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Fermented oat milk as a base for lactose-free sauce

Dmitrii V. Khrundin*, Vsevolod Ya. Ponomarev, Eduard Sh. Yunusov

Kazan National Research Technological University, Kazan, Russia

* e-mail: khrundin@yandex.ru

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Abstract:
Introduction. We studied the use of fermented oat milk to produce sauce and evaluated its properties. The research was motivated by the current demand for so called "plant milk" commonly perceived as an alternative to cow's milk.
Study objects and methods. The experimental samples were produced from oats-based drinks (1.5 and 3.2% fat) fermented with starter cultures of lactic acid microorganisms following the guidelines for yoghurt production. Apple pectin was used as a thickener. Rheological studies were performed using an RM-1 rotational viscometer and a CT-2 texture analyzer according to the standard methods. Sensory evaluation was based on a scoring scale. Physicochemical parameters were determined according to generally accepted methods.
Results and discussion. Oat milk was fermented to produce a sauce base. Acid accumulation increased throughout fermentation up to 135–137°T. Apple pectin (3%) was added to stabilize the structure and ensure the desired consistency. Higher concentrations of pectin increased the hardness and adhesive strength of the samples from both 1.5 and 3.2% oat milk. The 1.5% sauce scored highest in the sensory evaluation. Its physicochemical indicators met the standard requirements for related fermented milk products. We found the best consistency indicators at a pectin concentration of 3%.
Conclusion. The new fermented sauce based on low fat oat milk (1.5% fat) had high consumer appeal as well as physicochemical, sensory, and rheological characteristics. The sauce can be used by people with lactose intolerance and vegetarians.

Keywords: Oats, plant milk, sauce, fermentation, apple pectin, rheology, lactose-free

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INTRODUCTION

The relationship between nutrition and disease is in the spotlight of modern agenda [1, 2]. Half of global health risks identified by the World Health Organization are related to diet, including increased sodium and cholesterol intake, iron and zinc deficiency, etc. Therefore, new food products should be designed not only to satisfy hunger and provide the body with basic nutrients, but also to prevent nutrition-related diseases and improve our physical and emotional well-being [3].

On the one hand, consumers are becoming better aware of the relationship between food composition and health. These are both young people with an active lifestyle and older people who want to maintain and improve their quality of life. On the other hand, the need for special or alternative foods may be associated with a physiological inability to assimilate some vital food components. For example, people with allergies, whose number is on the rise, should avoid gluten, casein, lactose, and other components found in most balanced and affordable ingredients and products (flour, bread, milk, etc.). All this speaks to the relevance of recent research in this field [4–7].

The rising demand for healthy foods and eco-friendly bio-products has an immediate effect on the food market [8, 9]. New types of products are being developed that are enriched with individual components and multifunctional additives [10, 11].

Plant-based milk is a good example of this trend. Made from nuts or grains, it has a long history in both Eastern and Western cultures. Soy milk is the most popular type, although the demand is also growing for almond, coconut, rice, and oat milk. European countries, especially Spain, boast a 20% rise in the annual sales of soy milk and other non-dairy beverages. In 2011, the USA sold $1.3 billion worth of milk from soy, almond, rice, and other plants, and their sales have been growing ever since [12, 13].

Table 1 Oat milk profile*

Sample	Protein, %	Carbo-hydrates, %	Energy, kcal	Ingredients
Oat milk, 1.5% fat	1.0	6.5	45	Water, oat flour, rapeseed oil, calcium (tricalcium phosphate), vitamins D_2, and B_2
Oat milk, 3.2% fat	1.0	6.5	60	

Note: manufacturer's information (www. https://ne-moloko.ru)

Plant-based milk is currently marketed in a wide range of formulations: flavored, sweet, low fat, fortified, etc. It is a good alternative for people with a cow's milk allergy or lactose intolerance. In addition, this product can attract people who do not consume food of animal origin for religious or other reasons, for example, vegans and vegetarians.

Noteworthily, researchers are also searching for ways to improve plant milk, using biotechnology or fortifying it with additional components [14–23].

Following the global trend, the Russian food market is becoming more active in satisfying the new consumer demands. Along with the traditional criteria of consumer choice (price, taste, and quality), new criteria are emerging to indicate new models of consumer behavior. They include an increased interest in one's health and lifestyle, product safety, and others. A healthy lifestyle is gradually ceasing to be a fashionable trend and becoming a matter of routine.

Taking into account the demand for these products on the food market and a lack of information on them, we aimed to expand on the prospects of using plant materials to produce new types of foods. We selected oatmeal or oat flakes as the most suitable material. Our choice was based on its availability, chemical composition, nutritional and biological potential, and common use by the Russian population.

Oatmeal is obtained from processing oats. It contains vitamins A, E, K, and group B, as well as potassium, calcium, magnesium, phosphorus, sodium, and zinc. Oatmeal is rich in fiber and high-quality plant protein that helps construct body cells. Its protein is easily digestible and has a balanced amino acid composition. Also, oats-based products protect the walls of the stomach and reduce the acidity of gastric juice, which is important for people with gastrointestinal diseases: gastritis, peptic ulcer, or flatulence [24].

Historically, oatmeal was used in Russia to prepare not only hot dishes, but also kissel and other medicinal beverages. Therefore, oats-based products are still highly appealing. In addition, people like their pleasant smell, color, and a sweet taste.

Currently, we see a growing range of food products with a scientifically grounded composition and target properties. Particular attention is paid to products that have a positive effect on the human body. However, there is a lack of new formulations for foods with a wide range of applications, such as sauces. Sauces can improve the chemical composition and sensory properties of dishes, improve their digestion, etc. [25–27]. In addition, they are becoming an integral part of our daily diet, accompanying almost every dish.

Mayonnaise and ketchup are still the most popular sauces, both in public catering and at home. However, there is a new trend towards reducing the production and consumption of high-fat mayonnaise motivated by the modern food culture and the promotion of a healthy lifestyle [28].

Low-fat salad dressings, which appeared in the 1930s as an alternative to mayonnaise, only became popular at the end of the 20th century, especially in Western countries. In Russia, their use is limited to restaurants with foreign cuisine. Most Russians still know very little about this product.

Therefore, there is a need to formulate new sauces using various ingredients, including plant-based materials, and methods of treatment, including biotechnology. In our work, we aimed to formulate sauce based on oat milk and analyzed its sensory, physicochemical, and rheological parameters.

STUDY OBJECTS AND METHODS

The experimental samples were based on oat milk (1.5 and 3.2% fat, Nemoloko, Russia), with a commercial apple pectin (Pektowin, Poland) used as a thickener (Table 1).

The samples were fermented using the yoghurt technology [29]. The starter culture contained *Streptococcus thermophilus*, *Lactobacillus delbrueckii* ssp. *Bulgaricus*, *Lactobacillus acidophilus*, *Bifidobacterium lactis*, *Lactobacillus casei*, *Lactobacillus rhamnosus*, *Lactobacillus paracasei*, and *Bifidobacterium infantis*. It was introduced in line with the manufacturer's recommendations (https://vivostarters.com). The samples were fermented for 12 h at 38–40°C and then refrigerated for 24 h for curd to form.

The control sample was obtained by fermenting oat milk. The experimental samples were fermented oat milk samples with 2, 3, and 4% of pectin. The physicochemical analysis of the materials and the fermented samples was in line with the guidelines [30]. The rheological studies were carried out using an RM-1 rotational viscometer and a CT-2 texture analyzer according to the generally accepted methods [31, 32]. The sensory evaluation used the weight coefficients and the methods described by Glebova *et al.* and Khrundin *et al.* [33, 34].

All the experiments were performed in at least three repetitions, followed by statistical processing.

RESULTS AND DISCUSSION

To determine the degree of fermentation, we measured active and titratable acidities in 1.5% (Fig. 1a) and in 3.2% oat milk (Fig. 1b).

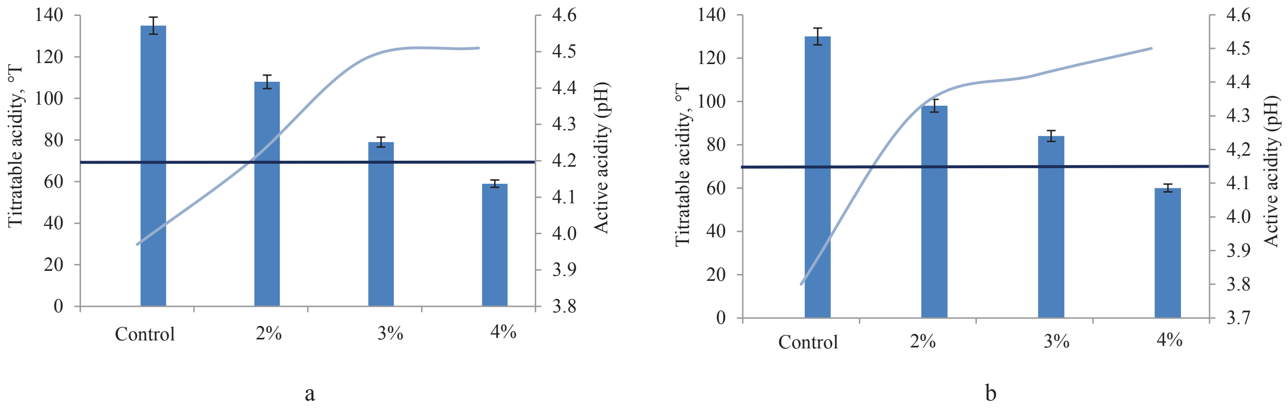

Figure 1 Acidity of control (pectin-free) and experimental (with 2, 3, and 4% of pectin) samples obtained from 1.5% oat milk (a) and 3.2% oat milk (b)

Both the 1.5 and 3.2% samples showed active acid accumulation (60–135 °T), which was within the standard values for similar fermented milk products (Fig. 1). Two of the experimental samples (with 2 and 3% of pectin) reached the threshold acidity of 75 °T, apart from the control. However, the sample with 4% of pectin also had certain features of a fermented product (characteristic smell, taste, and the presence of curd). Therefore, taking into account the product's composition, we can make correction for acidity. We found an increase in titratable acidity and a decrease in pH in both the 1.5 and 3.2% samples.

The physicochemical indicators of the control samples (Table 2) showed their similarity to the traditional fermented milk products.

Earlier studies showed layering and unstable curding in the oat milk samples, despite adequate fermentation [34].

When the samples stabilized following the introduction of pectin, we analyzed their physicochemical and sensory parameters, as well as structural and mechanical properties.

The physicochemical parameters of the experimental oat milk samples are shown in Table 3, respectively.

Table 2 Physicochemical properties of the control samples

Sample	Fat, %	Protein, %	Dry matter, %	Density, kg/m^3	Titratableacidity, °T	Active acidity (pH)
1.5% milk	2.01	2.79	8.43	1024.69	137	4.58
3.2% milk	2.89	2.32	9.37	1021.68	135	4.55

Table 3 Physicochemical properties of samples from 1.5 and 3.2% oat milk

Sample	Fat, %	Protein, %	Dry matter, %	Density, kg/m^3
1.5% oat milk				
Control (pectin-free)	2.01	2.79	8.43	1024.69
2% of pectin	1.81	3.18	8.66	1027.73
3% of pectin	1.88	3.85	8.16	1031.12
4% of pectin	1.97	3.70	9.06	1031.34
3.2% oat milk				
Control (pectin-free)	2.89	2.32	9.37	1021.68
2% of pectin	2.95	2.78	9.70	1025.16
3% of pectin	3.01	3.04	10.00	1027.06
4% of pectin	2.97	3.24	10.00	1028.58

Table 4 Sensory evaluation of oat milk samples

Parameter	Description
Appearance and consistency	Uniform, not viscous enough
Taste and smell	Pure and typical of fermented milk, with a pronounced taste and smell of a plant
Color	Uniformly white

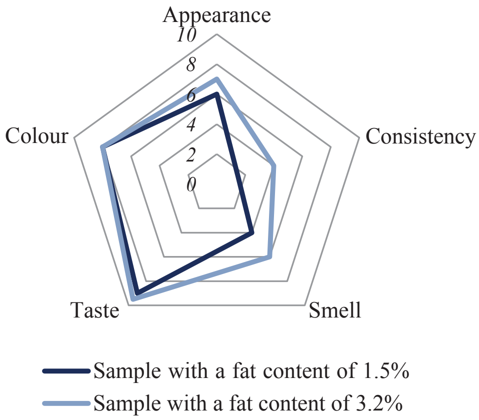

Figure 2 Sensory profile of experimental oat milk samples

Table 5 Effective viscosity of samples from 1.5 and 3.2% oat milk

Sample	Time of measurement, s					
	0	30	60	90	120	180
1.5% oat milk						
Control (pectin-free)	240	30	30	30	30	30
2% of pectin	280	160	150	150	150	150
3% of pectin	380	410	400	400	390	390
4% of pectin	860	880	870	830	830	830
3.2% oat milk						
Control (pectin-free)	120	20	20	20	20	20
2% of pectin	110	70	60	60	60	60
3% of pectin	140	130	130	120	120	120
4% of pectin	780	760	760	760	740	740

As we can wee, the physicochemical parameters of the samples were generally satisfactory and corresponded to those of the raw materials they were made from. We found a slight increase in protein in the experimental samples, which is associated with a higher content of pectin in them.

The sensory evaluation (Table. 4, Fig. 2) revealed a positive evaluation of all the parameters, except for consistency. It was marked as an indistinct liquid, which is not typical for this kind of products.

Fermented products are structured systems whose disperse phase particles interact with each other to form a network and give the system more or less pronounced properties of a solid. The resulting curd (gel) has certain mechanical properties: viscosity, plasticity, elasticity, and strength.

The textural and structural properties of food products are important indicators of the manufacturing process, the quality of the end product, its shelf life, etc. [35, 36]. We found it worthwhile to study the rheological characteristics of the fermented oat milk samples since there has been very little research in this area.

We performed preliminary measurements of shear stress to select optimal parameters for a better interpretation of experimental data. As a result, we chose to use rotor No. 3 at a spindle speed of 60 min^{-1} in the range from 0 to 180 s. Effective viscosity measurements are shown in Tables 5.

Table 6 Rheological characteristics of oat milk samples

Consistency indicators	Pectin concentration,%			
	Control (pectin-free)	2% of pectin	3% of pectin	4% of pectin
1.5% oat milk				
Hardness, g (*Fmax*, g)	17.0	18.3	20.0	20.7
Adhesive strength, g	3.4	3.9	4.2	5.5
General deformation, mm (h_{gen}, mm)	7	7	7	7
Elastic deformation, mm (h_{el}, mm)	6.461	6.454	6.219	4.844
Plastic deformation, mm (h_{pl}, mm)	0.539	0.546	0.781	2.156
Elasticity (Δh)	0.92	0.92	0.89	0.69
Relaxation depth, g	0.7	0.7	1.6	3.8
3.2% oat milk				
Hardness, g (*Fmax, g)*	17.4	17.2	19.1	31.8
Adhesive strength, g	3.9	4.1	4.5	8.9
General deformation, mm (h_{gen}, mm)	7	7	7	7
Elastic deformation, mm (h_{el}, mm)	6.547	6.602	6.586	2.648
Plastic deformation, mm (h_{pl}, mm)	0.453	0.398	0.414	4.352
Elasticity (Δh)	0.94	0.94	0.94	0.38
Relaxation depth, g	0.70	0.70	1.10	12.60

*h_{gen}, h_{el}, h_{pl} – general, elastic, and plastic deformations were determined by a texture analyzer

Table 7 Quality indicators of fermented oat milk

Quality indicator	Description and content
Consistency and appearance	Homogeneous, moderately viscous
Taste and smell	Pure, fermented milk-like, sweetish, with a pronounced taste and smell of oats
Color	Creamy white, uniform
Titratable acidity, °T	85–90
Active acidity, pH	4.2–4.5
Viable microflora cells, CFU/cm^3	3.1–3.4×10^7
Escherichia coli bacteria in 50 g	n.d.
Yeast per 1 g	n.d.
Mesophilic anaerobic bacteria spores in 1 g	n.d.

n.d. – not detected

We found that the fermented oat milk samples acted in a similar way to traditional fermented milk products and could be classified as abnormally viscous liquids. Initially, they displayed predominantly pseudoplastic properties which over time became more characteristic of Newtonian fluids.

Then, we analyzed the samples' hardness, adhesive strength, deformation indexes, and relaxation depth as the most important structural and mechanical characteristics of the product's internal structure and consistency (Table 6).

As can be seen in Table 7, higher pectin concentrations increased the hardness and adhesive strength of both 1.5 and 3.2% oat milk samples. This might be caused by the interaction of pectin and oat milk components, primarily fat, resulting in a well-developed spatial gel-like structure. The samples with a higher fat content (3.2%) showed a doubled adhesive strength due to pectin's ability to form stable emulsions with strong interfacial boundaries.

Table 8 Experimental formulation of the sauce based on fermented oat milk

Ingredient	Contents of ingredients for sauce formulations, %	
	Experimental	Control
1.5% fermented base	50.0	–
1.5% natural yoghurt	–	50.0
Olive oil	–	10.0
Dill	15.0	15.0
Cucumber	32.0	22.0
Salt	2.0	2.0
Black pepper	1.0	1.0
Total	100.0	100.0

Elasticity is the product's ability to deform under load, while relaxation depth indicates its ability to recover after load removal. These indicators are shown in Figs. 3 and 4.

As we can see in Fig. 3, increasing the pectin concentration to 3% hardly changed the samples' elasticity due to stress. However, its value sharply decreased at a 4% pectin content, especially in the 3.2% samples. This was probably because pectin thickened the emulsion and caused a denser curd to form. Changes in the relaxation depth indexes confirmed that finding (Fig. 4). We found that higher concentrations of pectin improved the samples' ability to restore their original structure after the load was removed. Noteworthily, all the textural indicators had maximum values at a pectin concentration of 4%.

Thus, our experiments confirmed that fermented oat milk could be used to develop new food products.

Further, we aimed to design a sauce based on fermented oat milk. In line with the current trend towards lower fat intake, we chose to use 1.5% milk.

The quality indicators of the fermented oat milk-based sauce are presented in Table 7.

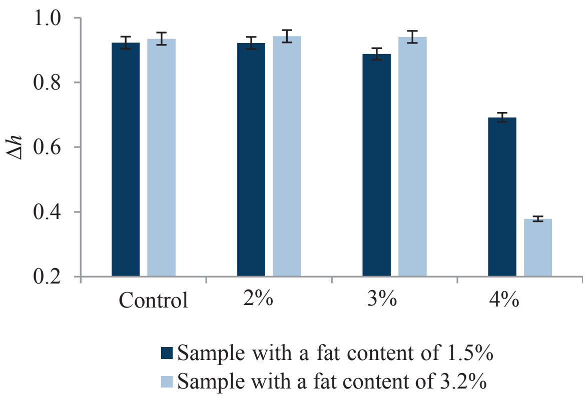

Figure 3 Elasticity of the control (pectin-free) and experimental (2, 3, and 4% of pectin) samples

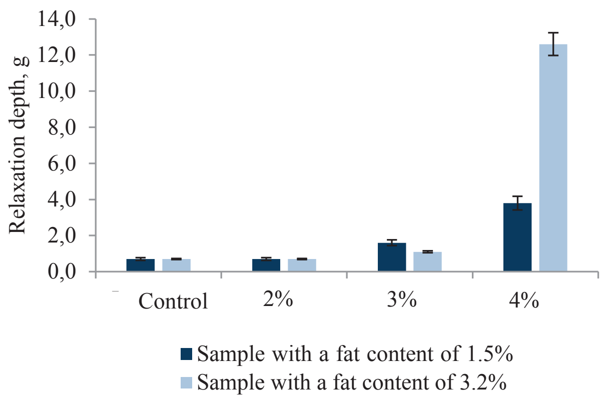

Figure 4 Relaxation depth of the control (pectin-free) and experimental (2, 3, and 4% of pectin) samples

Table 9 Sensory scores for the sauce based on fermented oat milk, points

Indicator	Sauce samples	
	Experimental	Control
Appearance	0.43	0.50
Color	0.5	0.5
Consistency	1.30	1.50
Smell	0.65	0.71
Taste and aftertaste	1.12	1.15

We formulated an experimental sauce using literature data [37–39]. Traditional (or Greek) yogurt sauce was used as a control. The formulations and ingredient ratios for the control and experimental sauces are presented in Table 8.

Sensory evaluation is key to quality control for this type of products. Sauces are currently evaluated according to State Standard 31986-2012. First, a sauce is poured in a thin stream to analyze its consistency and taste. It is followed by the evaluation of its color, the shape of slices, the consistency of fillers, as well as smell and taste. However, this evaluation is rather vague since it does not provide any quality gradation or objective quantitative analysis. Nor does it determine the product's quality level or identify its defects. Therefore, we applied the categorization method. In particular, we categorized the samples based on their score in a single or group sensory indicators (Table 9).

The use of fermented oat milk instead of cow's milk did not affect the sauce's sensory properties. Its consistency and appearance scored even higher than the control.

The quality indicators of the sauce based on fermented oat milk are presented in Table 10. As we can see, the sauce appealed to the consumers and showed stability during storage. In addition, it has a low energy value and therefore can be used in a low-fat diet.

Table 10 Quality indicators of the sauce based on fermented oat milk

Indicator	Description and content
Appearance, consistency	Homogeneous, sour cream-like, slightly viscous, jelly-like consistency with inclusions
Taste and smell	Slightly pungent and sour, typical of flavoring additives
Color	From white to creamy green, homogeneous or affected by the additives
Fat, %	0.8 ± 0.1
Protein, %	2.0 ± 0.1
Emulsion stability (% of unbroken emulsion), at least	97
Energy value, kcal	70

CONCLUSION

Our work showed a possibility of obtaining a new fermented product from plant-based materials. We studied the fermentation of, and acid accumulation in, oat milk. Then, we analyzed the samples' sensory, physicochemical, and rheological characteristics.

As a result of our experiments, we designed a sauce based on fermented oat milk, with 3% pectin used as a thickener. Various combinations of the ingredients in our formulation can create new food systems with high consumer appeal and thus expand the range of food products.

Further research is needed to get a clearer picture of the curds obtained. For example, in dishes with sauces, culinary treatment methods are just as important as the sauce's consistency and stability during storage. This will be the focus of our future study.

CONTRIBUTION

The authors were equally involved in writing the manuscript and are equally responsible for plagiarism.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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ORCID IDs
Dmitrii V. Khrundin https://orcid.org/0000-0002-7020-4709
Vsevolod Ya. Ponomarev https://orcid.org/0000-0003-1320-4881
Eduard Sh. Yunusov https://orcid.org/0000-0001-7847-7229