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Modern Approaches to Classification of Biotechnology as a Part of NBIC-Technologies for Bioeconomy

Igor Matyushenko[1*], Iryna Sviatukha[2] and Larysa Grigorova-Berenda[3]

[1]Technical Sciences, Department of International Economic Relations and Tourism Business, V.N. Karazin Kharkiv National University, Kharkiv, Ukraine (app.379, 6 Svobody Sq., 61022 Kharkiv, Ukraine).
[2]Department of International Economic Relations and Tourism Business, V.N. Karazin Kharkiv National University, Kharkiv, Ukraine (app.379, 6 Svobody Sq., 61022 Kharkiv, Ukraine).
[3]Department of International Economic Relations and Tourism Business, V.N. Karazin Kharkiv National University, Kharkiv, Ukraine (app.372, 6 Svobody Sq., 61022 Kharkiv, Ukraine).

Authors' contributions

This work was carried out in collaboration between all authors. Authors IM and IS designed the study, wrote the protocol and wrote the first draft of the manuscript. Author LGB wrote the protocol and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of the article is to systematize and improve existing theoretical approaches to the classification of biotechnology as a part of NBIC-technologies for bioeconomy.
Study Design: The reviews were carried out in the period 2005–15 on the basis of studying the world countries biotechnologies development trends as well as on the basis of the research results obtained by World and Ukrainian institutions and universities.
Place and Duration of Study: Department of International Economic Relations and Tourism Business of VN Karazin Kharkiv National University conducted the research between January 2016 and June 2016.

**Corresponding author: E-mail: igormatyushenko@mail.ru;*

Methodology: Content analysis and bibliographic retrieval have been used as the main methods of research, which allowed making a meaningful analysis of classic papers and works of modern economists-practitioners devoted to the Global and Ukrainian trends in biotechnologies' scientific research as a part of NBIC-technologies for bioeconomy.

Results: The article demonstrates that currently there is no common and unified classification of biotechnology. The authors systematized existing approaches to biotech typology by a wide range of criteria (objects, the level of human impact to biological systems, technologies, colours, and area of application) and proposed to improve them. The authors analyzed the "colour" classification, found its inconsistencies and disadvantages (e.g. separation of "white" biotechnology from "grey" one or expediency of "violet" biotechnology in this classification). With the help of the input-output matrix the authors expanded the scope of relationships between different biotech fields by supplementing new biotech application examples at the intersections of branches, adding extra fields ("brown", "black", "gold", and "violet") and particular cases of their interactions, namely, they: expanded the scope of application as to biomedicine, explained the role of biomedicine for development of bioterrorism as a feedstock supplier, defined the impact of biopharmaceutics on food industry and bioterrorism by means of concrete examples, considered industrial biotechnology as a platform for biomedicine development and supporting force for such a negative endeavor as bioterrorism, characterized the role of agricultural biotechnology in biopharmaceutics enhancement, added examples of interaction between arid zones and desert biotechnology on the one hand and food industry/ biopharmaceutics on the other hand, identified the area of arid zones and desert biotechnology application, included potential application of scientific results for enhancement of industrial biotechnology. Moreover, the authors developed the hierarchical model that reflects the ties between platform technologies (regenerative technologies, genetic engineering, synthetic biology, etc.), biotechnologies, and bioeconomy as a new type of economy based on biotechnology commercialization.

Conclusion: The authors developed the hierarchical model that reflects the relationships between platform technologies (regenerative technologies, genetic engineering, synthetic biology, etc.), biotechnologies, and bioeconomy as a new type of economy based on biotechnology commercialization. The enhanced version of the input-output matrix "origin - application" is a perspective pattern to be supplemented with the progress of global biotechnology industry, because it includes all the biotech branches that currently are more or less represented in the world. In addition, the model can be transformed and adapted for biotech industry of any country by reducing or splitting of the branches.

Keywords: Biotechnology; bioeconomy; NBIC-technologies; classification of biotech fields; input-output matrix; global and Ukrainian trends.

1. INTRODUCTION

Biotechnology is one of the area of top priority among a wide range of innovative sectors of any developed national economy and as a part of NBIC-technologies (nano-, bio-, info-, cogno-) for bioeconomy. Expansion of practical significance of the industry is driven by social and economic needs of society. Such pressing problems that human being has faced in the beginning of the XXI century, as water and nutrients deficit (especially proteins), environmental pollution, scarcity of raw materials and energy resources, necessity to generate new environmentally-friendly materials, development of new methods of diagnostics and therapies, cannot be solved in traditional way. So, it is necessary to engage principally new, emergent technologies (including NBIC-technologies) in order to support human life and increase its quality, and bioindustry is a platform for their development and advance. That is why systematization and renewal of scientific approaches to biotech typology are of key importance as to present-day fight against global challenges.

The scientific problem of biotechnology classification was studied by Sartakova, O.Yu. [1], McCormick, K., Kautto, N. [2], Kudriavtseva, O.V., Yakovlieva, K.Yu. [3], DaSilva, E.J. [4], Voynov, M.O., Volova, T.G., Zobova, N.V. [5], Matyushenko, I.Yu., Buntov, I.Yu., Moiseienko, Yu. M., Khaustova, V.Ie., Khanova, O.V. [6,7,8,9,10], Roco, M., Bainbridge, W., Tonn, B, Whitesides [11,12], Campano, R. [13], Silberglitt, R., Anton, P.S., Howel D.R. [14], Voyer, R. [15], Novikov, V., Sidorov, Yu., Shved O. [16] and other researchers from National Intelligence Council [17] and European Parliament [18].

2. METHODOLOGY

Content analysis and bibliographic retrieval have been used as the main methods of research, which allowed making a meaningful analysis of classic papers and works of modern economists-practitioners devoted to the Global and Ukrainian trends in biotechnologies' scientific research as a part of NBIC-technologies for bioeconomy.

General scientific methods make up a methodological foundation of the research. They include: description, comparison, statistics review, system analysis and others, which help characterize this phenomenon development in a more comprehensive way. We also apply the methods of dialectic cognition, structural analysis and logic principles that provide for making authentic conclusions as regards the investigated topic.

Official statistical data of the state institutions and international organizations, publications of reference character, analytical monographs, annual statistical bulletins, World and Ukrainian institutions and universities reports serve as the information grounds for our research.

3. RESULTS AND DISCUSSION

Diversity of typologies of such a multidisciplinary endeavor as biotechnology can be explained not only by difference of academic opinions, but also by the fact that the objects, methods and scope of biotechnology are constantly expanding and transforming. However, comparison and analysis of existing approaches to the biotechnology classification can help to structure the industry and define the range of biotech applications in various fields of human activity.

The objects of the biotech research are a huge variety of biological systems that are divided into five groups and correspond to five types of biotechnology by the object criterion, as follows:

- Plant biotechnology;
- Animal biotechnology;
- Biotechnology of microorganisms and its colonies (viruses, bacteria, fungi, algae, etc.);
- Cell and cell culture biotechnologies;
- Biotechnology of subcellular systems (organelles) [1, p. 33].

Human impact to any of the above biological systems (except the last – biotechnology of subcellular systems) are carried out at the molecular and cellular levels. According to this fact there are two types of biotechnology by the level of human intervention in a biological system: molecular biotechnology based on recombinant DNA technology and technology of microorganisms, and cell biotechnology focused on micromanipulations with nuclei and cells.

Special attention in the regard of biotech classification should be paid to the division by technological criterion, i.e. by the methods biotechnology borrowed from medicine, microbiology, biochemistry, biophysics and other related sciences. Table 1 contains the list of such technologies, methods and instruments [19,20].

According to the classification in Table 1 such technologies and scientific areas as gene therapy, bioinformatics, hybridization and others are considered as subtypes of biotechnology. On the other hand, these technologies can be defined as basic or platform ones and regarded as supportive tools. This opinion is shared by the authors of OECD report "The Bioeconomy to 2030: Designing a Policy Agenda", 2009. Consequently, a set of platform technologies forms the foundation for improvement of biotechnology. The last one, in its turn, creates the background for development of bioeconomy as a new type of economy in terms of which production of materials, chemicals, and energy is based upon renewable biological resources and their derivatives [2, p. 2590; 21, p. 4].

Analysis of both approaches to the "assistive" technologies that are mentioned above resulted in the model the authors built to illustrate their perception of hierarchical relationships between platform technologies, biotechnology and bioeconomy (Fig. 1).

In our view, the most important classification of biotechnologies is their division by area of application. In this regard one of the most common approaches is a "colour" method that was firstly proposed in 2003 by Dr. Rita R. Colwell. This typology includes ten colours, and each of them corresponds to a certain branch of economic activity (Table 2).

The most developed segments among those presented in Table 2 are "red", "blue", "green", "white", and "grey" biotechnology. "Red" (medical) one is the most significant area of modern biotechnology that includes the production of drugs and diagnosticums with the help of cellular technology and genetic engineering. “Blue” biotechnology is focused on the efficient use of ocean resources, particularly on the application of marine biota for food, technical, medical and biologically active substances. “Green” biotechnology covers the area of agriculture and is aimed to create biotechnological methods and products to control pests and pathogens of crops and livestock, production of biofertilizers, productivity of plants by means of genetic engineering tools. “White” biotechnology includes industrial biotechnology which concentrates on the manufacturing of goods previously produced by chemical industry, such as alcohol, vitamins, amino acids and other substances. “Grey” biotechnology deals with technologies and drugs protecting the environment, namely: soil recultivation, discharge treatment, pollution abatement, recycling and utilization of industrial waste, degradation of toxicants with the help of bioprocesses and biologically active agents [5, p. 10-11].

Table 1. Biotechnology classifications by technological criterion

Area of biotechnology use	Scientific technologies and methods
DNA – the coding	Genomics, pharmacogenetics Gene probes DNA sequencing/synthesis/amplification Genetic modification
Proteins and molecules – the functional blocks	Protein/peptide sequencing/synthesis Lipid/protein glycoengineering Proteomics Hormones and growth factors Cell receptors/signalling/pheromones
Cell/tissue culture/engineering	Cell/tissue culture, tissue engineering Embryo manipulation Hybridization Cellular fusion Vaccine/immune stimulants
Process biotechnologies	Bioreactors Fermentation, bioprocessing Bioleaching, biopulping, biobleaching, biodesulpherisation Bioremediation, biofiltration
DNA and RNA vectors	Gene therapy Viral vectors
Other	Bioinformatics Nanobiotechnologies Other

Composed by: [19, p. 33; 20, p. 156]

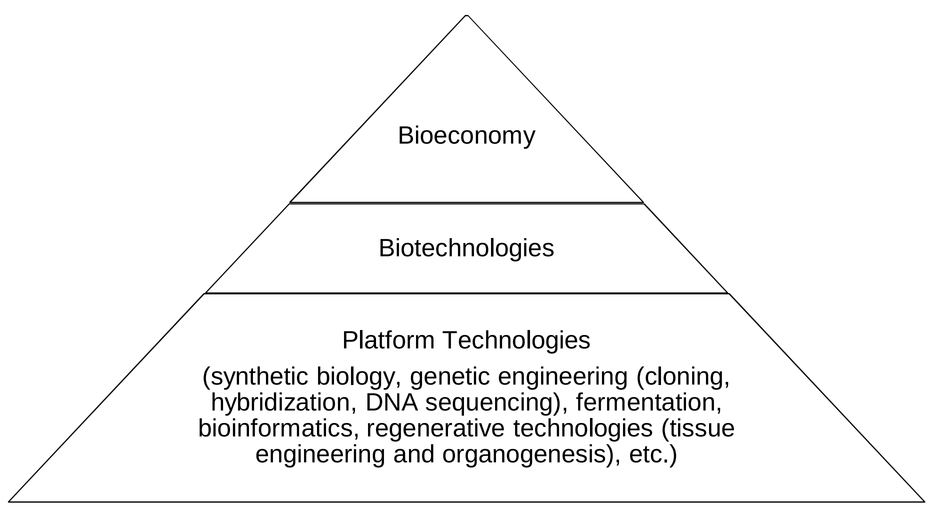

Fig. 1. Platform technologies, biotechnologies, and bioeconomy: Hierarchy of ties
Composed by: [22, p. 52-54]

Table 2. Biotechnology classifications by colours

Colour	Industries
Red	Biomedicine, Biopharmaceutics, Diagnostics
Yellow	Food Biotechnology, Nutrition Science
Blue	Aquaculture, Coastal and Marine Biotechnology
Green	Agricultural Biotechnology, Bioenergetics (Biofuels), Biofertilizers, Bioremediation, Geomicrobiology
Brown	Arid Zone and Desert Biotechnology
Black	Bioterrorism, Biowarfare, Biocriminology, Anticrop Warfare
Violet	Patents, Publications, Inventions, Intellectual Property Rights (Legal, Ethical and Philosophic Issues)
White	Industrial Biotechnology
Gold	Bioinformatics, Nanobiotechnologies
Grey	Environmental (Ecological) Biotechnology

Composed by: [3; 4]

As shown in Table 2, “white” and “grey” biotechnology mean the industrial and environmental biotechnology respectively. However, some researchers separate them according to the technological criteria: “white” biotechnology has everything that is based on genes, and “grey” one covers all biotechnology related to enzymes and classical bioprocesses. This separation is logical since a large number of industrial biotechnology have a positive environmental impact, so it is quite difficult to separate it from environmental biotechnology [3].

“Purple” biotechnology that involves legal, ethical and philosophical issues of biotech industry deserves particular consideration. In our opinion, this aspect of biotechnology is not its isolated class, because it serves just as a tool to codify the achievements of the industry and represent the results of its development reflected in patents and inventions. Therefore, we believe that the purple colour is odd in the above classification.

In addition to the “colour” typology, there are other classifications of biotechnology by area of application. For example, the OECD scientists define six spheres that are fully or partly based on biotechnologies. Table 3 demonstrates general and specific areas of biotechnology application.

It should be noticed that the classification in Table 3 includes only applied biotechnology and ignores a broad segment of developing biotech areas that currently can be considered theoretical. In addition, the obvious disadvantage of this classification is narrowing of the aquaculture biotechnology scope to marine biotechnology, because in this way the biota of other water reservoirs is excluded from the typology.

More detailed classification of biotechnology by sector of application is contained in the OECD report “The Bioeconomy to 2030: Designing a Policy Agenda”, 2009. According to the document, biotechnology is applied in three basic areas: primary bioproduction, health and industry (Fig. 2).

According to the Fig. 2, primary bioproduction includes application of all living natural resources such as forests, agricultural crops, livestock, insects, fish and other aquatic resources. Application in the sphere of health care involves pharmaceuticals, diagnostics, biologically active supplements, and some types of medical devices. Industrial biotechnology application covers production of chemicals, plastics, enzymes, mining, pulp and paper, energy, and soil treatment by means of bioremediation.

Deeper analysis of the three basic areas of biotechnology allows codifying them and creating more sophisticated typology by area of application that briefly describes the purpose of each biotechnology subtype.

According to Table 4, primary bioproduction comprises agriculture, forestry, water economy, and food industry; health covers biomedicine and biopharmaceutics, and, finally, industry encompasses bioenergy, environmental biotechnology, production of chemicals, biomaterials, industrial enzymes, biogeotechnology (geomicrobiology), and waste processing and recycling technologies.

Russian researchers Kudriavtceva, O. V. and Iakovleva, E. Iu. proposed to classify biotechnology with the help of input-output matrix that reflects relationships between biotech industries “origin – application”. The matrix covers both processes of production and consumption of biotech products and allows illustrating the ties between various biotechnology fields better. This model of classification differs from the typologies described above because they present biotech branches separately and classify them on the basis of distinguishing attributes without taking into account convergence of the fields. However, the scientists included into the matrix only those industries that are more or less developed in Russian Federation. That is why the authors enlarged the list of areas in the matrix relying on one of the most common classification mentioned above – the “colour” one.

According to the matrix in Table 5, “red” biotechnology is represented by biomedicine and biopharmaceutics in isolation from one another; the “white” corresponds to industrial biotechnology; “yellow” one is food biotechnology; aquaculture biotechnology is classically painted with blue; “green” biotechnology consists of agriculture, forestry, and bioenergetics; grey colour corresponds to environmental biotechnology including waste processing and utilization; biotechnology of arid zones and desert areas is brown; and, finally, bioterrorism is tinged with black. Moreover, the model contains a specific category, “science”, corresponding to the “violet” (patents, publications, inventions, intellectual property rights) and “gold” (bioinformatics, nanobiotechnology) biotechnology. In other words, this category covers theoretical aspects of biotechnology and represents an extremely important part of knowledge-intensive production.

Table 3. Biotechnology classifications by area of application

Area of biotechnology application	Specific area of application
Animal based biotechnologies	Animal genomics
	Animal improvement/reproductive technologies
	Animal health/nutrition
	Animal products (non-food) biopharming
Plant based biotechnologies	Plant genomics
	Plant improvement
	Plant health/protection
	Plant growth biopharming
Innovative foods and human nutrition	Food materials/ingredients
	Food production technologies
	Functional foods/nutriceuticals
	Diagnostics/biosensors/tests
	Food processing/preservation technologies
Bioprocessing technologies and biomanufacturing	Biomanufacturing
	New materials
	Process monitoring
	Extremophiles/enzymes
Marine biotechnologies	Aquaculture
	Marine-sourced bioactives
Environmental technologies	Bioremediation
	Mitigation technologies
	Biosecurity/pest control technologies
	Environmental indicators
	Biodiversity/ecology/evolution
Biomedical science and drug discovery	Oncology/cancer
	Diabetes/cardiovascular diseases
	Neurological/muscular diseases
	Immunological diseases/parasitology
	Infectious diseases
	Osteoperosis/bone health
	Medical diagnostics/devices
	Biomedical imagining/bioengineering
	Reproduction
	Brain/neural studies
	Small organic compounds
Impacts and integration of emergent technology	Environmental
	Social
Other	Other

Composed by: [19, p. 34]

So, the authors broadened the existing model by supplementing new biotech application examples at the intersections of branches, adding extra fields (“brown”, “black”, “gold”, and “violet”) and particular cases of their interactions, namely, they:

- deepened the scope of application as to biomedicine by including regenerative technologies aimed to address a wide range of human diseases (diabetes, cardiovascular diseases, cancer, etc.), traumas and aging, and to become an efficient alternative to donation of organs by means of stem cells application;
- described the role of biomedicine for development of bioterrorism as a feedstock supplier (e.g. criminal using microorganisms strains and bacteria created for biomedical purposes as biological weapons);
- explained the impact of biopharmaceutics on food industry and bioterrorism by means of concrete examples (application of biopharmaceuticals for manufacturing biologically active food supplements and using as source materials for creation of biological weapons);
- considered industrial biotechnology as a platform for biomedicine development (production of biopolymers, biosensors and biomedical facilities) and supporting force for bioterrorism (feedstock for biowarfare, means of disseminating biological agents);
- covered the role of agricultural biotechnology in biopharmaceutics enhancement (application of animal- and vegetable-based substances in production of new drugs);
- added examples of interaction between arid zones and desert biotechnology on the one hand and food industry/ biopharmaceutics on the other hand (e.g. microalgae propagation in deserts for antioxidant generation);
- described the area of arid zones and desert biotechnology application (e.g. demineralization of oil-contaminated soils within desert and semi-desert areas);
- included potential application of scientific results for enhancement of industrial biotechnology (e.g. brain studies for application in industry, analytical instrumentation).

In our view, the classification of biotechnology presented in Table 5 is the most useful owing to its applied character and demonstration of links between biotechnology fields based on specific examples and achievements of the industry. The biotechnology field tends to grow fast, so we believe that almost all cells of the above table can be filled in on a mid-term horizon.

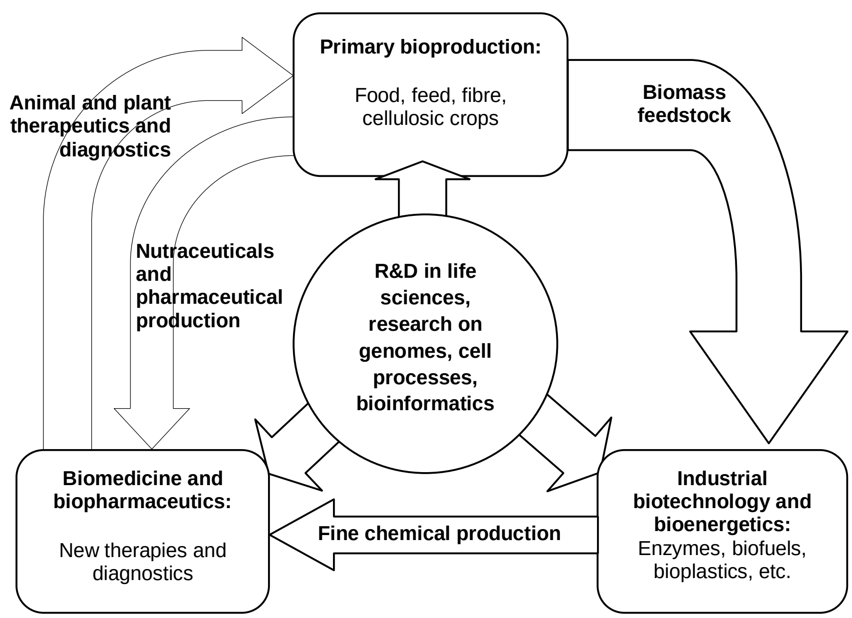

Fig. 2. Current and potential convergence of three basic industries of biotechnology application (size of arrows reflects the relative importance of integration)
Composed by: [22, p. 25]

Table 4. Complex classification of biotechnology by application

Primary bioproduction (agriculture, forestry, water sector, food industry)	Health (biomedicine and biopharmaceutics)	Industry (including bioenergetics and environmental biotechnology)
Plants - New crop varieties for food, feed, and fibre production - Forestry (new tree species for biofuels, pulp and paper, timber; propagation of trees; insect, bacterial, fungal, and salinity resistance; enhancement of wood quality/increasing of lignin content - Plant diagnostics (for prevention of plant diseases) **Animals (livestock, poultry, aquaculture)** - Animal breeding (for prevention of diseases, improving food characteristics (milk/blood), enhancement of growth rates and resistance to viruses, bacteria and cold temperatures) - Cloning - Diagnostics and Therapeutics - Management of endangered wild fish stocks - Use of marine organisms' characteristics to survive in high temperatures or reproduce very quickly	**Therapeutics** - Biopharmaceuticals - Experimental treatments (regenerative technologies: cell and tissue engineering; stem cells research; gene, antisense and RNAi therapies) - Small-molecule therapeutics (based on chemical synthesis; applied for testing drug candidate molecules, for identifying new therapeutic targets) **Diagnostics** - Diagnostics in natural conditions (in vivo) - Diagnostics in laboratory conditions (in vitro): immunological (identifies diseases, pregnancy) and molecular genetic (identifies mutations, particularly, cancer) tests **Pharmacogenetics** -Personalized medicine **Functional foods and nutraceuticals** **Medical devices** -Surgical instruments and equipment; in vitro diagnostics, tissue engineering, medical imaging equipment; biosensors (uses proteins to detect molecules)	**Chemicals** - Biofuels, enzymes, solvents, amino acids, organic acids, vitamins, antibiotics, biopolymers **Biomaterials** -Wood, cotton, packaging and containers, fabrics, and consumer durables - Biopolymers **Industrial enzymes** - Food, feed, and beverages -Detergent, textiles, and pulp and paper **Environment applications** - Bioremediation - Biosensors **Resource extraction (geobiotechnology)** - Metal ore mining by means of bioleaching - Oil recovery enhancement **Biorefineries** -Biomass feedstock processing for bioenergetics, food industry, medicine, and biomaterials production purposes **Biofuels** - Developing improved plant varieties as raw materials for biofuels - Advancing industrial process of biofuel generation

Composed by: [22, p. 55-84]

Table 5. Input-output matrix "origin – application"

Application / Origin	Biomedicine	Biopharmaceutics	Industrial biotechnology	Food biotechnology	Aquaculture biotechnology	Agricultural biotechnology	Forest biotechnology	Bioenergetics	Environmental biotechnology (grey)	Arid zones and desert biotechnology	Bioterrorism
Biomedicine	Experimental treatments (regenerative technologies), small-molecule therapeutics, diagnostics, biocompatible materials	Personalized medicine	Biocompatible materials (for lacquers, paints, clothes)			Animal and plant diagnostics, veterinary vaccines, feed antibiotics					Feedstock for biowarfare
Biopharmaceutics	Therapeutic enzymes, hormones, hematic drugs, substitutes of blood compounds, immunoglobulin, vaccines	Generic drugs import substitution, cytokines, monoclonal antibodies		Functional foods and nutritionals		Plant protecting agents and growth stimulants, probiotics, antimicrobial drugs, biopesticides	Forest protecting agents				Feedstock for biowarfare
Industrial biotechnology	Biopolymers for medical purposes, medical instruments and equipment, biosensors	Feedstock for pharmaceuticals	Organic acids, biocatalyzers and industrial enzymes, biopolymers, monomers for polymer chemistry, bioplastics, oil recovery enhancement, bioleaching	Organic acids, nutritive ingredients, enzymes, biopolymers (packaging)	Building of aquabiocentres	Key amino acids, vitamins, feed protein, feed enzymes	Reagents for pulp and paper, added-value wood processing	Advancing industrial process of biofuel generation, enzymes, industrial gases, bioenergetic machinery manufacturing, feedstock for biofuel	Oil decomposer		Feedstock for biowarfare, means of disseminating biological agents
Food biotechnology		Bioactive substances, vitamins, mineral substances, amino acids, biologically	Organic acids as feedstock for industry	Functional nutritive ingredients, tailor-made products, superstarts,	Aquaculture feed	Protein- and vitamin-rich complexes		Feedstock for biofuels			

Application / Origin	Biomedicine	Biopharmaceutics	Industrial biotechnology	Food biotechnology	Aquaculture biotechnology	Agricultural biotechnology	Forest biotechnology	Bioenergetics	Environmental biotechnology (grey)	Arid zones and desert biotechnology	Bioterrorism
		active supplement		food proteins							
Aquaculture biotechnology	Chitinous biopolymers, Microbiological hydrobiont-based mediums	Hydrolyzate, biologically active supplements (algae)	Biopolymers, new materials	Fish oil, functional nutritive products, food hydrolyzate	New kinds of hydrobionts, fishery, management of wild fish stocks	Fish flour, feed hydrolyzate out of hydrobionts, chitinous biopolymers, survival in high or low temperatures		Biodiesel out of algae	Chitinous biopolymers		
Agricultural biotechnology		Feedstock for pharmaceuticals	Protein isolates and textured proteins, food fibre	GMO, new crop varieties for food production, improving food characteristics by animal products quality enhancement		Biotechnological plants, ensilage inoculums, improving plant productivity, cloning, animal propagation programs, biofertilizers		Feedstock for biofuels (waste)			Feedstock for biowarfare
Forest biotechnology			Biorefining (full cycle), housebuilding, new tree species for pulp and paper				Tailored trees, wooded area monitoring	Feedstock for firm biofuels (pallets), bio-oil and biogas, propagation of new tree species for bioenergetic purposes	Cellulose processing		
Bioenergetics								Methods of fuel utilization factor enhancement, elimination of			Feedstock for biowarfare

Application / Origin	Biomedicine	Biopharmaceutics	Industrial biotechnology	Food biotechnology	Aquaculture biotechnology	Agricultural biotechnology	Forest biotechnology	Bioenergetics	Environmental biotechnology (grey)	Arid zones and desert biotechnology	Bioterrorism
								negative environmental effect by means of bioconversion, biocomponents for fuels			
Environmental biotechnology (grey)			Industrial waste processing, “earthship” Package processing	Food scraps processing		Waste utilization, soil recultivation	Utilization of forestry residues	Greenhouse gases utilization	Bioremediation, technology of environment well-being assessment, bioindication		
Arid zones and desert biotechnology		Microalgae propagation in desert for antioxidant generation		Microalgae propagation in desert for antioxidant generation						Demineralization of oil-contaminated soils within desert and semi-desert areas	
Science	Mapping of organisms’ genomes, biobanks, bioinformatics, systemic medicine, production of nano-based bactericides and viricides (potentially)		Brain studies for application in Industry; analytical instrumentation						Biological collections and bioresource centres		

Composed by: [22, p. 55-84; 3; 6]

4. CONCLUSIONS

Today there is no unified or standard classification of biotechnology due to different level of the industry development in different countries, diversity of scientific approaches, interdisciplinary nature of the field, and rapid pace of biotech upgrade that annually leads to application of new biological systems as the basis for research and emergence of new methods to process and modify them. This fact can be an obstacle to further profound elaboration of the biotech field and its particular branches. That is why we believe that the aim of the article – to consolidate and enhance existing theoretical approaches to the biotech classification – will serve not only for systematization of fundamental knowledge, but also for setting a solid scientific ground for applied industrial research.

Comparative analysis of the existing biotech classification by a wide range of criteria (objects, the level of human impact to biological systems, technologies, colours, and area of application) has shown the diversity and constant growth of biotech fields, methods and tools. The first two classifications (by objects and by the level of human impact to the biological systems) are closely linked to each other: the first one is focused on the type of organisms or their parts subjected to biotechnological manipulations, while the second is concentrated on the level of human interference into the living systems. Interdisciplinarity of biotechnology can be proven by tools and techniques the field borrowed from allied sciences; the list of those instruments grouped according to the area of biotechnology use represents biotechnology classification by technological criterion. Nevertheless, the most essential criterion for biotech typology is based on the field of application. The article contains three different interpretations of typology by this attribute; they slightly differ from one another, however, we can identify three main areas that are mentioned in each of three classifications in different wordings. These universal fields are industrial, health and agriculture biotechnology.

Despite the diversity of classification approaches, each of the above typology approach is limited to one classification attribute and does not take into account the multidisciplinary nature of biotechnology. Discussions arise even as to the “colour” classification of biotechnology that consists of ten branches and is quite widespread among scientists (e.g. reasonability to specify “violet” biotechnology as a separate group or distinction between “white” and “grey” biotechnology).

In our view, the most complete and perspective classification of biotechnology is the one designed in the form of input-output matrix origin – application that was enhanced in this article on the basis of existing scientific results. The authors of the paper expanded the scope of application as to biomedicine, explained the role of biomedicine for development of bioterrorism as a feedstock supplier, defined the impact of biopharmaceutics on food industry and bioterrorism by means of concrete examples, considered industrial biotechnology as a platform for biomedicine development and supporting force for such a negative endeavor as bioterrorism, characterized the role of agricultural biotechnology in biopharmaceutics enhancement, added examples of interaction between arid zones and desert biotechnology on the one hand and food industry/ biopharmaceutics on the other hand, identified the area of arid zones and desert biotechnology application, included potential application of scientific results for enhancement of industrial biotechnology.

Apart from this the authors developed the hierarchical model that reflects the relationships between platform technologies (regenerative technologies, genetic engineering, synthetic biology, etc.), biotechnologies, and bioeconomy as a new type of economy based on biotechnology commercialization.

To sum it up, the enhanced version of the input-output matrix “origin - application” is a perspective pattern to be supplemented with the progress of global biotechnology industry, because it includes all the biotech branches that currently are more or less represented in the world. In addition, the model can be transformed and adapted for biotech industry of any country by reducing or splitting of the branches.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sartakova O Iu. Osnovi mikrobiologii i biotechnologii. Polzunov Altai State Technical University. Barnaul; 2001.

2. McCormick K, Kautto N. The bioeconomy in Europe: An overview. Sustainability. 2013;5:2589-2608.
3. Кudriavtceva OV, Iakovleva E Iu. Biotechnological industries in Russia and in the world: Typology and development. Modern Management Technology. 2014; 7(43).
Available:http://sovman.ru/article/4307/
4. DaSilva Edgar J. The colours of biotechnology: Science, development and humankind. Electronic Journal of Biotechnology. 2004;3(7).
Available:http://www.ejbiotechnology.info/index.php/ejbiotechnology/article/view/1114/1496
5. Sovremenniye problemi i methodi biotechnologii. Voyinov NA, Volova TG, Zobova NV, etc. – Кrasnoiarsk. 2009;418.
Available:http://files.lib.sfu-kras.ru/ebibl/umkd/1323/u_manual.pdf
6. Matyushenko I. Bio-economy: Medical biotechnology in the world and Ukraine. Scientific Bulletin of Kherson State University. Series “Economics”. 2014;9(7): 52-58.
7. Matyushenko I, Moiseenko Yu. Outlook on bio-economy development in Ukraine: Introduction of molecular and cell biotechnologies in 2010-2013. International Journal of Economics, Commerce and Management. Rochester. 2015;3(5):764-772.
Available:http://ijecm.co.uk/wp-content/uploads/2015/05/3545.pdf
8. Matyushenko I, Khaustova V. Modern trends on bio-economy development in the world: The introduction of NBIC-technologies in biomedicine. Integrated Journal of British. 2015;2(2):103-118.
Available:http://www.ijbritish.com/Downloads.aspx?PA=IJBRITISH-279-PA.pdf
9. Matyushenko I Yu, Buntov I Yu. Prospects on bio-economy development: biotechnology in agriculture and environmental safety on the basis of NBIC-technologies. Acta Innovations. 2015;17:41-47.
Available:http://www.proakademia.eu/acta-innovations/wydania/numery2015/nr-17/
10. Matyushenko I, Moiseienko Yu, Khanova O. Prospects for constructing Nano-bio-economics in Ukraine: Using sensor systems on the basis of NBIC-technologies for medico-environmental and industrial needs. American Research Journal of Business and Management (An Academic Publishing House), Chicago. 2015;1(2): 37-43.
Available:https://www.arjonline.org/papers/arjbm/v1-i2/4.pdf
11. Roco M, Bainbridge W, Tonn B, Whitesides G, eds. Converging knowledge, technology and society beyond convergence of Nano-bio-info-cognitive technologies. Dordrecht, Heidelberg, New York, London; 2013.
12. Roco M, Bainbridge W, eds. Managing nano-bio-info-cogno innovations. Converging technologies in society. Heidelberg; New York; 2006.
13. Campano R, (eds). Converging application enabling the information society – Trends and prospects of the convergence of ict with cognitive science, biotechnology, nanotechnology and material sciences. Future Technologies Division of VDI Technologiezentrum GmbH, Düsseldorf; 2006.
Available:http://www.vditz.de/fileadmin/media /publications/pdf/band_69_screen.pdf
14. Silberglitt R, Anton PS, Howell DR, eds. The global technology revolution, in-depth analyses. Bio/Nano/ Materials/Information Trends, Drives, Barriers, and Social Implications (Prepared for the National Intelligence Council), Rand Corp; 2006.
Available:http://www.rand.org/content/dam/rand/pubs/technical_reports/2006/RAND_TR303.pdf
15. Voyer R, Makhija N. ICT/Life science converging technologies cluster study: A comparative study of the information and communications, life science, and converging next generation technology clusters in vancouver, Toronto, Montreal and Ottawa, Government of Canada, Ottawa; 2004.
Available:http://strategis.ic.gc.ca/epic/internet/inict-tic.nsf/en/it07730e.html
16. Novikov V, Sidorov Yu, Shved O. Commercial biotechnology development trends. Newsletter of Ukrainian National Academy of Science. 2008;2:25-39.
17. Global trends 2030: Alternative worlds. National Intelligence Council; 2012.
Available:http://globaltrends2030.files.wordpress.com/2012/11/global-trends-2030-november2012.pdf
18. Workshop "Converging technologies in the 21st century: Heaven, hell or down to earth?" European Parliament, Scientific

Technology Options Assessment (STOA) Annual Report 2006, European Parliament, Brussels. 20-36; 2007. Available:http://www.europarl.europa.eu/stoa/webdav/site/cms/shared/4_publications/annual_reports/2006_en.pdf

19. Statistics New Zealand (Tatauranga Aotearoa). Biotechnology in New Zealand 2005. Wellington. 2006;49.
20. OECD Factbook: Economic, environmental and social statistics. OECD. Paris. 2013; 235.
21. Building a bio-based economy for Europe in 2020. The European Association for bioindustries (EuropaBio). Brussels. 2010;14.
22. The bioeconomy to 2030: Designing a policy agenda. OECD. Paris. 2009;323.

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