Представлені дослідження впливу харчових волокон на бродіння молочної сироватки. Встановлено форми зв'язку вологи в сумішах молочної сироватки і харчових волокон з різним ступенем вологопоглинальної здатності. За основними показниками бродіння визначені оптимальні умови ферментації лактозозброджувальними дріжджами Zygosaccharomyces lactis 868-K сироватково-рослинного сусла. Доведено можливість використання результатів у технології сироваткових ферментованих напоїв підвищеної в'язкості

Ключові слова: молочна сироватка, харчові волокна, дріжджі Zygosaccharomyces lactis 868-K, ферментація, сироватково-рослинне сусло підвищеної в'язкості

Представлены исследования влияния пищевых волокон на брожение молочной сыворотки. Установлены формы связи влаги в смесях молочной сыворотки и пищевых волокон с разной степенью влагопоглощающей способности. По основным показателям брожения определены рациональные условия ферментации лактосбраживающими дрожжами Zygosaccharomyces lactis 868-K сывороточно-растительного сусла. Доказана возможность использования результатов в технологии сывороточных ферментированных напитков повышенной вязкости

Ключевые слова: молочная сыворотка, пищевые волокна, дрожжи Zygosaccharomyces lactis 868-K, ферментация, сывороточно-растительное сусло повышенной вязкости

UDC 663.86:637.344
DOI: 10.15587/1729-4061.2018.120803

# STUDY INTO EFFECT OF FOOD FIBERS ON THE FERMENTATION PROCESS OF WHEY

**S. Tsygankov**
Doctor of Technical Sciences, Senior Researcher
Institute of Food Biotechnology and Genomics NAS of Ukraine
Osypovskoho str., 2A, Kyiv, Ukraine, 04123
E-mail: tsygankov.iht@gmail.com

**O. Grek**
PhD, Associate Professor*
E-mail: grek.nupt@gmail.com

**O. Krasulya**
PhD, Associate Professor*
E-mail: olena_krasulya@ukr.net

**O. Onopriichuk**
PhD, Associate Professor*
E-mail: olena.onopriychuk@gmail.com

**L. Chubenko**
Engineer*
E-mail: lorkachub@gmail.com

**O. Savchenko**
PhD, Associate Professor**
E-mail: 63savchenko@gmail.com

**O. Snizhko**
PhD, Assistant**
E-mail: snezhkoolha@gmail.com

**O. Ochkolyas**
Assistant**
E-mail: lenokochkolyas@gmail.com

*Department of milk and dairy products technology
National University of Food Technologies
Volodymyrska str., 68, Kyiv, Ukraine, 03680

**Department of technologies of meat, fish and marine products
National University of Life and Environmental Sciences of Ukraine
Heroiv Oborony str., 15, Kyiv, Ukraine, 03041

## 1. Introduction

Whey as a by-product of cheese and curd manufacturing contains a number of valuable substances, which is why it is expedient to use it for obtaining refreshing drinks of the new generation. The addition of vegetable components will improve nutritional value, provide the beverage with original flavor; it will also increase viscosity and enhance the completeness of taste. There are various techniques for processing whey [1]. Membrane separation is widely used – ultrafiltration and nanofiltration for fractionating proteins and lactose [2], [3] demineralization, etc. Among those actively developed technologies are membrane filtration for processing whey using several modules – polyfiber, ceramic and spiral winding [4], as well as techniques for the concentration and purification of milk-whey proteins using ultrafiltration in combination with intermittent defiltration [5]. The shortcoming of such technologies is the need for specialized equipment and additional production areas.

Another direction in whey processing is the biotransformation into carbohydrate and nitrogen-containing derivatives (lactulose [6], ethanol [7], lactic acid [1], etc.). The implementation of such technologies requires not only a wide range of equipment, but also chemical preparations, which makes this direction of processing too expensive.

The most cost-efficient are the innovative technologies of milk-whey beverages (fermented, non-fermented, with hydrolyzed lactose, as well as from clarified or non-clarified whey), which can be obtained using equipment at any dairy enterprise [8]. This does not require additional investment and energy supply. Beverage production is characterized by seasonal match between consumer demand and the peak of raw materials supply [9].

Using plant ingredients that contain food fibers with functional and technological properties is promising for beverages of the new type. The drinks are designed with mango and linseed oil [10], with the addition of raw pear juice [11], enriched with extracts of flowers and berry fillers [12].

To substantiate the technology of fermented milk-whey beverages with enhanced viscosity, several tasks must be resolved. First, to select available plant ingredients and determine their regulated content in a product [13]. Second, to ensure waste-free production of milk-protein concentrates [14].

## 2. Literature review and problem statement

Scientific substantiation and implementation of technologies for obtaining products from whey have been addresses in numerous studies [15–17]. However, the problem of resource saving of the components of whey has not been fully solved in practice. There are technologies for manufacturing drinks based on whey, which use it in native form and after different processing techniques [18, 19]. Beverages made from non-clarified whey are biologically complete. They contain almost all of the components of milk, including whey proteins. Such drinks are less stable when stored.

Based on data from the scientific literature [8, 20], the following selection criteria were formulated for whey as a base for drinks:

– minimal pretreatment at existing equipment and the possibility of adjusting the technological modes;

– properties and composition of whey, its relative availability, low cost, safety;

– seasonal match between the maxima of beverage consumption and obtaining whey at milk processing enterprises;

– ecological need for resolving the task on disposal of whey;

– the possibility to combine whey with plant ingredients, which allows obtaining a product with appropriate organoleptic properties;

– affordability of blending operation in the technology for producing whey-based beverages with plant ingredients.

Whey proteins have high biological value owing to their content of indispensable branched-chain amino acids. Isoleucine, leucine and valine stimulate specific muscle protein synthesis pathways and are involved in hormonal reaction and insulin secretion [21].

Fermented beverages combine valuable components of both whey and products of metabolism of microorganisms, formed during fermentation (ethyl alcohol, enzymes, various aromatic compounds, etc.) [9, 14, 22–23]. Due to the total content of solid substances in whey at the level of 6 %, the taste of whey beverages is watery, weakly expressed compared with drinks based on fermented milk. It is required to either use producing leavening cultures or add hydrocolloids [23].

Relevant for the development of technologies for the new generation beverages is the study into fermentation process of the whey-plant mixtures – wort with increased viscosity. A working hypothesis was formulated, based on the following assumption. By applying systems with different structure and using special yeast, it is possible to obtain fermented beverages with predefined functional properties, viscosity and required quality indicators. The possibility was established of using ingredients of plant origin in dairy products, specifically, apple pectin in fiber (APF), and orange food fibers Citri-Fi [24]. APF consists of wheat bran, apple powder, and pectin. The application of a given concentrate will improve viscosity of whey wort, enrich it with carbohydrates, vitamins, macro- and micronutrients, food fibers (FF), as well as enhance the flavor. Wheat bran include both food fibers and biologically active substances. Antioxidants, phytoestrogens and lignans contribute to a sense of satiety, affect glycemic, lipid index, and possess prebiotic activity [25].

Apple powder is a rich source of carbohydrates, minerals, phenolic acids and flavonoids. This ingredient is characterized by high hydration properties, ability to swell and bind water, as well as functionality (for example, capability to reduce the oxidation of lipids) [26]. Pectin in turn can reduce cholesterol level [27]. Citri-Fi 200 is the orange fruit food fiber obtained from the cell tissues of dried pulp without chemical reagents, by using mechanical treatment. It has the following physical- chemical properties: mass fraction of fat – 1.08 %, carbohydrates – 82.55 %, total amount of fiber – 75.3 %, including soluble – 39.6 %, insoluble – 35.7 %, sugar – 5.38, proteins – 7.38 %, ash – 2.46 %. According to the producer, Citri-Fi 200 possesses capacity to absorb from 8 to 13 mass fractions of water per 1 mass fraction of fiber.

According to data from the scientific literature [28, 29], the lactose-fermenting yeast races *Kluyveromyces lactis, Saccharomyces lactis, Zygosaccharomyces lactis 868-K* actively accumulate fermentation products, including ethyl alcohol. As far as the fermented beverages are concerned, there is a limitation for the above indicator at the level not exceeding 1.2 % by volume. Given this information, the development of fermented beverages, enriched with orange fruit fibers, or with APF, as well as selection of lactose-fermenting yeasts with appropriate activity, is a promising task. It is expedient to establish the effect of food fibers on the whey wort fermentation process.

Development of technologies for producing fermented beverages with high biological value has been tackled in numerous studies. At the same time, results of theoretical research are not always applicable for industrial implementation in the absence of feasible technologies and conditions for the effective functioning under industrial setting.

## 3. The aim and objectives of the study

The aim of present study was to examine the effect of food fibers on the fermentation process of whey-plant mixtures with increased viscosity by the lactose-fermenting yeast *Zygosaccharomyces lactis 868-K*. This will make it possible to develop a technology for producing whey fermented beverages.

To accomplish the set aim, the following tasks have been solved:

– to explore the forms of moisture bonds in the mixtures of whey with food fibers with a different degree of moisture absorption capacity;

– to analyze whey-plant mixtures and establish parameters for the introduction of whey to the overall volume;

– to define conditions for the fermentation of wort with enhanced viscosity.

## 4. Materials and methods of research. Composition of whey-plant mixtures

The native cottage cheese whey was received from "Piryatinsky syrzavod" with the following parameters: (6.5±±0.33 % of dry substance, (4.6±0.23) % of lactose, (1.3±±0.07) % of protein, pH (4.5±0.23).

Apple pectin in fiber (APF) is manufactured in Ukraine according to TU U 30335750.001-2000. The plant ingredient was used to enhance the viscosity of whey wort based on whey. APF consists of pectin (2 %), extruded wheat bran (60 %), apple powder (38 %), containing sugar – 48.7 %, including reducing – 4.9 %, cellulose – 13.7 %, protein – 6.7 %, fat – 6.8 %. The concentrate has a solubility of (33.0±0.99) %, a moisture absorption capacity in water of (90.0±2.70) %, and in whey, respectively, of (84.0±2.52) %.

All the samples, prepared in the manner described above, underwent fermentation at the second stage. The process was organized in the following way: upon pasteurization, the samples were immediately cooled to a temperature of 30 °C, and then we added to each sample the lactose-fermenting yeast Zygosaccharomyces lactis 868-K. This culture of yeast was grown on bar platters with whey wort in a thermostat at a temperature of (30±2) °C for 24 hours. Next, we transferred the cells calculated as 1·106 CFU/cm$^3$ of the medium to bulbs with a volume of 2 dm$^3$ containing 1 dm$^3$ of sterile whey wort (8 % of dry substances). Yeast cultivation was conducted in a shaker at 220 rpm for 24 hours at a temperature of (30±2) °C. The grown biomass was isolated from the cultural liquid by filtering in the vacuum filter.

The materials and methods applied in the study are described in more detail in paper [30].

## 5. Results and discussion of studying the influence of food fibers on the process of whey fermentation

### 5. 1. Forms of moisture binding in whey-plant mixtures

Infrared (IR) transmission spectra of whey, food fibers of different origin, water-plant mixtures, whey-plant mixtures, obtained using FTIR spectrophotometer "Nexus", are shown in Fig. 1, 2.

The study conducted (Fig. 1) testifies to clear bands of spectral relations in the region of valence fluctuations of C=O (1,748 cm$^{-1}$), C–O (1,151 cm$^{-1}$) groups. Two bands of C=O, as well as C–O and OH, may indicate the presence of two types of carboxyl groups $\left(-C\langle^{O}_{O}\right)^{-}$.

Characteristic band of water is a broad band of OH-valent fluctuation in the region of 3,441 cm$^{-1}$ in the samples (2–4). A wide continuous absorption in the region of 2,688 cm$^{-1}$ (3) and below is caused by a moving proton of acids and alkali in water. The higher the acidity or alkalinity, the greater mobility of H$^+$, and the wider and more intense absorption in the range below 3,000 cm$^{-1}$, which is observed in the spectrum (2–4) – a band of 2,729 cm$^{-1}$. Continuous absorption below 3,000 cm$^{-1}$ shows the existence of strong hydrogen bonds and high concentration of the moving proton. A wide band of 2,159 cm$^{-1}$ if the samples (1–4) is predetermined by a bridge H$^+$-bond when a moving proton "tunnels" through the energy barrier between two oxygen atoms.

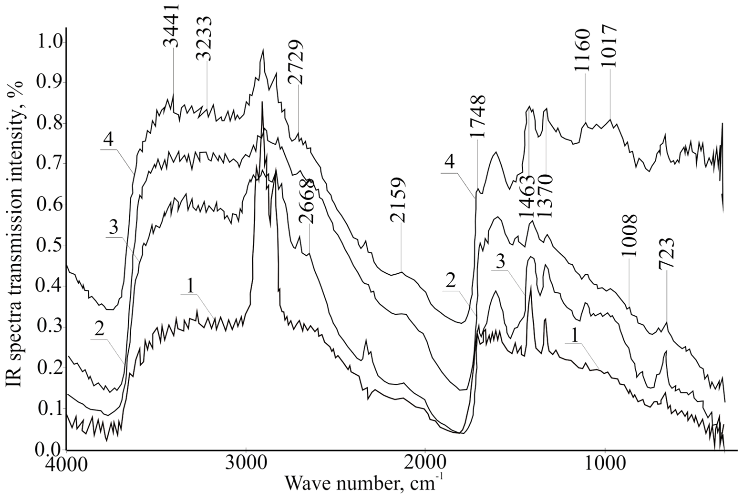



Fig. 1. IR spectra of transmission: 1 – dry whey; 2 – dry APF; 3 – mixture of water with APF; 4 – mixture of whey with APF

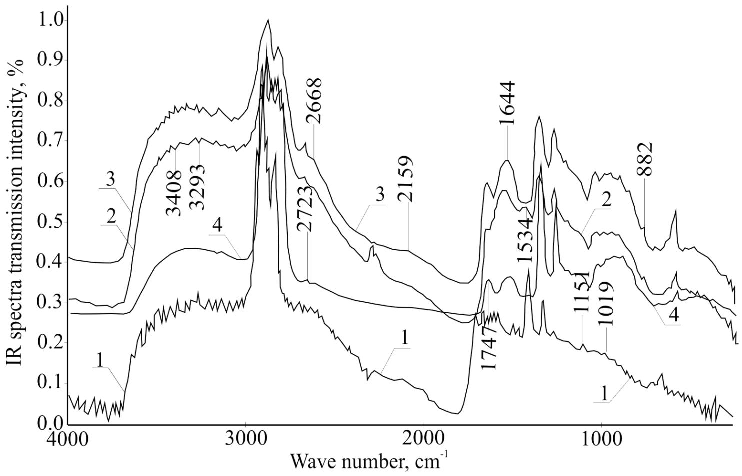



Fig. 2. IR spectra of transmission: 1 – dry whey; 2 – Citri-Fi; 3 – mixture of water with Citri-Fi; 4 – mixture of whey with Citri-Fi

We observed in the IR transmission spectra (Fig. 2) fluctuating bonds of C=O (1,753 cm$^{-1}$), C–O (1,151 cm$^{-1}$) and weakly H$^+$-associated O–H (3,408 cm$^{-1}$ groups. There is a broad band of 2,159 cm$^{-1}$ of samples (2 and 3), due to the bridge H$^+$ connection. The emergence of bands of 2,668 and 2,723 cm$^{-1}$ in the samples (2–4) may testify to the formation of solid H$^+$-connections of the bridge type and the emergence of the dissociated movable proton. Spectral manifestations of such connections were found in the sample of mixture of water with orange fruit food fibers (3) (the band of 2,159 cm$^{-1}$). Relative intensity of the bands for water is the largest in the spectrum of mixture of water with Citri-Fi (2), in which, in addition to the H$^+$-form of carboxylic group, there is also a salt form (the band of 1,534 cm$^{-1}$).

A characteristic feature of the spectra of composition mixtures with Citri-Fi is a clear increase in the relative intensity of the band of 1,741 $cm^{-1}$ 1 (3), which is typical for the $H^+$-form of carboxyl group.

**5. 2. Rheological analysis of whey mixtures with Citri-Fi**

We constructed multifactor mathematical models, which adequately express a change in the effective viscosity of whey-plant mixtures with Citri-Fi at variation in 3 independent factors. We measured shear stress τ (Pa) using the Reotest II viscometer, changing the gradients of shear tension γ in the range of 0.33...145.8 $cm^{-1}$ for direct motion. The corresponding regression equation takes the form:

$$Y_1=2.545+0.0172\,C_1+ +0.0092\,C_2+0.0505\,C_3,$$

where $Y_1$ is the effective viscosity of whey plant mixtures with Citri-Fi, Pa·s, $C_1$ is the content of food fibers Citri-Fi in the mixture, %; $C_2$ is the mixing time, min; $C_3$ is the swelling temperature, °C.

Adequacy of the model was tested for determination coefficient $R^2 Y_1$=95 %, demonstrating a high qualitative characteristic of coefficients relation. It was also tested by employing the F-test (the Fisher criterion) and Student's t-distribution in order to estimate reliability of correlation coefficients. Analysis of mathematical model allows us to assert that all 3 parameters exert a significant influence on the viscosity of whey-plant mixtures.

Linear growth of the varied parameters ($C_1$, $C_2$, $C_3$) leads to an increase in the indicator of effective viscosity of the mixture. The discovered quadratic effects indicate the existence of regions of extrema of the response function: a maximum for the input parameters. When adding the food fiber Citri-Fi in the amount exceeding 7 % into part of whey during preparation, there occurs a sharp increase in viscosity. In this case, there may be some problems with the transportation and introduction of the viscous mixture into the bulk of whey. Selection of the correlation of surface, related to the parameters of the yield and their permanent line of values, makes it possible to determine optimal values for the preparation of a whey-plant mixture. These parameters, which correspond to the optimal values of effective viscosity, are the mass fraction of Citri-Fi 4...5 %, mixing time of 10...15 min, a swelling temperature of 30...35 °C.

In the second part of present study we performed modeling of the impact of three variables parameters of the process (mass fraction of Citri-Fi, mixing time, and the temperature of introduction to the bulk of whey) on the dynamic viscosity of a fermented drink with whey-plant mixtures. The resulting regression equation takes the form:

$$Y_2=2.8262857-0.00061C_1+0.0095C_2-0.021267\,C_3,$$

where is $Y_2$ is the dynamic viscosity of beverage with a whey-plant mixture, $10^{-3}$ Pa·s; $C_1$ is the amount of whey-plant mixture, %; $C_2$ is the duration of mixing, min; $C_3$ is the temperature of introduction into whey, °C.

We constructed three-dimensional regression models of change in the dynamic viscosity of a beverage. For the first model, the independent parameters are the amount of a whey-plant mixture and duration of mixing with the basic amount of whey. For the second model, respectively, these are the amount of whey-plant mixture and the temperature of introduction.

**5. 3. Parameters of fermentation of whey beverages with a plant ingredient**

Parameters of whey-plant wort after fermentation, depending on the process duration, are given in Table 1.

Table 1

Parameters of whey-plant wort after fermentation

| Duration, hours | Yeast cell concentration, mln/ml | | | $CO_2$ concentration, g/100 ml | | |
|---|---|---|---|---|---|---|
| | Whey (control) | Whey+APF | Whey+ +Citri-Fi | Whey (control) | Whey+APF | Whey+ +Citri-Fi |
| 0 | 40±0.343d | 40±0.063a | 40±0.063a | 0 | 0 | 0 |
| 6 | 45±0.230c | 40±0.045a | 42±0.089a | 0.5±0.003III | 0.3±0.001II | 0.34±0.002I |
| 12 | 51.2±0.093a | 42.3±0.162b | 45.9±0.221b | 0.75±0.003III | 0.55±0.004IV | 0.65±0.002I |
| 18 | 61±0.275b | 51.69±0.439c | 55.2±0.359c | 0.98±0.002I | 0.7±0.002I | 0.82±0.002I |
| 24 | 70±0.532d | 60.59±0.460c | 67±0.241b | 1.2±0.004II | 0.87±0.003II | 1.1±0.004II |
| 30 | 73.1±0.257b | 65.15±0.425c | 71.3±0.607d | 1.45±0.009III | 1.02±0.005III | 1.2±0.009IV |
| 36 | 67±0.177b | 62.84±0.354c | 65.1±0.367c | 1.42±0.005II | 1.06±0.004II | 1.19±0.002I |

*Note:*
*– yeast cell concentration, mln/ml: a – <0.1; b – 0.1...0.3; c – 0.3...0.5; d – >0.5;*
*– $CO_2$ concentration, g/100 ml: I – 0.001...0.003; II – 0.003...0.005; III – 0.005...0.007; IV – 0.007...0.009*

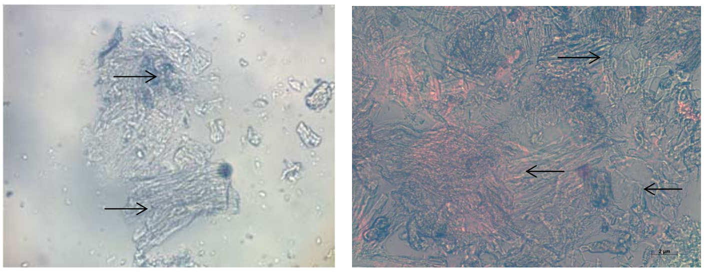
Fermented whey-plant wort underwent distillation in order to determine the mass fraction of alcohol in the distillate. The total number of yeast cells, colored with a Lugol solution, in 1 $cm^3$ was determined by direct counting in the Goryaev chamber. Measurements were taken every 6 hours of fermentation over 36 hours. All the experiments were repeated three times.

Logarithmic phase of the growth of *Zygosaccharomyces lactis 868-K* was observed in the period from hour 6 to hour 24 of the wort fermentation. The maximum concentration of yeast cells was registered at hour 30 of cultivation. The increment of yeast cells ranged from 42.3 to 71.3 mln/$cm^3$ depending on the composition of wort. In the sample with Citri-Fi, the number of accumulated yeast cells was lower by 3...5 % compared with control.

Thus, by using autofluorescence, we derived a microphotograph of Citri-Fi 200 that visualized the open and dissolved cell structure of fibers whose links are capable of binding a large amount of liquid and retaining it. The image indirectly confirms the moisture-absorbing properties declared by the manufacturer.

In order to register changes occurring to dry Citri-Fi when swelling in whey, we applied the dye Acridine Orange. This allowed us to observe the process in which tubular fibers grow in volume by several times while adsorbing the moisture. Some fragments are deformed due to changes in the soluble fiber (Fig. 3).

There is the persistence of fibrous structure and a sharp increase in the fragment's volume at the expense of absorbing the whey, as was mentioned above.



a b

Fig. 3. Localization of deformed fragments of the food fiber Citri-Fi: *a* – dry; *b* – hydrated

The results are in line with other studies [31] in which the maximum accumulation of biomass of *Zygosaccharomyces lactis 868-K* was achieved in 28 hours after whey fermentation. To determine the rational fermentation modes, we estimated concentration of yeast cells, the amount of accumulated ethanol and $CO_2$ in the wort with enhanced viscosity (Table 2).

The dynamics of $CO_2$ accumulation is positively correlated with the dynamics of biomass accumulation. Maximum $CO_2$ content was observed in 30 hours of cultivation (1.2 and 1.45 g/100 ml at fermentation of wort with apple pectin in fiber and in control, respectively). According to data, when using the yeast *Zygosaccharomyces lactis 868-K,* the rational whey-plant wort fermentation temperature is 30...32 °C. At this temperature, there is the maximum accumulation of yeast cells – 70.5... 71.2 mln/cm$^3$ and ethyl alcohol – 0.64...0.69 % by volume. With a further increase or decrease in temperature these indicators are reduced, suggesting a decrease in the activity of cell enzymes.

The amount of ethyl alcohol in control sample at a temperature of 32 °C is 1.02 % by volume. For the whey with APF this indicator is fixed at a level of 0.6 9 % by volume. According to the requirements of normative documents on soft drinks (DSTU 4069:2002), the amount of ethyl alcohol allowed in a product should not exceed 1.2 % by volume. The results obtained are complying and could be used to implement the technology for producing fermented whey beverages with enhanced viscosity.

## 6. Discussion of results of studying the effect of food fibers on the fermentation process of whey

The results obtained testify to the high moisture-binding ability, which is achieved mainly due to the open and extended cell structure of the orange fruit food fiber. The latter is capable of binding a considerable amount of moisture and retaining it over the entire industrial process and during product storage. For further research, we have chosen particularly Citri-Fi.

Regression equations that we constructed make it possible to predict the behavior of the mixture whey+Citri-Fi throughout the entire technological process. It was established that the suboptimal amount of whey-plant mixture is 10...12.5 %, at the following modes of introduction to the bulk of whey: temperature – 50...60 °C, duration of mixing – 8...10 min. Under these conditions, the indicator of dynamic viscosity of wort is (2.64...2.68) $10^{-3}$ Pa·s.

It was confirmed that yeast cells develop more actively in the whey without food fibers. This is due to the complexity of the process of disposal of carbohydrates in the presence of insoluble compounds (cellulose, lignin). The result is the lower affordability of substrate for yeast.

It was established that the orange fruit food fibers in the form of plates with a solid monolithic tubular structure are typical for the high-polymeric complexes. Separate cellular cells are damaged in some places as a result of mechanical treatment.

In addition, the orange food fibers in the non-hydrated state are characterized by a multilayered structure formed from the damaged walls of fiber with micro-cracks. Such a structure defines high specific surface of the carbohydrate matrix, and, accordingly, increased moisture-absorbing ability, which was confirmed by the image of the hydrated sample of Citri-Fi.

The results reported have determined parameters for the fermentation of whey beverages with plant ingredients. The amount of ethanol in control sample at a temperature of 32 °C was 1.02 % by volume; for whey and Citri-Fi, this indicator reached 0.79 % by volume. The presence of Citri-Fi in wort, as was mentioned above, leads to a decrease in the activity of yeast, and, as a consequence, reduces the amount of ethyl alcohol

Table 2

Dependence of concentration of yeast cells, the content of ethanol and $CO_2$, on the fermentation temperature of wort with enhanced viscosity

| Temperature, °C | Yeast cell concentration, mln/ml | | | $CO_2$ concentration, g/100 ml | | | Alcohol content, % by volume | | |
|---|---|---|---|---|---|---|---|---|---|
| | Whey (control) | Whey+APF | Whey+ Citri-Fi | Whey (control) | Whey+APF | Whey+ Citri-Fi | Whey (control) | Whey+APF | Whey+ Citri-Fi |
| 24 | 72.00±0.257a | 68.25±0.401b | 71.30±0.326b | 0.69±0.002I | 0.69±0.003IV | 0.69±0.005II | 0.60±0.005IV | 0.30±0.002III | 0.45±0.002II |
| 26 | 75.90±0.465b | 70.20±0.465b | 74.40±0.381b | 0.73±0.004III | 0.70±0.001II | 0.73±0.006II | 0.72±0.005II | 0.35±0.001II | 0.55±0.005V |
| 28 | 79.00±0.300a | 72.26±0.460b | 76.90±0.140a | 0.83±0.004II | 0.78±0.005III | 0.82±0.005II | 0.85±0.002I | 0.49±0.002II | 0.68±0.005III |
| 30 | 83.10±0.706d | 77.26±0.623c | 81.30±0.528c | 0.94±0.007II | 0.84±0.006IV | 0.91±0.006III | 0.95±0.005III | 0.64±0.005IV | 0.82±0.007IV |
| 32 | 82.20±1.365e | 74.69±0.296a | 80.20±0.529c | 0.95±0.006III | 0.87±0.007IV | 0.90±0.003I | 1.02±0.005II | 0.69±0.002II | 0.89±0.002I |
| 34 | 78.90±0.465b | 73.18±0.672c | 77.50±0.350b | 0.86±0.007IV | 0.82±0.003II | 0.85±0.004III | 0.90±0.006III | 0.53±0.002II | 0.80±0.006IV |
| 36 | 76.90±0.434b | 70.26±0.280a | 74.80±0.571d | 0.73±0.006IV | 0.70±0.001I | 0.72±0.004I | 0.85±0.003II | 0.44±0.001I | 0.69±0.002I |

*Note:*

*– yeast cell concentration, mln/ml: a – <0.3; b – 0.3...0.5; c – 0.5...0.7; d – 0.7...0.9; e – >0.7;*

*– $CO_2$ concentration, g/100 ml, and alcohol content, % by volume: I – 0.001...0.003; II – 0.003...0.005; III – 0.005...0.007; IV – 0.007...0.009; V – >0.009.*

## 7. Conclusions

1. By using the method of IR spectroscopy, we estimated effect of food fibers on the forms of moisture binding in mixtures based on whey and water. In the mixtures with Citri-Fi we revealed a continuous absorption of IR spectra of bands of water in the region of oscillations at 2,668 and 2,723 $cm^{-1}$, which indicates the presence of strong hydrogen bonds. The visualization of dry and hydrated samples of orange fruit food fibers, given in the present work, showed the presence of complex polygonal associates, combined in a strong fibrous structure with large number of shell fragments.

2. The optimal parameters for the preparation of whey-plant mixtures were established: the amount of Citri-Fi is 4...5 %, duration of mixing is 10...15 minutes, swelling temperature is 30...35 °C. We also determined the rational amount of whey-plant mixture in the amount of 10...12.5 % for the introduction to the bulk of whey. It is necessary to observe the following modes: temperature is 50...60 °C, duration of mixing is 8...10 min.

3. An increase in the whey wort viscosity led to a decrease in the fermentation indicators: the content of carbon dioxide, the amount of isolated ethyl alcohol and yeast cells. Compared to control, the process slowed down by 6 hours on average. The information obtained could be used to develop technologies for producing fermented beverages with enhanced viscosity.

References


1. Khramtsov A. G. The phenomenon of milk whey: monograph. Saint Petersburg: Profession, 2011. P. 145–152.
2. Potential of Membrane Separation Processes in Cheese Whey Fractionation and Separation / Hinkova A., Zidova P., Pour V., Bubnik Z., Henke S., Salova A., Kadlec P. // Procedia Engineering. 2012. Vol. 42. P. 1425–1436. doi: 10.1016/j.proeng.2012.07.536
3. A study of demineralization of whey by nanofiltration membrane / Pan K., Song Q., Wang L., Cao B. // Desalination. 2011. Vol. 267. P. 217–221. doi: 10.1016/j.desal.2010.09.029
4. Rektor A., Vatai G. Membrane filtration of Mozzarella whey // Desalination. 2004. Vol. 162. P. 279–286. doi: 10.1016/s0011-9164(04)00052-9
5. Baldasso, C., Barros, T. C., Tessaro, I. C. Concentration and purification of whey proteins by ultrafiltration // Desalination. 2011. Vol. 278, Issue 1-3. P. 381–386. doi: 10.1016/j.desal.2011.05.055
6. Efficient production of lactulose from whey powder by cellobiose 2-epimerase in an enzymatic membrane reactor / Wu L., Xu C., Li S., Liang J., Xu H., Xu Z. // Bioresource Technology. 2017. Vol. 233. P. 305–312. doi: 10.1016/j.biortech.2017.02.089
7. Zohri A.-N. A., Gomah N. H., Maysa A. A. Utilization of cheese whey for bio-ethanol production // Universal Journal of Microbiology Research. 2014. Vol. 2, Issue 4. P. 57–73.
8. Whey as a raw material for the production of functional beverages / Bulatovic M., Rakin M., Mojovic L., Nikolic S., Vukasinovic-Sekulic M., Djukic-Vukovic A. // Hemijska industrija. 2012. Vol. 66, Issue 4. P. 567–579. doi: 10.2298/hemind111124009b
9. Jelicic I., Bozanic R., Tratnik L. Whey based beverages – new generation of dairy products // Mljekarstvo. 2008. Vol. 58, Issue 3. P. 257–274.
10. Utilization Whey in Production of Functional Healthy Beverage "Whey-mango Beverages" / S. Gad A., H. Emam W., F. Mohamed G., F. Sayd A. // American Journal of Food Technology. 2013. Vol. 8, Issue 3. P. 133–148. doi: 10.3923/ajft.2013.133.148
11. A physical stability study of whey-based prickly pear beverages / Baccouche A., Ennouri M., Felfoul I., Attia H. // Food Hydrocolloids. 2013. Vol. 33, Issue 2. P. 234–244. doi: 10.1016/j.foodhyd.2013.03.007
12. Modelling formulae of strawberry whey drinks of prophylactic application / Tkachenko N., Nekrasov P., Vikul S., Honcharuk Y. // Food Science and Technology. 2017. Vol. 1, Issue 11. P. 80–88. doi: 10.15673/fst.v11i1.303
13. Farah J. S., Araujo C. B., Melo L. Analysis of yoghurts', whey-based beverages' and fermented milks' labels and differences on their sensory profiles and acceptance // International Dairy Journal. 2017. Vol. 68. P. 17–22. doi: 10.1016/j.idairyj.2016.12.008
14. Gallardo-Escamilla F. J., Kelly A. L., Delahunty C. M. Mouthfeel and flavour of fermented whey with added hydrocolloids // International Dairy Journal. 2007. Vol. 17, Issue 4. P. 308–315. doi: 10.1016/j.idairyj.2006.04.009
15. Evdokimov I. A., Volodin D. N. Sovremennoe sostoyanie i perspektivy pererabotki molochnoy syvorotki // Pererabotka moloka. 2016. Vol. 8. P. 10–13.
16. Al'ternativnye varianty promyshlennoy pererabotki molochnoy syvorotki / Hramtsov A. G., Nesterenko P. G., Evdokimov I. A. et. al. // Molochnaya promyshlennost'. 2014. Vol. 11. P. 44–48.
17. Whey Processing. Utilization and Products // Encyclopedia of Dairy Sciences. 2011. P. 731–737. doi: 10.1016/b0-12-227235-8/00511-3
18. Kumar N., Vandna, Hati S. Fermented and non fermented whey beverages // Beverage & food world. 2015. Vol. 42, Issue 4. P. 28–31.
19. Whey Based Beverage: Its Functionality, Formulations, Health Benefits and Applications / Chavan R. S., Shraddha R. C., Kumar A., Nalawade T. // Journal of Food Processing & Technology. 2015. Vol. 6, Issue 10. doi: 10.4172/2157-7110.1000495
20. Suhih S. A., Frolov S. V. Technology of tonics based on the secondary raw milk // Achievements of Science and Technology of AIC. 2008. Vol. 5. P. 54–55.

21. Functional fermented whey-based beverage using lactic acid bacteria / Pescuma M., Hébert E. M., Mozzi F., Font de Valdez G. // International Journal of Food Microbiology. 2010. Vol. 141, Issue 1-2. P. 73–81. doi: 10.1016/j.ijfoodmicro.2010.04.011
22. Eltcova E. V. Development of technology for soft drinks based on fruit and berries with whey // Kemerovo University of Food Technology. 2001. P. 1–19.
23. A physical stability study of whey-based prickly pear beverages / Baccouche A., Ennouri M., Felfoul I., Attia H. // Food Hydrocolloids. 2013. Vol. 33, Issue 2. P. 234–244. doi: 10.1016/j.foodhyd.2013.03.007
24. Grek O., Krasulya O. Study of effect fibers on the communication forms of moisture in mixture with milk whey // Food chemistry and technology. 2013. Vol. 47. P. 15–21.
25. Wheat bran-based biorefinery 1: Composition of wheat bran and strategies of functionalization / Prückler M., Siebenhandl-Ehn S., Apprich S., Höltinger S., Haas C., Schmid E., Kneifel W. // LWT – Food Science and Technology. 2014. Vol. 56, Issue 2. P. 211–221. doi: 10.1016/j.lwt.2013.12.004
26. Effect of apple pomace powder addition on farinographic properties of wheat dough and biscuits quality / Kohajdová Z., Karovičová J., Magala M., Kuchtová V. // Chemical Papers. 2014. Vol. 68, Issue 8. doi: 10.2478/s11696-014-0567-1
27. Utilization of pectin-enriched materials from apple pomace as a fat replacer in a model food system / Min B., Bae I. Y., Lee H. G., Yoo S.-H., Lee S. // Bioresource Technology. 2010. Vol. 101, Issue 14. P. 5414–5418. doi: 10.1016/j.biortech.2010.02.022
28. Kluyveromyces lactis: An emerging tool in biotechnology / Spohner S. C., Schaum V., Quitmann H., Czermak P. // Journal of Biotechnology. 2016. Vol. 222. P. 104–116. doi: 10.1016/j.jbiotec.2016.02.023
29. Growth kinetics and physiological behavior of co-cultures of Saccharomyces cerevisiae and Kluyveromyces lactis, fermenting carob sugars extracted with whey / Rodrigues B., Lima-Costa M. E., Constantino A., Raposo S., Felizardo C., Gonçalves D. et. al. // Enzyme and Microbial Technology. 2016. Vol. 92. P. 41–48. doi: 10.1016/j.enzmictec.2016.06.012
30. Methods of determination of parameters of whey with food fibers / Tsygankov S., Grek O., Krasulya O., Onopriichuk O., Chubenko L., Savchenko O. et. al. // EUREKA: Life Sciences. 2018. Issue 1. P. 69–76. doi: 10.21303/2504-5695.2018.00534
31. Comparative biochemical characterization of soluble and chitosan immobilized β-galactosidase from Kluyveromyces lactis NRRL Y1564 / Lima A. F., Cavalcante K. F., de Freitas M. de F. M., Rodrigues T. H. S., Rocha M. V. P., Gonçalves L. R. B. // Process Biochemistry. 2013. Vol. 48, Issue 3. P. 443–452. doi: 10.1016/j.procbio.2013.02.002