		0.84	34.40
	4	0.71	30.60		0.80	45.38
1G	0	0.71	39.50	2G	0.78	49.60
	–5	0.73	47.20		0.78	50.12
	4	0.92	87.27		0.89	130.60
1S-M	0	0.92	98.57	2S-M	0.90	152.18
	–5	9.93	119.18		0.90	207.21
	4	0.89	92.37		0.91	107.16
1G-M	0	0.91	95.85	2G-M	0.90	140.85
	–5	0.90	135.71		0.92	160.42
	4	0.80	24.43		0.80	23.80
3S	0	0.79	29.06	3G	0.80	28.96
	–5	0.80	35.34		0.76	44.22

added. The samples prepared with egg yolk had significantly higher consistency than those with whole egg.

Temperature lowering caused viscosity increase, as a rule, by ca 45 %. The lowest temperture at which viscosity was measured was limited by sample's freezing temperature.

In ice cream mixture preparations, glycerol and egg yolk can be recommended.

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