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## THE INFLUENCE OF STARCH PRODUCTS ON THE RHEOLOGICAL, PHYSICAL AND CHEMICAL PROPERTIES OF YOGURT

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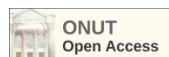
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**Abstract.** Expanding the assortment of low-fat yogurt with natural structuring sweeteners and regulated quality indicators is an actual direction of scientific research. The purpose of the study is to study the patterns of influence of the products of enzymatic hydrolysis of corn starch with different dextrose equivalents on the rheological, physical and chemical characteristics of yogurt. The functional and technological properties of starch products of different chemical composition were studied – maltodextrin MD-10, glucose syrup IG-42 and glucose-fructose syrup GFS-42. The possibility of completely replacing dry skimmed milk and sugar in the composition of yogurt with a fat content of 1% drinkable with an equivalent content of dry substances of maltodextrin MD-10 and glucose syrup IG-42, which ensure the formation of rheological characteristics inherent high-quality yogurt. Yogurt with sucrose, which inhibits the organization of macromolecular chains of milk proteins, has the lowest thixotropic ability, and yogurt with maltodextrin MD-10 and glucose syrup IG-42 has the highest. The predominance of higher sugars in the composition of MD-10 maltodextrin lengthens, and the increased content of monosaccharides in GFS-42 accelerates the duration of fermentation of milk mixtures in the technological process of production of yogurt with a fat content of 1.0%. Monosaccharides in the composition of GFS-42 significantly affect the activity of water and at the same time reduce the moisture-retaining capacity of the sour-milk yogurt curd. The degree of influence on the rheological characteristics and moisture-binding capacity of yogurt increases with a decrease in the dextrose equivalent of starch products in the following sequence: GFS-42 → IG-42 → MD-10. So, it is the dextrose equivalent of starch products that is an objective criterion of their technological activity as part of yogurt. The results of the study will allow purposeful management of the process of forming low-fat yogurt quality indicators.

**Key words:** yogurt, starch molasses (syrups), maltodextrin, effective viscosity, thixotropic ability, degree of syneresis, water activity, active acidity.

### Introduction. Formulation of the problem

A characteristic feature of yogurt is a gentle, moderately dense consistency, due to the increased content of dry non-fat milk substances in the range from 9% to 16% [1]. To ensure the indicated chemical composition, skim milk powder, milk protein isolates, milk protein concentrates, whey protein isolates, micellar casein and caseinates are added to yogurt [2].

A strong clot of Greek yogurt is obtained with an increased content of dry substances by pre-concentrating milk or separating part of the whey from the clot, or by making a recombined yogurt with a given content of dry substances [3]. The high protein content in Greek yogurt (6.38-6.61%) provides the best sensory and physicochemical characteristics even with a low fat content (1.37–1.38%) [4]. For additional structuring of the milk-protein curd of classic low-fat

yogurt, milk proteins are partially replaced by proteins of plant origin, which is accompanied by the formation of a mixed gel [5,6], and in order to make the product cheaper and thicken the curd, structural stabilizers are widely used – mostly polysaccharides [7,8]. At the same time, it is quite possible to use starch molasses, syrups and maltodextrins in a wide range of dextrose equivalent values, which are able to structure and at the same time sweeten the product [9]. Thus, studies aimed at the use of products of enzymatic hydrolysis of starch with different dextrose equivalents in yogurt are of scientific and practical interest.

#### Analysis of recent research and publications

From a technological point of view, starch and products of its enzymatic and acid hydrolysis are multifunctional ingredients that are widely used in the production of bakery and confectionery products, sauces and drinks [10-13]. Products of starch hydrolysis, in particular fructose, enhance the flavor of fruit fillers, and higher sugars structure, slightly reduce the sweetness of dessert products and simulate the presence of fat. In addition, glucose and fructose reduce water activity, which can affect the shelf life of food products [14]. Products of starch hydrolysis, depending on the degree of its destruction, are characterized by a rather wide range of dextrose equivalent (DE) values – from 3–10 to 97–98. Dextrins and molasses with low DE are a source of dry matter, effectively bind water and structure food systems, and monosugars activate fermentation processes [15,16]. But the use of these natural ingredients in dairy products is still limited and mainly concerns ice cream, desserts and non-fermented milk drinks [17-19].

So, we can conclude that syrups, molasses and dextrins obtained from starch can be used purposefully in the composition of yogurt to replace dry milk, sugar and structural stabilizers. Depending on DE, the technological functions of starch hydrolysis products may also change, which requires a scientific approach to their selection, depending on the given characteristics of yogurt. Scientific research in this direction is quite limited, as scientists are more interested in glucose-galactose syrup as a natural sweetener [20], as well as modified starches as thickeners [21]. Eroglu A. et al investigated the possibility of using high-sugar molasses from mulberry (content of fructose 27.68%, glucose 28.56%, sucrose 2.05%) in the composition of yogurt with a fat content of 5% and found that increasing the content of molasses from 5 to 15% significantly thins the yogurt structure, reduces the resistance to deformation and the internal viscosity of the product [22].

At the same time, the authors of the article previously proved the expediency of using low-sugar molasses (DE=30–40) in yogurt, but did not investigate its rheological characteristics and water activity, including maltodextrins. [9,23,24]. On the other hand, it is known that maltodextrins from oats can improve the

organoleptic properties of yogurt [25] and show a structuring ability [26], therefore it is advisable to study the functional and technological properties of more accessible and cheaper maltodextrin from corn starch. It should also be noted that the biggest problems with texture formation occur precisely for yogurt with a low fat content [27]. Therefore, a more in-depth study of the functional and technological properties, including the structuring ability, of corn starch hydrolysis products with different dextrose equivalents in the composition of yogurt is of scientific and practical importance. The results of such a study will allow purposeful management of the process of forming low-fat yogurt quality indicators.

**The purpose of the research** is to study the patterns of influence of corn starch hydrolysis products with different dextrose equivalents on the rheological and physical and chemical characteristics of yogurt.

To achieve the goal, it is necessary to solve the following **tasks**:

1. to investigate the rheological properties of yogurt samples with complete replacement of sugar and skimmed milk powder in the composition of low-fat yogurt with an equivalent dry matter amount of starch products with different degrees of saccharification;
2. to study the influence of molasses, syrup and dextrin from corn starch on the activity of water, the dynamics of the fermentation process and the degree of yogurt syneresis;
3. to determine the dependence of the formation of yogurt quality indicators on the dextrose equivalent of starch enzymatic hydrolysis products as a source of dry substances, sugar substitutes and structure stabilizers.

#### Research materials and methods

The products of enzymatic hydrolysis of corn starch (Intercorn Corn Processing Industry PJSC, Ukraine) were selected for the study:

- dry maltodextrin brand MD-10;
- dry glucose syrup – IG-42 molasses;
- glucose-fructose syrup GFS-42.

The chemical composition and properties of selected starch products, including in accordance with the requirements of DSTU 2211:93 and 4498:2005, are given in the Table 1.

Yogurt samples with a fat content of 1% were prepared according to the current technological instructions and requirements of DSTU 4343: 2004 "Yogurts. General technical conditions" by fermentation of normalized pasteurized milk mixtures with yogurt sourdough on pure cultures of lactic acid microorganisms *Streptococcus thermophilus*, *Lactobacillus delbrueckii*ssp. *Bulgaricus* (TM "Iprovit" Institute of Food Resources of the National Academy of Sciences, Ukraine). Before fermentation, bacterial preparations were activated in part of the pasteurized milk included in the recipes for 2 hours at the fermentation temperature.

**Table 1 – Physical and chemical parameters of maltodextrin, dry glucose syrup and glucose-fructose syrup [28]**

Indicator	Type of starch product		
	MD-10	IG-42	GFS-42
Mass fraction of dry substances, %, not less	95	95	70
Mass fraction of glucose, % dry matter	1.0	16	54
Mass fraction of fructose, % dry matter	-	-	42
Mass fraction of maltose, % dry matter	3.4	15	2
Mass fraction of maltotriose, % dry matter	5.0	16	1
Mass fraction of higher sugars, % dry matter	90.6	53	1
Sweetness index	10	36	98
Dextrose equivalent (reducing substances)	10	40	97.7

Starch products and other recipe ingredients were added to normalized milk before pasteurization. Heat treatment of normalized mixtures was carried out at a temperature of  $87 \pm 2^\circ\text{C}$  for 2–3 minutes. The pasteurized mixtures were cooled to a temperature of  $41 \pm 1^\circ\text{C}$  and fermented until the titrated acidity values were not lower than pH 4.8. The dynamics of fermentation of the control and test samples were studied. After fermentation, the yogurt was cooled to a temperature no higher than  $6^\circ\text{C}$ , kept for up to 14 days, and the characteristics of the product were determined.

Classic yogurt containing 4% skimmed milk powder and 5% sugar was chosen as the basic recipe. In the studied samples, sugar and skimmed milk were completely replaced by the equivalent content of dry products of starch destruction in terms of dry substances. Such a replacement is scientifically substantiated in previous studies based on a set of quality indicators of yogurt with starch hydrolysis products [23,24].

The designation of yogurt samples is given below:

- control sample No. 1 (without dry skimmed milk and sugar);
- control sample No. 2 (4% skimmed milk powder + 5% sugar);
- sample No. 1 (9% maltodextrin MD 10 dry substances);
- sample No. 2 (9% dry substances of glucose syrup IG-42);
- sample No. 3 (9% dry substances of GFS glucose-fructose syrup).

In order to maintain the balance in terms of the content of dry substances in the samples of yogurt with GFS-42, it was taken into account that this syrup

contains at least 70% of dry substances. The difference in protein content in samples with dry products of starch destruction and liquid GFS-42 was compensated by adding an equivalent content of dry skimmed milk to sample No. 3.

The total content of dry substances, including protein, in samples of yogurt with a mass fraction of fat of 1% is given in Table 2.

Active acidity is determined by the potentiometric method using a laboratory pH/MV/ISE/Temp ADWA AD1200 ATC meter.

Water activity ( $A_w$ ) was measured using a water activity meter "HygroLab 2" (Rotronic, Switzerland), with an accuracy of  $\pm 0.001$  units of  $A_w$ . Water activity was expressed as values from 0.00 to 1.00  $A_w$  (0–100% rh). Before measurement, the device was calibrated according to a special humidity standard (95% HR). The measurements were carried out at a temperature of  $20^\circ\text{C}$  [29].

Syneresis of yogurt samples was determined by centrifugation of yogurt samples. For this,  $25\text{ cm}^3$  of yogurt, after mixing in a calibrated test tube, was centrifuged using a Sigma 2-6E laboratory centrifuge (Germany) for 20 minutes at 1000 rpm and a temperature of  $20^\circ\text{C}$ , and the volume of the separated whey was measured, which was expressed in  $\text{cm}^3$  per 100 g of product [30].

The viscosity of the studied mixtures was measured on a Kinexus Pro+ rotary rheometer (Malvern Instruments Ltd, United Kingdom). The upper geometry – C25 DIN L0142 SS, which is a cylinder, and the lower geometry PC25 DIN C0350 AL – were used for research. Yogurt was gently mixed for 30 s and placed in a cylinder, the upper geometry was lowered, brought to a temperature of  $10^\circ\text{C}$  and kept for 5 min. Viscosity curves were determined by changing the shear rate in the forward direction with its gradual increase in the range of  $0.1\text{--}400\text{ s}^{-1}$  and in the reverse direction  $400\text{--}0.1\text{ s}^{-1}$ . The viscosity and thixotropic ability of the control and experimental yogurt samples were determined on the 14th day of storage, which is the average shelf life of the product with the most pronounced viscous characteristics.

The mass fraction of dry substances in yogurt samples was determined by the well-known method of drying the samples to a constant mass using a Memmert UF260 drying oven (Germany), followed by the calculation of the mass fraction of dry substances in percent [31].

All results for 3–5 repetitions were statistically processed using the Statistics 10 program. Diagrams were created in Microsoft Excel 2016.

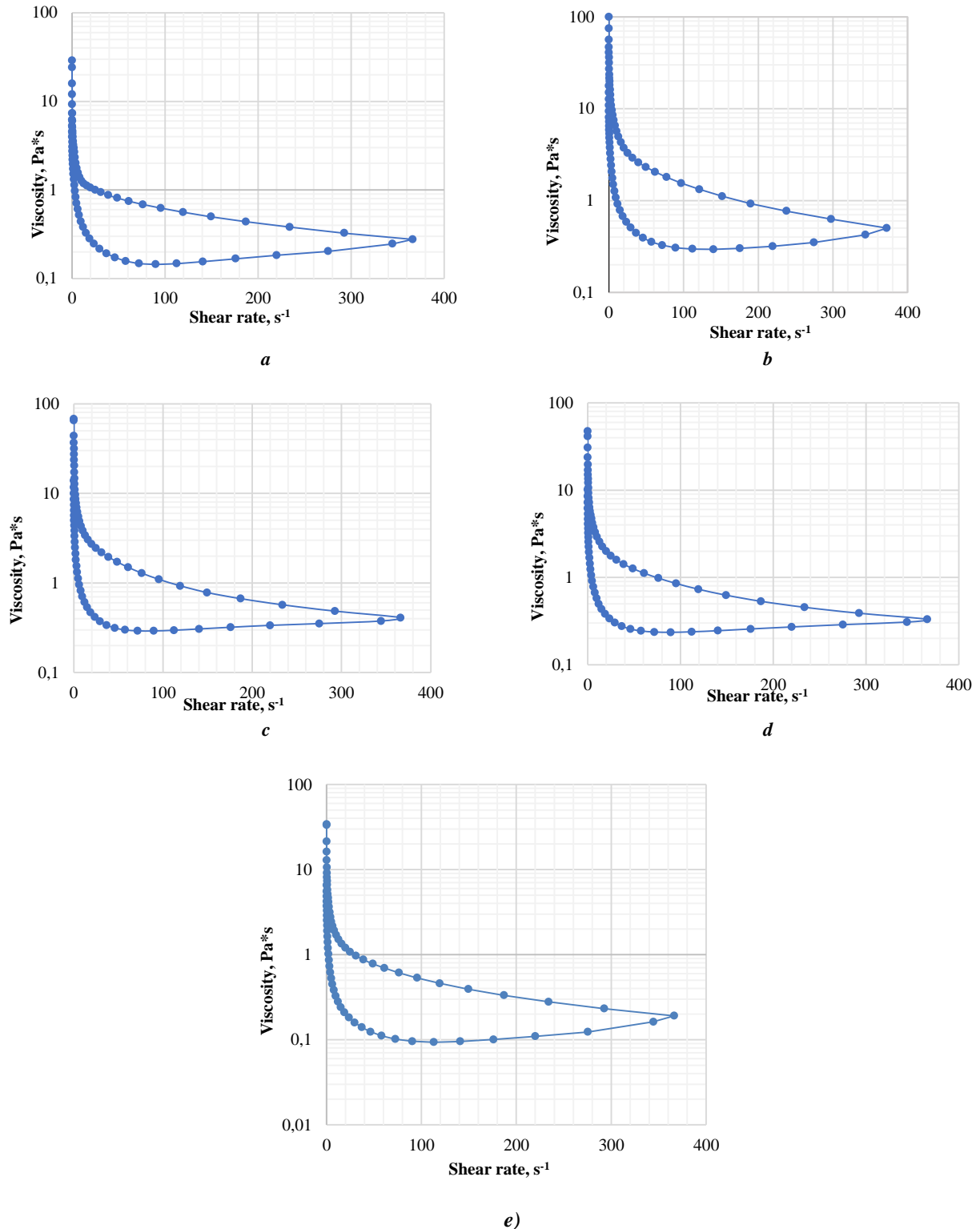
**Table 2 – Dry matter and protein content of yogurt samples**

Constituent components, %	Type of yogurt sample				
	Control No. 1	Control No. 2	Sample No. 1	Sample No. 2	Sample No. 3
Total dry matter content, including protein	$9.1 \pm 0.6$	$17.19 \pm 0.8$	$17.18 \pm 0.6$	$17.18 \pm 0.7$	$17.18 \pm 0.6$
	$3.2 \pm 0.1$	$4.1 \pm 0.2$	$2.9 \pm 0.1$	$2.9 \pm 0.1$	$2.9 \pm 0.1$

**Results of the research and their discussion**

The dynamics of changes in the viscosity of control and experimental yogurt samples during rheometric measurement at variable shear rates are shown in Fig. 1.

For a more detailed interpretation of the research results in Table 3 shows the numerical values of individual viscosity-speed characteristics of yogurt samples



**Fig. 3. Sorption isotherms of samples of multifunctional film from intestinal raw materials, which were dried at temperatures, °C: 1 – 40; 2 – 50; 3 – 60; 4 – 70**

Table 3 – Viscosity-speed characteristics of experimental samples of yogurt

Samples	Effective viscosity (Pa*s) under variable shear rate gradient			The degree of restoration of the structure, %
	$\gamma = 0,1 \text{ s}^{-1}$ (straight course)	$\gamma = 366,3 \text{ s}^{-1}$	$\gamma = 0,1 \text{ s}^{-1}$ (reverse course)	
Control No. 1	28.76±1.33	0.14±0.01	6.03±0.17	20.97
Control No. 2	99.77±2.93	0.29±0.02	17.72±0.89	17.76
Sample No. 1	67.9±2.07	0.29±0.01	13.94±0.43	20.53
Sample No. 2	47.33±1.95	0.24±0.01	10.12±0.77	21.38
Sample No. 3	33.95±1.11	0.09±0.004	6.44±0.19	18.96

The results of the study presented in Fig. 1 and Table. 2, testify to the important role of dry substances in the process of structuring the yogurt clot, which is confirmed by the significant difference in the values of the effective viscosity of the practically intact structure of control sample No. 1 and control sample No. 2 due to the difference in the content of dry substances in them of 8%. Almost two times higher content of dry matter in samples with starch products, compared to the control sample, even with a decrease in protein content (Table 2), contributed to the formation of a stronger yogurt clot.

Analysis of the structuring ability of starch hydrolysis products with different dextrose equivalents in the composition of yogurt revealed a direct influence on this characteristic of higher sugars. Thus, with a 1.4 times lower protein content for sample No. 1 with maltodextrin compared to control No. 2 with full replacement of dry skimmed milk and sugar, the closest approximation of the effective viscosity to this characteristic was found for control No. 2 (99.77 Pa\*s). With a decrease in the content of higher sugars from 90.6% (MD-10) to 53% (IG-42) and to 1% (GFS-42), the effective viscosity of the practically intact structure of yogurt samples with these ingredients was consistently reduced by 1, 4 and 2 times.

A high shear rate weakens the electrostatic and hydrophobic interactions inside the yogurt protein gel and leads to its mechanical destruction [5], so a significant drop in the effective viscosity was observed for all samples. At the maximum shear rate gradient, control No. 2 (classical yogurt) and sample No. 1 with maltodextrin showed the greatest and equal resistance to the destructive force (0.29 Pa\*s). This characteristic was quite similar for sample No. 2 with glucose syrup (0.24 Pa\*s). The detected effect is explained by the higher energy of intermolecular non-covalent bonds in the presence of higher sugars and milk proteins, compared to sample No. 3 in the absence of higher sugars and control No. 1 with a low dry matter content.

The thixotropic ability of yogurt samples of different chemical composition, which was numerically expressed through the degree of structure recovery (%) during the reverse course of the measurement,  $\gamma = 0.1 \text{ s}^{-1}$  turned out to be quite unexpected. The lowest thixotropy was found for the sample with sucrose disaccharide (control No. 2, mass fraction of sucrose disaccharide 5%), the thixotropy

was slightly higher for the sample with monosugars (sample No. 3, mass fraction of glucose and fructose 8.64%, maltose disaccharide – 0.18 %).

Thus, it has been confirmed that sucrose, compared to monosugars, most suppresses the manifestation of thixotropy in food systems by inhibiting the organization of macromolecular chains of milk proteins. It is sucrose molecules with equatorial hydroxyl groups that prevent the rearrangement of chains of protein macromolecules, which leads to the formation of a weaker structure, while molecules with axial hydroxyl groups (fructose) have the opposite effect [32]. The specified feature of sucrose as a sweetener should be taken into account. In our case, to increase the thixotropic ability of yogurt, it is advisable to replace sucrose with higher sugars and even monosugars in its composition.

The ability to restore the structure for control No. 1 and samples No. 1 and No. 2 was found to be practically at the same level. Higher sugars in samples No. 1 and No. 2 fully compensated for the decrease in protein content by 0.3%, compared to control sample No. 1, but did not reveal a significant increase in the thixotropic ability of yogurt. The fairly high thixotropy of control No. 1 can be explained by the natural ability of milk proteins to self-restore low-energy bonds in the absence of any biopolymers of a different nature.

At the next stage, water activity was determined in yogurt samples of different chemical composition. The measurement results are shown in Fig. 2.

According to fig. 2, the activity of water in yogurt is most affected by GFS-42, which is quite expected, considering that this syrup contains 96% of glucose and fructose from the total content of dry substances [33]. As the content of monosaccharides in IG-42 and MD-10 syrup decreases, the activity of water increases, compared to yogurt with GFS-42. Sucrose in control No. 2 is close to the sample with IH-42 in terms of its effect on water activity. Considering the revealed influence of starch products on water activity, it is advisable to check the influence of mono-, di- and higher sugars present in them on the activity of lactic acid microflora and the storage capacity of yogurt.

The indirect effect of starch products on the vital activity of lactic acid bacteria in the composition of sourdough for yogurt was investigated by the dynamics of the fermentation process of the studied mixtures (Fig. 3).

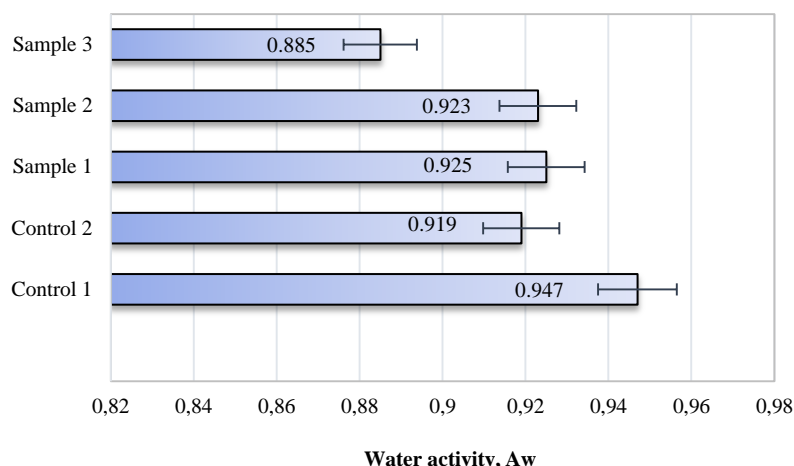


Fig. 2. Water activity in experimental yogurt samples

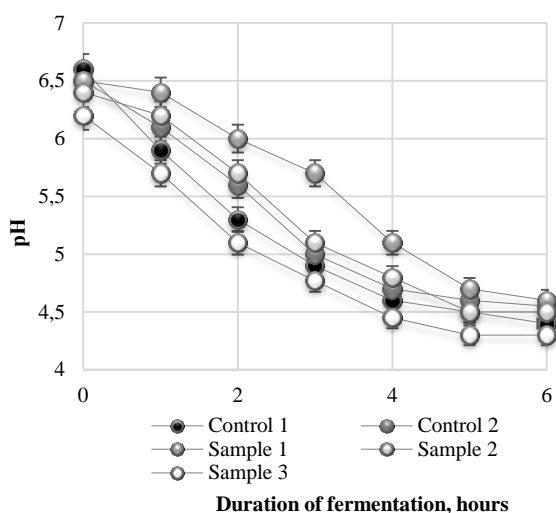


Fig. 3. Dynamics of the fermentation process of samples of normalized milk mixtures with starch products

According to Fig. 3, the greatest inhibition of the vital activity of lactic acid microorganisms was found for MD-10 and IH-42, which is explained by the presence of a sufficient number of higher sugars in the composition of these starch hydrolysis products, which effectively bind water as a medium for the vital activity of microorganisms. Instead, glucose and fructose in GFS-42 activate lactic acid bacteria, which shortens the fermentation time of milk mixtures.

The general regularities of the nature of fermentation of yogurt samples as a whole are similar to the features of the activity of lactic acid microflora discovered by the authors in previous studies, where mixtures with liquid starch molasses/syrups were studied: glucose-fructose syrup, glucose syrup, low-sugar molasses, the dextrose equivalent of which was 97–98, 40–42 and 30, respectively [21]. According to Fig. 3, the general trend of dependence of the duration of fermentation of milk mixtures on the dextrose equivalent of starch products in the amount of 9% is confirmed.

At the next stage, the dynamics of changes in acidity and the syneretic capacity of yogurt samples during storage for 14 days were investigated. Taking into account the fact that higher sugars effectively bind moisture and show structuring ability, and mono- and di-sugars are effective sweeteners, it is possible to predict different effects of these starch products on the degree of syneresis of milk-protein curds in yogurt and on their acidity. The results of checking this assumption are shown in Fig. 4 and Fig. 5.

According to Fig. 4, the role of higher sugars in MD-10 and IG-42 (samples No.1 and No.2) in increasing the moisture-holding capacity of yogurt is obvious. Probably, high-molecular products of starch hydrolysis contribute to the formation of a more compact, cross-linked gel, which increases its ability to retain moisture in the clot during storage [34].

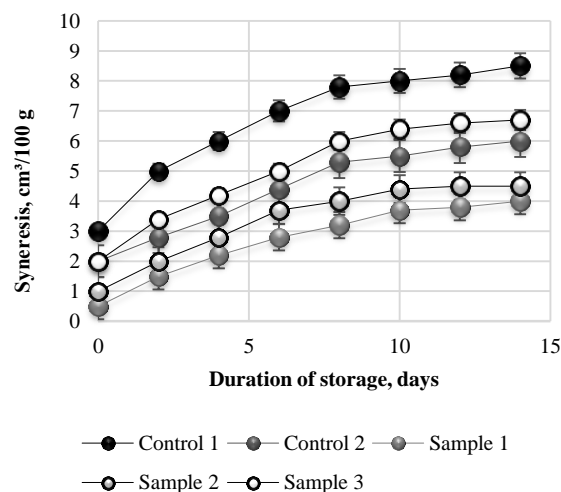
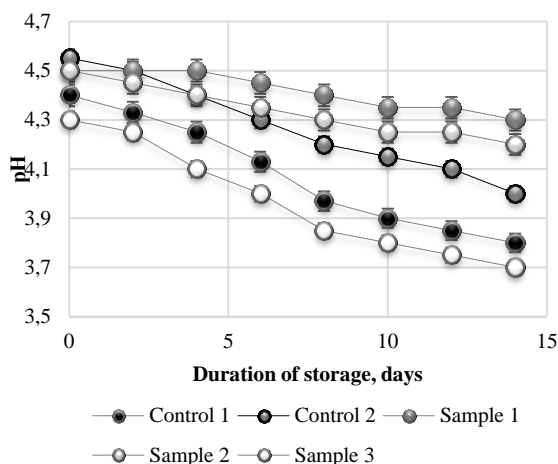


Fig. 4. Dynamics of changes in syneresis of yogurt clots during storage



**Fig. 5. Dynamics of changes in the active acidity of yogurt samples during storage**

On the Fig. 5 demonstrated the different nature of the activity of lactic acid bacteria during storage for yogurt samples was also revealed. It is worth pointing out the relatively high activity of acid-forming bacteria in the presence of monosugars (sample No. 1) and the suppression of this activity in the presence of higher sugars (samples No. 1 and No. 2). Activation of the vital activity of lactic acid bacteria in the presence of fructose was proven by Zielińska D. at all [35] and is confirmed by those shown in Fig. 2, 3 and 5. Thus, it has been confirmed that the decrease in water activity in the presence of monosaccharides indirectly affects the activity of lactic acid bacteria.

**Approbation of research results.** The results of the conducted research are of practical significance, since the revealed regularities of the influence of starch products of varying degrees of saccharification on the rheological and physical and chemical properties of low-fat yogurt will allow purposeful management of the process of forming its quality indicators. Starch hydrolysis products are natural sweeteners and structuring ingredients, quite cheap and available on the market, so their wide use in the production of low-

fat and low-fat yogurts will expand the assortment of fermented milk drinks for dessert purposes.

### Conclusion

The possibility of completely replacing sugar (5%) and dry skimmed milk (4%) in the composition of yogurt with a fat content of 1% with an equivalent amount of dry substances of maltodextrin MD-10 or glucose syrup IG-42, which contain 90.6% and 53% of structuring higher sugars and ensure the formation of proper rheological characteristics characteristic of a high-quality product. Yogurt with sucrose, which inhibits the organization of macromolecular chains of milk proteins, and GFS-42 has the lowest thixotropic ability, and the highest - with maltodextrin MD-10 and glucose syrup IH-42.

The predominance of higher sugars in the composition of MD-10 maltodextrin lengthens, and the increased content of monosaccharides in GFS-42 accelerates the duration of fermentation of milk mixtures in the technological process of production of yogurt with a fat content of 1.0%. Glucose and fructose in GFS-42 have the greatest effect on water activity and reduce the moisture-holding capacity of yogurt.

The degree of influence on the rheological characteristics and moisture-binding capacity of yogurt increases with a decrease in the dextrose equivalent of starch products in the following sequence: GFS-42 → IG-42 → MD-10. Thus, it is the dextrose equivalent (degree of saccharification) of starch products that is an objective criterion of their technological activity as part of yogurt.

The prospect of further research consists in studying the influence of selected starch products on the activity of certain types of lactic acid bacteria during fermentation of milk mixtures and storage of yogurt. It is also planned to carry out a sensory evaluation of yogurt samples with starch products to select the best recipe composition of the product, which will be recommended for implementation.

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## ВПЛИВ КРОХМАЛЕПРОДУКТІВ НА РЕОЛОГІЧНІ ТА ФІЗИКО-ХІМІЧНІ ВЛАСТИВОСТІ ЙОГУРТУ

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**Анотація.** Розширення асортименту йогурту низької жирності з натуральними структуруючими підсолоджувачами і регульованими показниками якості є актуальним напрямом наукового дослідження. Мета дослідження – вивчення закономірностей впливу продуктів ферментативного гідролізу кукурудзяного крохмалю з різним декстрозним еквівалентом на реологічні та фізико-хімічні характеристики йогурту. Досліджено функціонально-технологічні властивості крохмалепродуктів різного хімічного складу – мальтодекстрин MD-10, глюкозний сироп П-42 і глюкозно-фруктозний сироп ГФС-42. Встановлено можливість повної заміни сухого знежиреного молока і цукру у складі йогурту жирністю 1% питного на еквівалентний вміст сухих речовин мальтодекстрину MD-10 і глюкозного сиропу П-42, які забезпечують формування належних реологічних характеристик, властивих продукту високої якості. Найнижчу тиксотропну здатність виявляє йогурт з сахарозою, яка інгібує організацію макромолекулярних ланцюгів молочних білків, а найвищу – йогурт з мальтодекстрином MD-10 і глюкозним сиропом П-42. Переважання вищих цукрів у складі мальтодекстрину MD-10 подовжує, а підвищений вміст моноцукрів у ГФС-42 прискорює тривалість ферментації молочних сумішей в технологічному процесі виробництва йогурту жирністю 1,0%. Моноцукри у складі ГФС-42 суттєво впливають на активність води і водночас знижують вологоутримувальну здатність кисломолочного згустку йогурту. Ступінь впливу на реологічні характеристики і вологозв'язувальну здатність йогурту підвищується зі зменшенням декстрозного еквіваленту крохмалепродуктів у такій послідовності: ГФС-42 → П-42 → MD-10. Таким чином, саме декстрозний еквівалент крохмалепродуктів є об'єктивним критерієм їхньої технологічної активності у складі йогурту. Результати дослідження дозволяють цілеспрямовано управляти процесом формування показників якості йогурту низької жирності.

**Ключові слова:** йогурт, крохмальна патока (сиропа), мальтодекстрин, ефективна в'язкість, тиксотропна здатність, ступінь синерезису, активність води, активна кислотність.