

Methods for obtaining and using succinic acid in the food industry: A Scoping Review

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ABSTRACT

Introduction: Succinic acid is the final metabolite of many microorganisms. It has antioxidant, tonic properties, and also takes part in the metabolic processes of a living organism. Its use in food formulations will help expand the range of functional food products aimed at improving metabolism.

Purpose: Description of methods for obtaining and features of the use of succinic acid in the food industry for the production of functional foods and biologically active food additives.

Materials and Methods: Information search was carried out in the databases Scopus, Web of Science, PubMed, RISC for the period from 01/01/1994 to 03/01/2024. Marketing research reports on the use of succinic acid in the food industry for the period 2016-2023 were also analyzed. The review included review and empirical articles that met the selection criteria in English and Russian. This review of the subject field is based on the PRISMA-ScR protocol.

Results: Currently, succinic acid is produced by chemical or biotechnological methods. The most common method is the chemical method (paraffin oxidation, catalytic hydrogenation, maleic acid or maleic anhydride). There is also a biotechnological method based on the cultivation of microorganisms that produce succinic acid. Various organic substrates, including food industry waste, can be used to cultivate microorganisms. It has been shown that succinic acid is included in the list of safe food additives and is used in food production as an acidity regulator. However, due to the fact that it has proven biological effectiveness, succinic acid can be included in the formulations of various food products, thereby providing them with additional functional properties.

Conclusion: To introduce the biotechnological method into the real sector of the economy, it is necessary to solve a number of limiting factors. It has been established that succinic acid can be used not only as a traditional food additive (acidity regulator), but also as a dietary supplement. The volumes of production and demand for succinic acid are slowly but increasing, which indicates the need to introduce new technologies for the production of succinic acid in order to meet the demand for this product.

Keywords: succinic acid, cell engineering, succinylation, functional foods, food additives, human health

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Методы получения и применение янтарной кислоты в пищевой промышленности: обзор предметного поля

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АННОТАЦИЯ

Введение: Янтарная кислота является конечным метаболитом многих микроорганизмов. Она обладает антиоксидантными, тонизирующими свойствами, а также принимает участие в обменных процессах живого организма. Её применение в рецептуре продуктов питания будет способствовать расширению ассортимента функциональных продуктов питания, направленных на улучшения метаболизма.

Цель: описание методов получения и особенностей применения янтарной кислоты в пищевой промышленности для производства функциональных продуктов питания и биологически активных добавок к пище.

Материалы и методы: Поиск информации реализовывался в базах данных Scopus, Web of Science, PubMed, РИНЦ за период с 01.01.1994 г по 01.03.2024. Также были проанализированы отчеты о маркетинговых исследованиях в области использования янтарной кислоты в пищевой промышленности за период 2016-2023 гг. В обзор включены обзорные и эмпирические статьи, отвечающие критериям отбора, на английском и русском языках. Данный обзор предметного поля выполнен с опорой на протокол PRISMA-ScR.

Результаты: В настоящее время янтарную кислоту получают химическим или биотехнологическим методом. Наибольшую распространенность имеет химический метод (окисления парафинов, каталитического гидрирования, малеиновой кислоты или малеинового ангидрида). Существует также биотехнологический метод, основанный на культивировании микроорганизмов-продуцентов янтарной кислоты. Для культивирования микроорганизмов можно использовать различные органические субстраты, в том числе отходы пищевой промышленности. Показано, что янтарная кислота включена в список безопасных пищевых добавок и применяется при производстве пищевых продуктов в качестве регулятора кислотности. Однако в связи с тем, что она обладает доказанной биологической эффективностью янтарную кислоту можно включать в рецептуры различных пищевых продуктов, тем самым наделяя их дополнительно функциональными свойствами.

Выводы: Для внедрения биотехнологического метода в реальный сектор экономики необходимо решить ряд ограничительных факторов. Установлено, что янтарная кислота может быть использована не только в качестве традиционной пищевой добавки (регулятора кислотности), но и в качестве биологически активной добавки. Объемы производства и спроса янтарной кислоты медленно, но увеличиваются, что свидетельствует о необходимости внедрения новых технологий по производству янтарной кислоты для того, чтобы удовлетворить спрос на данный продукт.

Ключевые слова: янтарная кислота, клеточная инженерия, сукцинирование, функциональные продукты питания, пищевые добавки, здоровье человека



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INTRODUCTION

Succinic acid is a dicarboxylic acid with a variety of practical applications. For instance, it is a popular food additive (Ahn, 2020). Succinic acid is known for its multifaceted therapeutic effect on human health. Its antihypoxic, hepatoprotective, and anti-stress properties are well documented (Stepanova, 2010). In addition, succinic acid is a powerful adaptogen that regulates muscle exertion; it facilitates the synthesis of protein, hemoglobin, and glycogen in the liver, as well as improves glucose absorption. Succinic acid is an important part of geriatric diets and sports nutrition (Kovalenko, 2000).

Succinic acid and its salts are officially approved to be used in the food industry as pH regulators in various food systems, e.g., as part of food additive E363 (Stolyarskaya, 2021). Given its strong physiological effect, the level of prior studies in succinic acid and its derivatives seems to be a relevant review issue. This article offers a comprehensive review of succinic acid: modern production methods, performance as a biologically active component in functional foods, application in various food systems, and the current state of the succinic acid market in Russia and the world.

The past decade has seen a remarkable rise in publications on succinic acid (Iragavarapu, 2023; Ahn, 2020; Li, 2021; Gao, 2016; Li, 2019); however, its application as a food additive has many scientific gaps. The research objective was to describe its most relevant production methods and applications in the food industry.

STUDY OBJECTS AND METHODS

Protocol and transparency statement

This review is a transparent, accurate, and honest report that relied on the PRISMA-ScR protocol.

Selection criteria

The review featured scientific publications made by Russian and foreign authors that reported general information, production methods, and use of succinic acid in the food industry. It covered research articles, reviews, and conference reports. The selection criteria were in line with the mnemonic of Population, Concept, and Context (Table 1).

Table 1

Selection criteria

Criterion	Included	Excluded	Grounds for exclusion:
Population	Microbial producers of succinic acid	The microorganisms are not used in the food industry; the microorganisms produce no succinic acid as a metabolite.	The research focuses on microorganisms that produce other metabolites or non-food-grade succinic acid.
Concept	Development of microbial producers of succinic acid; microorganisms within bacterial or fungal consortia that produce succinic acid	The research features the effect of microorganisms on the concentration of non-food-grade succinic acid in the finished product or microorganisms that are not part of a consortium that produces food succinic acid. The research does not go beyond the culture media.	The publication clarifies microbial cultivation to facilitate further research on the development of products with succinic acid.
Context	Food industry	The research focuses on other industries or food products without succinic acid.	The research reviews papers on products with food-grade succinic acid.
Language	Russian, English	Other languages	Most publications on food-grade succinic acid were in Russian and English.
Time	Before March 1, 2024	After March 1, 2024	January 1, 1994 – March 1, 2024; no articles published before 1994 met the search requirements.
Origin	Developed and rapidly developing countries	Countries with underdeveloped economies and low living standards	Only developed and developing countries are interested in succinic acid as part of functional foods.

These criteria served as grounds for a publication to be included or excluded from the review. Free access to full-text articles served as an additional selection criterion. In its absence, we sent a request to the authors; if the full text was not provided, the work was excluded from the review.

Search strategy

The review covered articles registered in Scopus, Web of Science, PubMed, and Russian Research Citation Index between January 1, 1994, and March 1, 2024. The publications were represented by reviews and original research articles published in English and Russian.

The list of search queries involved such words and word combinations (in English and Russian) as “succinic acid in the food industry”, “cell engineering in succinic acid production”, “succinylation”, “succinic acid in functional foods”, “food additives with succinic acid”, and “effect of succinic acid on human health”.

Selection

Duplicate articles and sources that did not meet the selection criteria were excluded. The first scanning stage involved titles only. At the second stage, we moved on

to the abstracts. The third stage presupposed full-text scanning. Each stage revealed a number of irrelevant sources, which were excluded.

RESEARCH RESULTS AND DISCUSSION

Search results and selection

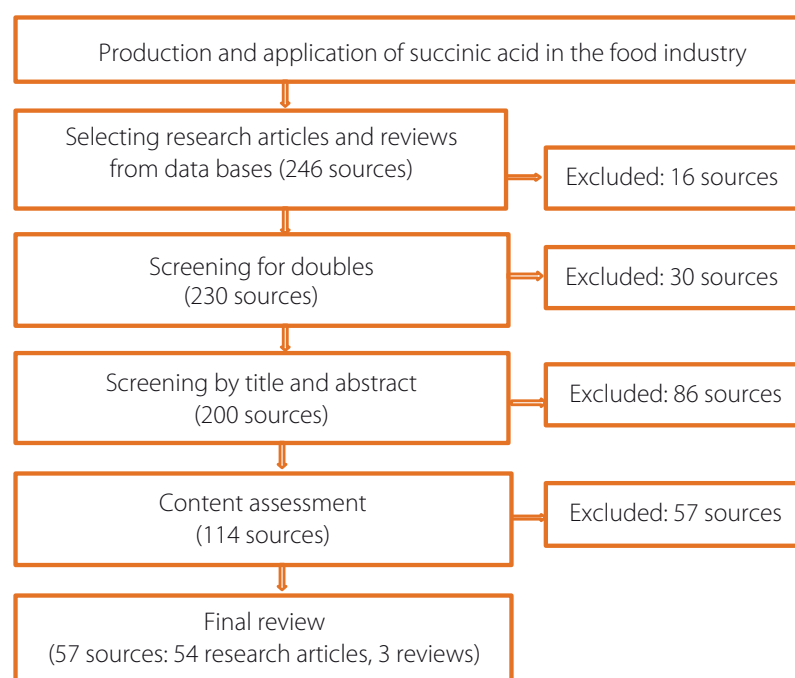
The initial search query yielded a total of 246 potential sources registered in Scopus, Web of Science, PubMed, and Russian Research Citation Index (Figure 1). Of these publications, 16 were excluded prior to the analysis: six articles had no full-text access, and ten were preprints. Of the remaining 230 papers, 30 were excluded as doubles.

The analysis of titles and abstracts made it possible to exclude 86 studies articles. By screening the full texts, we excluded 57 of the 114 remaining articles as not fitting our primary concept and objective.

Data extraction and analysis

Most of the selected publications reported results of experimental studies published in 2006-2024. In general, 96.6% of the articles were published in the last five years.

Figure 1
PRISMA-ScR protocol for selecting review sources



The year of 2020 saw the largest number of publications (37.9%).

The articles were published by research teams from 16 countries, mostly from China, South America (Brazil, Argentina, Chile), and Russia; 91.0% were written in English and 9.0% in Russian.

Succinic acid production methods and bioproducers

Contemporary science knows two methods for obtaining succinic acid and its derivatives (Figure 2).

Succinic acid production is of considerable industrial significance, especially by chemical methods. Petroleum, hydrocarbon oil, and liquefied petroleum gas are the most popular raw materials (Song, 2006). Paraffin oxidation (Escanciano, 2022), catalytic hydrogenation, and electrochemical reduction of maleic acid or maleic anhydride (Deng, 2023; Nghiem, 2017) are the most popular processes used to synthesize succinic acid. Paraffin oxidation involves catalysts based on calcium or manganese; the isolation and purification are carried out by distillation, crystallization, and drying. However, this method results in low yields and purity (Sadare, 2021).

Chemical methods are more cost-effective; however, they are associated with the rising oil prices and numerous environmental issues (Song, 2006; Nghiem, 2017). Biotechnological methods offer a more sustainable alternative. Some microorganisms, e.g., *Actinobacillus*

succinogenes, accumulate succinic acid under anaerobic fermentation (Thuy, 2017; Liu, 2022a; Liu, 2022b). *A. succinogenes* grow in media fortified with an organic substrate, e.g., whey, cane molasse, various agricultural wastes, etc. They can utilize a variety of carbon sources (Wan, 2008; Zheng, 2009; Li, 2010).

Kumar *et al.* [Kumar, 2020] developed a membrane bioreactor process followed by electrodialysis. The method produces a highly concentrated sodium succinate solution. The high yield confirmed the economic and commercial potential of this method. Chen *et al.* (Chen, 2023) used *Corynebacterium crenatum* in an anaerobic mineral medium.

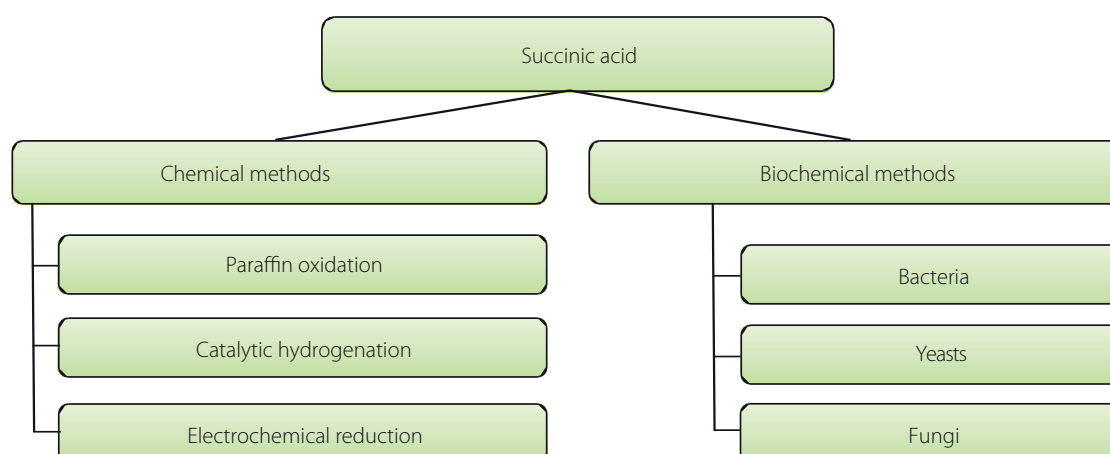
Such fungi and yeasts as *Aspergillus niger* and *Saccharomyces cerevisiae* produce succinic acid as a metabolic by-product (Sadare, 2021; Contreras-Ruiz, 2023; Matthews, 2019; Escanciano, 2022). Despite their potential environmental and economic benefits, biotechnological methods remain complex and expensive in terms of production and purification. New microorganisms or genetically modified old ones might mitigate these limitations (Mitrea, 2024).

Succinic acid as a bioactive food ingredient

Succinic acid is on the list of safe food additives in Europe and Russia. It renders functional properties to various food products (Alexandri, 2022). Succinic acid has numerous therapeutic effects. It possesses antihypoxic, hepatotropic, and anti-stress properties, as well as adapts the body to intense physical activity (Lieshchova, 2020). Succinic

Figure 2

Succinic acid production methods



Note. Adapted from Deng, 2023; Nghiem, 2017; Thuy, 2017; Carvalho, 2016; Contreras-Ruiz, 2023; Show, 2015.

Table 2

Succinic acid in the food industry

Product	Function
Alcohol	Antitoxic effect; withdrawal syndrome relief (e.g., Yantalak GF dietary supplement)
Mayonnaise, instant drinks and soups, desserts, vodka, beer, wine, caramel, chewing gum	pH regulator and preservative
Isotonic drinks	Prevents dehydration; improves water-salt balance
Functional drinks for people working in unsafe conditions	Antidote (removes arsenic, mercury, lead, ammonia, nitrates, nitrites, and toxins)
Margarine (Tonus 1)	Antioxidant
Marmalade	Flavoring and fortifying additive
Baking yeast cake	Activates yeasts; reduces fermentation time

Note. Adapted from Kosinets, 2012; Prabhu, 2020.

acid facilitates the synthesis of protein, hemoglobin, and glycogen in the liver; it is involved in glucose metabolism, exhibiting an insulintropic effect in diabetic models (Tosato, 2022). Finally, succinic acid is known for its alcohol-protective effect (Prabhu, 2020).

Succinic acid participates in the energy production in the cell, promotes oxygen utilization, and activates oxidation-reduction enzyme systems (He, 2021). It is good for the hematopoiesis, heart, brain, and central nervous system (Sapozhnikova, 2022).

The food industry uses succinic acid as a pH regulator in mayonnaise, sauces, desserts, instant soups, alcoholic beverages, and soft drinks (Prabhu, 2020). As a flavoring agent, sodium succinate offers a healthier alternative to monosodium glutamate. Dilycine succinate serves as a salty flavoring agent in low-sodium products (Yin, 2024). Table 2 structures some examples of how succinic acid is used in the food industry.

Succinic acid is safe and health-beneficial even at very low doses (10 mg/kg), which makes it a valuable component for new-generation smart medicines and food additives (Kosinets, 2012).

Succinic acid market

The global succinic acid market remains rather small, with chemically synthesized succinic acid dominating its biological alternatives. Chemically synthesized succinic

requires lower financial and capital costs while the reliable supply and availability of raw materials guarantee regular production. The global succinic acid market was \$117.20 million in 2021 and reached \$171.34 million by 2022. The moderate growth rate is likely to result in \$272.4 million by 2030 (Mitrea, 2024).

By 2025, 15% of global demand in chemicals will come from biological sources (Narisetty, 2022). The global succinic acid market is expected to grow by 27.4% by 2025 to reach \$1.8 billion, i.e., 768 million tons at a price of \$2.3 per 1 kg (Nghiem, 2017).

Multinational companies stimulate competition on the succinic acid market (Table 3). These companies invest in R&D and modernization to improve production technologies (Magalhães, 2021; Narisetty, 2022; Guo, 2022). Like in any sector of the global market, innovations are of great strategic importance in the face of fierce competition.

The USA, Mexico, Canada, Germany, France, Italy, Spain, and China are the largest producers of succinic acid, not to mention Turkey, Saudi Arabia, Brazil, Argentina, India, and Australia (Cok, 2014)¹. Europe is the current market leader (Table 3).

As for the Russian market of succinic acid, its volume amounted to 332.54 tons in 2017 and reached 392.8 tons in 2018, which was 4.2% below the level of 2016. It

¹ Succinic Acid Market by Type (Bio-based Succinic Acid, Petroleum-based Succinic Acid), End-Use Industry (Industrial, Food & Beverage, Coatings, Pharmaceutical) and by Region (North America, Europe, Asia Pacific, South America, Middle East and Africa) Global trends and forecasts from 2023 to 2029. Exactitude consultancy. <https://exactitudeconsultancy.com/ru/reports/19185/succinic-acid-market/>

Table 3

Major producers of succinic acid

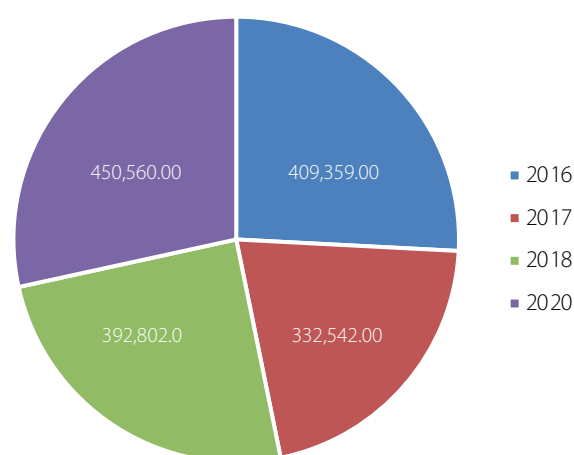
Company	Origin
BioAmber, Mitsui	Canada
Reverdia	Italy
BASF, Purac	Spain
Kemira	China
HUGESTONE ENTERPRISE CO. LTD	China
PTT Public	Thailand
Company Limited (Myriant)	USA
Mitsubishi Chemical Corporation	Japan
LCY Biosciences	Canada

Note. Asapted from Magalhães, 2021; Narisetty, 2022; Guo, 2022

was 405.60 tons in 2020 but decreased slightly in 2023 (Figure 3). In monetary terms, the Russian succinic acid market grew from \$937.62 thousand in 2017 to \$1,166.01 thousand in 2018.

Figure 3

Succinic acid market in Russia¹



Note. Asapted from Cok, 2014.

The Russian succinic acid market heavily depends on imports. In 2017, the imports accounted for 97.2%, with the domestic production as low as 10,025.8 kg, i.e., \$209.31 thousand. In 2018, the volume of succinic acid production in Russia amounted to \$216.43 thousand. The domestic production volume in 2020 was \$65.22 thousand² with the imports exceeding it by 14.7 times (\$955.05 thousand). China is the leader in the succinic acid imports to Russia (322,853 kg, i.e., 41.0% of total imports).

The list of major Russian succinic acid producers includes OAO MARBIOFARM (Yoshkar-Ola), AO KHIMREAK-TIVSNAB (Ufa), and OOO Polisintez (Belgorod). AO Kaliningradskiy Yantarniy Kombinat, the largest amber miner in Russia, has recently launched succinic acid production. However, the volumes do not exceed 200 kg per month, and the raw material has to go to St. Petersburg for purification³.

Our review covered the current methods for obtaining succinic acid, its application in the food industry, and the analysis of the Russian succinic acid market in relation to the global data. It focused on the biotechnological production methods, which remain less popular than the chemical ones, e.g., the saponification of dinitriles, the oxidation of oxy- and oxoacids, the synthesis from malonic acids, or the synthesis of symmetrically substituted succinic acid and its esters through interacting α -carbanions (Zorin, 2016; Zorin, 2015).

However, the biotechnological methods possess certain advantages that are currently bringing them to the fore. These methods require milder conditions, e.g., standard pressure and low temperatures. As a result, they cause less environmental pollution than their chemical alternatives (Mitrea, 2024; Liu, 2021; Li, 2021).

Bacteria, molds, and yeasts are able to synthesize succinic acid (Liu, 2022; Gonzales, 2020). An ideal bioproducer of succinic acid uses a variety of carbon sources, is resistant to high osmotic pressure, and produces no by-products. The concentration of acid synthesized in the culture liquid is another key parameter. Genetic engineering opens up new opportunities for creating new strains of

¹ Succinic Acid Market by Type (Bio-based Succinic Acid, Petroleum-based Succinic Acid), End-Use Industry (Industrial, Food & Beverage, Coatings, Pharmaceutical) and by Region (North America, Europe, Asia Pacific, South America, Middle East and Africa) Global trends and forecasts from 2023 to 2029. Exactitude consultancy: <https://exactitudeconsultancy.com/ru/reports/19185/succinic-acid-market/>

² Analysis of succinic acid market in Russia (import vs. export): <https://drgroup.ru/2388-analiz-rynka-yantarnoj-kisloty-v-Rossii.html>

³ Analysis of succinic acid market in Russia: https://marketpublishers.ru/report/industry/chemicals_petrochemicals/analiz-rinka-yantarnoy-kisloty-v-rossii.html

microorganisms and yeasts with predesigned properties (Louasté, 2020; Grimalizzi, 2018; Wahl, 2017).

As for the food industry, functional marmalade with succinic acid improves adaptation and prevents stress (Romanov, 2017; Komarov, 2021; Tabatorovich, 2019). Juices offer succinic acid another vessel for its functional properties (Stolyarskaya, 2021).

The prospects of using succinic acid in the food industry stretch far beyond its traditional application as a food additive: it is a promising biologically active component that renders food products a functional status. However, the Russian market of succinic acid relies heavily on the import, which seriously limits its development. The current production volumes grow so slowly that only innovative technologies will allow the domestic producers to meet the growing demand. The method of environmentally friendly microbiofactories may increase the yield and speed up the production process. In addition, biotechnological succinic acid requires standardization to provide reliable therapeutic properties (Mitrea, 2024).

Finally, the global succinic acid market is not big in volumes but highly competitive due to the activity of large transnational companies.

CONCLUSION

Succinic acid is an organic acid with a great industrial potential. However, its safe production methods and prospects for the food industry remain understudied. The commercial production of succinic acid is mostly chemical and uses petroleum raw materials, which means that the arising environmental restrictions pose the challenge

of finding alternative, more sustainable methods. The biotechnological method seems to be an option in terms of upscaling and environmental sustainability.

The food industry uses succinic acid as a pH regulator in mayonnaise, sauces, desserts, instant soups, alcoholic beverages, and soft drinks. However, the scientific data in favor of its numerous beneficial biological effects expand its prospects further to functional foods and products for particular nutritional uses.

The review revealed a strong need for innovative strategies for biosynthesized succinic acid. The approach will make the process environmentally sustainable, technically efficient, and economically profitable. The development and optimization of the biotechnological production methods require more research efforts while new potential applications in the food industry seem to be another promising direction.

CONTRIBUTION

Olga O. Babich: supervised the project, as well as wrote and proofread the manuscript.

Olga B. Kalashnikova: was responsible for the formal analysis.

Elena V. Ulrich: developed the research methodology and drafted the manuscript.

Stanislav A. Sukhikh: developed the research concept, supervised the project, drafted and proofread the manuscript.

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