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Impact of Lactose Hydrolysis on Physical and Sensory Properties of Reduced Sugar Ice-cream

Fatma BÜDÜŞ[1], M. Serdar AKIN[2], Büşra PALABIÇAK[3], Çağım AKBULUT ÇAKIR[4]

[1] *H. Ü., Mühendislik Fakültesi, Gıda Mühendisliği Bölümü, Şanlıurfa, TURKEY, ORCID ID 0009-0008-0040-3690*
[2] *H. Ü., Mühendislik Fakültesi, Gıda Mühendisliği Bölümü, Şanlıurfa, TURKEY, ORCID ID 000- 0001-7569-1983*
[3] *H. Ü., Mühendislik Fakültesi, Gıda Mühendisliği Bölümü, Şanlıurfa, TURKEY, ORCID ID 0000-0002-0983-8577*
[4] *H. Ü., Mühendislik Fakültesi, Gıda Mühendisliği Bölümü, Şanlıurfa, TURKEY, ORCID ID 0000-0002-2754-0133*

Corresponding Author: Çağım AKBULUT ÇAKIR, cagim@harran.edu.tr

Abstract

It is estimated that about two third of the world population encounters lactase deficiency at different levels. Lactose constitutes about one third of the solid matters in ice-cream and can exert several texture problems due to crystallization. There is a growing trend towards healthy foods with less added sugar and lactose-free products. In this study, we wanted to reduce the added sugar amount in ice-cream by the help of the increase in sweetness after lactose hydrolysis. Ice-creams were produced at 4 different sugar content (18%, 16%, 14%, 12%), and 100% hydrolysis of the lactose was ensured. Control group wasn't treated with β-galactosidase. Ice creams were stored for 60 days and their physical, chemical and sensory properties were examined during this period. Hydrolysis of the lactose improved the sweetness scores of ice-cream samples. Reducing the sugar content down to 14% was possible by lactose hydrolysis, receiving a similar sweetness with 18% control. Lactose hydrolysis increased the viscosity and overrun of ice-cream samples while firmness scores declined. We observed differences in melting trends of enzyme treated samples depending on the sugar content. At 12% sugar content, enzyme treated ice-creams resisted longer to the melting than the control. However, as the sugar content increase, enzyme treated samples exhibited faster melt than the control. This study provides an alternative way of sweetening the ice-cream without the use of sweeteners which are not label friendly.

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Keywords

Lactose Hydrolysis, Ice-Cream, Low Sugar

Highlights

Reducing the sugar content down to 14% was possible by lactose hydrolysis, receiving a similar sweetness with 18% control.
Viscosity and overrun of ice-cream samples increased by lactose hydrolysis while firmness scores decreased.
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Our findings are also important to show how sugar reduction influence several textural attributes of the ice-cream when lactose is completely hydrolysed.

Laktoz Hidrolizinin Şekeri Azaltılmış Dondurmanın Fiziksel ve Duyusal Özellikleri Üzerindeki Etkisi

Özet

Dünya nüfusunun yaklaşık üçte ikisinde farklı seviyelerde laktaz eksikliği olduğu tahmin edilmektedir. Laktoz, dondurmadaki katı maddelerin yaklaşık üçte birini oluşturur ve kristalleşme nedeniyle çeşitli doku sorunlarına neden olabilir. Laktoz içermeyen ürünlere artan ilginin yanı sıra, daha az ilave şeker içeren sağlıklı gıdalara yönelik artan bir eğilim var. Bu çalışmada laktoz hidrolizi ile oluşan tatlılık artışından yararlanılarak dondurmanın şeker içeriğinin düşürülmesi amaçlanmıştır. Bu çalışmada, dondurma örnekleri 4 farklı şeker oranında (%18, %16, %14, %12) üretilmiş ve laktozun %100 hidrolizi sağlanmıştır. Kontrol grubu β-galaktosidaz ile muamele edilmemiştir. Dondurmalar 60 gün depolanmış ve bu süreçte fiziksel, kimyasal ve duyusal özellikleri incelenmiştir. Laktozun hidrolizi, dondurma örneklerinin tatlılık puanlarını artırmıştır. Laktoz hidrolizi ile şeker içeriğinin %14'e düşürülmesi mümkün olmuş ve %18 kontrol ile benzer bir tatlılık elde edilmiştir. Dondurma örneklerinin viskozitesi ve hacim artışı laktoz hidrolizi ile artarken, sertlik skorları azalmıştır. Enzimle muamele edilmiş numunelerin erime trendleri şeker içeriğine bağlı olarak değişmiştir. %12 şeker içeriğinde, enzimle muamele edilmiş dondurmalar, kontrole göre erimeye daha uzun süre direnmiştir. Bununla birlikte, şeker içeriği arttıkça, enzimle muamele edilmiş numuneler, kontrolden daha hızlı erime sergilemiştir. Bu çalışma, etiket dostu olmayan tatlandırıcılar kullanılmadan dondurmayı tatlandırmak için alternatif bir yol sunmaktadır. Bulgularımız, laktoz tamamen hidrolize edildiğinde şeker oranını düşürmenin dondurmanın çeşitli tekstürel özelliklerini nasıl etkilediğini göstermek açısından da önemlidir.

Anahtar Kelimeler

Laktoz Hidrolizi, Dondurma, Şeker Oranı Azaltılmış

Öne Çıkanlar

Şeker içeriğinin %14'e düşürülmesi laktoz hidrolizi ile mümkün oldu ve %18 kontrol ile benzer bir tatlılık elde edildi.

Dondurma örneklerinin viskozitesi ve hacmi laktoz hidrolizi ile artarken, sertlik puanları azaldı

1. Introduction

There is a demand on food products that contain less added sugar. Ice-cream can contain 17 to 20% sugar in its formulation [1]. Lactose hydrolysis would increase the sweetness and that would favour sweetening of the ice-cream with less added sugar. Relative sweetness of lactose is comparatively low and is almost only about half of the

monosaccharides that make it up. Hydrolysing the 70% of the milk lactose brings about a sweetness as much as adding 2% sugar [2]. Depending on the nonfat milk solids (NFMS) and fat content of the mix, ice-cream can contain about 7% lactose. Lactose is a disaccharide that is broken down to glucose and galactose by the lactase enzyme during digestion in the small intestine. Lactose intolerance occurs when the lactase level is not sufficient (hypolactasia) or there is no lactase in the digestive system. It is believed that around two third of the world population encounters digestion problems with dairy products due to lactase deficiency at different levels [3]. Presence of the lactose in ice-cream is a problem not only for lactose intolerant people but also for textural properties. Lactose could exert several textural defects such as crystallization, sandiness, and iciness [4]. Lactose is susceptible to crystallization during freezing, and this could result in formation of sandy texture. It is also reported that lactose hydrolysis reduces the hardness and increase the melting rate. Matak *et al.* [4] reported that, decrease in the hardness and freezing point could produce a more extrudable ice-cream, which would make it easier to transfer the ice-cream when dipping. Freezing point of the ice-cream decreases with lactose hydrolysis [4], and the decrease in the freezing point of the ice-cream help forming smaller ice crystals [1]. Occurrence of ice crystals in ice-cream gives a gritty sensation. It is reported that lactose hydrolysis greatly prevents ice recrystallisation [5].

Lactose free product market is estimated to grow 8.7% annually by 2025 [6]. While the high cost of lactose free products is an obstacle for this growth, adding health benefits to lactose free foods, such as reducing the sugar content at the same time, can increase the consumer demand. Although there is a growing interest on lactose free products with added benefits, the number of the studies are relatively low. In this study we aim to evaluate how much sugar can be reduced from ice-cream by lactose hydrolysis without impairing the sweetness sensation. We also evaluated the impact of lactose hydrolysis on several texture and sensory properties in parallel with sugar reduction. Reducing the sugar content of the ice-cream would reduce the solids content of the formulation and that would first influence the freezing point and several textural properties of the ice-cream [1]. Hydrolysis of the lactose to its monosaccharides is also a change in solutes of the ice-cream mix that would have an impact on mentioned attributes. Therefore, it is important to determine the impact of lactose hydrolysis at different sugar concentrations.

2. Material and Method

2.1. Material

The skim milk powder (96% total solids), milk cream (35% fat) (Pınar Dairy, Turkey), lecithin (Sosa Ingredients, S.L. Ctra de Granera, Spain) as emulsifier and a blend of stabilizers that contain equal amounts of Karragenan (E 407), Guar gum (E 412), Sodium alginat (E 401), Xanthan gum (E 415) and dekstrose (KATPA Katkı Maddeleri Gıda Sanayii ve Ticaret Ltd. Şti., Türkiye) and β-galaktosidase (GODO-YNL2 Yeast Neutral Lactase, Danisco DuPont, Denmark) was used for ice-cream production. Megazyme K-LACGAR 12/05 enzymatic test kit (Megazyme Intenational Ireland Limited Co. Wicklow, Ireland) was used for determining lactose and galactose content of ice-cream mixes.

2.2. Method

Ice-cream production

Four batches of ice-cream mixes were prepared to contain different ratios of sugar, 18%, 16%, 14% and 12% respectively, 12% NFMS, 3.6% fat, 0.8% emulsifier (??? adı ve oranı) and 0.2% stabilizer (??? adı ve oranı). The amount of lactose in all ice-cream samples were 6.6% before adding enzyme. Required amount of β-galactosidase enzyme for 100% hydrolysis of lactose in ice-cream mixes was determined by preliminary tests. Preliminary tests were done with 18 and 12% sugar content ice-cream test mixes. After each test mix was prepared using the same ingredients and ratios with the actual mix and pasteurised, it was cooled down in cold water bath down to 45°C while stirring. Enzyme was added at 45°C while stirring continuously until 20°C and mix was then placed in cold room and aged for 24h at 4°C. Lactose analysis was done on the test mixes after the aging period using Megazyme K-LACGAR 12/05 enzymatic test kit. Tested enzyme concentrations were 0.1, 0.15, 0.3, 0.4 and 0.5%. We obtained 100% lactose hydrolysis at both sugar levels for 0.4 and 0.5% enzyme levels, and we chose 0.5% enzyme concentration to make sure of complete hydrolysis. On the day of ice-cream production, all ingredients were mixed well with a hand blender and pasteurized at 80°C for 1 min. After cooling down in cold water bath to 45°C, %0.5 (12.5 mL) β-galactosidase was added to ice-cream mixes while stirring continuously until 20°C and all ice-cream mixes were then placed in cold room and aged for 24h at 4°C. One group from each production was set as control and no enzyme was added. Mixes were frozen using a freezing machine (Uğur, Nazilli, Turkey) and was packed in 200 mL cups and stored at −18˚C.

Proximate analysis of ice-cream samples

Fat [7], total solids, ash, pH and titratable acidity [8] were determined 1 week after the production. Lactose content of ice-cream mixes was determined using spectrophotometer with Megazyme K-LACGAR 12/05 enzymatic test kit at 360 nm in 1 cm kuvette with final volume of 2.75 mL (sample solution: 4-80 µg D-galactose or 8-160 µg lactose) [9].

Physical analysis of ice-cream samples

A Brookfield Viscometer (Model DV-II; Bookfield Engineering Laboratories, Inc., Stoughton, MA, USA) with spindle no 5 was used to measure the apparent viscosity of the melted ice-cream samples (4°C) [10].
The overrun of the ice-cream samples was estimated using the following equation [11]:

Overrun = (Weight of unit mix - weight of equal volume of ice-cream) / (Weight of equal volume of ice-cream)*100

Melting rate, was evaluated by weighing 80±5 g ice-cream sample on a 0.2 cm wire mesh screen and it was left to melt at room temperature (24±2°C) [12, 13]. The melted ice-cream weight collected in the beaker under the mesh was recorded at the 30^{th}, 45^{th}, 60^{th} and 75^{th} min. Time of complete melting was also recorded.

Sensory analysis

Sensory analysis was conducted by ten untrained panelists. A 10-point hedonic scale was used to evaluate sweetness, flavor and odor, firmness, and sandiness (1=strongly unacceptable, 10=very good) as described by Aime *et al.* [14].

Statistical analysis

Analysis of variance (ANOVA) was performed by SPSS version 16 (SPSS Inc., Chicago, IL). Statistically different groups were determined by the Duncan multiple comparison test.

3. Results and Discussion

Composition and physical properties of ice-creams

The average pH value of the ice-cream samples was 6.4±0.2 and the titration acidity was 0.36±0.02%. Lactose hydrolysis and sugar reduction had no impact on pH and titratable acidity values (P>0.05). Total solids contents were in parallel with the added sugar level and at 18, 16, 14 and 12% sugar, total solids were 37±1.77, 34±0.49, 30±0.44, 27±0.64% respectively. Enzyme treatment didn't affect the total solids content as expected. The average fat percentage was 3.45±0.24 (reduced fat) and ash content was 1.13±0.07% with no significant difference between ice-cream samples (P>0.05).

Table 1. Apparent viscosity of the ice-cream samples

	Storage time					
	Day 1		Day 60			
Sugar (%)	Control	Enzyme treated	Control	Enzyme treated	E	SxE
18	2080±212^{a}	2420±113^{a}	2085±205^{a}	2424±131^{a}	*	NS
16	1786±76^{a}	2224±249^{ab}	1730±101^{b}	2164±149^{ab}	**	
14	1476±6^{b}	2072±113^{b}	1439±8^{bc}	2056±90^{b}	**	
12	1236±170^{b}	1400±102^{c}	1233±178^{c}	1400±112^{c}	NS	

The values are mean ± standard deviation.

^{a,b,c} Values with different superscript letter in the same row are significantly different ($p<0.05$)

E: Effect of enzyme treatment, SxE: Interaction effect of storage time x enzyme treatment

NS: Nonsignificant $p>0.05$ *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Apparent viscosity values of the ice-cream samples are showed in Table 1. There was a decrease in viscosity depending on the decrease in sugar content. Impact of enzyme treatment was also significant; lactose hydrolysed ice-creams had higher viscosity, and the difference were more obvious at higher sugar contents. Previous studies have also reported an increase in viscosity with lactose hydrolysis [15, 16]. They claimed that there was an increase in viscosity together with the increase in lactose hydrolysis level.

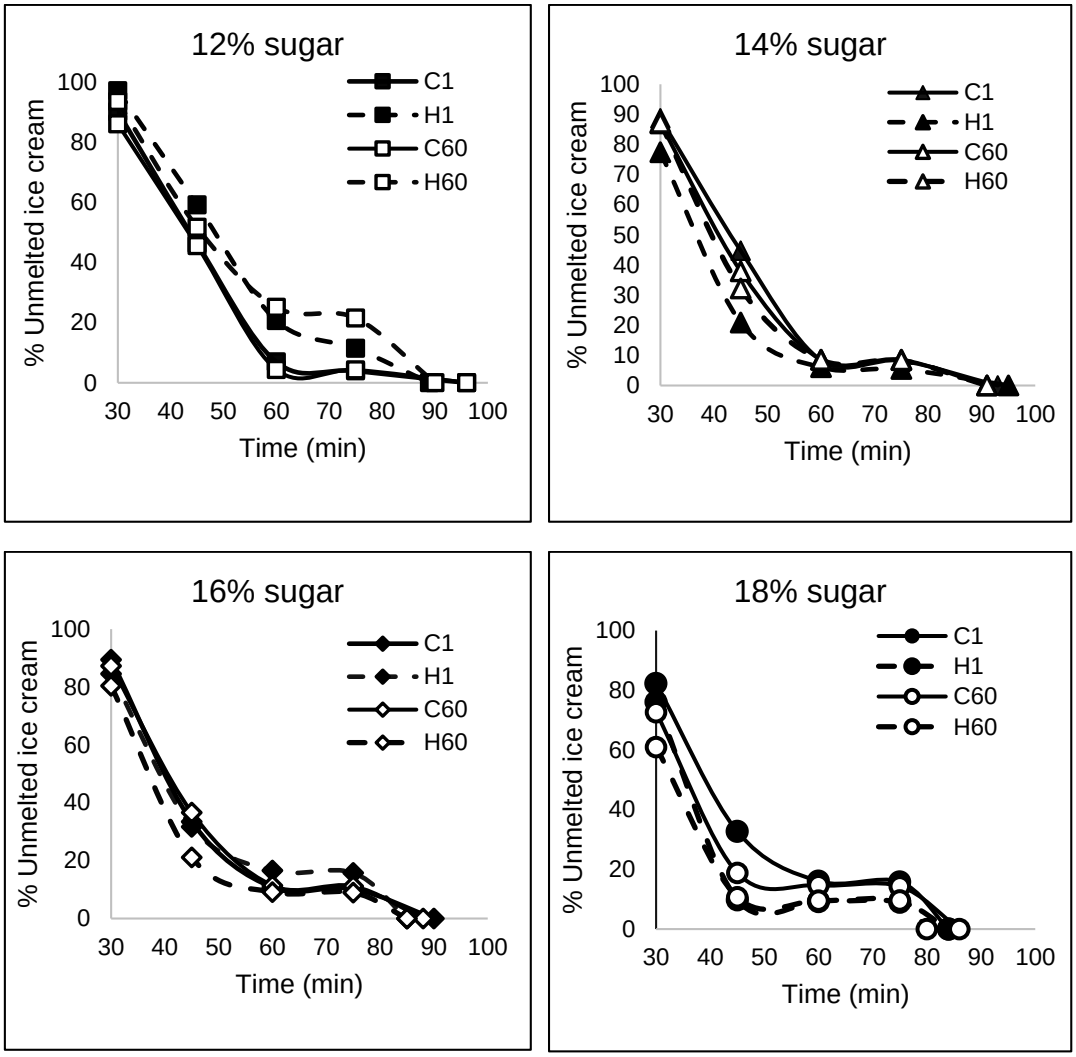

Figure 1. Melting curves of control and enzyme treated ice-creams at different sugar concentrations (18, 16, 14 and 12 %) on day 1 and day 60. Values are the mean of three replicates. C1: Control at day 1, H1: Enzyme treated at day 1, C60: Control at day 60, H60: Enzyme treated at day 60

We observed differences in melting trends of enzyme treated samples depending on the sugar content. At 12% sugar content, enzyme treated ice-creams resisted more to the melting than the control (Figure 1). However, when the sugar content increase, enzyme treated samples mostly exhibited faster melt than the control. Other studies have also reported a rise in melting rate of the ice-creams in relation with the increase in lactose hydrolysis level [15, 17] where higher amounts of sugar (>14%) were used. On the other hand, El-Nehaway *et al.* [16] found a decline in melting rate of ice-creams at all lactose hydrolysis levels (0, 50 and 75%). Abbasi and Saeedabadian [15] also determined a decline in melting percentages with lactose hydrolysis at reduced sugar ice-creams. Hydrolysis of the lactose depresses the freezing point of ice-cream mix [17]. Melting rate of an ice-cream is directly related with the freezing point, where ice-creams with low freezing point will melt down faster [1]. The higher the sugar percentage of the samples, the higher the melt rate was in accordance with past studies [11, 15], which again could be due to well-known impact of sugar on freezing point. The observed decrease in the

melting rate with reduced sugar (<14%) lactose hydrolysed ice-cream samples could be due to a rise in the freezing point larger than the drop caused by lactose hydrolysis and could be also due to other reasons such as the dominance of other milk solids in the mix with the removal of sugar. Tsuchiya *et al.* [18] reported a decline in melting rate of lactose hydrolysed ice-creams when whey powder was used.

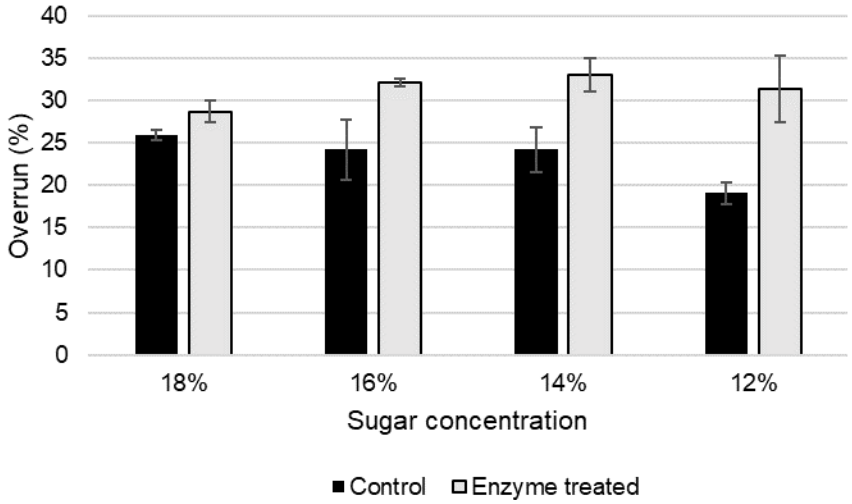

Figure 2. Effect of enzyme treatment at different sugar concentrations on the overrun level of the ice-cream samples. The values are mean and error bar represents standard deviation.

Overrun is one of the most important parameters as a measure of how much air is incorporated in the ice-cream and determines several textural attributes leading to consumer liking along with the cost of the end product [1]. Effect of the enzyme treatment at different sugar concentrations on the overrun level of the ice-cream samples is given in Figure 2. Our overrun levels were in a low range (26 to 33%) due to use of batch freezer. We observed increase in overrun with lactose hydrolysis and the difference between control and enzyme treated samples was more significant at lower sugar contents. Reducing the sugar content of the control ice-creams reduced the overrun level; however, enzyme treated samples were stable at all sugar levels. Tsuchiya *et al.* [18] and El Neshawy *et al.* [16] has also reported a higher overrun with lactose hydrolysis. While some studies did not find any influence of the lactose hydrolysis on overrun [19, 20], Abbasi and Saeedabadian [15] observed the opposite effect where lactose hydrolysis (≥50%) reduced the overrun. Overrun is influenced by several factors such as formulation of the ice-cream mix and processing conditions [1]. Differences between past studies could be due to compositional differences of the mixes, such as different sugar and fat contents, different processing parameters and equipment used for freezing the mix. Akin *et al*. [11] also showed that higher sugar content of the ice-cream resulted in higher overrun. Level of the lactose hydrolysis is also important and below a certain level of hydrolysis, no impact on overrun was observed in previous studies [15, 16].

Sensory analysis results

Table 2. Sensory analysis results of the ice-cream samples

Parameter	Sugar (%)	Storage time					
		Day 1		Day 60			
		Control	Enzyme treated	Control	Enzyme treated	E	SxE
Sweetness	18	7.5±1.5^{a}	9.3±1.0^{a}	8.3±1.7^{a}	9.1±1.0^{a}	*	NS
	16	6.7±1.4^{a}	8.6±1.3^{a}	7.4±1.5^{a}	8.2±1.2^{b}	*	
	14	4.2±0.8^{b}	7.0±2.1^{b}	6.0±1.0^{b}	6.6±1.1^{c}	**	
	12	3.0±0.7^{b}	5.1±2.1^{c}	4.7±1.2^{c}	5.4±1.3^{d}	**	
Flavor and odor	18	8.2±1.6^{a}	8.6±1.0^{a}	8.1±1.5^{a}	8.2±1.1^{a}	NS	NS
	16	7.7±1.0^{a}	8.1±1.3^{a}	7.3±1.1^{a}	7.6±1.0^{a}	NS	
	14	6.6±0.9^{ab}	7.3±1.4^{ab}	6.2±1.3^{ab}	6.3±1.3^{ab}	NS	
	12	5.4±2.7^{b}	6.6±1.9^{b}	5.4±1.6^{b}	5.4±1.8^{b}	NS	
Firmness	18	9.0±1.3^{a}	6.1±3.4^{a}	7.9±2.0^{a}	6.8±2.3^{a}	*	NS
	16	8.2±1.2^{ab}	6.9±1.5^{a}	7.8±1.2^{a}	6.7±1.6^{a}	NS	
	14	7.0±1.6^{ab}	6.1±1.3^{a}	7.7±1.1^{a}	6.5±1.3^{a}	NS	
	12	6.4±1.7^{b}	5.3±1.7^{a}	7.5±2.0^{a}	6.4±1.7^{a}	NS	
Sandiness	18	4.3±3.1^{a}	3.8±3.1^{a}	2.8±2.1^{a}	2.6±2.6^{a}	NS	NS
	16	4.3±3.0^{a}	4.0±3.1^{a}	3.3±2.2^{a}	3.1±2.5^{a}	NS	
	14	4.7±3.2^{a}	3.8±3.4^{a}	3.3±2.2^{a}	3.3±2.2^{a}	NS	
	12	4.4±3.2^{a}	4.3±3.6^{a}	3.9±2.4^{a}	3.9±2.5^{a}	NS	
Smoothness	18	8.3±1.8^{a}	8.7±0.8^{a}	8.1±1.7^{a}	8.3±1.6^{a}	*	NS
	16	7.9±1.4^{a}	8.1±1.5^{a}	7.8±1.6^{a}	7.7±1.5^{a}	NS	
	14	6.7±2.0^{ab}	6.8±2.4^{ab}	7.8±1.6^{a}	7.3±1.4^{a}	NS	
	12	6.1±2.1^{b}	6.0±2.4^{b}	6.4±2.0^{b}	6.9±2.0^{a}	NS	
Coldness	18	6.6±2.5^{a}	7.8±1.5^{a}	6.1±2.7^{a}	6.3±2.6^{a}	NS	NS
	16	6.1±1.5^{a}	7±1.2^{a}	6.3±2.5^{a}	6.0±2.1^{a}	NS	
	14	4.9±2.1^{b}	5±1.6^{b}	6.3±2.5^{a}	4.4±1.4^{b}	NS	
	12	4.2±2.3^{b}	4.5±1.9^{b}	3.8±2.4^{b}	4.5±3.0^{b}	NS	
Mouth coating	18	7.4±2.7^{a}	8.1±1.4^{a}	8.7±1.2^{a}	8.8±1.2^{a}	NS	NS
	16	6.9±2.1^{a}	7.7±0.5^{a}	7.6±1.5^{a}	7.8±1.1^{ab}	NS	
	14	5.9±1.4^{a}	6.2±1.1^{ab}	7.6±1.5^{a}	6.9±1.2^{bc}	NS	
	12	5.1±1.7^{a}	5.6±1.3^{b}	5.7±1.9^{b}	5.8±1.7^{c}	NS	
Iciness	18	2.8±2.1^{a}	1.4±1.0^{a}	2.8±2.8^{a}	3.3±3.0^{a}	*	NS
	16	3.3±2.2^{a}	2.1±1.4^{a}	4.1±3.5^{ab}	4.0±3.3^{ab}	NS	
	14	3.8±1.9^{a}	2.9±1.7^{a}	4.1±3.5^{ab}	4.1±2.2^{ab}	NS	
	12	5.0±2.5^{a}	4.8±3.3^{a}	5.8±2.4^{b}	5.3±2.8^{b}	NS	

The values are mean ± standard deviation.
^{a,b,c} Values with different superscript letter in the same column are significantly different ($p<0.05$)
E: Effect of enzyme treatment, SxE: Interaction effect of storage time x enzyme treatment
NS: Nonsignificant $p>0.05$ *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

When ice-creams were served to panelists in pairs (control – enzyme treated) for each sugar concentration, at least 50% of all panelists noted a difference between sweetness level of the control and lactose hydrolyzed ice-cream samples (Figure 3). The number of panelists who detected the difference were higher at 14 and 12% sugar content. However, after the storage (on day 60), less panelists were able to differentiate the lactose hydrolyzed samples.

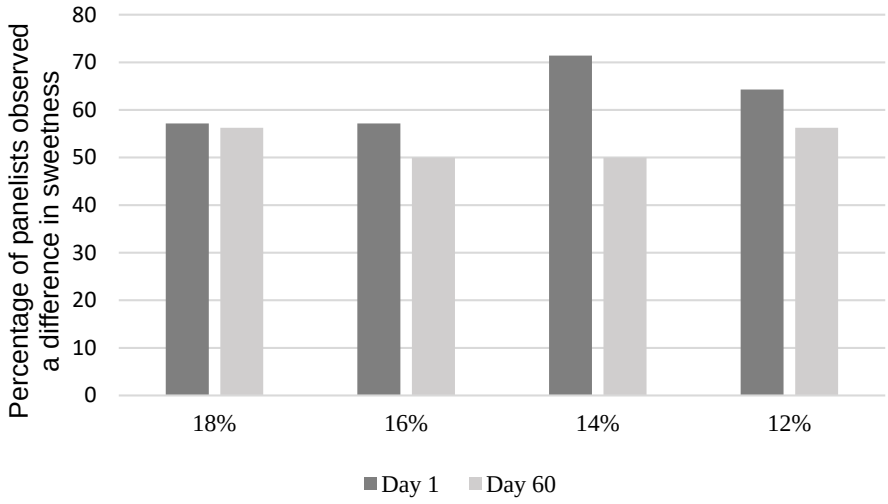

Figure 3. Percentage of the panelists who detected a difference in sweetness level between enzyme treated and control ice-creams at different sugar concentrations (18, 16, 14 and 12%) on Day 1 and Day 60.

Sensory evaluation results are given in Table 2. Hydrolyzing the lactose significantly increased the sweetness scores, and the difference was even more significant ($P<0.01$) at lower sugar contents (14 and 12%). Reducing the sugar content to 14% was possible by lactose hydrolysis, receiving a similar sweetness with 18% control. Monosaccharides of the lactose are almost twice as sweet as lactose. Thus, lactose hydrolysis would enhance the sweetness which would favor sweetening the dairy products [21]. Li *et al.*, [22] studied the impact of lactose hydrolyzation as an alternative sweetening for chocolate milk and achieved the sweetness of sucrose by hydrolyzing added >7.5% lactose.

Lactose hydrolysis and storage didn't influence the flavor and odor, sandiness, coldness, and mouth coating scores significantly at any sugar level ($P>0.05$). Hydrolyzing the lactose tended to increase the smoothness and reduce the iciness and firmness of the ice-cream at all sugar levels, while only at 18% sugar level the difference was statistically significant ($P<0.05$). Hydrolyzing the lactose results in a smoother texture in ice-cream since lactose is prone to crystallization [1]. Previous studies reported that lactose hydrolysis reduced the sandiness and stiffness and yielded with better organoleptic properties [15, 16, 4].

4. Conclusion

Lactose hydrolysis influenced the viscosity, melting properties and overrun of the ice-cream samples as well as several sensory properties. The impact of lactose hydrolysis on most parameters were sugar content dependent. There was an increase at sweetness scores and overrun with lactose hydrolysis and the difference between control and enzyme treated samples were more significant at lower sugar contents. At 18% sugar concentration, hydrolysing the lactose increased the smoothness, and reduced the iciness and firmness, while at lower sugar contents no statistical difference was observed. At higher sugar contents enzyme treated samples mostly exhibited faster melt than the control, while the opposite happened at 12% sugar. Therefore, when formulating lactose-free ice-cream, sugar content should also be adjusted carefully for desirable ice-cream properties. Our results also showed that, reducing the sugar content of the ice-cream down to 14% was possible by lactose hydrolysis, receiving a similar sweetness with 18% control. That means, lactose hydrolysis can help reduce the sugar content up to 14% without the need for sweeteners.

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Çıkar Çatışması

We declare that there is no conflict of interest between us as the article authors.

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