

Advanced Specialized Foods Production Technologies within the Framework of Foodnet

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Abstract—The object of this paper is to conduct an evidence-based study of lactose hydrolysis by special enzymes: how different amount of lactose in milk has an effect on the quality of specialized foods at the end of technological process. Conducted studies revealed that the addition of Maxilact enzyme leads to the removal of almost 99% of lactose from raw milk. Based on the data obtained, a mathematical analysis was carried out and 3D dependencies on a number of parameters were created. Studies of lactose hydrolysis results, together with other ones, form the basis of advanced technologies for specialized foods within the framework of Foodnet market. Developed technologies are also considered in terms of products for baby food and preschool nutrition what allows full market coverage.

Keywords—*lactose, hydrolysis, advanced technologies, specialized foods, Foodnet.*

I. INTRODUCTION

Currently, both in Russia and in other countries, the process of scientific background and practical development of a fundamentally new generation of foods is in active progress; in connection with it, the development of new technologies for specialized foods production takes place.

One of the most controlled sectors is the specialized food ingredients sector. In European countries these are checked and controlled by special EU services [1, 2].

The National Technological Initiative is currently developed and implemented in Russia.

A. The National Technological Initiative (NTI)

One of NTI areas is the development of the production of foods and nutrients, and this is Foodnet market.

Foodnet is a market for the production and sale of nutrients and final food products (personalized and general, made with traditional raw materials and their substitutes), as well as related IT solutions. Foodnet is an advanced development strategy for the agro-industrial complex of the Russian Federation. It suggests that digitalization, genome changes, and alternative sources of raw materials will be widely applied in agriculture. The formation of new Foodnet market will be influenced by key stakeholders (final consumers), according to the capabilities of modern scientific technologies based on intellectualization, automation of production processes throughout product life cycle – from production to consumption [3,4,5].

Personalized Nutrition Digital Platform is being developed for Foodnet Market

Personalized nutrition is a segment which includes technologies for analyzing the nutritional and micronutrient status of a person using genome and post-genome methods, personalized food products, services for selecting personal diets, as well as innovative delivery services. Each product will have a specific composition, and will also be personalized in taste and flavor.

One of the areas of Foodnet Market is the technology for the production of low-lactose and lactose-free dairy products using various enzymes to obtain different degrees of lactose hydrolysis.

Lactose content in cow's milk amounts to 4.4-4.9%. In its pure form, lactose is a disaccharide that can disintegrate into separate glucose and galactose molecules. Dilute acids, enzymes, and ion-exchange resins can influence the hydrolysis of this disaccharide. [6,7].

Significant contribution to the study of the physicochemical properties of lactose was made by Russian and foreign scientists: M.S. Kovalenko, A.G. Khrantsov, K.K. Polyansky, A.N. Fialkov, A.A. Rozanov, V.A. Pavlov, E.F. Kravchenko, A.I. Gnezdilova, I.A. Evdokimov, B.L. Herrington et al. [9,10]

II. RESEARCH METHODOLOGY

Core studies were carried out in the laboratories of the Federal State Budgetary Educational Institution of Higher Education Stolypin Omsk State Agrarian University; of KemTIPPa Research and Educational Center (at present – Kemerovo State University); of Manros-M Accredited Production and Testing Laboratory, the branch of WBD JSC.

Objects subject to investigation were:

- Maxilact enzyme preparation;
- milk raw material.

In experimental studies, standard and generally accepted methods for determining the chemical parameters of products were used [7].

Lactose hydrolysis tests were performed in specialized laboratory boxes:

- a hydrolytic enzyme was added to the samples of raw milk at the temperature of $(35.6 \pm 0.5)^\circ\text{C}$;
- the mixture was prepared at the temperature of $37 \pm 1^\circ\text{C}$;
- temperature in the box was maintained at the level from 9 to 55°C ; the acidity of medium was from 5.0 to 8.5 pH units; hydrolysis process duration varied from 1 to 24 hours;
- then titration was carried out to find the degree of hydrolysis.

III. RESULTS AND DISCUSSION

From the large number of methods for milk sugar hydrolysis, enzymatic one is used more frequently because does not require sophisticated equipment. This method allows saving the nutritional and biological value of product.

Maxilact enzyme was chosen as the main object; it is a chemical substance based on purified lactase which is obtained by isolation from selected strains of milk yeast *Saccharomyces (Kluyveromyces) marxianus va. lactis*. This preparation has the following characteristics: pH (5.0-8.5), working reaction temperature, ($^\circ\text{C}$) from 9.0 to 55.0, and enzyme activity (NLU/L) of not more than 2020.

In food production technologies used for trainings, this enzyme is preferable due to its optimal effect in neutral environment.

The above preparation hydrolyzes milk disaccharide into two monosaccharides: glucose and galactose. Some factors such as temperature, acidity, reaction time, lactose and enzyme concentration determine the reaction rate [8].

Skim milk became the model medium; its physicochemical characteristics are shown in Table 1. This medium is maximally adapted for the production of a personalized low-lactose food product.

In such an environment, the complex of biologically active substances is also preserved, with a small energy value.

TABLE I. PHYSICOCHEMICAL CHARACTERISTICS OF MODEL MEDIUM

Physicochemical characteristics	Value
Titrated acidity, °T	16-21
Active acidity, pH	6.5
Mass fraction of protein, %	2.8
Mass fraction of lactose, %	4.76
Mass fraction of fat, %	0.5
Density, g/cm	1.030

Disaccharide stability activity is improved in the presence of magnesium (10-4 M), manganese (10-3 M) and potassium (10-5 M). Concentration of phosphates up to 10-2 M has a somewhat positive effect on stability due to the binding of calcium ions. Actually, in the goods there are both activating and inhibiting minerals, and the actual effect of metal ions should be determined for each substrate. No additional special conditions are required if the milk or sweet whey is hydrolyzed in stainless steel equipment. If the adjustment of medium acidity is required (usually for pH increase), it is recommended to use potassium hydroxide since potassium increases activity greatly.

The first – and one of most important – factor in the process of milk disaccharide hydrolysis is temperature.

In order to make our approach more clear and rational, the experiment was conducted with the temperature range from 9.0°C to 55.0°C , for 2-5 hours, with constant active acidity (6.55 ± 0.03) pH units. Temperature was increased by 10.5°C in order to see how the reaction proceeded with non-meeting the requirements for enzyme preparation. The amount of added Maxilact preparation varied from 0.02% in the first test to 0.10% in the fifth test.

Test results and temperature effect on reaction duration are shown in Figure 1.

Furthermore, the data obtained were processed using mathematical logarithmic dependencies, and regression equations were obtained which are presented in Table 2.

It should be noted that at certain temperatures, lactose is hydrolyzed almost completely, more precisely up to 91.90%; such temperatures are in the range from 35.60 to 40°C . In the description using second order polynomial, a high value of correlation coefficient was obtained.

The fact that hydrolysis process is accelerated along with temperature increase can be explained by the fact that the abovementioned enzyme preparation is of yeast origin and was used in optimal dosages.

During the study, it was assumed that a decrease in the degree of carbohydrate hydrolysis in a model medium is also possible. This assumption was confirmed; this phenomenon can be theoretically associated with the “partial” loss of enzyme preparation activity what can then lead to its catalytic activity.

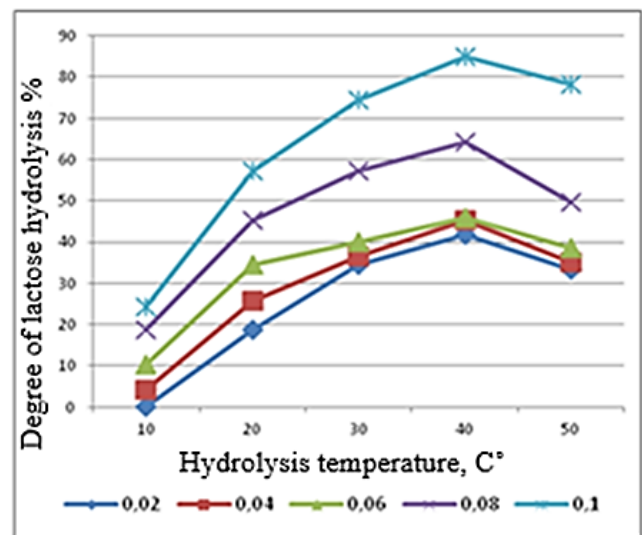


Fig. 1. Ratio of hydrolysis temperature to its degree in a model medium at various enzyme concentrations

Considering all the data obtained during the study, it becomes clear that temperature is of great importance that should be emphasized. In this case, milk sugar hydrolysis in low-fat milk proceeded efficiently at average temperatures from 35 to 40 degrees Celsius. If the temperature during the hydrolysis is maintained at about 35 degrees, then it is possible to obtain a degree of lactose hydrolysis up to 92% while the

properties of final product will acquire no negative characteristics.

TABLE II. RELATION OF LACTOSE HYDROLYSIS LEVEL TO PROCESS TEMPERATURE AT VARIOUS ENZYME CONCENTRATION

Enzyme dose, %	Type of regression equation	Correlation coefficient	Average forecast error, %
0.02	$Y = -0.0392 x^2 + 3.1735 x - 25.608$	0.984	4.98
0.04	$Y = -0.0436 x^2 + 3.3942 x - 24.05$	0.989	6.39
0.06	$Y = -0.0442 x^2 + 3.3305 x - 17.488$	0.988	5.44
0.08	$Y = -0.0624 x^2 + 4.5476 x - 20.836$	0.994	2.45
0.10	$Y = -0.0641 x^2 + 5.1702 x - 20.946$	0.999	1.21

Next step was to find the dependence of the process on its duration. In order to find the effect of process duration on the degree of disaccharide hydrolysis in pasteurized and chilled to a certain temperature low-fat milk, enzyme preparation at the concentration of 0.02 and 0.10 percent was used. Special attention during this process was paid to temperature regime and active acidity level of medium.

Data and parameters obtained in the course of this test were analyzed, processed and shown in Figure 2.

Different factors can influence process efficiency, including exposure. Exposure and its impact on process effectiveness were studied during one day at the certain temperature. Results obtained allowed concluding that there was a negative effect since desired hydrolysis degree has not been obtained.

The abovementioned dependence is presented in the form of a polynomial with the extremely high value of correlation coefficient. This third-order polynomial and the reliability of results confirm the minimal values of forecast error parameters.

After the systematic analysis of all changes during performing hydrolysis in an experimental medium (including process duration and the concentration of enzyme added), it was found that the rate of obtaining equivalent values for the degree milk disaccharide hydrolysis is higher in the samples with higher enzyme concentration.

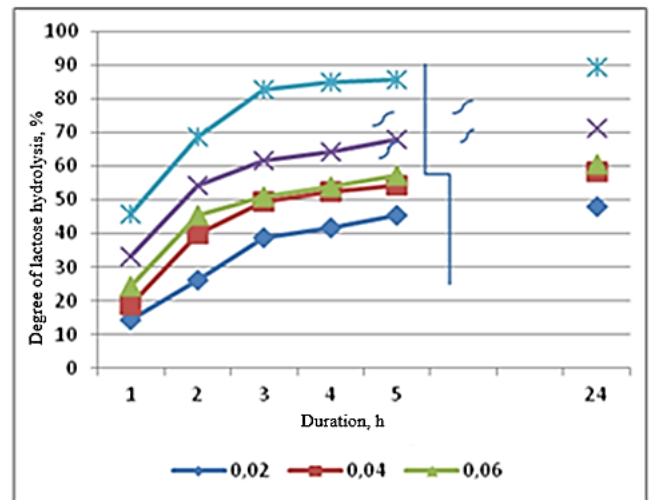


Fig. 2. Ratio of changes in lactose hydrolysis degree in a model environment to process duration and enzyme amount

Data obtained during this test are shown in Figure 3.

Mathematical analysis of these data allowed obtaining the regression equations which are presented in Table 3.

TABLE III. RELATION LACTOSE HYDROLYSIS STAGES TO THE ACTIVE ACIDITY OF MILK AT DIFFERENT ENZYME CONCENTRATION

Enzyme dose, %	Type of regression equation	Correlation coefficient	Average forecast error, %
0.02	$Y = -13.684 x^2 + 194.18 x - 641.35$	0.976	9.28
0.04	$Y = -14.871 x^2 + 209.81 x - 688.64$	0.985	5.42
0.06	$Y = -14.552 x^2 + 205.26 x - 668.75$	0.954	7.33
0.08	$Y = -16.354 x^2 + 229.72 x - 743.45$	0.963	5.43
0.10	$Y = -23.684 x^2 + 326.61 x - 1044.6$	0.958	6.58

Adjusting process duration and enzyme amount can provide desired degree of hydrolysis. This plays an important role in reducing the cost of personalized, specialized, low-lactose food product.

TABLE IV. RELATION OF LACTOSE HYDROLYSIS LEVEL TO PROCESS TEMPERATURE AT VARIOUS ENZYME CONCENTRATION

Enzyme amount, %	Regression equation	Multiple correlation	Forecast error, %
Change in lactose hydrolysis degree over time			
0.02	$Z = \frac{15,367 - 0,0647 \ln(y)}{1,133 - 1,238 \ln(y) + 0,628 \ln(y)^2 - 0,101 \ln(y)^3}$	0.994	4.18
0.04	$Z = \frac{25,486 - 0,0647 \ln(y)}{1,267 - 1,238 \ln(y) + 0,628 \ln(y)^2 - 0,101 \ln(y)^3}$	0.995	2.88
0.06	$Z = \frac{35,177 - 0,0647 \ln(y)}{1,4003 - 1,238 \ln(y) + 0,628 \ln(y)^2 - 0,101 \ln(y)^3}$	0.996	3.24
0.08	$Z = \frac{50,074 - 0,0647 \ln(y)}{1,534 - 1,238 \ln(y) + 0,628 \ln(y)^2 - 0,101 \ln(y)^3}$	0.999	1.86
0.10	$Z = \frac{75,813 - 0,0647 \ln(y)}{1,667 - 1,238 \ln(y) + 0,628 \ln(y)^2 - 0,101 \ln(y)^3}$	0.994	1.19
Change in lactose hydrolysis degree associated with temperature			
0.02	$Y = -0.0392x^2 + 3.1735x - 25.608$	0.985	4.91
0.04	$Y = -0.0436x^2 + 3.3942x - 24.05$	0.989	6.44
0.06	$Y = -0.0442x^2 + 3.3305x - 17.488$	0.983	5.38
0.08	$Y = -0.0624x^2 + 4.5476x - 20.836$	0.995	2.32
0.10	$Y = -0.0641x^2 + 5.1702x - 20.946$	0.998	1.28
Change in lactose hydrolysis degree associated with active acidity			
0.02	$Y = -13.684x^2 + 194.18x - 641.35$	0.978	9.29
0.04	$Y = -14.871x^2 + 209.81x - 688.64$	0.999	5.35
0.06	$Y = -14.552x^2 + 205.26x - 668.75$	0.960	7.27
0.08	$Y = -16.354x^2 + 229.72x - 743.45$	0.975	5.63
0.10	$Y = -23.684x^2 + 326.61x - 1044.6$	0.953	6.42

It was also necessary to analyze how the progress of hydrolysis process depends on the active acidity of medium. For this, samples of skim milk were prepared with the acidity from 5.0 to 8.5 in increments of 0.4 pH units.

To do this, four normal solution of potassium hydroxide was added to milk. Enzyme preparation in the amount from 0.02 in the first test to 0.1% in the fifth test was added to the obtained samples which consisted of model medium after pasteurization and cooling to the temperature of 35.60°C. Interval was 0.02%. Measurement error could be 0.005%. Hydrolysis process was carried out at constant temperature and time which amounted to 4±0.5 hours.

The findings of studying how the degree of carbohydrate hydrolysis in a model medium depends on the active acidity of medium at different enzyme concentrations suggest that the greatest degree was achieved with the acidity of (6.35±0.05) pH units. The course of this process with the optimal acidity value for the active action of enzyme, in its turn, allows reducing the amount of enzyme used and reducing the cost of final product [8]

The degree of influence of the enzyme with the trade name of Maxilact on hydrolysis process efficiency can be figured out on the basis of mathematical modeling based on total findings obtained during this study.

Based on the mathematical analysis of these data, graphical dependencies were made in the form of response functions for different parameters (Table 4). Mathematical models of changes of hydrolysis degree in a model medium were obtained depending on process duration, temperature and active acidity of medium at different concentrations of the enzyme under the trade name of Maxilact.

By combining all obtained findings and their mathematical modeling and by analyzing the graphic dependencies of regression equations, rational technological modes for carbohydrate hydrolysis in skim milk (model medium) were defined:

- process temperature (35.6 ± 0.5) °C;
- process duration (4.5±0.5) h;
- active acidity of fermentation medium (6.35±0.05) pH units.

IV. CONCLUSIONS

1. Adding Maxilact enzyme to milk raw materials allows obtaining lactose hydrolysis up to almost 99%.
2. Evidence-based analysis of experimental data allows concluding that the most rational dosage of enzyme preparation is 0.1%; it leads to an increase in hydrolysis degree up to 90%. This hydrolysis degree is the most optimal for obtaining specialized low-lactose foods.
3. With the further development of technologies for obtaining personalized low-lactose and lactose-free food products as part of the resource-saving technologies of the Foodnet market, it is necessary to correlate the temperature conditions of fermentation and adding new components and starter cultures; by forming dependencies at different concentrations, it is possible to obtain a product with the shelf life of 5 to 7 days at storage temperature 4 ± 2°C.

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