Food system of sugar production: structure and characteristics

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Abstract. The food system for sugar production plays a crucial role in ensuring a country's food security, and its effective functioning requires an in-depth study of the features of its formation. This study used logical analysis, generalization, and systematization of scientific and practical knowledge in sugar technology to consider the technological flow of beet sugar production. The structure of the food system was determined, consisting of 14 selected local systems based on 6 types of processes - mechanical, mass transfer, chemical, physicochemical, thermal, and separation. This indicates the complexity of the food system and the significant transformation of sugar beets as a raw material. The mechanisms of formation of local systems were detailed, showing a transformative effect on the modification of the raw material flow. The characteristics of two local systems - diffusion juice and massecuite of the first stage of crystallization - were considered in detail, revealing them as complex disperse systems that differ in composition, dispersion, technological properties, stability indicators, and instability factors. The systematized data obtained can be used to create effective technological solutions in the sugar production food system.

1 Introduction

The food system, a complex that unites the chain from the production of raw materials to the consumption of food products, which includes producers, suppliers, sellers, consumers and waste disposal organizations, creates conditions for the country’s food security [1]. One of the elements of the food system is the production system itself (food system), in which technological processes are carried out to change the quality characteristics of production objects [1, 2]. The effective functioning of food systems makes it possible to obtain, based on technologies of deep processing of raw materials with an intravitally formed composition and properties, high-quality safe products of a given composition [3]. Therefore, the country’s industrial policy in the field of processing and food industries of the agro-industrial complex in the future is associated with innovative developments, which will raise the quality of nutrition to a new level [4]. For this purpose, the patterns of functioning of food systems are being studied depending on the quality of raw materials, production conditions, and

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storage of products [5, 6], and emphasis should be placed on identifying and studying key factors in the development of situations [7].

The food system of sugar production serves as a source of supply of this product to the economies of all countries of the world, and its involvement in ensuring the sustainable development of the regions where they are located is very high [8].

In Russia, the annual production of sugar from sugar beets is about 6 million tons, guaranteeing the country's food independence for this product, meeting the needs of food manufacturers, and supplying wholesalers with a value of approximately 225-230 billion rubles [9]. Further innovative development of the food system for sugar production involves deepening knowledge about the structural laws of its structure, properties and features of functioning in various conditions.

2 Materials and methods

To consider the structure of the sugar production food system, the process flow was decomposed into local systems and assigned a numerical index. The criterion for identifying a local system was the main process of transforming the input stream, which led to changes in its qualitative characteristics in accordance with the goals and objectives of the food system. Processes were designated based on the generally accepted classification for food production according to the type of technological impact on the object [10] with additional detail. Next, for each local system, an input stream was identified in the form of semi-finished products and supplied reagents for carrying out chemical and physicochemical reactions, and an output stream in the form of semi-finished products; substantiated the mechanism for the formation of a local system, revealing the transformative effect on the modification of the raw material flow.

Local systems were considered as complex dispersed systems that are in a certain physical and chemical equilibrium, since the multicomponent chemical composition of sugar beets as an input stream into the food system of sugar production, along with the mechanisms of formation of local systems, determines precisely their structure. To characterize local systems, we used the state of aggregation and type of dispersed system according to the generally accepted classification [11]; the ability to perform local tasks was expressed through technological properties.

An important characteristic of a system was considered to be the ability to function stably over time [12], synchronously with other local systems, when changes in one local system are consistent with transformations in subsequent ones.

The stability of systems was considered as a set of stability parameters and instability factors. Signs of stability were representative indicators, the change of which relative to their threshold values transfers the system to an unstable state; they were individually justified for each local system; Potentially undesirable physicochemical processes that create the risk of the system going out of balance were considered factors of instability of local systems.

Logical analysis, methods of generalization and systematization of scientific and practical knowledge of sugar technology were used as tools [13-15]. Exclusively the main product flow was considered, without taking into account side streams, such as the preparation of the extractant, lime milk; processing of pulp by-product, massecuite outflow from the first stage of crystallization, etc.

3 Results and discussion

The purpose of the food system for the production of sugar from sugar beets is the formation of the following products, set out in the reverse order of production in the process stream:

- white sugar with quality indicators that meet the requirements of the standard;
- sucrose crystals with specified physicochemical properties from a sugar-containing solution;
- sugar-containing solution with specified characteristics from sugar beets.

Solved problems of the food system to achieve the goals:

- processing of sugar crystals;
- concentrating the sugar-containing solution to supersaturation, crystallizing sucrose from the solution, separating the crystals from the liquid phase;
- dosing and processing of sugar beets, extraction of sucrose from raw materials, purification and thickening of the sugar-containing solution.

Based on the presented goals and objectives of the food system, its structure has been formed, including interconnected local systems arranged sequentially along the flow of the technological flow. Table 1 shows the selected local systems with a description of features and attributes.

Table 1. Local systems in the structure of the sugar production food system.

Local System Index	Main process of the system	Input stream	Mechanism for forming a local system	Output stream
1	Grinding (mechanical process of giving raw material particles a certain shape and size)	Sugar beet	Cutting root vegetables with knives into thin slices 1.2-1.4 mm thick, 2.0-2.5 mm wide	Beet chips
2	Extraction (mass transfer process of extracting sucrose from a solid into a liquid)	Beet chips	Thermal destruction of protoplasm of beet tissue cells and maintaining the difference in sucrose concentrations in beet chips and extractant at pH 6.2-6.5	Diffusion juice
3	Pre-defecation (physico-chemical process of precipitation of acid anions and high molecular weight compounds with calcium)	Extractant (prepared water)	Coagulation effect of calcium ions on high molecular weight compounds, precipitating effect on acid anions with a gradual increase in alkalinity to pH 12	Pre-defecated juice
4	Defecation (chemical process of alkaline-thermal decomposition of non-sugars)	Diffusion juice	Decomposition of reducing substances, acid amides, ammonium salts under conditions of pH 12, specified temperature and duration	defecated juice

5	The first stage of saturation (physico-chemical process of formation of calcium carbonate precipitate and adsorption of non-sugars on its surface)	Lime milk $Ca(OH)_2$	The interaction of calcium hydroxide with carbon dioxide at a given temperature and duration under conditions of a total inactive concentration of calcium hydroxide of 1.8-2.0% CaO with a gradual transition to active to an optimal alkalinity of 0.08-0.12% CaO to obtain a positively charged precipitate; adsorption of negatively charged non-sugars on it	Juice of the first stage of saturation
6	Filtration (the process of separating a coarse suspension of juice with a solid content of 40-60 kg/m3 through a porous partition)	Pre-defecated juice	Separation of the solid phase by forming a compressible sediment on the surface of the filter partition	Filtered juice of the first stage of saturation
7	Second stage of saturation (physico-chemical process of formation of calcium carbonate precipitate and adsorption of non-sugars on its surface)	Lime milk $Ca(OH)_2$	The interaction of calcium hydroxide with carbon dioxide at a given temperature and duration under conditions of a gradual decrease in alkalinity from 0.4% CaO to 0.02% CaO and maximum precipitation of calcium salts to obtain a positively charged precipitate; adsorption of negatively charged non-sugars, mainly coloring substances, on it	Juice of the second stage of saturation
8	Filtration (the process of separating a coarse suspension of juice with a solid phase content of 2-5 kg/m3 through a porous partition)	defecated juice	Separation of the solid phase by forming an incompressible sediment on the surface of the filter partition	Filtered juice of the second stage of saturation
9	Sulfitation (chemical process of inhibiting the growth of colorants)	CO_2 saturation gas	Blocking of carbonyl groups of reducing substances by sulfite ions, reduction of coloring substances	Sulfated juice

			into colorless compounds	
10	Filtration (the process of separating a thin suspension of juice with a solid phase content of 0.3-0.5 kg/m3 through a porous partition)	Juice of the first stage of saturation	Solid phase separation by trapping particles inside the filter membrane	Purified juice
11	Evaporation (the thermal process of concentrating a product by converting part of the solvent into vapor)	Filtered juice of the first stage of saturation	Removal of water under conditions of solution boiling in a multi-effect evaporation plant with a sequential decrease in the boiling temperature in the bodies from 126 to 68 °C	Syrup
12	Filtration (the process of separating a thin suspension of syrup with a turbidity content of 0.05-0.5 kg/m3 through a porous partition)	CO_2 saturation gas	Removal of suspended particles by trapping them inside the filter membrane	Purified syrup with clarified syrup
13	Crystallization of sucrose (mass transfer process of isolating a solid from solution)	Juice of the second stage of saturation	Formation of sucrose crystals from a supersaturated solution with a coefficient of 1.25-1.30 under boiling conditions at a temperature of 72-78 oC and a given vacuum	Massecuite of the first stage of crystallization
14	Centrifugation (the process of separating a rough suspension with a solid phase content of 50-55% through a porous partition in a field of centrifugal forces)	Filtered juice of the second stage of saturation	Separation of sugar crystals by forming a layer of them on a porous partition of a centrifuge with a separation factor of 1500, washing with water	Wet sugar

A total of 14 local systems have been identified, which are based on 6 types of basic processes, which indicates the complexity of the food system and the significant transformation of raw materials. The transforming effect in local systems is carried out by the following processes: mechanical – in 1; mass transfer – in 2; chemical – in 2; physico-chemical – in 3; divisions - in 5; thermal - 1.

The mechanism of formation of the local system is presented in the form of a transformative effect that completely changes the state of the food system and is expressed as a set of main factors: cutting, thermal destruction, coagulation action, decomposition, interaction of components, separation of the solid phase, removal of water, formation of crystals and their processing.

The characteristics of local systems are more informative and variable, therefore Table 2 shows, as an example, brief characteristics of two local systems - diffusion juice and massecuite of the first stage of crystallization.

Table 2. Characteristics of individual local systems of the sugar production food system.

Local System Index	State of aggregation and dispersion	Technological properties	Stability indicators	Factors of instability
2	Liquid, DM = 13-15%. Polydisperse system: dispersion medium – true and colloidal aqueous solutions of sucrose and non-sugars; dispersed phase – solid particles of raw materials and colloidal particles of non-sugars. Particle size range 10^{-9}-10^{-3} m	Ability to: diffusion of sucrose from a solid into an extractant; minimal transfer of non-sugars into the extractant; minimal decomposition of sucrose; minimal transition of insoluble pectin substances into soluble ones	Sucrose content 89.0-92.0% by weight of dry substances; the content of small particles of raw materials is less 1.0 g/dm^3; lactic acid content less than 150 mg/kg	Foaming, development of microbiological processes, gas evolution, formation of polysaccharides
13	Viscous mass, DM = 92.0-92.5%. Polydisperse system: dispersion medium – true and colloidal concentrated solutions of sucrose and non-sugars; dispersed phase – sucrose crystals and colloidal particles of non-sugars. Particle size range 10^{-6}-$2\cdot10^{-3}$ m	Ability to: grow sucrose crystals on artificially introduced crystallization centers; minimal inclusion of non-sugars in crystals; minimal degradation of sucrose	Crystal content 50.0-55.0%; content dry substances no more than 92.0-92.5%	Formation of coloring matter, foaming, gas evolution

The local food system of diffusion juice is formed from beet chips - a capillary-porous body and prepared water as an extractant in countercurrent movement at pH 5.5-6.0 and temperature 70-72 oC. The task of the formed system is the maximum extraction of the target component of sucrose from beet tissue and the minimum transfer of non-sugars [16, 17]. The local food system of massecuite at the first stage of crystallization is formed as a viscous mass of crystals and intercrystalline solution with a sucrose supersaturation coefficient of 1.25-1.30 under boiling conditions at a vacuum of 0.08-0.09 MPa and a temperature of 72-78 oC. The task of the formed system is the maximum release of sucrose in crystalline form with minimal inclusion of non-sugars in the crystals [18, 19].

In general, it is noted that all local systems are dispersed with a different range of particle sizes. Moreover, for systems with an index of 2-13, sucrose and non-sugars are in a dispersive aqueous medium in the form of true and colloidal solutions, and solid particles of raw materials, colloidal particles of non-sugars, sediment of calcium carbonate with non-sugars adsorbed on it, sucrose crystals ranging in size from 10^{-9} to $2 \cdot 10^{-3}$ m – in the dispersed phase. For systems with index 1 and 14, the dispersion medium is represented by solid particles of raw materials measuring $5 \cdot 10^{-2}$x$2.5 \cdot 10^{-3}$x$1.2 \cdot 10^{-3}$ m and sucrose crystals measuring $0.4 \cdot 10^{-3}$-$0.8 \cdot 10^{-3}$ m, and dispersed phase - true and colloidal solutions of sucrose and non-sugars. All local systems have different tasks and, accordingly, differ in technological properties in the form of the ability to undergo a given transformation under the targeted influence of factors of different nature. Signs of stability, expressed by representative parameters of the output stream and their threshold values for each system, are individual due to significant differences in semi-finished products in organoleptic and physicochemical parameters; The key ones are highlighted among them. Against the background of different factors of instability of all local systems, systems with index 2-13 are also characterized by the same factors - foaming and gas evolution.

4 Conclusion

During the research, 14 local systems were identified for the sugar production food system. It is shown that processes occur in local systems: mechanical, mass transfer, chemical, physico-chemical, thermal, separation, which indicates the complexity of this food system and a significant transformation of raw materials in it. The mechanisms for the formation of local systems, which indicate a transformative effect on the modification of the raw material flow, are detailed.

Detailed characteristics of local systems are presented using the example of diffusion juice and massecuite of the first stage of crystallization. They are shown as complex disperse systems differing in composition and dispersion, technological properties and stability indicators. The key indicator of stability for these local systems is a representative parameter that reflects the completeness of extraction of the target component: for diffusion juice - sucrose content with a threshold value of at least 89.0-92.0% by weight of dry substances, for massecuite - crystal content with a threshold value in the range of 50.0-55.0 %. Foaming and gas evolution were identified as identical factors of instability of these local systems, which transform two-phase systems into three-phase ones, making it difficult to solve technological problems. The considered characteristics of local systems showed a combination of technological properties and stability indicators.

The obtained systematized data will allow us to better understand the mechanism of formation and functioning features of the sugar production food system in order to create effective technological solutions.

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