Journal of Engineering Science *Vol. XXIX, no. 4 (2022), pp. 164 - 175*
Fascicle *Food Engineering* *ISSN 2587-3474*
Topic *Food Technologies and Food Processes* *eISSN 2587-3482*

https://doi.org/10.52326/jes.utm.2022.29(4).13
UDC 637.146.34:637.144

EFFECTS OF LACTOSE HYDROLYSIS AND MILK TYPE ON THE QUALITY OF LACTOSE-FREE YOGHURT

Liliana Popescu, ORCID: 0000-0003-3381-7511,
Viorica Bulgaru *, ORCID: 0000-0002-1921-2009,
Rodica Siminiuc, ORCID: 0000-0003-4257-1840

Technical University of Moldova, 168 Stefan cel Mare blvd., Chisinau, Republic of Moldova
*Corresponding author: Viorica Bulgaru, *viorica.bulgaru@tpa.utm.md*

Received: 11. 01. 2022
Accepted: 12. 16. 2022

Abstract. The purpose of the work was to investigate the influence of different lactose hydrolysis processes, the contribution of the enzyme and the milk type on the characteristics of the obtained lactose-free yogurt. The analysis was performed on non-hydrolyzed yogurt (control sample), the pre-hydrolyzed yogurt (that was hydrolyzed before fermentation), and the co-hydrolyzed yogurt (concurrent addition of β-galactosidase and starter culture). According to the obtained results, at the end of the fermentation time, an advanced hydrolysis degree was reached (over 80%) both for yogurt samples obtained from pre-hydrolyzed milk and obtained by co-hydrolysis. The optimal method from the economic point of view is to obtain yogurt by co-hydrolysis. The sensory quality of the yogurt samples obtained from hydrolyzed milk by co-hydrolysis was characterized by a better flavor than the control sample, for yogurt from both types of milk. This may be due to the availability of a greater amount of glucose for the production of aromatic compounds, a sweeter taste than natural yogurt, with a light caramel flavor, a firm coagulum, a porcelain appearance, without whey removal. Cow's milk yogurt showed higher viscosity values to goat's milk yogurt for both pre-hydrolyzed and co-hydrolyzed milk. Lactose hydrolysis determined the reduction of the syneresis index of the yogurt compared to the control samples. The studies led to the development of lactose-free yogurt with improved sensory and rheological properties recommended for people with lactose intolerance.

Keywords: *co-hydrolysis, pre-hydrolysis, β-galactosidase, fermentation, lactose, yogurt.*

Rezumat. În articol a fost investigată influența diferitelor procese de hidroliză a lactozei, tipul enzimei și a laptelui asupra caracteristicilor iaurtului fără lactoză. Analiza a fost efectuată pe iaurt nehidrolizat (probă martor), iaurt pre-hidrolizat (care a fost hidrolizat înainte de fermentare) și iaurt co-hidrolizat (adăugarea concomitentă de β-galactozidază și cultura starter). Conform rezultatelor obţinute, la sfarşitul timpului de fermentaţie s-a atins un grad avansat de hidroliză (peste 80%) atît în cazul probelor de iaurt obţinute din lapte pre-hidrolizat cît şi în cazul celui obţinut prin co-hidroliză. Metoda optima, din punct de vedere economic, este obţinerea iaurtului delactozat prin co-hidroliză. Calitatea senzorială a probelor de iaurt obținute din laptele hidrolizat prin co-hidroliză a fost caracterizată printr-o aromă mai bună decât proba martor. Acest lucru se poate datora disponibilității unei cantități mai mari de glucoză pentru producerea de compuși aromatici, un gust mai dulce decât iaurtul natural, cu o aromă ușoară de caramel, un coagul ferm, un aspect de porțelan, fără separare de zer. Iaurtul din lapte de vacă a prezentat valori mai mari ale vâscozităţii în comparaţie cu iaurtul din lapte de capră atât pentru laptele pre-hidrolizat, cât și pentru cel co-hidrolizat. Hidroliza lactozei a determinat reducerea indicelui de sinereză al iaurtului comparativ cu probele martor. Studiile au condus la dezvoltarea iaurtului fără lactoză, cu proprietăți senzoriale și reologice îmbunătățite, recomandat persoanelor cu intoleranță la lactoză.

Cuvinte cheie: *co-hidroliză, pre-hidroliză, β-galactozidază, fermentație, lactoză, iaurt.*

1. Introduction

Yogurt is a dairy product obtained by fermenting milk under the action of specific microorganisms from the *Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp. bulgaricus* starter culture which can be supplemented with other probiotic cultures such as *Lactobacillus acidophilus* and *Bifidobacterium bifidus* [1]. Probiotics are live microorganisms that, administered in adequate amounts, confer health benefits to the consumer [2]. Consummation of yogurt and other fermented dairy products is considered to be beneficial for the digestive and general health of consumers [3]. Yogurt contains important amounts of protein, calcium, iodine and vitamin B_{12}, and can be recommended for people with high risk of obesity and cardiovascular diseases, both in children and adults. [4]. In addition, several regulatory bodies, including the European Food Safety Authority, have approved health claims related to the consumption of yogurt and the reduction of symptoms caused by inadequate lactose digestion [5]. Two different theories have been put forward to explain this phenomenon [6, 7].

It has been suggested that lactobacillus in fermented milk that synthesize lactase continue metabolic activity in the gastrointestinal tract, participating in (total or partial) lactose digestion. Monosaccharides are both consumed by bacteria and absorbed in the small intestine, so the symptoms of lactose intolerance are reduced. This hypothesis is valid only if the lactic acid bacteria in the yogurt and the lactase enzyme synthesized by them will pass the gastric juice barrier [7].

A second explanation that has been put forward suggests that the lactose in yogurt is better digested. This fact is due to the slower intestinal transit of viscous yogurt compared to liquid milk. For this reason, lactase synthesized in the small intestine will have longer time to digest lactose and therefore reduce the symptoms of intolerance [8].

Several bacterial strains have been tested in people with lactose intolerance. Lactose intolerance was measured based on increased hydrogen concentrations in exhaled air after lactose ingestion. Hydrogen accumulates as a result of the fermentation of unhydrolyzed lactose under the colon microflora action of people with lactose intolerance [9]. Short-term benefits have been demonstrated for *Lactobacillus reuteri* administration through respiratory hydrogen reduction and improved symptom score after 10 days [10]. Malolepszy et al., 2006 [11] show that after 43 days of eight lactic acid probiotics administration did not reduce the level of hydrogen in the exhaled air and respectively the lactose intolerance symptoms. Yet another study using two probiotics, *Lactobacillus casei strain Shirota* and *Bifidobacterium breve* showed a short-term benefit after four weeks and even after three months, when the probiotics had already been stopped [12]. A recent review of 15 studies on the use of 8 different probiotics to reduce symptoms of lactose intolerance led the authors to demonstrate that although efficacy varied, there was an overall positive benefit for this type of treatment. The rate of lactose hydrolysis in fermented dairy products is influenced by the microbial cells number or lactase activity as well as other factors, such as intracellular substrate transport, etc. [9, 13].

Therefore, the lactose in yogurt is better digested than that in milk, as a result of the microorganism's ability to synthesize lactase. However, a low lactose content in yogurt is not suitable for people with lactose intolerance [14, 15] Thus, the most reliable remedy seems to be complete lactose enzymatic digestion in yogurt. This can be done by adding β-galactosidase to milk before pasteurization (pre-hydrolysis) as well as adding β-galactosidase along with the starter culture after pasteurization of milk (co-hydrolysis).

Only a few studies refer to the lactose hydrolysis influence on the fermented milk characteristics. Some studies reported a reduction in fermentation time in the case of free lactose fermented milk [16], while others [17] observed an increase in fermentation time or lactose hydrolysis did not influence the fermentation process period.

Yogurt is most often produced from cow's milk, less often from goat's, sheep's, buffalo's milk, etc. Goat's milk is appreciated for its nutritional and hypoallergenic properties, and indicated in the diet of children allergic to bovine milk [18, 19]. Between 40-100% of patients allergic to cow's milk proteins tolerate goat's milk [20]. The importance of goat's milk consists in its high digestibility and nutritional value, as well as its dietary and nutraceutical characteristics [21]. Goat milk is an excellent source of high quality proteins and peptides [21], with important biological activity such as antimicrobial, antioxidant, immunomodulatory, antihypertensive, hypocholesterolemic and activities [22]. Recent research has also shown that goat milk has better digestibility, higher iron and magnesium bioavailability, and higher calcium and copper content than bovine milk [20, 23] and it is rich in niacin, thiamin, riboflavin and pantothenate [24]. Goat milk, due to its health benefits, can be the basis for the creation of new dairy products through enzymatic processes and membrane separation [25, 26]. The aim of the study was to investigate the different enzymes influence, lactose hydrolysis methods and the milk type on the obtained yogurt characteristics. For a systematic approach, non-hydrolyzed yogurt (control sample), pre-hydrolyzed yogurt (which was hydrolyzed before fermentation) and co-hydrolyzed yogurt (concurrent addition of β-galactosidase and starter culture) were performed simultaneously.

2. Materials and Methods

Materials. Commercial enzymes β-galactosidase obtained from *Bacillus licheniformis*, activity 5500 BLU·g/1 NOLA Fit 5500 (Chr. Hansen, Denmark) and β-galactosidase obtained from *Kluyveromyces lactis*, activity 5000 NLU·g/1 Maxilact LGi 5000 (Sedim Cedex – France), according to information provided by the manufacturer. Cow's milk with a 2.5% fat content, proteins 3.2% and lactose 4.75% produced by "Lapmol" S.R.L., Republic of Moldova. Goat's milk with a 5.5% fat content, protein 3.0% and lactose 4.45% produced by "Vilador" S.R.L., Republic of Moldova. Yogurt freeze drying starter cultures containing *Streptococcus thermophilus*, *Lactobacillus delsbrueckii subsp. bulgaricus, Lactobacillus acidophilus, Bifidobacterium* (YAB 352B, Sacco, Italy).

Lactose hydrolysis. In the case of lactose pre-hydrolysis, β-galactosidase enzymes were added before pasteurization. The pre-hydrolysis regime was carried out according to the following regimes: enzymes from *B. licheniformis* Nola Fit 5500 in 0.3% proportion, hydrolysis time 4 hours at a temperature of 4-6°C and enzymes from *K. lactis* Maxilact LGi 5000 in 0.3% proportion, hydrolysis time 12 hours at temperature 4-6 °C [27]. The hydrolyzed milk was pasteurized at a temperature of 85°C for 10 minutes. In the case of lactose co-hydrolysis, the enzyme NOLA Fit 5500 and Maxilact LGi 5000, in 0.15% proportion, were added together with the starter culture to the pasteurized milk cooled to the temperature of 39 °C [27].

Milk fermentation. Fermentation of the control, pre-hydrolyzed and co-hydrolyzed sample was performed simultaneously at the fermentation temperature of 39°C in the same thermostat until pH 4.6. After fermentation, the yogurt samples were aged at 4°C for 24 hours. During the yogurt samples fermentation, the evolution of the pH and the degree of lactose hydrolysis was monitored. Yogurt samples were evaluated on the 1^{st} and 14^{th} days of storage to determine the evolution of sensory and rheological characteristics. All samples were done in triplicate and the analysis of the samples was repeated three times.

Analytical determination of a lactose. The free D-glucose concentration, as well as the D-glucose component of lactose was determined by glucose spectrophotometric method using the lactose test kit (k-LOLAC, Megazyme). The method includes pre-treatment steps to clarify and deproteinate samples and also to remove the high levels of free D-glucose in the samples. The determinations were carried out in accordance with the method for the measurement of lactose in low-lactose and lactose-free products under method [28]. The reading of the samples absorbance was carried out at a wavelength of 340 nm using UV Vis spectrophotometer Shimadzu UV-1900.

The yogurt samples **sensory analysis** was determined using the 5-point scoring scale according to ISO 22935-3:2009 [29]. The sensory properties of the individual yogurt samples were analyzed by a group of nine-member evaluators, who were selected in accordance with ISO 8586:2012 [30].

Syneresis. Syneresis was determined by centrifuging 10g of yogurt sample at 1600 rpm for 10 min. After centrifugation, the supernatant was decanted and weighed on an analytical laboratory balance [31].

Viscosity was determined with rotational viscometer Brookfield DV-III Ultra at the storage temperature of yogurt samples according to the method presented by Özge Dönmez et al. 2017 [32] with some modifications. Yogurt samples were mixed gently 30 times for homogenization. Viscosity was determined using spridler 04 at shear rate (75 rpm).

The **pH** was measured with a digital pH-meter (Si Analytics TitroLine 5000) at 20°C.

Statistical analysis. The variance analysis of the results was carried out by least square method with application of Student test and Microsoft Office Excel program version 2010. All assays were performed in triplicate. The experimental results are expressed as average ± SD.

3. Results and Discussion

Degree of hydrolysis of lactose in yogurt

The lactose hydrolysis degree of non-hydrolyzed yogurt samples (control sample), pre-hydrolyzed yogurt, and yogurt obtained by co-hydrolyzation are shown in table 1.

Table 1

Evolution of the lactose hydrolysis degree during milk fermentation

Sample code		Lactose hydrolysis degree, %	
		until fermentation	after fermentation
Cow milk			
C1	Control	0	12.57±0.65

Continuation Table 1

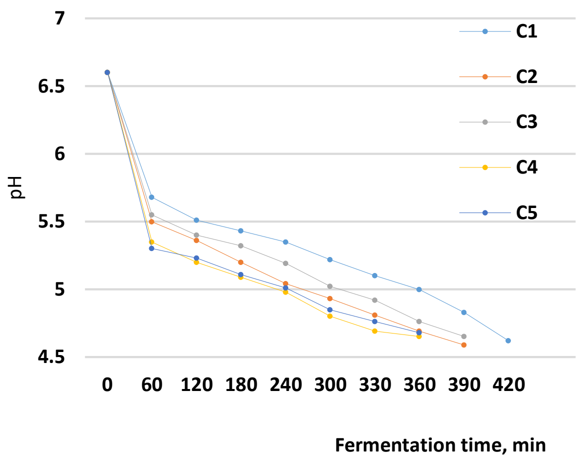
C2	Pre-hydrolyzate with NF	93.80±0.28	98.56±1.01
C3	Pre-hydrolyzate with M	89.76±1.95	97.03±0.37
C4	Co-hydrolyzed with NF	0	84.25±1.44
C5	Co-hydrolyzed with M	0	81.83±1.29
Goat milk			
G1	Control	0	13.98±0.65
G2	Pre-hydrolyzate with NF	92.15±1.09	96.47±0.94
G3	Pre-hydrolyzate with M	87.40±0.42	92.61±0.27
G4	Co-hydrolyzed with NF	0	82.77±1.11
G5	Co-hydrolyzed with M	0	80.02±0.72

Note. NF – Nola Fit 5500, M - Maxilact LGi 5000. Values in the table represent means of three replicated trials ± standard deviation.

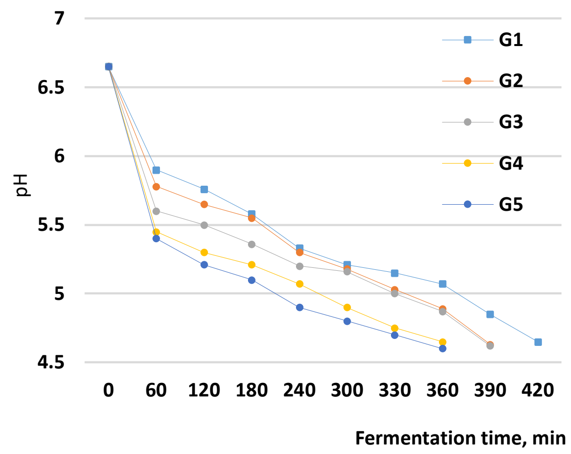
According to the data presented in table 1, it was note that in the cow and goat milk control samples, the lactose hydrolysis was achieved only under the action of β-galactosidase synthesized by the starter culture lactic bacteria, the degree of hydrolysis reaching values of 12.57 and 13.98% respectively. At the end of the fermentation time, an advanced hydrolysis degree was reached (over 80%) both in the case of yogurt samples obtained from pre-hydrolyzed milk and the one obtained by co-hydrolysis. Therefore, the process of obtaining yogurt by co-hydrolysis reduced the production time by excluding the lactose pre-hydrolysis technological stage and reduced the production costs. The optimal method from the economic point of view is to obtain yogurt by co-hydrolysis.

Evolution of pH during milk fermentation. Establishing the fermentation time.

The influence of lactose hydrolysis (before or during fermentation) on fermentation time, yogurt sensory and rheological properties was investigated using two types of β-galactosidase enzymes and two milk types (cow's milk and goat's milk). In each trial (control, pre-hydrolyzed and co-hydrolyzed milk), fermentations were performed simultaneously with the same starter culture. The pH value evolution was determined by the lactic acid bacteria development from the starter culture, as well as by the lactose hydrolysis method (figure 1).



a)



b)

Figure 1. pH evolution during milk fermentation: a) cow's milk; b) goat's milk.

The increase in fermented milk acidity depends mainly on the type and amount of carbohydrates. To reach pH 4.60 the yogurt samples fermentation time generally varied between 5 and 7 hours. In yogurt samples obtained by milk fermentation in which the prior milk lactose hydrolysis was performed, the fermentation was accelerated by 30 minutes compared to the respective references, suggesting that the lactose hydrolisis improved the fermentation process.

The process of obtaining yogurt by co-hydrolysis further accelerated the fermentation, reducing the fermentation time from 420 to 360 minutes, during which the lactose hydrolysis and fermentation took place simultaneously, which led to an increase in the available glucose amount to the rapid multiplication of the starter microorganisms. It should be noted that upon simultaneous addition of β-galactosidase and starter culture, only a limited time remains for lactose hydrolysis. The enzymes used in the study are completely inactivated at a pH < 5.5 [27], which is reached after 2.5-3.0 hours of yogurt fermentation.

The decrease in the yogurt samples fermentation time obtained from pre-hydrolyzed milk or by co-hydrolysis is probably determined by the rapid lactic acid production from the first hours of fermentation. The goat's milk fermentation time was longer, while the gelation pH values were lower, compared to those of cow's milk, because of low levels of α_{s1}-casein and a higher level of β-casein in goat milk compared to cow's milk. This aspect characterizes the lower coagulation capacity of goat's milk, but which gives it a higher digestibility [33].

No significant differences between the used enzymes type were identified.

Schmidt et al. (2016) [34] published similar results in obtaining low-lactose yoghurt with five thermophilic yoghurt starters (mixtures of *Streptococcus thermophilus* and *Lactobacillus delbrueckii ssp. Bulgaricus)*. They demonstrated that the complete lactose hydrolysis before inoculation accelerated fermentation compared to the references. Sfakianakis et al. (2014) [35] presented the cooperation between *Streptococcus thermophilus* and *Lactobacillus bulgaricus*, namely the intensive production of lactase enzyme by *Streptococcus thermophilus* is necessary for the lactose hydrolysis and then *Lactobacillus bulgaricus* is capable of rapidly producing lactic acid from glucose as a result of the monosaccharides accumulation in milk from the lactose hydrolysis. The studies presented by Kárnyáczki et al. (2017) [36] claim the opposite, that pre-hydrolysis inhibits the activity of some yogurt cultures probably due to the transition from lactose to glucose as the main carbon source or due to the increase in osmotic pressure in lactase hydrolyzed milk.

Sensory analysis of yogurt samples

The yogurt sensory quality, after production and storage period, is one of the determining factors in consumer choice. To evaluate the acceptability of the lactose-free yogurt, sensory analysis was performed. The results of sensory analysis and overall acceptability were presented in table 2.

Yogurt samples are characterized by firm consistency curd, with a porcelain appearance, without removal of whey. Color was yellowish-white, uniform. The odor of yogurt is due to the lactic acid production, acetaldehyde and other carbonyl compounds during fermentation by the starter microorganisms.

Yogurt samples obtained from both pre-hydrolyzed and co-hydrolyzed milk are characterized by a better taste than the control sample, for cow's milk yogurt, the score increased from 4.24 (C1) to 5.00 for all lactose-free yogurt samples. The same thing is observed in the case of goat's milk yogurt samples This may be due to the availability of more glucose for the aromatic compounds production.

Table 2

Evolution of yogurt samples sensory properties

Sensory properties	Yogurt samples	Cow milk		Goat milk	
		Storage time, days / Sensory scores on 5-point scale			
		1	14	1	14
Appearance and consistency	Control	4.05±0.07	4.25±0.10	3.92±0.02	4.05±0.05
	Pre-hydrolyzate with NF	4.62±0.19	4.76±0.19	4.42±0.03	4.63±0.08
	Pre-hydrolyzate with M	4.68±0.06	4.72±0.16	4.65±0.01	4.84±0.03
	Co-hydrolyzed with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
Color	Control	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Pre-hydrolyzate with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Pre-hydrolyzate with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
Odor	Control	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Pre-hydrolyzate with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Pre-hydrolyzate with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
Taste	Control	4.24±0.02	4.47±0.02	4.18±0.06	4.35±0.03
	Pre-hydrolyzate with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Pre-hydrolyzate with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
Overall acceptability	Control	4.57±0.09	4.68±0.13	4.53±0.02	4.60±0.04
	Pre-hydrolyzate with NF	4.91±0.06	4.94±0.06	4.86±0.05	4.91±0.03
	Pre-hydrolyzate with M	4.92±0.10	4.93±0.07	4.91±0.02	4.96±0.03
	Co-hydrolyzed with NF	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00
	Co-hydrolyzed with M	5.00±0.00	5.00±0.00	5.00±0.00	5.00±0.00

Note. NF – Nola Fit 5500, M - Maxilact LGi 5000. Values in the table represent means of three replicated trials ± standard deviation.

Also, the yogurt samples obtained from both pre-hydrolyzed and co-hydrolyzed milk are characterized by a considerably sweeter taste than natural yogurt, with a light caramel flavor. Regardless of the milk type, not detected obvious differences in sensory properties between yogurt from non-hydrolyzed and co-hydrolyzed milk.

Similar results were reported by Vènica et al. (2013) [37] who did not detect differences in sensory properties between drinking yogurt from non-hydrolyzed and co-hydrolyzed milk, while the experimental results reported by Ibarra et al. (2012) [17] demonstrated that the sensory quality of yogurt decreased with increasing degree of lactose hydrolysis. Yogurt obtained from milk with a lactose hydrolysis degree of 50 and 70% respectively (hydrolysis was carried out before fermentation) presented a creamier texture and a better flavor than yogurt from non-hydrolyzed milk, while lactose hydrolysis of 90% resulted in products with a softer consistency and an overly sweet flavor. Therefore, yogurt samples obtained by lactose pre-hydrolysis or co-hydrolysis are characterized by a lactose hydrolysis high degree as well as a sweeter taste as a result of the accumulation of reducing monosaccharides with a higher sweet taste compared to that of lactose. In lactose-free or partially lactose-free yogurt, the amount of added sugar can be reduced, resulting in a product with a lower energy value.

The yogurt samples sensory analysis showed insignificant variations for color, odor, taste scores depending on the milk type and significant variations for appearance and consistency scores. Compared to cow's milk yogurts, goat's milk yogurt had a weaker consistency, ranging from 3.92 (G1) to 4.05 (C1), which also determined a decrease in the overall acceptability value. Lactose hydrolysis led to an increase in the score for the appearance and consistency of the yogurt samples, especially those obtained from goat's milk.

During the storage period, the sensory quality of the yogurt samples obtained by lactose pre-hydrolysis or co-hydrolysis did not change. So post-acidification during shelf life can be reduced as a result of lactose hydrolysis in yogurt. This can be explained by the fact that yogurt bacteria are less active in the absence of lactose or have difficulty switching from one carbon source (lactose) to another (glucose), which leads to a better sensory stability of the product [38].

Rheological properties of yogurt samples

When evaluating the yogurt quality, one of the most important aspects to consider is the rheological properties. Fermented dairy products have a highly sensitive gel-like protein matrix, which is highly dependent on the milk composition, but is also affected by the technological operations of homogenization, pasteurization, the microorganisms species in the starter culture and the fermentation temperature [34]. Two rheological parameters were measured in this study: viscosity and syneresis index (table 3).

Table 3

Evolution of yogurt samples rheological properties

Sample code		Storage time, days			
		Viscosity, Pa·s		Syneresis index, %	
		1	14	1	14
Cow milk					
C1	Control	0.69±0.02	0.51±0.01	41.65±0.78	40.24±1.49
C2	Pre-hydrolyzate with NF	0.76±0.02	0.73±0.01	37.89±0.73	36.77±0.51
C3	Pre-hydrolyzate with M	0.80±0.01	0.78±0.01	38.76±0.73	37.36±0.45
C4	Co-hydrolyzed with NF	0.92±0.01	0.86±0.02	36.67±0.23	36.03±0.68
C5	Co-hydrolyzed with M	0.96±0.01	0.90±0.01	36.41±0.98	35.76±0.45
Goat milk					
G1	Control	0.58±0.01	0.48±0.01	45.62±0.26	43.38±0.43
G2	Pre-hydrolyzate with NF	0.64±0.01	0.58±0.03	44.76±0.31	43.31±0.48
G3	Pre-hydrolyzate with M	0.71±0.01	0.70±0.02	44.37±0.44	43.37±0.44
G4	Co-hydrolyzed with NF	0.77±0.01	0.72±0.01	43.61±0.27	42.01±0.70
G5	Co-hydrolyzed with M	0.85±0.01	0.80±0.01	43.73±0.19	42.27±0.51

Note. NF – Nola Fit 5500, M - Maxilact LGi 5000. Values in the table represent means of three replicated trials ± standard deviation.

Differences in apparent viscosity at a shear rate of 75 rpm between the yogurt samples were more pronounced, while the storage-induced decrease in viscosity was negligible.

Sensory scores of the appearance and consistency correlated with the rheological properties expressed by the apparent viscosity and the syneresis index.The apparent viscosity of low-lactose yogurt (co-hydrolyzed with the Nola Fit enzyme from cow's and goat's milk) showed a significantly higher viscosity (by 33 and 23%, respectively) than the respective control samples. The control yogurt sample showed a significantly lower apparent viscosity value than the corresponding yogurt from pre-hydrolyzed and co-hydrolyzed milk, for the cow's milk yogurt from 0.69 Pa·s (C1) to 0.96 Pa·s (C5) and for the yogurt from goat's milk 0.58 Pa·s (G1) to 0.85 Pa·s (G5). This results may be due to the increased monosaccharides content that are more soluble and have a softer body and creamier texture or the exopolysaccharides concentration synthesized in a higher amount in yogurt samples from hydrolyzed milk compared to non-hydrolyzed milk [34].

Cow milk yogurt showed significantly higher apparent viscosity values compared to regular goat milk yogurt for both pre-hydrolyzed and co-hydrolyzed milk. This is mainly due to the higher content of α-casein in cow's milk compared to goat's milk, which allows the formation of a larger number of structure-relevant bonds in milk gels. The given results are in correlation with other authors [33, 39]. The syneresis index determines the susceptibility of lactose-free yogurt to water-binding capacity, which is an important sensory attribute from the consumer's point of view. Regardless of the milk type and the lactose hydrolysis process, the yogurt syneresis index varied between 36.41% and 44.76%. Lactose hydrolysis determined the reduction of the yogurt syneresis index compared to the control samples. The improved water-binding capacity caused by the lactose hydrolysis is a clear advantage in the yogurt manufacture, especially that obtained from goat's milk, it can increase the consumer acceptance of the final product and can also lead to the finished product shelf life extension.

5. Conclusions

Lactose hydrolysis in milk (before or during fermentation) influences the fermentation time, textural properties and sensory attributes of yogurt. In yogurt samples obtained from pre-hydrolyzed and co-hydrolyzed milk fermentation process was accelerated compared to the control samples, suggesting that lactose hydrolisis improves the fermentation process. At the end of the fermentation time, an advanced hydrolysis degree is reached (over 80%) both in yogurt samples obtained from pre-hydrolyzed milk and the one obtained by co-hydrolysis, in the case of yogurt samples from cow's milk and from goat's milk. Obtaining yogurt by co-hydrolysis reduces the yogurt production time by excluding the lactose pre-hydrolysis technological stage and, respectively, production costs. The economic effect is also confirmed by the results of the yogurt samples sensory and rheological analysis. Sensory properties of lactose-free yogurt are superior to those of natural yogurts. The yogurt samples obtained from both pre-hydrolyzed milk and co-hydrolyzed milk were characterized by a light caramel, sweeter taste than the control sample, which also led to an increase in the score from 4.24 (C1) to 5.00 for all samples of lactose-free cow's milk yogurt. The same is observed in goat milk yogurt samples.Consequently, in yogurt obtained by lactose co-hydrolysis, the amount of added sugar can be reduced, resulting in a product with a lower energy value. Lactose hydrolysis also caused an increase in yogurt viscosity compared to control samples, for the cow's milk yogurt from 0.69 Pa·s (C1) to 0.96 Pa·s (C5) and for the yogurt from goat's milk 0.58 Pa·s (G1) to 0.85 Pa·s (G5)Cow's milk yogurt showed significantly higher apparentviscosity values compared to regular goat's milk yogurt. The improved water-binding capacity caused by the lactose hydrolysis is a clear advantage in the yogurt manufacture, especially that obtained from goat's milk, it lead to the increase the consumer acceptance of the final product from 4.53 in the case of yogurt sample G1 until 5.00 in the case of yogurt samples G4 and G5.

Acknowledgments: The research was funded by State Project 20.80009.5107.10 “Personalized nutrition and intelligent technologies for my well-being”, running at Technical University of Moldova.

Conflicts of Interest: The authors declare no conflict of interest.

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Citation: Popescu, L.; Bulgaru, V.; Siminiuc, R. Effects of lactose hydrolysis and milk type on the quality of lactose-free yoghurt. *Journal of Engineering Science* 2022, 29 (4), pp. 164-175. https://doi.org/10.52326/jes.utm.2022.29(4).13.

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