Technological Platform for the Best Available Technologies for Processing Universal Agricultural Raw Materials

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Abstract. The article discusses the historically formed spiral cycles of development of the technological platform for the best available whey processing technologies. The characteristics of the stages of development repeated at each cycle, reflecting the level of scientific and technological progress in this area are presented. The main technological trends and concepts of milk whey processing in the near, medium and longer term are considered. It is shown that in the future, breakthrough achievements in food technologies will be based on the results of digital transformation of production, the introduction of innovative technologies for digital modeling and design, quantum computing, robotic automation and additive technologies.

1. Introduction
Whey, as a universal agricultural raw material and the main by-product of the dairy industry, is the most important source of essential nutrients, and above all protein components, the biological value of which significantly exceeds the value of most of the known food proteins consumed by humans. About 50% of valuable dry substances pass into whey: 20% of proteins, 80% of minerals, 95% of lactose, 10% of milk fat [1]. The total world resources of whey are about 200 million tons per year [2, 3]. Theoretically, this is an opportunity to additionally receive more than 1.2 million tons of protein and 1.4 million tons of minerals, 800 thousand tons of milk fat and about 9 million tons of lactose per year.

2. Discussion
The formation and development of a technological platform of the Best Available Techniques (BAT) for processing whey around the world is associated with resource efficiency, which is a fundamental concept for the transition of the dairy industry to a new technological level [4, 5]. This process can be represented in the form of a historically established spiral sequence of technological cycles (turns), each of which is due to a new stage of technology development and consists of repeating interrelated stages (table 1). At the end of the last stage, a transition to a new cycle occurs, in which the sequence of stages is repeated.

The first technological cycle is associated with the first industrial revolution and the mechanization of production. The second – with the second industrial revolution, the use of electricity and conveyors. Next – with the third industrial revolution, electronics and automation. And finally, the modern cycle – with the fourth industrial revolution, the Internet of things, machine learning, industrial and household robots, means of communication, interaction models supported by digital transformation.
Table 1. Development of a technological platform for the best available techniques for whey processing.

| Stages of development | Technological cycles (turns) of the spiral of development |
|-----------------------|----------------------------------------------------------|
| **Scientific and technical** | The emergence of mechanical devices for the production and use of whey, the transition from a primitive artisanal method | The use of whey as a food component, for medicinal purposes, for making bread, food and drinks, feeding animals | Use of whey powder in food production | The ripening of the need to ensure social and regulatory measures in the field of environmental safety and economic feasibility in food technologies |
| **Technical and economic** | Increase in the production and use of milk whey, improvement of its processing technology | Development of technologies using milk whey in various branches of the food industry | Use of a wide range of dry whey products in food production and in the pharmaceutical industry | Tightening of environmental legislation, abandoning of environmentally friendly technologies |
| **Economic and social** | Increasing the productivity of processes for the production, processing and use of milk whey in an industrial-branch way | Development of technologies for whey powder and its dry derivatives (concentrates, isolates, etc.) | The need for deep processing of whey and the production of such components as lactose, lactulose and its other valuable components | Development and phased implementation of BAT requirements, appearance of BAT manuals and other guidance materials |
| **Socio-regulatory** | Methods for processing and using milk whey no longer met the needs of industry and the population | Methods for processing and using milk whey no longer met the needs of modern industry and the population. | Methods of processing and use no longer met the requirements of ecology, the needs of modern industry and the population. | Development and implementation of innovative technologies for fractionation and deep (waste-free and resource-saving) processing of whey and its components |

The first technological cycle – early industrial processing of whey. In the Middle Ages (from the X–XI to the XVIII centuries), with the growth in the production of cheese and cottage cheese, the amount of whey obtained increased. It was used mainly for food, baked goods, medicinal purposes, and for feeding domestic animals. The period from the beginning of the XVIII century to 1878–1882 is characterized by the accumulation of knowledge on milk processing technology, its composition and the possibilities of whey processing [6].
From the second half of the XIX century to the first half of the XX century the first cheese and dairy factories appeared in cities using an amazing invention – a centrifugal separator (the first separator by Gustaf de Laval (Carl Gustaf Patrik de Laval), 1878) and other specialized equipment [1].

The second technological cycle is the beginning of the technological development of industrial processing of milk whey. With the increase in the volume of obtained milk whey, the problem of its use arose. Industrial technologies for its processing with the production of condensed concentrates, drinks, milk sugar, lactic acid, calcium lactates and other products became widespread. [1, 7]. Technologies for extracting the largest fractions and components from milk whey and their use with the subsequent processing of purified whey using technologies that do not require high-tech specialized equipment are being intensively developed. Whey and its components are actively used in bakery, beverage production, liquid whole milk substitute, other products and fermented whey for feed purposes.

The third technological cycle is the improvement of whey processing technologies. A century after the first experiments with synthetic membranes (Thomas Graham, England, 1861), the first industrial membrane technology appeared in the mid-60s of the XX century. By the 80s, the total volume of produced milk whey exceeded 10 million tons per year [6]. The increase in its production in an industrial-sectoral way sharply exacerbated the problem of processing and use of whey, led to discharges into wastewater, the first signs of a negative impact on the environment.

The development of scientific and technological progress in the field of whey processing was facilitated by a significant number of design and research work on the improvement and development of technological processes, the creation of specialized equipment and processing plants [6]. Abroad and in our country, vacuum evaporation, drying, membrane processes and technologies began to be used for whey processing. Their implementation made it possible to organize the production of a wide range of condensed and dry whey concentrates: lactose and lactulose, bifidogenic preparations, food and feed mixtures, whey protein concentrates, demineralized whey and dry permeate, microparticulated proteins and other products for the food and pharmaceutical industries.

The fourth technological cycle – increasing environmental friendliness, energy intensity and efficiency of whey processing, transition to the principles of the best available technologies. Against the background of the transition to the concept of environmental protection and the search for new additional food resources all over the world, the prerequisites for the need developed and technological capabilities emerged for deeper processing and fractionation of significant volumes of milk whey into food products and feed products.

Improvement of technologies for industrial processing of whey and its availability in liquid and dry form – fractions and whey protein concentrate – WPC, whey protein isolate – WPI (and in the future – deeper fractionation of the entire amino acid pool, obtaining hydrolysates), lactose and lactulose, dry permeate, allowed to use it in children's, dietary, sports and medical nutrition, in soups, sausages, ice cream, whey pastes and cheeses, confectionery, pharmaceutical, yeast and other products [1]. Technologies of this type can be attributed to low-waste, resource-saving, innovative and therefore the best available, since they are based on a combination of high-tech processes with energy-intensive but efficient equipment (vacuum evaporation, modern types of drying, etc.), which allows to reduce overall energy consumption [7]. The range of manufactured products and technologies is constantly expanding, and the prospects for the development of a technological platform for the best available techniques for processing milk whey remain broad and promising.

Based on a brief analysis of the existing cycles and the current stage of development, the following trends in the processing of whey can be predicted [1, 2, 3, 5, 9–13].

In the short term:
1. General trends in the development of technologies for industrial processing of whey:
   – food technology based on the full and rational use of all whey components (condensed and dry food products, jellies, creams, mousses, fresh, fermented drinks, etc.);
   – technologies for the separate use of its components (purification and isolation of proteins, fat, lactose, etc.).
technologies of whey derivatives, production and biotransformation of its components (hydrolysates of whey proteins, glucose-galactose syrups, lactulose, microparticulated protein, etc.).

– technologies for modeling processes and products, for example, reagent-free biotransformation of lactose with access to the practice of digitalization and digital transformation of the production of its anomers;

– gradual transition of technologies to a digitalization platform with modeling at the molecular level of the resulting products.

2. General trends in the use of new physical methods for processing whey in the near future:

– improvement of the processes of preliminary purification of milk whey from casein dust (vibration filtration, cavitation treatment, etc.), condensation and gentle drying;

– improvement of baromembrane (ultrafiltration, nanofiltration, reverse osmosis) and electromembrane processes for processing milk whey (electrodialysis, electroructivation);

– application of cavitation processes and technologies (hydro-cavitation and ultrasonic cavitation);

– isolation of proteins by cryoconcentration, use of separation freezing to obtain casein-albumin mass, concentrates of whey proteins and proteins with polysaccharides (chitosan, pectin, etc.)

A decisive role is to be played by modern membrane, electrophysical, baric, ultrasonic methods of processing milk whey with subsequent bioconversion of processed products.

In the medium and long term.

The trends discussed above show that new technological processes in the food industry and in the processing of whey, in particular, are associated with an increase in the complexity of the production process. The prospects for their development largely depend on the level of digital transformation of production. The main results of a breakthrough nature in food technology will be associated with the implementation of the fourth industrial revolution and solutions within its framework of the following technological trends and concepts [14–16]:

1. “Digital twins”. Creation of digital copies of the processes of processing whey and real products of group and individualized nutrition. Looping design, production and implementation processes into a single ecosystem that has its own digital twin. The ability to design complex science-intensive and high-tech products with guaranteed consumer properties and track their behavior throughout the entire life cycle will ensure the leadership of enterprises in the food industry. Such innovative technologies will allow mobile analysis of consumer offers coming in online format, for example, through smartphone applications, and make changes and adjustments to product release processes that would be too risky or expensive to test on a real physical object.

2. “Quantum computing”. Powerful and incredibly fast quantum computers represent a new class of computing devices that implement the principles of quantum mechanics. They will be able to solve the currently unsolvable analytical and computational problems associated with modeling the structure and interactions of various components of milk whey at the atomic-molecular level, properties and presentation of finished food products. The transfer of developments to optimize processes and technologies into the field of quantum computing will take place not only in scientific laboratories, but also directly in production.

3. “Robotic process automation”. This technology will affect every industry, will make it possible, on the basis of sensors, to receive, regulate and automate information on any structural changes, including in the production of fractionated whey products at all stages of the technological chain of its processing. The interaction of technical systems with each other and with the operator of the production process will be based not only on traditional algorithms and methods of information management, but also on the use of promising interfaces for analyzing the electrical activity of the human brain and muscles with reverse force-torque connections.

4. “Mass personalization and micro-moments”. A new global task has been set for the food industry – it is necessary to satisfy the individual needs of each consumer and, at the same time, to avoid a significant increase in the cost of such production. Digital transformation is the main way to solve this problem. Thanks to the development of digital technologies such as Industrial Internet, Big Data, Artificial Intelligence and Digital Twins, innovative food technologies are entering a new development
cycle with the release of personalized products on a massive scale. The term “micromoments” implies taking into account and responding to consumer needs in on-line mode, the ability to quickly make changes to any link in the food chain - from farms to packaging and food production, storage and delivery services.

5. “Additive Manufacturing”. Together with the development of digital design and supercomputer engineering of complex food systems and whey processing processes, as well as mass personalization, 3D and 4D printing of food products will become widespread. Additive technologies are of enormous importance for ensuring the competitiveness of an enterprise through rapid model testing and prototyping, development and release of new products in the shortest possible time. In addition, advancing the principles of additive manufacturing will provide significant benefits in the rapidly evolving personalized food market.

3. Conclusion
Current trends and development directions of the technological platform of the best available techniques for processing whey indicate that instead of a highly specialized approach, there is a transition to cross-industry research, followed by digital transformation of production, modeling at the molecular and macro levels, robotic automation and the introduction of additive technologies. This testifies to the completion of the next stage in the development of technologies, to the fact that within the framework of the old one a new technological order was born and begins to take shape.

A new paradigm of digital design and modeling of globally competitive products of a new generation is gradually coming to the fore [17]. It acts as a driver for complex BAT solutions and the creation of digitalized Virtual Factories of the Future.

References
[1] Khramtsov A G 2011 Whey phenomenon (St. Petersburg: Profession) 804 p
[2] 2020 Dairy Ingredients Market by Type, Application, Livestock, Form And Region - Global Forecast to 2025 (New York: GLOBE NEWSWIRe) 229 p
[3] Khramtsov A G, Anisimov G S, Shkola S S, Kravtsov V A, Yeremina A I and Dykalo N Ya 2020 Molasses processing: present and future Dairy industry 12 54–6
[4] Khramtsov A G 2017 Scientific foundations of the new technological structure of the dairy industry (Beau-Bassin: LAP LAMBERT) 117 p
[5] Lopez E R, Doval R, Martinez M and Bello Bugallo M P 2017 Integrated environmental permit through Best Available Techniques: Evaluation of the dairy industry Journal of Cleaner Production 162 512–28
[6] Nesterenko P G, Evdokimov I A and Khramtsov A G 2008 Historical aspects of the use and processing of whey Dairy industry 11 32–4
[7] Evdokimov I A, Zolotoreva M S, Volodin D N and Somov V S 2013 Analysis of whey processing and the creation of promising resource-saving technologies Science. Innovation. Technologies 1 37–44
[8] Khramtsov A G, Borisenko A A, Bratsikhin A A, Evdokimov E A, Borisenko A A, Borisenko L A, Ryabtseva S A and Lodygin A D 2020 Issues of implementation of the best available techniques Proceedings of universities. Food technology 2–3 8–13
[9] Kounfieg N V Y, Suwal S J, Mikhailin S, Beaulieu L and Bazinet L 2016 Simultaneous electroseparation of anionic and cationic peptides: Impact of feed peptide concentration on migration rate, selectivity and relative energy consumption Separation and Purification Technology 157 53–9
[10] Kostenko K, Bratsikhin A, Borisenko A, Salmanova D and Leshchenko E 2017 Computer modeling of whey protein β-lactoglobulin behavior in the activated liquid systems Journal of Hygienic Engineering and Design 20 70–4
[11] Babenyshev S, Mamay D, Bratsikhin A, Borisenko A, Mamay A and Amanova S 2020 Ultrafiltration of cottage cheese whey for cleaning of nitrogenous substances Journal of
Hygienic Engineering and Design 33 219–224

[12] Jambrak A R, Mason T J, Lelas V, Paniwnyk L and Herceg Z 2014 Effect of ultrasound treatment on particle size and molecular weight of whey proteins Journal of Food Engineering 121 15–23

[13] Dufton G et al. 2018 How electrodialysis configuration influences acid whey deacidification and membrane scaling J. Dairy Sci. American Dairy Science Association 2016 1–18

[14] Schwab K 2016 The Fourth Industrial Revolution (Switzerland: World Economic Forum) 285 p

[15] Babkin A V et al. 2019 Digital economy and end-to-end technologies: theory and practice (St. Petersburg: Polytech-Press) 623 p

[16] Sen K O, Durakbasa N, Erdol H, Berber T, Bas G and Sevik U 2017 Implementation of Digitalization In Food Industry DAAAM International Scientific Book 91–104

[17] Borovkov A I et al. 2017 Digital production: methods, ecosystems, technologies (Moscow: Skolkovo) 80 p