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State support and digitalisation in the innovative development of Ukraine's biotechnology sector

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Abstract. The relevance of the research lies in determining the role of state support and digitalisation in ensuring the innovative development of biotechnologies in Ukraine in conditions of war and economic instability. The purpose of the work was a comprehensive analysis of the relationship between state policy, digital transformations and innovative development of the biotechnology sector of Ukraine. The research methodology included a systematic analysis of strategic documents, state support programs, the startup ecosystem, and the practical implementation of digital technologies in biotechnology, including the analysis of cases of Ukrainian companies and startups. It has been established that the state policy of Ukraine in the field of biotechnology, in particular the Concept of Bioeconomy Development until 2030 and the Biosafety Strategy, creates systemic conditions for the development of innovative products in pharmaceuticals, agrobiotechnologies, and bioenergy. The impact of digitisation on the sector is analysed, in particular the introduction of artificial intelligence, bioinformatics, big data, blockchain and the Internet of Things, which ensures optimisation of production processes, improvement of management efficiency and reduction of costs. It was found that the interaction of the Ukrainian IT sector and biotechnology forms a competitive advantage, accelerates the transformation of scientific potential into commercial products and ensures the sustainability of the startup ecosystem even in war conditions. The practical value of the results lies in the possibility of their application by public administration specialists, economists and innovation managers for the formation of an effective policy of post-war economic recovery and stimulation of innovative development of the biotechnology sector of Ukraine

Keywords: innovation infrastructure; digital transformation of the industry; artificial intelligence in biotechnology; big data; blockchain technologies; IT-biotech synergy; managerial and economic efficiency

INTRODUCTION

Biotechnology is recognised as one of the most dynamic and economically promising sectors globally, transforming key areas of the economy from medicine and pharmaceuticals to agro-industry and energy. The global biotechnology market demonstrates sustained growth driven by the active adoption of digital technologies, in particular artificial intelligence (AI), the development of personalised medicine, and increased investment in knowledge-intensive research. Ukraine possesses significant potential in this field by virtue of its highly qualified human capital, developed IT sector and scientific base, as well as its unique natural resources. At the same time, digitalisation processes are

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becoming a key factor in increasing research effectiveness and accelerating innovation. Under conditions of economic turbulence, wartime challenges, and resource constraints, examining the interaction between state support and digitalisation as a foundation for biotechnology sector development becomes especially pertinent. The multifaceted nature of this issue generates growing scholarly interest, reflected in research spanning a broad range of questions from an analysis of global digitalisation trends to the study of sector-specific barriers and prospects in biotechnology.

In the study by R. Kostiuk & R. Romanov (2023), dedicated to analysing the economic problems and challenges facing Ukrainian biotechnology organisations under crisis conditions, the critical role of digitalisation and the automation of managerial and production processes is substantiated as a factor in stabilising the sector. Although the work made an important contribution to understanding intra-sector barriers and possible strategies for overcoming them, the question of integrating Ukrainian startups into global value chains through digital platforms remained beyond the scope of detailed consideration. This aspect is important for creating a favourable regulatory environment for biotechnology; however, the specific characteristics of "regulatory sandboxes" for biotechnological innovations were not examined in the paper. In their work, scientists A. Rachynskyi & O. Tytarenko (2024) analysed the "servitisation" of public administration to improve the provision of public services and reduce bureaucracy. This aspect is important for the creation of a favorable regulatory environment for biotechnologies, however, the specifics of "regulatory sandboxes" specifically for biotechnological innovations have not been investigated in the paper.

Research by H. Honchar & O.L. Shpatakova (2024) demonstrated how digital technologies increase efficiency and productivity, contributing to the development of new economic sectors and job creation that is, the potential of biotechnology sector digitalisation as amechanism for productivity growth. However, quantitative modelling of AI's impact on reducing R&D costs in the biotechnology sector would constitute a valuable contribution. Researchers O. Brechko & N. Kryvokulska (2023) connected digital transformation with environmental objectives through IT systems, however, the economic effect of introducing blockchain in agrobiotechnology was left unaddressed. Y. Liu *et al*. (2025) summarised contemporary scientific achievements regarding the application of AI in drug development processes and the creation of biotechnological products, with an emphasis on key performance indicators. The authors emphasised that the adoption of AI significantly transforms the therapeutic development landscape, bringing qualitative changes to research approaches and helping to overcome longstanding sector challenges in particular, excessively high development costs (exceeding one billion US dollars), prolonged timelines for bringing drugs to market (exceeding ten years), and a significant rate of failures at various stages of clinical trials.

A. Bhushan & P. Misra (2025) conducted a comprehensive study of AI applications in biotechnology and digital medicine, encompassing both the economic dimensions of its impact and ethical considerations, including the question of equitable technology implementation. The authors substantiated how AI integration has significantly transformed the biotechnology sector accelerating drug discovery, advancing genomics, improving medical imaging, and introducing personalised medicine, thereby contributing to increased healthcare system efficiency and reduced costs. The paper analyses the economic effects of AI, its role in stimulating innovation, and its impact on decision-making at both the research and policy levels. Particular attention is devoted to the quantitative assessment of AI's economic impact on the biotechnology sector. The review of the literature revealed a number of unresolved issues directly related to the research topic. In particular, the specifics of AI implementation in biotechnology under martial law and resource constraints remain insufficiently studied, as does the relationship between state support, the level of digitalisation, and indicators of innovative development in the sector. Academic works lack systemic models and applied mechanisms for the implementation of strategic decisions, as well as an analysis of the effectiveness of state support instruments (grants, tax incentives, regulatory simplifications) in terms of maximising returns on limited budgetary resources. At the same time, the synergy potential of the IT sector and biotechnology as a unique competitive advantage for developing countries has not been sufficiently articulated. This necessitates a comprehensive study aimed at addressing these gaps and developing practical recommendations.

The aim of this article was a comprehensive examination of the impact of state support instruments and digitalisation processes on the innovative development of Ukraine's biotechnology sector under martial law and global digitalisation, the identification of managerial and economic effects of digital technology adoption and the substantiation of practical recommendations for enhancing the sector's competitiveness in global markets, drawing on international experience and contemporary technological trends. To achieve this aim, the following objectives were identified: to identify key problems and challenges facing Ukraine's biotechnology sector, to analyse the managerial advantages and economic effects of digital technology adoption in the biotechnology domain, including impacts on investment, costs, productivity, and market expansion and to formulate practical recommendations for strengthening public policy and stimulating innovative development in the biotechnology sector under conditions of limited resources and wartime challenges.

MATERIALS AND METHODS

The methodological foundation of this research comprises a set of general scientific and specialised methods, ensuring a systematic analysis of the influence of state support instruments and digitalisation processes on the innovative development of Ukraine's biotechnology sector under wartime conditions and in anticipation of post-war recovery. The research drew on: regulatory and legal acts of Ukraine (Decree of the President of Ukraine No. 668/2021, 2021; Law of Ukraine No. 3339-IX, 2023); strategic state policy documents in the field of biotechnology and digitalisation (Concept of the Bioeconomy Development..., 2019; BioTech Sectoral Strategy, 2024); international analytical reports (Precednce Research, 2025; Precedence Research, 2026); statistical data (UANIPIO statistics and reports, n.d.; Seeds of Bravery, n.d.); and scientific publications indexed in

scientometric databases (Kostiuk & Romanov, 2023; Rachynskyi & Tytarenko, 2024).

The sample includes sources meeting the following criteria: relevance, thematic pertinence (innovative development, biotechnology, digitalisation, state policy), and scientific and practical significance. To achieve the stated aim, the following research methods were employed: systematic analysis for the comprehensive examination of the inter relationship between state support, digitalisation, and the development of the biotechnology sector as an integrated system; comparative analysis to compare Ukrainian approaches to supporting biotechnology with international practices, and to evaluate the effectiveness of various state regulatory instruments; analysis and synthesis for the processing of scientific sources, statistical data, and analytical materials, and for the formation of generalised conclusions regarding sector development trends; structural-functional analysis to determine the role of digital technologies in transforming managerial and production processes in biotechnology; economic analysis to assess the managerial and economic effects of digital technology adoption (changes in costs, productivity, and investment attractiveness); and the method of generalisation for formulating practical recommendations to improve the effectiveness of state policy in the field of innovative biotechnology development.

The empirical basis of the analysis comprised open statistical data on the development of the biotechnology sector, investment activity, and research and development (R&D) funding (UANIPIO statistics and reports, n.d.; Seeds of Bravery, n.d.), as well as information on the implementation of state and international innovation support programmes, grant programmes, startup initiatives, digital platforms (Brovinska, 2022; Horizon Europe Office in Ukraine, n.d.; Diia.City, n.d.). The research was conducted in several stages. The first stage involved an analysis of the scientific literature and regulatory framework. The second stage entailed the systematisation of state support instruments and digital technologies applied in the biotechnology sector. At the third stage, an assessment of their impact on managerial and economic indicators of sector development was carried out. The final stage involved the generalisation of results and the formulation of practical recommendations. The methodology applied ensures the reproducibility of the research and allows other scholars to employ an analogous approach when analysing the innovative development of sectors undergoing digital transformation under conditions of limited resources.

RESULTS

Ukraine's state policy regarding the innovative development of the biotechnology sector is characterised by a systemic approach reflected in a range of strategic documents and initiatives. The Concept of the Bioeconomy Development Strategy in Ukraine until 2030 defines biotechnology as the basis for creating new types of high-value-added products and provides for the development of biopharmaceuticals, agrobiotechnology, bioenergy, and related fields (Concept of the Bioeconomy Development..., 2019). The objective of this strategy is to lay systemic foundations for the development of the bioeconomy and to ensurethe establishment of new sub-sectors of industry focused on innovativebiotechnological products for the chemical, petrochemical, pharmaceutical, andwood-processing industries. The implementation of this Concept is directed not onlyat modernising industry but also at stimulating demand for research outputs,supplementing existing support systems in agriculture, medicine, and pharmaceuticals.

An important step towards ensuring national security and developing biotechnology was the approval of the Decree of the President of Ukraine No. 668/2021 (2021). This document defines the goals, objectives, and principal directions of state socioeconomic policy with respect to biosecurity and biological protection as a component of Ukraine's national security. This approach enables the transformation of biotechnology's role from a purely economic one into an interdisciplinary sphere combining economic, security, and social functions. Such a status makes it possible to provide the sector not only with financial support but also with expedited regulatory procedures, priority access to resources, and integration into defence and security programmes. This will afford biotechnology significant advantages over sectors viewed in purely economic terms, and is also capable of attracting investment oriented towards resilience and security rather than profitability alone.

A significant contemporary approach to implementing state policy in the field of biotechnology is the application of the Strategy for the Digital Development of Innovative Activity of Ukraine until 2030 WINWIN. This strategy envisages the formation of a mutually beneficial model combining state support, private investment, and scientific capacity, grounded in digital tools, the development of innovative ecosystems, and the commercialisation of research outputs, with the aim of creating competitive innovative products. For the state, implementing the "win-win" approach means increasing the economy's technological capacity, strengthening biosecurity, and increasing tax revenues; for business reducing innovation risks and simplifying access to financial resources and digital infrastructure; for scientific institutions expanding opportunities for the practical application of research results and integration into international research networks (WINWIN. Global innovation strategy of Ukraine, n.d.).

The BioTech Sectoral Strategy is an integral component of WINWIN's broader global innovation strategy for Ukraine, which also encompasses digital transformation, artificial intelligence, and environmental initiatives. This strategy provides for the integration of modern biotechnologies in biopharmaceuticals, bioenergy, and agrobiotechnology. During 2025, the provisions of the Strategy for the Digital Development of Innovative Activity until 2030 began to be implemented through the expansion of grant programmes, public-private partnership instruments, and support for deep-tech and biotechnology startups. In particular, support for innovative projects combining digital and biotechnological developments – through both state and international funding was strengthened (WINWIN. Global innovation strategy of Ukraine, n.d.). This contributes to the formation of a sustainable innovation ecosystem and the practical implementation of "win-win" principles.

As noted above, active state support for the innovative development of Ukraine's biotechnology sector and the "win-win" concept enshrined in the WINWIN Strategy are complementary factors in the sector's development. Through modern technologies and the automation of

production processes, the efficient use of limited resources is enhanced and conditions are created for transforming scientific potential into tangible economic results something of particular importance in the context of Ukraine's post-war economic recovery. Financial support for innovation in the biotechnology sector is delivered through a number of programmes. The "Seeds of Bravery" programme has become a significant source of funding for Ukrainian startups, providing 117 companies with € 3.5 million (Seeds of Bravery, n.d.). Grants ranging from € 25,000 to € 50,000 were directed at innovative services, innovative entrepreneurship, deep-tech incubators, Ukraine's reconstruction, and the scaling and acceleration of deep-tech startups. Among the supported projects in the Agricultural and Biotechnology domain were, for example: Yes Straws, Mosqitter, MELT WATER Inc., AgriMSME, HOWCOW, GreenSync.ai, Foodwise, PROFEED, Parostok, Agrobon:prelude, and Biogenic Silver. In the Healthcare domain, support was received by, inter alia: InTempo, eXtra Vision, CheckEye, Anima, Clearly, WildfiresUA, and Health Helper (Yarova, 2025).

The WINWIN strategy also provides financial support for start-ups and enterprises through grants and tax breaks. Companies engaged in R&D can become residents of "Action.City", which opens up new opportunities for technology development and additional tax advantages for business (Diia.City, n.d.). Furthermore, the integration of Ukrainian BioTech companies into EU cooperation and research and development support programmes in particular Horizon Europe, which provides access to significant financial resources and collaboration opportunities is being actively promoted (Horizon Europe Office in Ukraine, n.d.). Non-financial support includes the creation of a favourable regulatory environment for product registration and clinical trials, with the aim of simplifying procedures and reducing bureaucratic obstacles. The adoption of Law of Ukraine No. 3339-IX (2023) is an example of such efforts. Infrastructure development is also envisaged, including the establishment of shared equipment centres, the modernisation of laboratory equipment, and the launch of pilot production facilities for scaling biotechnological developments. The creation of biotechnology clusters is proposed to facilitate the exchange of ideas, resources, and expertise among business, science, and the state. To strengthen cooperation, the Ministry of Education and Science, the Ministry of Digital Transformation, and the Ministry of Economic Development, Trade and Agriculture of Ukraine are conducting surveys of business representatives to enable the effective allocation of budgetary funds for research and development. This contributes to establishing systematic communication among the state, business, higher education institutions, and scientific organisations to enhance the competitiveness of Ukrainian products and services.

Despite considerable potential and existing support programmes, Ukraine's biotechnology sector faces a number of significant problems and challenges, the most acute of which is limited funding and insufficient scientific and technical support. The overall level of expenditure on scientific and technical activities as a percentage of GDP has shown a downward trend: from 0.70% in 2013 to 0.29% in 2021, with a slight increase to 0.33% in 2022-2023. This indicator is substantially lower than in EU countries, where the average level in 2023 stood at 2.22% of GDP (WINWIN. Global innovation strategy of Ukraine, n.d.). According to experts, at a research intensity of less than 0.3% of GDP, Ukrainian science has practically ceased to perform an economic function, being limited to a socio-cultural one (Pysarenko *et al.*, 2023). This leads to the degradation of the discipline and the emigration of specialists abroad in search of better conditions for developing their potential.

There is a paradox between Ukraine's enormous scientific potential and abundance of qualified personnel on the one hand, and low research and development expenditure and brain drain on the other. This gap points to a systemic inability to translate existing capacity into truly innovative products and economic growth. Low research and development expenditure (0.17% of GDP) and the outflow of specialists are interconnected manifestations of a systemic crisis in Ukrainian science. The root causes lie in institutional and economic conditions: governance quality, weak regulatory policy, limited access to funding, the ineffectiveness of innovation commercialisation mechanisms, weak science-business interaction, and the absence of adequate incentives for retaining and developing talent within the country. Consequently, the brain drain and insufficient funding which fails to sustain the minimum research intensity required for science to fulfil an economic function initially manifest as symptoms of an ineffective environment and subsequently become independent drivers of the system's further decline. This leads to the erosion of scientific potential and an intensified outflow of specialists, which diminishes the effective use of available resources and ultimately gives rise to a vicious cycle in which consequences reinforce causes.

Without addressing these systemic problems, even increased funding may not produce the expected results, as innovations will not be effectively translated into commercial products and services, and skilled workers will continue to seek employment abroad. Resolving this issue requires a comprehensive approach encompassing not only funding but also regulatory reform, infrastructure development, and a culture of commercialisation. In this regard, digitalisation can serve as a tool for bridging a certain gap. Serious obstacles are also posed by the instability of state policy and the inadequacy of legislation. Frequent legislative changes in the sector and insufficient protection of intellectual property rights hinder investment and innovation. Although the genetically modified organisms (GMO) law has been adopted, the entire legal framework particularly with respect to genome editing and clinical trials is outdated and does not conform to contemporary scientific trends or international standards.

Ukrainian enterprises face challenges that constrain the adoption of modern biotechnologies. There is insufficient expertise in the development and commercialisation of biological technologies, which slows the market entry of innovative products. The weak level of cooperation among scientific institutions, business, and the state also inhibits commercialisation. Additional obstacles include an outdated material and technical base and the absence of systematic audits of laboratory equipment, which reduce innovation capacity. Low purchasing power and a conservative business environment limit the potential for growth in demand for biotechnology products and solutions. Moreover, low trust in biological products amongst workers and

the general public constitutes a significant barrier to their wider adoption. Over the past two decades (2005-2025), the implementation of advanced information technologies in Ukraine has been marked by notable progress. During this period, modern communication systems were established, advanced information systems were introduced into industry, and mass access to the internet and mobile communications was achieved. The modern development of biotechnology is impossible without digital infrastructure.

By increasing labour productivity and reducing costs, AI plays a key role in transforming biotechnology. Ukraine is actively adopting these technologies: for example, RECEPTOR.AI develops AI platforms for the identification of biopharmaceutical compounds, whilst DEEPTRAIT creates AI tools for genome analysis (Brovinska, 2022). AI transforms managerial functions from reactive (post-occurrence problem monitoring) to predictive (real-time risk prevention). Because RECEPTOR.AI's machine learning algorithms automate the drug discovery phase, for instance, the development cycle is shortened. Consequently, the managerial function is transformed: managers receive automated recommendations based on current data, the management structure becomes decentralised, and responsiveness to market changes (shifts in drug demand, new regulatory requirements, competitive products, clinical trial results, etc.) increases. Big data analysis is of great importance for scientific research and development in biotechnology. Through big data, for example, genomic sequence monitoring for the management control function shifts from selective to continuous, giving rise to hybrid organisational units in which biologists, IT specialists, and managers operate within a single ecosystem in contrast to traditional departmental structures. Bioinformatics is also an important area of development, encompassing the collection, storage, and processing of genetic information, as well as the development of software for biological analysis. The adoption of such advanced technologies requires biocluster infrastructure with access to computing power and AI.

The Internet of Things (IoT) and blockchain, along with cloud computing and mobile services, are fundamentally transforming business structures and automating production processes. IoT shifts operational management from centralised to adaptive, adjusting processes through edge computing, reducing waste, and enabling company management with minimal or no middle management layers between leadership and operators. A concrete example of blockchain use in agrobiotechnology is Agrobon: prelude an agricultural marketplace built on a Ukrainian digital blockchain platform (AgroBon, n.d.). Blockchain transforms the supply chain coordination function: payments and the certification of genetically modified crops occur without intermediaries, and the vertically integrated corporate governance model is replaced by a decentralised network of stakeholders (farmers, suppliers, and biotechnology firms). Advanced technologies such as tissue engineering and bioprinting make it possible to create artificial tissues and organs using innovative technologies to «print» living cells and biological materials into predetermined forms. The Ukrainian company Biodrook, for example, produces implants based on biopolymer materials and 3D printing, capable of replacing bone tissue. Genome editing, which enables precise modifications to the genetic structure of organisms, opens new possibilities for the treatment of genetic diseases and the development of accurate diagnostic methods. Synthetic biology as a branch of biotechnology involves the creation and modification of living systems to develop new biological structures or improve existing ones (Zayonts, 2026).

In Ukraine, a powerful IT sector serves as a prerequisite for the accelerated development of biotechnology through bioinformatics, artificial intelligence, and big data analysis not merely as a parallel industry. Such interaction provides Ukraine with a unique competitive advantage. Importantly, the IT sector offers not only technology but also highly skilled professionals, software development methodologies, data processing infrastructure, and a culture of rapid innovation – all of which are critical to the biotechnology sector. This enables Ukrainian biotech startups to develop and test solutions more rapidly using advanced computational capabilities. Such interaction may allow Ukraine to bypass certain stages of traditional biotechnology development and focus on deep technologies and data-driven innovation, where IT expertise is particularly valuable. It also renders the Ukrainian biotechnology sector attractive to international investors seeking the integration of biological and digital solutions (BioTech Sectoral Strategy, 2024).

The managerial effect of digital technology adoption in Ukraine's biotechnology sector is clearly evident through the optimisation of business processes, enhanced transparency, analytical capabilities, improved management efficiency and decision-making, and the reduction of bureaucracy. Among the important components of this effect are the digital transformation of companies and business models, as well as the automation of production processes. The introduction of digital applications and other solutions optimises operations, minimises bureaucracy, and increases the efficiency of, for example, accounting and reporting systems, internal corporate management, and state administration. AI enables the forecasting of demand for goods and services through data analysis, allowing companies to optimise production processes and improve marketing effectiveness.

Ukrainian companies are actively researching and implementing digital solutions in their management systems. For example, YURIA-PHARM LLC is actively investigating the organisational and economic dimensions of digitalising its management system, assessing its current level and developing proposals for improvement (YURIA-PHARM, n.d.). This indicates awareness of the importance of digital transformation at the level of individual biotechnology enterprises. The digital transformation of public administration in Ukraine reflects a trend towards "servitisation", whereby the state focuses on delivering high-quality, accessible services through digital channels (Rachynsky & Tytarenko, 2024). Although this applies to government as a whole, this paradigm can be extended to the government's interaction with the biotechnology sector, simplifying procedures, reducing administrative barriers, and enhancing the effectiveness of support. Rather than the traditional approach of regulation and control, the government becomes a "service provider" to business. Outcomes of such collaboration include streamlined licensing, rapid approval of research and development projects, prompt access to state support programmes, and a

reduction in bureaucracy one of the key priorities for the biotechnology sector. Such a paradigm shift at the government level can significantly accelerate the biotechnology innovation cycle, shorten time-to-market, and increase Ukraine's investment attractiveness, as businesses will encounter a more flexible and supportive government system.

Prior to the full-scale invasion, Ukraine had firmly established itself on the international startup map. According to the Global Innovation Index and the Ministry of Digital Transformation of Ukraine, the total value of Ukrainian startups reached € 27.1 billion, and the number of active projects exceeded 1,500. The country consistently ranked amongst the top 50 most innovative countries worldwide. Biotechnology companies created breakthrough solutions, from innovative prosthetics to health monitoring systems. Following 24 February 2022, Ukraine's startup ecosystem underwent a significant transformation. In 2022, a 45% decline in investment was observed due to general uncertainty. However, 2023 saw a partial market recovery, with US $ 292 million in investments 34% more than in 2022. In the first quarter of 2024, US $ 42 million was raised. State and grant support plays an important role in attracting investment. The "Seeds of Bravery" programme provided € 3.55 million to 117 Ukrainian startups, including those in the deep-tech, HealthTech, and AgriTech domains (Seeds of Bravery, n.d.). Ukrainian startup Esper Bionics, which develops bionic prostheses, attracted significant investment and appeared on the cover of Time magazine; its product, Esper Hand, was recognised as one of the 200 best inventions of 2022 (Sabadyshina, 2024). Other successful examples include the startup Releaf Paper, which raised € 2.5 million for a factory producing paper from fallen leaves (Pykalo, 2024).

The global biotechnology market competes actively with IT for investment, ideas, and human capital. In Ukraine, despite a low overall level of research and development expenditure (0.33% of GDP in 2022), there are examples of attracting substantial funding to biotechnology research and development pr ojects. In particular, investment in a biotechnology platform for the development and licensing of protein therapies amounted to US $ 18 million (of which US $ 6 million has already been received), alongside a US $ 13 million grant from Google (Investment in a biotechnology platform..., 2025). This attests to targeted successes and continued interest in high-technology biotech solutions.

In 2022, there was a significant decline in investment in Ukrainian startup projects. Nevertheless, despite the ongoing war, investment activity is recovering, and the inherent resilience and value of technological solutions continue to attract capital. This resilience is not fortuitous. It is attributable to several factors: the high quality of human capital; reorientation towards needs that have emerged in wartime and reconstruction contexts (e.g., bionic prostheses and agricultural technologies for food security); and active grant support, including from international sources. These factors enable continued investment attraction and development even under difficult conditions. Such resilience serves as an important signal to potential investors and international partners that the Ukrainian biotech sector, despite its challenges, is a promising destination for long-term investment, as it is focused on solving real and urgent problems and has demonstrated an adaptive character.

The positive economic effect of digitalisation is evident through cost reduction, increased labour productivity, and enhanced investment attractiveness. These benefits include time savings, reduced transport costs (especially for rural residents), and the elimination of the need for physical visits to various facilities. One of the key economic effects is a reduction in production costs. AI technologies are used to automate production processes, thereby increasing productivity and reducing production costs. This is particularly relevant for biotechnology, where the automation of laboratory research, data analysis, and production lines enables significant process optimisation, cost reduction, quality improvements, and additional competitive advantages on markets. As marginal costs decrease, digital services become cheaper and more accessible. Digitalisation constitutes a driver of economic growth, founded on increasing efficiency and productivity through the use of digital technologies. Research shows that companies employing AI are able to improve customer interaction productivity through rapid data processing and first-contact problem resolution (Haan & Watts, 2023). Digital transformation can improve the efficiency of existing infrastructures and reduce costs across contemporary business models.

Digitalisation plays an important role in combating corruption by creating conditions for zero tolerance and reducing opportunities for corrupt practices. The actual economic and anti-corruption effect of introducing services in Diia over two years amounts to UAH 16.3 billion, whilst the potential effect is estimated at UAH 48 billion (Banik, 2023). This demonstrates the direct economic impact of digitalisation on the efficiency of public administration and the business environment. Under wartime conditions and economic instability, digitalisation not only optimises processes but also becomes an essential instrument for the survival and competitiveness of biotechnology companies. Cost reduction through automation and greater transparency allows companies to use limited resources more effectively and remain profitable. The ability of digitalisation to optimise costs (operational, transactional, and corruption-related) under crisis conditions when every resource is precious is not merely an advantage but a necessity. For biotechnology companies, which frequently face high research and development costs, this frees up resources for innovation and operational continuity. Thus, digitalisation not only contributes to long-term economic growth but also ensures short-term stability and the adaptability of the biotechnology sector to adverse external conditions a key factor in its survival and development in Ukraine.

The COVID-19 pandemic and growing attention to ESG factors have accelerated the sustained growth of the global biotechnology market. According to forecasts, the market is expected to double in size by 2030 (Precedence Research, 2025; 2026). This global trend creates enormous opportunities for Ukrainian biotechnology enterprises. Through digitalisation, Ukraine has the opportunity to accelerate economic recovery, strengthen its position in the international arena, and integrate into the European digital space, whilst simultaneously enhancing the competitiveness of its economy. Ukraine's integration into the EU

and legislative harmonisation will facilitate the export of Ukrainian biotechnology products to international markets.

Digital transformation is associated with the emergence of new, high-quality business models and increased profitability. The development of new economic sectors, the creation of new jobs, and the establishment of a foundation for the development of all industries including the digital economy are prospects opened up by digital technologies. The WINWIN 2030 Digital Innovation Development Strategy envisages the opening of markets in priority industries, the development and support of innovative infrastructure, and the deregulation of innovative activity, with the aim of creating new jobs. Patent activity is an important indicator of innovation potential. In 2022, 2,760 applications for inventions were filed in Ukraine (18.6% fewer than in 2021) and 1,566 patents were issued (31.9% fewer than in 2021), of which 630 (40.2%) were in the name of domestic applicants. In 2023, the State Biotechnology University received 19 patents (all utility models), whilst the National University of Life and Environmental Sciences of Ukraine received 50 patents (11 inventions and 39 utility models) (UANIPIO statistics and reports, n.d.). This reflects the active patenting activity of universities, although utility models predominate.

Digitalisation enables Ukraine to strategically position its biotechnology sector in global markets not only focusing on exports but also gaining a reputation as a centre of digital innovation. This attracts foreign investment and partnership, particularly given Ukraine's lower research and development costs compared with EU countries and North America. A focus on deep technologies and AI-based solutions, combined with market access through digital platforms, can accelerate market penetration and allow Ukraine to capture a larger share of the growing global biotechnology market. In order to fully realise the potential of Ukraine's biotechnology sector under conditions of digitalisation, a comprehensive approach to its development is necessary. Above all, this concerns increasing the efficiency of investment in scientific research and establishing mechanisms for the commercialisation of developments. The formation of a flexible and predictable regulatory environment capable of responding promptly to technological change is of considerable importance. The creation of specialised digital infrastructure in particular, high-performance computing capacity and platforms for the analysis of biological information is becoming increasingly important. At the same time, it is necessary to establish innovation communities bringing together scientific institutions, business structures, and state bodies. Investment in developing human potential and ensuring conditions for retaining highly qualified employees also warrants particular attention. Simultaneously, encouraging domestic consumption and strengthening public trust in biotechnology products will contribute to expanding the domestic market and reinforcing the sector's competitive capacity.

DISCUSSION

The results of the study confirm the growing importance of the synergistic interaction between state support mechanisms and digitalisation processes as key drivers of innovation development in the biotechnology sector, particularly under conditions of heightened uncertainty and wartime challenges. The findings demonstrate that digital transformation not only enhances operational efficiency but also fundamentally reshapes the economic architecture of the sector, supporting the hypothesis that sustainable development of biotechnology requires systemic integration of technological, institutional, and managerial components. The study by S. Aliyah & A. Widiyatmoko (2023) demonstrates the effectiveness of entrepreneurship-based biotechnology e-modules in enhancing students' critical and creative thinking, emphasising the role of digital educational tools in strengthening innovation-oriented competencies. This conclusion aligns with the findings of research, which identify digitalisation as a key driver of transformation in the biotechnology sector, capable of improving efficiency, fostering innovation, and supporting the development of resilient ecosystems even under conditions of resource constraints and external shocks. However, this study extends argument by showing that the foundations of such transformation lie in human capital development: without the integration of entrepreneurial and digital competencies at the educational level, the practical implementation of digitalisation strategies and the realisation of the sector's potential particularly in contexts such as Ukraine, characterised by institutional instability, underfunding, and wartime challenges remain significantly constrained.

At the same time, the results resonate with the findings of O. Annahlka & A. Diniati (2025), who highlight the importance of digital communication strategies for increasing brand awareness in biotechnology startups. While their research focuses on marketing aspects, this study broadens the discussion by positioning digital communication not only as a promotional tool but as a critical element of market integration and trust-building in conditions of low consumer awareness. In the Ukrainian biotechnology sector, where scientific products often remain poorly commercialised, the role of digital platforms and content strategies becomes essential for bridging the gap between research and market demand.

The study also contributes to the ongoing debate on the development of biotechnology sectors in latecomer economies, as analysed by K. Szczygielski *et al*. (2022). Their findings on the role of innovation activity in overcoming structural disadvantages are partially confirmed. However, this research argues that innovation alone is insufficient without effective institutional support and digital infrastructure. In contrast to Poland`s relatively stable development trajectory, Ukraine faces compounded challenges of institutional instability and wartime risks, which significantly limit the realisation of innovation potential despite high scientific capacity. Technological advancements in biotechnology, particularly in nanobiotechnology, as discussed by A. Bharadwaj *et al*. (2024), further reinforce the transformative potential of digitalisation. This study supports their conclusion regarding the role of advanced technologies in improving efficiency and personalisation. However, it also highlights a critical limitation: without adequate state support and investment mechanisms, the diffusion of such technologies remains constrained, particularly in developing or crisis-affected economies. Similarly, the findings of P. Nayak *et al*. (2026) on the role of green biotechnology in promoting sustainability are consistent with the results of this study. The integration of digital

technologies can significantly enhance resource efficiency and environmental performance. Nevertheless, this study emphasises that in the Ukrainian context, sustainability strategies must be complemented by economic feasibility and security considerations, particularly in light of disrupted supply chains and energy constraints.

A significant point of discussion concerns the role of artificial intelligence in biotechnology. The results are consistent with the findings of A. Bhushan & P. Misra (2025), who demonstrate the economic efficiency and transformative potential of AI in genomics and personalised medicine. However, this study adds a critical dimension by highlighting the importance of state regulation and ethical governance in ensuring equitable access to these technologies. Without such frameworks, digital transformation risks exacerbating existing inequalities within the sector. The issue of biosecurity, raised by N. Wheeler (2025), introduces an important policy dimension. This study supports the need for balancing innovation with risk management but extends the argument by emphasising that in wartime conditions, biosecurity becomes not only a technological concern but also a matter of national security. Consequently, digital monitoring systems and transparent data governance should be integral components of state support policies. The importance of digital infrastructure for enabling AI applications, as discussed by A. Holzinger *et al*. (2023), is fully confirmed by the findings of this study. The integration of big data and AI technologies significantly enhances research productivity and reduces development timelines. However, the study argues that the lack of a unified digital ecosystem in Ukraine limits the scalability of these innovations, pointing to the need for coordinated national digital strategies.

The application of AI in drug development, as analysed by M. Mulat *et al*. (2025), is also supported by the results. The study confirms that digitalisation reduces costs and accelerates innovation processes. Nevertheless, it critically highlights the insufficient integration of these technologies into digital business models and market platforms, which limits their commercialisation potential. This gap is particularly relevant for Ukraine, where the transition from research to market remains one of the key barriers to the development of the industry. The study also contributes to the ongoing debate on the role of artificial intelligence in the development of biotechnology and healthcare systems, as analysed by S. Quazi (2022). The findings on the potential of artificial intelligence and machine learning to enhance precision and genomic medicine are partially confirmed. However, this research argues that technological advancements alone are insufficient without adequate digital infrastructure, data accessibility, and institutional support. In contrast to the advanced healthcare systems considered in aforementioned study, the Ukrainian biotechnology sector operates under conditions of infrastructural constraints and wartime disruptions, which significantly limit the effective implementation of AI-driven solutions.

The study also contributes to the scientific debate on the role of deep learning technologies in the development of biotechnology and medical systems, as discussed by A. Anaya-Isaza *et al*. (2021). Their findings regarding the significant potential of deep learning in increasing the accuracy of medical diagnosis and image processing are partially confirmed. At the same time, this study substantiates that the implementation of such technologies is insufficient without proper digital infrastructure, access to quality data and institutional support. Unlike the conditions considered by the authors, where the emphasis is on technological capabilities, the Ukrainian context is characterised by limited resources and the influence of crisis factors, which significantly complicates the scaling and effective use of solutions based on deep learning. The findings of S. Askin *et al*. (2023) regarding the possibilities of using AI to improve the efficiency of clinical trials in particular, the optimisation of participant selection and data management are partially supported. At the same time, this study substantiates that the adoption of AI technologies is insufficient without proper institutional support, access to quality data, and developed digital infrastructure. Unlike the conditions considered by the authors where the emphasis is on technological capabilities and improving the efficiency of clinical processes the Ukrainian context is characterised by institutional instability, limited resources, and the influence of military risks, which significantly complicates the scaling and practical implementation of AI solutions in the biotechnology sector.

An important aspect of the scientific discussion is the role of biotechnology in the development of sustainable wastewater treatment and circular economy models. The obtained results are consistent with the conclusions of A. Das *et al*. (2025), which prove the effectiveness of biotechnological solutions in restoring resources and ensuring environmental sustainability. At the same time, this study expands their approach, focusing on the need to integrate digital technologies, in particular artificial intelligence and data analytics, to improve the efficiency and monitoring of these processes. In addition, the key role of public policy and regulatory support in scaling such innovations is emphasised, especially in the context of economic recovery and limited resources. The results of this study are consistent with P. Pokataiev *et al*. (2022), who emphasise biotechnology as a strategic sector contributing to economic diversification, technological progress, and cross-industry multiplier effects. Building on their analysis, this study demonstrates that in the Ukrainian context, the development of biotechnology is increasingly shaped by mechanisms of adaptive resilience, in which digitalisation and institutional support act as important tools for growth and survival during wartime. In addition, digital platforms and communication strategies are critical for bridging the gaps between research, market engagement, and consumer trust, extending the focus to human capital and infrastructure.

Overall, this study contributes to the existing literature by integrating the analysis of digitalisation, state support, and innovative development within a unified framework adapted to crisis conditions. It introduces the concept of digitalisation as a resilience mechanism rather than solely an efficiency tool and emphasises the necessity of institutional coordination, financial support, and regulatory stability. The findings suggest that the key challenge for Ukraine is not a lack of technological potential but rather an inability to effectively translate this potential into sustainable economic outcomes. Therefore, the focus of policy should shift from fragmented support

measures towards the creation of an integrated digital and institutional ecosystem that enables innovation, ensures transparency, and strengthens the global competitiveness of the biotechnology sector.

CONCLUSIONS

In the course of this research, the key systemic problems and challenges constraining the development of Ukraine's biotechnology sector were identified, and the complex interrelationship among state support, digitalisation, and the innovative development of Ukrainian biotechnology was elucidated. Despite strategic initiatives and scientific potential, the sector faces underfunding of research, legislative instability, staff emigration, and insufficient integration of science and business. This creates a paradox of unrealised potential in the presence of all the prerequisites for leadership. The work substantiates the necessity of translating strategies into practical action. At the same time, it has been demonstrated that digitalisation is the driving force behind the transformation of the sector. The analysis confirms that the adoption of digital technologies contributes to improved management efficiency, cost optimisation, productivity growth, expanded investment opportunities and access to new markets, and the creation of new business models. The interaction between Ukraine's IT sector and biotechnology constitutes a competitive advantage for focusing on data-driven innovation and ensures the resilience of the startup ecosystem even under wartime conditions. On the basis of the results obtained, a set of practical measures is proposed, aimed at improving state policy and stimulating the innovative development of biotechnology whilst accounting for resource limitations and wartime risks. The results of this research have direct practical significance for the formation of post-war economic recovery policy. Further research directions include the evaluation of the effectiveness of individual state support programmes, comparative analysis with successful international practices in scaling innovation, and the examination of the ethical and social consequences of introducing advanced biotechnologies into the public sphere.

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Державна підтримка та цифровізація в інноваційному розвитку біотехнологічного сектору України

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Анотація. Актуальність дослідження полягає у визначенні ролі державної підтримки та цифровізації у забезпеченні інноваційного розвитку біотехнологій в Україні в умовах війни та економічної нестабільності. Метою роботи був комплексний аналіз взаємозв'язку між державною політикою, цифровими трансформаціями та інноваційним розвитком біотехнологічного сектору України. Методологія дослідження включала системний аналіз стратегічних документів, програм державної підтримки, стартап-екосистеми, а також практичного впровадження цифрових технологій у біотехнологіях, зокрема аналіз кейсів українських компаній і стартапів. Встановлено, що державна політика України у сфері біотехнологій, зокрема Концепція розвитку біоекономіки до 2030 року та Стратегія біобезпеки, створює системні умови для розвитку інноваційної продукції у фармацевтиці, агробіотехнологіях і біоенергетиці. Проаналізовано вплив цифровізації на сектор, зокрема впровадження штучного інтелекту, біоінформатики, великих даних, блокчейну та Інтернету речей, що забезпечує оптимізацію виробничих процесів, підвищення ефективності управління та зниження витрат. З'ясовано, що взаємодія українського IT-сектору та біотехнологій формує конкурентні переваги, прискорює трансформацію наукового потенціалу у комерційні продукти та забезпечує стійкість стартап-екосистеми навіть в умовах війни. Практична цінність результатів полягає у можливості їх застосування фахівцями публічного управління, економістами та менеджерами інновацій для формування ефективної політики післявоєнного відновлення економіки та стимулювання інноваційного розвитку біотехнологічного сектору України

Ключові слова: інноваційна інфраструктура; цифрова трансформація галузі; штучний інтелект у біотехнологіях; великі дані; блокчейн-технології; IT-біотех синергія; управлінська та економічна ефективність