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Исследование физико-химических и технологических показателей инулин-содержащего концентрата из корнеплодов цикория корневого сорта «Ярославский-1»

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Аннотация. Современная пищевая промышленность ориентирована на производство функциональных продуктов, среди которых особое место занимают пребиотики. Ключевым и перспективным пребиотиком является инулин, который не только стимулирует рост полезной микрофлоры кишечника, но и обладает ценными технологическими свойствами. Основным источником для его промышленного производства является корневой цикорий. В связи с этим актуальной задачей является оценка качества инулинового концентрата, полученного из новых сортов, таких как отечественный сорт «Ярославский-1». Целью данного исследования являлась оценка физико-химических, технологических и функциональных свойств инулинового концентрата, экстрагированного из корнеплодов цикория сорта Ярославский-1. Результаты исследования показали, что полученный концентрат характеризуется высоким содержанием инулина (78,2 г/100 г сухих веществ). Содержание моносахаридов, в частности глюкозы и фруктозы, было относительно не высоким на уровне 4,8 и 6,2 % соответственно, что свидетельствует о незначительном гидролизе полисахарида. Инулиновый концентрат имел слабокислую реакцию среды (pH=5,8) и умеренную вязкость (2,8 мПа·с), что благоприятно для его технологического применения. Биологические испытания подтвердили выраженные пребиотические свойства, так как экстракт стимулировал рост и развитие бифидобактерий *Bifidobacterium bifidum* и *Bifidobacterium longum* и повышал их устойчивость к кислотному стрессу и желчным кислотам. Кроме того, было установлена значительная антиоксидантная активность (IC₅₀ в тесте с DPPH – 0,45 мг/мл). Таким образом, инулиновый концентрат из цикория корневого сорта Ярославский-1 обладает высоким качеством и комплексом функциональных свойств, что делает его ценным ингредиентом для создания обогащенных пищевых продуктов с заданными свойствами и антиоксидантными характеристиками.

Ключевые слова: инулиновый концентрат, цикорий корневой, пребиотик, качество продукции, функциональные продукты, антиоксидантная активность, физико-химические свойства.

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Research article

Investigation of physico-chemical and technological parameters of inulin-containing concentrate from chicory root crops of the «Yaroslavsky-1» root variety

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Abstract. The modern food industry is focused on the production of functional products, among which prebiotics occupy a special place. A key and promising prebiotic is inulin, which not only stimulates the growth of beneficial intestinal microflora, but also has valuable technological properties. The main source for its industrial production is chicory root. In this regard, an urgent task is to assess the quality of inulin concentrate obtained from new varieties, such as the domestic variety Yaroslavsky-1. The purpose of this study was to evaluate the physico-chemical, technological and functional properties of inulin concentrate extracted from chicory roots of the Yaroslavsky-1 variety. The results of the study showed that the resulting concentrate is characterized by a high inulin content (78.2 g/100 g of solids). The content of monosaccharides, in particular glucose and fructose, was relatively low at the level of 4.8 and 6.2%, respectively, which indicates a slight hydrolysis of the polysaccharide. The inulin concentrate had a slightly acidic reaction of the medium (pH=5.8) and a moderate viscosity (2.8 MPa·s), which is favorable for its technological application. Biological tests confirmed the pronounced prebiotic properties, as the extract stimulated the growth and development of *Bifidobacterium bifidum* and *Bifidobacterium longum* Bifidobacteria and increased their resistance to acid stress and bile acids. In addition, significant antioxidant activity was found (IC₅₀ in the DPPH test was 0.45 mg/ml). Thus, inulin concentrate from chicory of the Yaroslavsky-1 root variety has high quality and a complex of functional properties, which makes it a valuable ingredient for creating fortified foods with desired properties and antioxidant characteristics.

Keywords: inulin concentrate, root chicory, prebiotic, product quality, functional products, antioxidant activity, physico-chemical properties

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Introduction. The modern food processing industry is undergoing a structural transformation due to the growing demand for functional foods and food ingredients. One area of production for such products is the development of prebiotic ingredients—substances that selectively stimulate the growth of beneficial intestinal microflora, which, in turn, has a positive effect on overall human health. One such promising component is the polysaccharide inulin, a leading fructosan. In addition to its proven prebiotic properties, it boasts a number of beneficial technological benefits, such as improving food texture and regulating blood sugar levels [1, 2].

The primary source of renewable plant material is chicory root, which accumulates approximately 20% or more of this polyfructosan in its roots based on dry weight. Of particular interest in this regard are new domestically bred varieties, particularly the "Yaroslavsky-1" chicory root variety. This variety is zoned for the central non-chernozem zone of the Russian Federation, and its high inulin content makes it an ideal crop for industrial cultivation [3].

The key product of chicory processing is inulin concentrate, the quality of which directly determines its functional properties, technological efficiency of application and, consequently, consumer value. An important task of the process technology is the most efficient extraction of inulin from the matrix of plant raw materials with the maximum yield and preservation of its molecular structure, which directly affects the prebiotic activity. The decisive factor determining the quality of inulin concentrate is a number of microbiological, technological and physicochemical indicators. Among the most significant of these are the total content of inulin and the proportion of its high-molecular fractions; the proportion of monosaccharides, such as glucose and fructose, as well as ballast substances - sucrose, ash, in the resulting concentrate; the biological value of the product, including the characteristics of prebiotic properties and antioxidant activity; the value of pH and viscosity; organoleptic (color, taste, presence of foreign flavors, solubility) and microbiological characteristics [4, 5].

Thus, the analysis of complex indicators of the quality of inulin concentrate is a necessary condition for the possibility of predicting its quality and functional changes in the composition of food products and for the development of documentation (regulations) ensuring the release of a standardized product with certain specified properties [6].

The aim of this study was to comprehensively evaluate the key physicochemical and technological indicators of the quality of inulin concentrate obtained from chicory roots and to establish correlations between these indicators and the conditions of the technological process.

Materials and research methods. The object of the study was inulin concentrate from Chicory root crops of the Yaroslavsky-1 variety, harvested in 2023, grown in the fields of the breeding center and experimental base of the All-Russian Research Institute of Vegetable Gardening, a branch of the Federal Scientific Center of Vegetable Gardening in the Moscow Region. Quantitative determination of the mass fraction of inulin was performed enzymatically using the Megazyme K-INUL 03/19 reagent kit. Measurement procedures were carried out spectrophotometrically using a Shimadzu UV-1800 instrument (Japan) [7]. Analysis of the glucose and fructose content in the juice sample was carried out by high-performance liquid chromatography (HPLC) equipped with a refractometric detector (RID). An Agilent 1260 Infinity II LC System with a RID detector was used. The separation process of the components was carried out on an Aminex HPX-87C column (300x7.8 mm, Bio-Rad). The hydrogen index (pH) in the inulin concentrate was measured potentiometrically using a Mettler Toledo SevenCompact S220 pH meter equipped with an InLab Expert Pro calibrated electrode. The dynamic viscosity coefficient of the inulin concentrate was determined using a VPZh-2 capillary viscometer (capillary diameter 0.8 mm). The effect of inulin concentrate on the growth rate of bifidobacteria was studied under conditions of culturing *Bifidobacterium bifidum* ATCC 29521 and *Bifidobacterium longum* ATCC 15707 strains in a modified MRS (de Man, Rogosa and

Sharpe) nutrient medium. Bacterial growth intensification was assessed by measuring the optical density (OD₆₀₀) of suspensions using a Shimadzu UV-1800 spectrophotometer [8].

To test resistance to acid stress and bile acids, bifidobacteria were grown, then pelleted by centrifugation, washed, and resuspended in a buffer solution with a pH of 2.5 (simulating gastric juice) and in a solution containing 0.3% (w/v) bile acids. Microorganism viability was assessed by counting colony-forming units (CFU/ml) on Petri dishes with MRS agar medium before and after incubation.

– The antioxidant potential was studied using the stable free radical DPPH (2,2-diphenyl-1-picrylhydrazyl). Inulin extract at various concentrations (from 0.1 to 1 mg/ml) was mixed with a methanol solution of DPPH. After incubating the mixtures for 30 minutes at room temperature, the absorbance was measured at a wavelength of 517 nm using a Shimadzu UV-1800 spectrophotometer [9].

Study results and discussion. The most important quality indicator of the resulting inulin concentrate is its content of the target component, namely, inulin. The data obtained during the experiment are summarized in Table 1.

Table 1. The results of the determination of the mass fraction of inulin in inulin extract, expressed in g / 100 g of dry matter

Expressed in g/100 g of dry matter					Average value
Option					
1	2	3	4	5	
Mass fraction of inulin, g/100 g dry matter					
79.80	75.60	79.10	78.60	77.90	78.2±2.0

Interpretation of the results presented in Table 1 allowed us to establish that the average mass fraction of inulin in the dry matter of inulin concentrate reached a value of 78.2 (g/100 g).

The data obtained confirm that the inulin extract under study is a product rich in inulin, which opens up prospects for its use in the creation of functional food products, such as specialized products for people with diabetes or products that improve the functioning of the digestive system due to the prebiotic effect.

The results of the experiment to determine the concentration of mass fractions of glucose and fructose are shown in Table 2.

Table 2. Results of determining the mass fraction of glucose and fructose in inulin concentrate, expressed in g per 100 g of dry matter

Expressed in g per 100 g of dry matter					Average value
1	2	3	4	5	
Mass fraction of fructose, g/100 g dry matter					
6:30	6.40	6.50	6.10	5.70	6.20±0.40
Mass fraction of glucose, g/100 g dry matter					
4.50	4.40	5.10	4.90	5.10	4.80±0.40

Based on the data in Table 2, it can be concluded that the glucose and fructose concentrations in the juice were 4.8 ± 0.4 g/100 g and 6.2 ± 0.4 g/100 g dry matter, respectively. The presence of these monosaccharides may be due to partial hydrolysis of inulin during the extraction and juice preparation stages, as well as their initial presence in the chicory root in free form. The observed slight excess of fructose over glucose (a ratio greater than 1) is typical of inulin-containing products, as its hydrolysis predominantly results in the formation of fructose.

Determining the pH value is a crucial step in both its technological and qualitative characterization due to the influence of environmental acidity on microbiological contamination, the overall biological and technological stability of the target component, and its potential for successful interaction with other ingredients in functional food systems. The results of the pH experiment in inulin concentrate are presented in Table 3.

Table 3. Results of determination of the pH value in inulin concentrate by the potentiometric method

Experiment number					Average value
1	2	3	4	5	
pH value					
5.80	5.70	5.60	5.70	6.20	5.80±0.3

According to Table 3, the pH of the inulin concentrate was 5.8 ± 0.3 , indicating a slightly acidic pH. This level of acidity is favorable for both maintaining inulin stability and inhibiting the growth of undesirable microflora.

The next stage of the study involved determining the dynamic viscosity coefficient of the product. This parameter can be used to predict and control functional and technological properties, such as the strength of structure formation, the stability of the resulting suspensions, and water-holding capacity. This parameter closely correlates with the degree of polymerization and the molecular weight of inulin itself.

The results of the studies conducted in this part of the research are presented in Table 4.

Table 4. Results of the determination of the dynamic viscosity coefficient of inulin concentrate

Table 4. Results of the determination of the dynamic viscosity coefficient of main concentrate					
Option					Average value
1	2	3	4	5	
Viscosity, mPa s					
2.90	2.70	2.80	2.50	3.10	2.80±0.3

Moderately viscous inulin concentrates (2.8 ± 0.3 mPa s) tend to form gels when exposed to water. This property may be useful for replacing the fat fraction in low-fat dairy products (yogurts, cottage cheese). These values are due to the high concentration of polysaccharides, particularly inulin. High viscosity indicates that inulin has a high water-holding capacity, which directly impacts the consistency and shelf life of functional food products made with it.

Further research into the inulin concentrate involves assessing its biological value or biological efficacy. For this purpose, methods were used to analyze probiotic properties and assess antioxidant activity, as well as evaluate its resistance to the specific characteristics of the gastrointestinal tract.

Adding inulin concentrate to the nutrient medium stimulated the growth of *B. bifidum* and *B. longum*. At the optimal juice concentration of 1%, optical density (OD600) increased 1.8-fold for *B. bifidum* and 2.1-fold for *B. longum*, respectively, compared to the control (medium without additives). The stimulating effect was comparable to that of the well-known prebiotic fructooligosaccharides (FOS). These results suggest that the components of inulin concentrate exert a protective effect on bacterial cells, enhancing their tolerance to stress factors typical of the gastrointestinal tract.

Furthermore, bifidobacteria pre-adapted to a medium containing 1% inulin concentrate demonstrated increased resistance to low pH and bile acids. The survival rate of *B. bifidum* after two hours of incubation in a medium with a pH of 2.5 was 65%, and in a bile acid solution, 72%. For the *B. longum* strain, these figures were even higher—70% and 78%, respectively.

Inulin concentrate demonstrated significant antioxidant activity across the methods used. In the DPPH test, the IC50 value (the concentration required to suppress 50% of radicals) was 0.45 mg/ml. In the FRAP test, the reducing power of the juice was estimated at 350 ± 15 $\mu\text{mol Fe}^2$ equivalents per gram of dry matter. This demonstrates the juice's pronounced ability to act as a reducing agent and confirms the presence of compounds with high antioxidant activity.

The studies conducted collectively demonstrate the high biological value of inulin extract obtained from chicory root. The extract possesses pronounced probiotic properties, stimulating

the growth of beneficial bifidobacteria and increasing their survival under conditions simulating the gastrointestinal tract. The juice also exhibits significant antioxidant activity, likely due to the presence of phenolic compounds and other antioxidants.

Conclusion. Based on the conducted research, it can be concluded that the inulin-containing extract, or inulin concentrate, derived from the Yaroslavsky-1 chicory root variety possesses a combination of valuable properties. This product is characterized by a high inulin concentration and good rheological, microbiological, and organoleptic properties. The product has proven its biological effectiveness and offers broad potential for use in various sectors of the food industry and nutrition science. The obtained results convincingly demonstrate that the inulin concentrate produced from the Yaroslavsky-1 chicory root variety possesses valuable physicochemical properties and pronounced biological activity. The high inulin content, confirmed antioxidant activity, and the ability to selectively stimulate the growth of beneficial intestinal microflora allow us to characterize the product obtained from the Yaroslavsky-1 chicory root variety as possessing a combination of valuable properties that determine its high technological and functional potential.

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