

## ON THE POSSIBILITY OF CONVERTING SUGAR FACTORIES TO PROCESS ROOT CHICORY INTO INULIN, OLIGOFRACTOSE AND OTHER PRODUCTS

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### Abstract

The article examines the possibility of converting low-profit and non-operating sugar factories to process chicory root into inulin, oligofractose and other products that have a number of beneficial properties, including prebiotic properties, increased immunity, reduced insulin resistance, etc., and can be consumed as dietary supplements or added to various food products and dishes. In Russia, there is no production of inulin and oligofractose, but it is known that the technology for obtaining inulin from chicory root is generally similar to that for obtaining sugar from sugar beet. The article describes cases of converting foreign sugar factories to process chicory root into these products. Technologies for the production of standard (native) inulin, long-chain inulin and oligofractose from chicory root are indicated. A scheme of converting a Russian sugar factory is developed. It is proposed to use a diffusion pulsating apparatus developed and manufactured by the Ingehim Company instead of a conventional diffusion apparatus to reduce operating and production costs. It is determined that the same climatic zones as for sugar beet growing are suitable for growing root chicory, and the agrotechnical methods of cultivating the two crops are also similar. A positive result is obtained when growing root chicory of the Petrovsky variety on a test field in central Russia. The achieved yield with the chosen planting scheme is comparable to the yield in other countries.

**Keywords:** *sugar factory, modernization, conversion, root chicory, inulin, oligofractose, diffusion, diffusion pulsating apparatus, Ingehim*

## **INTRODUCTION**

Recently, there has been a growing global demand for healthy food products, functional foods, and dietary supplements, driven particularly by the increasing prevalence of diseases such as obesity, hypertension, and diabetes [1]. In this context, inulin and oligofructose, which possess a variety of functional properties, are gaining popularity among the general population. These substances cannot be synthesized and can only be produced from plant materials. Chicory roots are predominantly used worldwide for the industrial production of these products [2]. Their significance lies in their wide range of benefits, including reducing insulin resistance [3], improving digestion, and enhancing immunity, among others [4]. In many countries, inulin and oligofructose have long been utilized as dietary supplements, sources of fiber, prebiotics, and sugar substitutes [5]. They are extensively used in the industrial production of various food products, including baby food, dietary foods, beverages, functional foods, confectionery, cheese, yogurt, ice cream, and chocolate bars. Additionally, they serve as sugar and fat substitutes in cooking, contributing to a delicate texture and other desirable qualities in food products [2, 5]. The average daily consumption of inulin and oligofructose worldwide ranges from 2 to 12 grams [6].

The global production of inulin and oligofructose is experiencing annual growth, while these products are not currently produced in Russia [7]. However, the technology for extracting inulin from chicory root is generally similar to the process of producing sugar from sugar beets [5]. This similarity suggests the potential for converting non-operational and low-profit, low-productivity sugar factories into facilities that produce these new types of commercial products, which have a market value that is two or more times higher than that of granulated sugar.

This article explores the global experience of converting sugar factories to process root chicory into inulin and oligofructose. It evaluates the climatic conditions suitable for growing root chicory and discusses the agrotechnical methods employed in its cultivation. Additionally, it highlights our own experiences in cultivating this crop in central Russia and presents a schematic representation of the sugar factory conversion, indicating the sections that can be utilized without significant modifications

## **GLOBAL EXPERIENCES OF CONVERTING SUGAR FACTORIES INTO INULIN PRODUCTION FACILITIES**

In the 1920s, several sugar factories in Germany began producing inulin from chicory, similar to the way sugar is extracted from sugar beets. The resulting chicory extract, enriched with inulin, contained numerous impurities, which were removed using an adsorbent. The inulin then precipitated, and the sediment was dried and ground to produce a white powder—known as inulin [8].

In 1991, in Roosendaal, located in the southern Netherlands, the Dutch company Sensus (formerly known as Benuline) converted a sugar factory to process root chicory for the production of inulin and oligofructose [9]. Initially, Sensus produced only fructose by fermenting chicory chips without extraction, and it began producing inulin and oligofructose only in the 2000s.

In 2004, a sugar factory in northern France, owned by the Belgian company Cosucra, was converted to process chicory root into inulin and oligofructose, with a production capacity of 45,000 tons per year [10]. Subsequently, this inulin factory expanded its production capacity.

An analysis of global experiences in converting sugar factories has demonstrated that utilizing existing infrastructure, traditional processes, and sugar production equipment to extract inulin from chicory roots significantly reduces the costs and time associated with technology development, the launch of new inulin production, and ultimately, the payback period. Evidence suggests that modernizing a sugar factory for inulin production can be up to twice as cost-effective as establishing a new facility [10].

## INULIN TYPES AND TECHNOLOGIES FOR THEIR PRODUCTION FROM ROOT CHICORY

The primary types of inulin produced from chicory root by the Belgian companies Beneo-Orafti and Cosucra, as well as the Dutch company Sensus, are presented in the table. The data indicate that as the average degree of polymerization ( $DP_{ave}$ ) of inulin increases, both the solubility in water at room temperature and the sweetness level decrease.

**Table.** Characteristics <sup>1</sup> of the primary <sup>2</sup> types of inulin from root chicory

Inulin type	$DP$ <sup>3</sup>	$DP_{ave}$	Sweetness level <sup>4</sup> , %	Solubility in water at room temperature	Form	Main applications <sup>5</sup>
Standard (native)	2–60	12	10–30	Low	Powder	Dietary supplement
Long-chain	10–60	25	0	Very low	Powder	Dietary supplement, fat substitute
Oligofructose <sup>6</sup> (short-chain)	2–10	4	30–50	High	Syrup <sup>7</sup> , powder	Dietary supplement, sugar substitute

<sup>1</sup> The values in the table are indicative and may vary depending on the manufacturer

<sup>2</sup> There are many more types of inulin; for details, please visit the Beneo-Orafti website [11]

<sup>3</sup> The degree of polymerization ( $DP$ ) of inulin determines the chain length and the number of fructose units in a linear polysaccharide molecule

<sup>4</sup> Sweetness level: % versus sucrose

<sup>5</sup> The application is much broader; for example, it can help reduce insulin resistance

<sup>6</sup> Oligofructose is also known as fructooligosaccharides (FOS)

<sup>7</sup> Due to its high solubility in water at room temperature, oligofructose is also produced in syrup form

Standard inulin is the native form of inulin that has not undergone fractionation, meaning it contains all the inulin fractions present in the original chicory raw material. The process for producing standard inulin from chicory is similar to the method used to extract sugar from sugar beets. Chicory roots are washed, cleaned of stones and tops, and then cut into chips, known as cosettes, which are transported to a diffusion (extraction) apparatus. The resulting diffusion juice, an aqueous extract of chicory, is enriched with inulin. Purification of diffusion juice from secondary components is carried out using beet sugar production technologies. First, defecosaturation and filtration of the juice are carried out. Then, ion exchange methods used in the

liquid sugar production are applied. As a result, salts are removed and the juice is decolorized. To prevent inulin hydrolysis at low pH, ion exchange is carried out at low temperatures. The characteristic bitter taste of chicory, caused by the presence of the glycoside intibin, is eliminated by adsorption cleaning, which also removes residual color. The purified inulin juice is concentrated by evaporation to a dry matter content of 70% and dried to obtain a powdered product with a dry matter content of 95%.

Long-chain inulin is a type of inulin that does not contain low-*DP* fractions. Fractional crystallization is an effective method for its production. When the chicory diffusion juice, which contains seed crystals, is cooled, the high-*DP* fractions precipitate first. The resulting crystals are then separated from the supernatant through centrifugation or filtration. The precipitate is subsequently dissolved in hot water, and the solution is concentrated by evaporation to achieve a dry matter content of 70%. Finally, the solution is dried to produce a powdered product with a dry matter content of 95%.

Oligofructose is a form of inulin with a low *DP*. Partial enzymatic hydrolysis is an effective method for producing oligofructose from chicory diffusion juice. The resulting oligofructose is purified from other components in a manner similar to the purification of inulin from non-inulin substances. The purified oligofructose juice is then concentrated through evaporation to achieve a syrup consistency with a dry matter content of 70%. This syrup-like oligofructose serves as a finished commercial product. Additionally, after undergoing spray drying, powdered oligofructose with a dry matter content of up to 95% can be produced.

## **PROPOSED SCHEME FOR SUGAR FACTORY CONVERSION**

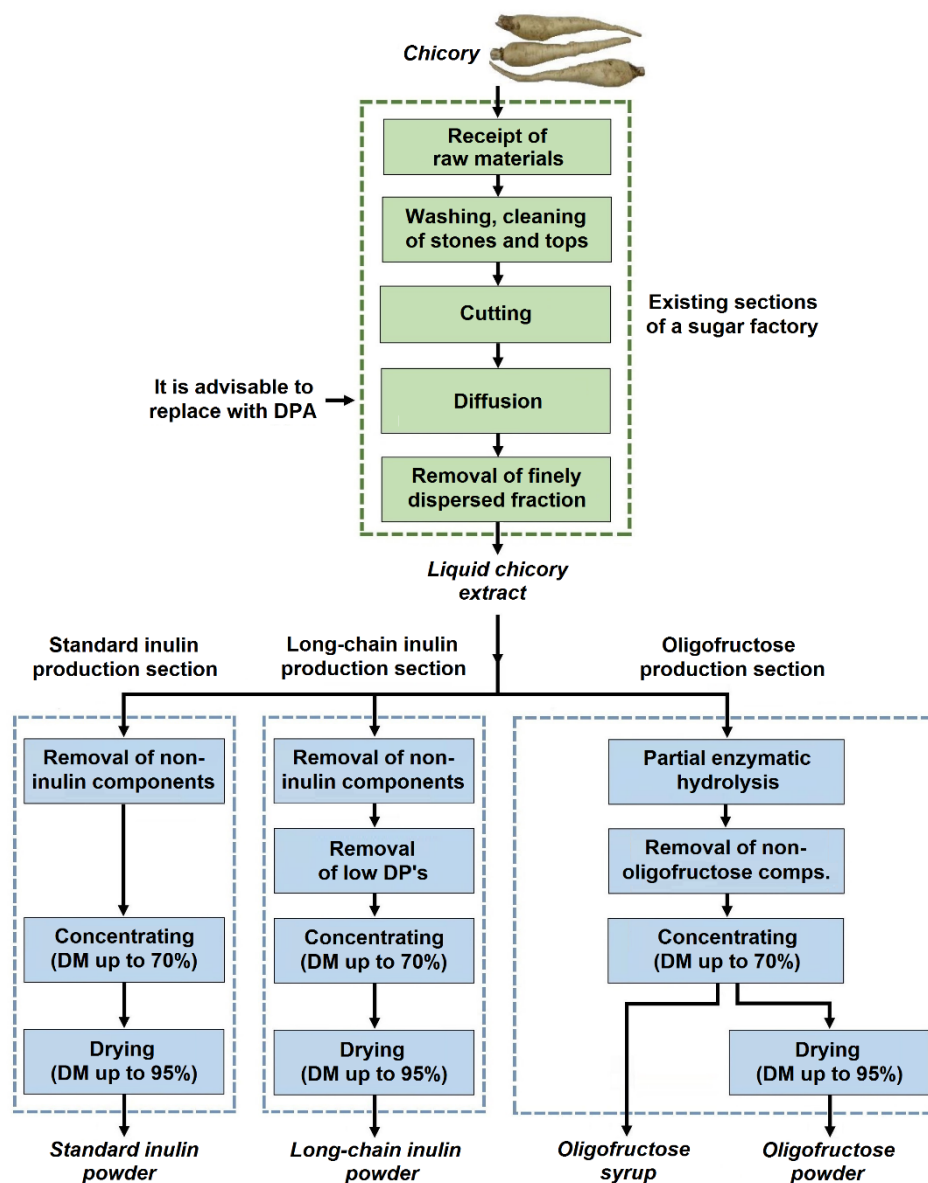
Data analysis indicates that the average capacity of sugar factories converted for processing root chicory is approximately 3,000 tons per day [10]. Notable examples include the sugar factory operated by the Belgian company Cosucra in northern France and the inulin factory in Chile, which was constructed by the Belgian company Beneo-Orafti. The conversion of these sugar factories to produce new inulin products is justified by the fact that such low-capacity enterprises become unprofitable when producing sugar and struggle to compete with larger companies in the industry. This level of output is typical for low-productivity, low-profit sugar factories in Russia.

When converting a sugar factory to process chicory roots, most sections and equipment can remain largely unchanged. However, the product section must be either reconstructed or newly built to accommodate the new types of commercial products and the technologies required for their production. The conversion scheme is illustrated in Fig. 1. The sections that remain largely unchanged are marked in green in the figure, while the newly created sections are highlighted in blue. These newly created sections include the standard inulin production section, the oligofructose production section, and the long-chain inulin production section.

During the modernization of the sugar factory, it is more logical to first initiate the production of standard inulin. Subsequently, the focus can shift to mastering the production of oligofructose and long-chain inulin.

The process of extracting inulin from chicory is generally similar to the extraction of sucrose from sugar beets. Diffusion, or extraction, is the key process that determines both the quantitative and qualitative yield of the target component, whether it is sucrose or inulin. This stage of production is one of the most energy-intensive. Enhancing the efficiency of the diffusion process directly contributes to lowering the cost of the commercial product.

To reduce operating costs and enhance profitability, as well as to facilitate import substitution for equipment, it is advisable to utilize a diffusion pulsating apparatus (DPA) developed and manufactured by Ingehim Company, rather than a conventional diffusion apparatus [12]. This apparatus operates in a counter-current, non-stationary mode, which optimizes the interaction between raw materials and water, thereby maximizing the extraction of water-soluble components and achieving higher concentrations in the extract. The DPA is smaller in size and weight than conventional diffusion apparatuses, requires smaller energy and water expenditures as well as other operating costs for obtaining the extract. The absence of moving parts increases its overhaul period. Smaller temperature and processing time in the DPA reduces inulin losses during diffusion and increases quality of the resulting commercial products. The DPA is universal and capable of processing both fresh chicory chips and roasted cubes of the chicory roots (for the instant chicory production) [13].



**Fig. 1.** Schematic representation of the conversion of a sugar factory to produce inulin (both standard and long-chain) and oligofructose from chicory roots. Existing sections of the sugar factory are highlighted in green, while new sections, which can also utilize existing sugar factory equipment, are indicated in blue

When processing chicory, as with sugar beet, pulp is produced. The quantity of chicory pulp is comparable to that of sugar beet pulp due to the similarities in processing technologies. Like sugar beet pulp, chicory pulp can be used as feed for farm animals [14]. This enables sugar factories to supply livestock breeders with high-quality feed additives while generating additional income.

A positive outcome from the commercialization of chicory pulp as cattle feed, marketed under the trademark Cigarant<sup>®</sup>, was reported by the Dutch company Sensus [15]. The study indicated that when 83% of the standard concentrated feed additive was replaced with the Cigarant<sup>®</sup> product, milk yield, fat content, protein content, and other milk quality indicators remained stable [16]. Research conducted at the University of Nebraska-Lincoln (USA) examined the substitution of sugar beet pulp with root chicory pulp in the diets of yearling steers. The findings revealed that these products have similar compositions. Consequently, the live weight gain of the cattle remained virtually unchanged following the substitution [17]. Based on this data, it is reasonable to anticipate that chicory pulp could be sold in quantities comparable to those of sugar beet pulp.

With some modifications to the process flow—specifically, cutting chicory roots into cubes instead of chips and roasting them prior to diffusion—it is possible to establish the production of roasted chicory extracts at the same DPA due to its versatility. This approach also allows for the creation of an additional line for producing syrup and instant chicory in the product section. The popularity of these products is increasing each year, particularly among individuals who enjoy the taste of coffee but are sensitive to caffeine. Roasting eliminates the glycoside intibin and imparts a coffee-like flavor to chicory. The purification stage of chicory extract for syrup and instant chicory production is significantly simpler compared to the processes involved in producing inulin and oligofructose. Both roasted and dried chicory, in cube form, can be stored for an extended period and are indeed commercially viable products on their own [18, 19]. According to Nestlé, dried chicory with a residual moisture content of no more than 12% remains stable for several years [20]. The same varieties of root chicory are suitable for the production of both instant chicory and inulin [14].

In order to produce new commercial products year-round, the overall technological process can be divided into two stages.

The first stage involves processing the maximum possible quantity of chicory to obtain diffusion juice (aqueous extract) at an operational sugar factory in the shortest time possible. The resulting extract is then concentrated, and appropriate conditions for its storage are established.

The second stage involves processing chicory extract into inulin, oligofructose, and various inulin-containing products at the same facility or at a specially constructed factory throughout the year. If the option of building a separate factory is selected, the processing of extracts can be organized from multiple supplier enterprises, which will help reduce both capital and operating costs.

The conversion of a sugar factory facilitates a seamless transition from sugar production to inulin production. Given the varying ripening, harvesting, and storage times of chicory and sugar beet, it is more efficient to process chicory first and then sugar beet during the remaining months of the season. The ratio of the raw materials can be gradually increased from season to season.

## PROVIDING THE FACTORY WITH ROOT CHICORY

According to [21], root chicory can be cultivated in the same climatic zones as sugar beet. Both crops are sown from seeds, but the seeding rate (kg/ha) for chicory is up to three times lower than that of beet seeds.

The following are the main differences in the cultivation of these crops:

- The mass of root chicory seeds is approximately an order of magnitude less than that of sugar beet seeds. Therefore, for sowing chicory seeds, it is recommended to pellet them or utilize various devices designed for sowing small seeds.
- The mass of chicory roots at the stage of technical maturity is, on average, half that of sugar beet roots, necessitating specific adjustments to harvesting equipment.

Due to the elongated conical shape of chicory roots, which differs from the round shape of sugar beet roots, it is more effective to use machines equipped with vibratory excavating devices for harvesting chicory [21]. The Belgian company Beneo-Orafti successfully adapted beet harvesting machines for the purpose of harvesting root chicory [14]. This modification was necessary because chicory roots are thinner than beet roots. Additionally, Russian domestic equipment designed for excavating carrots and other root crops can also be utilized for harvesting chicory [19].

In [14], it is indicated that chicory is more drought-resistant than sugar beet. During periods of drought, its yield remains stable, whereas the yield of sugar beet decreases by as much as 20%.

A critical issue in industrial cultivation is the availability of domestic seeds for root chicory. In Russia, the selection and production of seeds for this crop are managed by the Federal Scientific Center for Vegetable Growing (formerly known as VNISSOK). One of the notable achievements included in the State Register of Protected Selection Achievements of the Russian Federation is the Petrovsky variety, which has the following characteristics: the root is short and wide, the shoulders are slightly rounded, the dry matter content is 20.5%, including 17.3% inulin, and the growing period lasts 137 days.

To evaluate the potential for cultivating root chicory of the Petrovsky variety in central Russia, we conducted a study in 2022 in the Laishevsky District of the Republic of Tatarstan (Russia) on a test field (Fig. 2). The planting scheme employed consisted of an inter-row spacing of 37.5 cm and a spacing of 8-10 cm between plants in a row. The yield recorded was 49.7 t/ha. However, in the context of industrial chicory cultivation, it is important to consider the inevitable losses associated with mechanized harvesting and other factors, which will likely result in a lower yield. Comparative data on chicory yields in other countries (t/ha) are as follows: Belgium - 46.9; France - 47.4; Serbia - 36.9; Kazakhstan - 29.6; Netherlands - 17.5 [22].



**Fig. 2.** A bed with root chicory of the Petrovsky variety on a test field in the Laishevsky District of the Republic of Tatarstan, Russia (October 2022)

For comparison, Figure 3 illustrates the sugar beet root (harvested in 2022 from the Buinsky District, Republic of Tatarstan, Russia) alongside the chicory root of the Petrovsky variety (our 2022 harvest from the test field). It is evident that the chicory root has a more conical shape, resembling that of a carrot, while the sugar beet root is closer to spherical in form, although the former weighs approximately half as much. Notably, the yield of chicory cultivated on the test field per hectare is comparable to that of sugar beet in Russia [22]. The processing technologies for these crops, as previously mentioned, share many similarities. However, the chicory root possesses a denser structure, and the chips produced from it, unlike those made from sugar beet, exhibit higher fracture strength and are less prone to damage from mechanical impact. This characteristic is likely to positively influence the reduction of finely dispersed fraction formation and enhance the stability of technological processing modes.



**Fig. 3.** Comparison of a sugar beet root (upper root) and a chicory root of the Petrovsky variety (lower root)

To enhance the processing of chicory root and align it more closely with sugar beet processing, it is essential to develop root chicory varieties that lack the glycoside intibin, which contributes to bitterness and complicates the extract purification process. Researchers in Europe have already begun tackling this challenge. Recently, as part of the European CHIC project, Dutch breeders successfully developed root chicory varieties devoid of this compound [23]. However, they employed the CRISPR/Cas9 gene editing technique, which has not yet received approval in the European Union. Currently, efforts are underway to achieve similar results using traditional breeding methods [24].

## **CONCLUSIONS AND RECOMMENDATIONS**

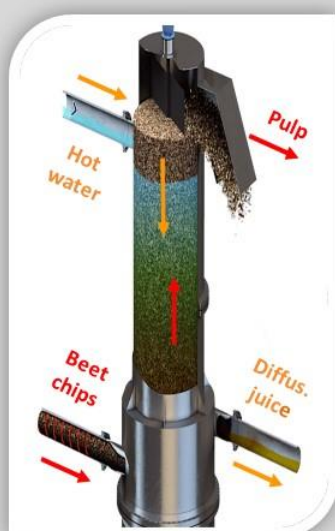
The research conducted leads to the following key conclusions.

1. Inulin has been utilized globally for many years. Industrial production of inulin from root chicory began over a century ago with the conversion of a sugar factory. According to recent data, converting a sugar factory is up to twice as cost-effective as establishing a new inulin production facility.
2. The technology for processing root chicory into inulin is, in many ways, similar to the technology used for processing sugar beets into sugar. Chicory can be utilized to produce standard (native) inulin, long-chain inulin (native inulin from which short-chain fractions have been removed), oligofructose (short-chain inulin), and pulp for feed production.
3. A scheme for converting a sugar factory to produce standard inulin, long-chain inulin, and oligofructose is presented, utilizing most of the existing sections and equipment of the sugar factory. To minimize inulin losses during diffusion, enhance the quality indicators of commercial products, and reduce production operating costs, it is proposed to use a DPA from the domestic company Ingehim instead of a conventional diffusion apparatus.
4. By refining the processing technology—such as altering the cutting mode and utilizing roasting techniques—it is possible to initiate the production of additional commercial products, including dried chicory, roasted chicory, chicory syrup, and instant chicory.
5. A gradual transition from processing sugar beets into sugar to processing root chicory into inulin and other new commercial products is proposed, with an increasing ratio of raw materials from these crops each season.
6. It has been demonstrated that the climatic zones suitable for growing sugar beet are also appropriate for cultivating root chicory. The agronomic practices for both crops are largely similar; however, root chicory exhibits greater drought resistance than sugar beet.
7. An organization has been identified that specializes in the selection and production of root chicory seeds in Russia: the Federal Scientific Center for Vegetable Growing (formerly known as VNISSOK).
8. Positive experiences have been observed in growing root chicory of the Petrovsky variety in central Russia. The crop yield on the test field, utilizing the selected planting scheme, was found to be comparable to yields in other countries as well as to the yield of sugar beets in Russia. The chicory root demonstrates greater technological advantages for processing, as it reduces the formation of finely dispersed fractions and maintains stability in technological processes compared to sugar beet roots.

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