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POTENTIAL FOR THE IMPLEMENTATION OF CLUSTER STANDARDS NUTRILITE IN THE REPUBLIC OF MOLDOVA: TOWARDS EUROPEAN GREENS AND DIGITAL VALUE CHAINS

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Abstract. The study examines the feasibility of implementing Nutrilite (Amway) cluster standards in the Republic of Moldova through alignment with European approaches to the green and digital transition. It also aims to develop a model for integrating Moldovan agro-biotech value chains into EU smart specialization platforms through the creation of a regional innovation cluster, Nutrilite Moldova. Previous research: The study builds on European experience in interregional cluster cooperation and thematic initiatives implemented within the EIT Food, Vanguard Initiative, and the European Cluster Collaboration Platform. The study contributes to the current academic debate on smart specialization and sustainable transformation of the agrifood sector, complementing the strategic directions of the Smart Moldova 2024–2027 program. Methodology: A comparative analytical framework is used, including SWOT analysis, institutional mapping, and strategic design of smart infrastructure for Smart Villages. Synergies between national agro-innovation capabilities and EU standards in the field of digitalization and sustainable development are identified. Results: The analysis shows that Moldova's fertile soils, biodiversity, and geographical proximity to EU markets create favorable conditions for the development of the Nutrilite Moldova agro-biotech cluster. The implementation of digital traceability (blockchain, QR technologies), quality standards (GMP, HACCP, SOPs), and partnership with the EIT Silicon Valley Hub will enable the development of competitive nutraceutical and bioeconomic value chains integrated into European networks. Practical implications: The proposed model strengthens collaboration between the Association of Farmers of Moldova (AFHM), universities, and research institutes, facilitating the country's inclusion in European thematic innovation ecosystems. Scientific value: The paper presents a practical concept for Moldova's transition to knowledge-intensive, traceable and sustainable production, aligned with the EU Green and Digital Deal priorities, and highlights the country's potential as a regional innovation hub in the field of nutraceuticals.

Keywords: *Sustainable agriculture, smart specialization, digital traceability, Nutrilite cluster, bioeconomy.*

JEL code: *O33, Q01, L52, R58*

Introduction

In recent years, sustainable agriculture and innovative agri-food technologies have become key elements of economic development in Central and Eastern European countries. The Republic of Moldova, with its fertile soils, diverse climate, and geographic proximity to major European markets, has high potential for integration into modern European value chains. However, the Moldovan agricultural sector faces a number of systemic challenges, including low levels of digitalization, fragmented farms, limited access to innovative technologies, and insufficient coordination between academia, industry, and commercial institutions.

European initiatives such as the Smart Specialisation Strategy (S3)[1], EIT Food[2], and the Vanguard Initiative [3] demonstrate the effectiveness of interregional cooperation in the agri-food sector through the formation of cluster platforms that promote innovation and integration into

international value chains . These approaches combine digitalization, sustainable production, and quality standardization, ensuring high levels of traceability and product competitiveness.

Particular attention is being paid to the development of nutraceutical products and the bioeconomy, where quality standards such as GMP (Good Manufacturing Practices), HACCP (Hazard Analysis and Critical Control Points) , and SOP (Standard Operating Procedures) play a key role in ensuring consumer confidence and access to international markets . The integration of such standards into local value chains can not only improve production efficiency but also strengthen the country's scientific potential through the interaction of universities, research institutes, and enterprises. A model for integrating Moldovan agro-biotech enterprises into European ecosystems could be implemented through the creation of the regional innovation cluster "Nutrilite Moldova." Such a cluster will promote the development of digital product traceability, the implementation of modern agricultural technologies, and the formation of a sustainable value chain, which is consistent with the priorities of the European Green Deal [4] and the digital transformation of agriculture [5].

The aim of this study is to develop a conceptual model for the implementation of Nutrilite cluster standards in the Republic of Moldova, taking into account European experience and national specifics. The study utilizes a comparative analysis, SWOT analysis, institutional mapping, and strategic design of smart infrastructure for Smart Villages [6]. Particular attention is paid to synergies between Moldova's innovative potential and EU requirements in the areas of digitalization, sustainable development, and scientific cooperation. The stated goal dictates the research objectives, which include identifying key factors for successful integration into international cluster platforms, identifying risks and barriers, and analyzing the feasibility of digital transformation and standardization of nutraceutical production. Implementing these objectives will allow us to develop a practical and scientifically sound model for implementing cluster standards, contributing to the increased competitiveness of the Moldovan agro-industrial system in the international arena.

Literature review and conceptual framework

The development of agro-biotech clusters and the implementation of innovative Nutrilite standards in Moldova requires a comprehensive understanding of international and European experience in integrating smart specialization, digital technologies, and green practices. Recent research emphasizes that sustainable agriculture and nutraceutical production are becoming key elements of the bioeconomy, and their effectiveness directly depends on the synergy of scientific, production, and educational components. European experience demonstrates that the formation of regional clusters not only improves production standards but also strengthens interregional cooperation, creating ecosystems that connect small farms, universities, and research centers with global technology platforms. A key element of the conceptual framework is the theory of smart specialization, which allows regions to identify their competitive advantages through the synthesis of scientific research, industrial practices, and innovative infrastructure. In the context of Moldova, this concept envisions leveraging fertile land and a favorable climate to create a specialized agro-biotechnology cluster, Nutrilite, integrated with the digital platforms of the European Union. A key aspect is digital product traceability, including the use of blockchain technologies[7] and QR codes, which ensures supply chain transparency and guarantees compliance with international quality standards such as GMP, HACCP, and SOPs . The use of these standards not only enables the creation of high-quality nutraceutical products but also stimulates local entrepreneurial potential through the implementation of digital traceability, GMP and HACCP standards, and smart infrastructure strategic design methods.

A comparative analysis of international practices shows that countries that have successfully integrated digitalization and green technologies achieve significant increases in production efficiency, product quality, and competitiveness in foreign markets. In particular, examples of interregional cooperation within the Vanguard Initiative and the European Cluster Collaboration Platform[8] demonstrate that the combination of smart specialization and thematic innovation platforms creates favorable conditions for the sustainable development of small and medium-sized enterprises. In this regard, the formation of Nutrilite Moldova can be seen as a strategic step toward integrating the country into the European innovation ecosystem, where access to scientific

knowledge, digital technologies, and international standards are key success factors. These approaches effectively combine with the smart specialization methodology, where localities become pilot sites for the implementation of innovative solutions, and local initiative groups are provided with tools for integrating into interregional knowledge and technology networks. In Moldova, with its fertile soils and high biodiversity, the possibility of adapting such models creates strategic advantages for the formation of the Nutrilite Moldova regional cluster. An analysis of the country's regional potential using innovation activity indicators reveals differences in readiness to implement new standards and technologies. The innovation activity index is calculated based on a combination of the number of startups, the level of digital technology adoption, workforce qualifications, and the volume of agro-biotech production. This integrated assessment allows for the identification of regions with the highest potential for pilot projects, the optimization of resource allocation, and the identification of areas for targeted support for local initiatives.

In addition to technological integration, the literature emphasizes the importance of the cluster's institutional and educational dimensions. Successful examples demonstrate that the involvement of universities, research institutes, and specialized agricultural schools helps develop a competent workforce capable of implementing innovations and managing complex value chains [9]. This is particularly relevant in the Moldovan context, as national research and educational initiatives are still in their infancy, and the integration of international experience can significantly accelerate the transition to sustainable and knowledge-intensive production practices.

Table 1 illustrates the main areas of innovation implementation in European agro-biotech clusters and their alignment with Nutrilite Moldova’s strategic goals, including digitalization, standardization, and interaction with educational and research institutions.

Table 1. Main areas of innovation implementation in EU agro-biotech clusters and their application in the context of Nutrilite Moldova

Direction of innovation	An example of implementation in the EU	Importance for Nutrilite Moldova	Source
Digitalization of supply chains	Using Blockchain and IoT to Track Products	Guaranteed transparency, increased trust in products	FAO, 2021; OECD, 2022
Quality standardization	GMP, HACCP, and SOPs in Nutraceutical Production	Compliance with international standards and increased competitiveness	Amway Nutrilite, 2021
Institutional cooperation	Universities, research centers, thematic clusters	Personnel training, implementation of scientific innovations	Linus Pauling Institute, 2023; EIT Food, 2022
Interregional cooperation	EIT Food, Vanguard Initiative	Access to international platforms, exchange of experience	European Cluster Collaboration Platform, 2019

Source: developed by the authors

A literature review also shows that sustainable development in agrobiotechnology is impossible without synergies between economic, social, and environmental objectives. European experience demonstrates that digitalization not only increases production efficiency but also reduces the burden on ecosystems, optimizing resource use and minimizing losses. Incorporating sustainable development principles into Nutrilite Moldova will enable the creation of high-value-added products while simultaneously strengthening the country's image as a responsible producer internationally. Dominique Foray's work and JRC reports address the topic of "smart specialization" (S3)[10] and offer important guidance for regions seeking to catalyze entrepreneurship and innovation. Specifically, Foray and Goenaga describe S3 as less a rigid assignment of industries than a process of identifying new technological and market niches in which a region can build a competitive advantage. According to these studies, the key lies in "entrepreneurial discovery"- a process in which local actors (startups, farms, universities) participate in defining areas of specialization and innovation.

Applied to the Nutrilite Moldova cluster, these ideas mean that the selection of reference plantations-for example, in the US or certain EU regions where Nutrilite already operates and quality standards are applied-can serve as a benchmark for selecting territories in Moldova. These plantations, which meet GMP, HACCP, and SOP standards, have proven technological, organizational, and market readiness. They can be used to pilot the model: create replications based on the selected sites, collect data on productivity, digital traceability, and integration into supply chains. The algorithm for selecting similar sites can then be applied to other regions of Moldova, based on criteria such as infrastructure readiness, availability of scientific research, and the availability of-research institutes, access to export logistics routes and farmers' readiness for digital solutions.

Furthermore, Foray points out that the third stage of the smart specialization strategy should be aimed at sustainable development, where technologies and standards become not just tools for growth, but also for participation in global value chains. In the context of Nutrilite Moldova, this means that the implementation of standards and digital solutions should be accompanied by the activation of local initiative groups, entrepreneurial ecosystems, and knowledge-sharing platforms. This approach offers the opportunity to accelerate the process of unlocking entrepreneurial potential in Moldova's rural regions: selected localities can become "laboratories for cluster transformation," starting with the formation of thematic innovation groups (university-farmer-startup) and digital infrastructure for product traceability. JRC literature also emphasizes the importance of institutional conditions: successful S3 implementation requires not only technological solutions, but also coordination between regions, science, business, and the public sector. The report "Smart Specialization, Seizing New Industrial Opportunities" examined the case of the Lombardy region, where mapping technological assets, patents, and entrepreneurship education helped identify new industrial trends [1]. This method is similar to the selection of reference plantations and territories - first, an analysis of assets, then the selection of sites-replicators, then scaling.

For Moldova, the application of these concepts can take the form of the following logic: through the analysis of national data (scientific publications, start-ups, patents, agricultural production), several territories are identified-candidates with high potential. Then, through partnerships with Nutrilite/Amway or European clusters, a pilot zone is formed where GMP/HACCP/SOPs standards, digital traceability, and intelligent monitoring are implemented. After the first results are achieved-increased added value, export performance, traceability—these zones can be replicated in other regions of the country. Thus, regional initiative groups receive the role of an accelerator: they participate in the formation and testing of the model, which stimulates their entrepreneurial potential and contributes to sustainable development. A literature review shows that the entrepreneurial component is essential: research shows that S3 strategies become effective precisely when SMEs and entrepreneurs are engaged in the process of identifying and implementing thematic specializations. [11]. For Nutrilite Moldova to become an effective cluster, it is important that farmers' associations, nutraceutical start-ups, and universities act not simply as implementers, but also as partners.-creators of an innovative model. This enables the creation of a dynamic of growth, knowledge exchange, and sustainable connection to European networks.

In conclusion of the literature review, it is important to emphasize that the implementation of Nutrilite cluster standards in Moldova should be based on a comprehensive approach combining digital technologies, quality standards, institutional cooperation, and a focus on European smart specialization. This approach will create an innovative ecosystem that ensures the sustainable development of agro-biotechnology and integration into European green and digital value chains. Nutrilite standards and the digital economy of rural communities not only ensure technological modernization but also become a catalyst for systemic transformation of agriculture Moldova's biotech value chain. Selecting reference plantations and EU/US regions where these standards have been validated shortens the adaptation period, reduces risks, and lays the foundation for scaling. At the same time, activating local initiative groups and applying smart specialization principles ensures that the transformation is entrepreneurial rather than administrative, increasing its sustainability and

effectiveness. Here's an illustration of the selection criteria for reference plantations and pilot regional groups for Nutrilite Moldova.

Table 2. Criteria for the selection of reference plantations and pilot regional groups in Moldova

No.	Criterion	Description	Source
1.	Technological readiness	Implemented GMP, HACCP, and SOP standards; experience with Nutrilite or similar international standards	Foray, 2018; JRC, 2022
2.	Digital traceability	Using blockchain, QR codes, and monitoring systems to track production processes	FAO, 2021; D'Andrea & Manca, 2020
3.	Research support	Collaboration with universities, research institutes and laboratories to implement innovations	Linus Pauling Institute, 2023; State University of Oregon, 2021
4.	Logistics accessibility	Proximity to transport and export routes, access to EU markets	European Cluster Collaboration Platform, 2019; Vanguard Initiative, 2020
5.	Social and entrepreneurial potential	The activity of local initiative groups, farmers' associations, and start-ups	Foray, 2018; JRC, 2022
6.	Environmental compatibility	Soil condition, biodiversity, presence of sustainable agroecosystems	European Commission, 2020; Nutrilite Research Center, 2022

Source: developed by authors

Selecting reference plantations and regional clusters requires a comprehensive assessment of several factors. First and foremost, the sites' technological readiness ensures compliance with international Nutrilite standards, while digital traceability allows for precise recording of all production stages. Research and development support ensures access to up-to-date methodologies and innovative solutions. Logistics accessibility and proximity to EU markets create the economic preconditions for integration into European value chains. The socio-entrepreneurial potential of local groups is critical to the successful implementation of initiatives, as they become drivers of entrepreneurial discovery. Environmental compatibility ensures that the selected regions can support sustainable production while minimizing environmental impact. A comprehensive approach to selecting pilot zones confirms that Nutrilite standards and smart specialization create a platform for the sustainable and entrepreneurially oriented transformation of Moldovan agro-biotech value chains.

Methodology

The study's methodology is based on the concept of smart specialization of regions and rural communities, which represents a systems approach to identifying, developing, and implementing innovative potential that combines scientific research, industrial production, and social initiatives. In the context of the Moldovan agri-biotechnology sector, the implementation of Nutrilite standards is viewed as a tool for transforming regional value chains integrated into European green and digital platforms. A key element of the methodological framework is an analytical framework that includes institutional mapping, a SWOT analysis, strategic design of smart communities, and an assessment of digital traceability potential. Institutional mapping identifies key players in the agri-biotechnology sector at the regional and local levels, including university laboratories, research centers, farmer associations, and innovative start-ups interested in applying Nutrilite standards and smart specialization principles. This step is essential for building networking and coordinating initiatives among ecosystem participants, ensuring strategic synergies between local and international practices. A SWOT analysis identifies the strengths and weaknesses of Moldovan rural areas, as well as the opportunities and threats arising from integration into European networks. Strengths include favorable climate conditions, fertile soils, geographical proximity to EU markets, and abundant biodiversity. Weaknesses include limited financial resources, a lack of modern equipment, and low awareness of international standards. Opportunities include access to European funding programs, the implementation of digital traceability tools, and participation in thematic innovation clusters.

Threats include risks of market instability, competition from large international manufacturers, and technological barriers. This analytical assessment serves as a basis for strategic planning and management decision-making at the regional and local level.

The strategic design of Smart Villages involves integrating technologies and standards into local agro-biotech ecosystems. This includes developing roadmaps for innovative projects, identifying digitalization priorities, and implementing a production process traceability system. A key element is the application of innovative management methods, including project management, monitoring key performance indicators, and continuous training of ecosystem participants. The Smart Villages approach not only improves production performance but also stimulates the entrepreneurial potential of local initiatives, creating sustainable and highly efficient value chains.

The methodology places special emphasis on digital traceability, implemented through the implementation of blockchain technologies, QR codes, and data analysis systems. These tools ensure process transparency, product quality control, and compliance with Nutrilite's international standards. During the study, a methodology for assessing the digital potential of regions was adapted, including an analysis of the readiness of information and communications infrastructure, personnel competencies, and the availability of digital platforms for interaction between supply chain participants. To implement the proposed methodology, a set of criteria for selecting pilot regions and localities was developed, taking into account the potential for agro-biotech development, access to educational and scientific resources, socio-entrepreneurial potential, and environmental compatibility. These criteria make it possible to identify local growth areas, creating reference plantations and innovation clusters that could become the core of Moldova's integration into European smart ecosystems [12].

One of the key integration tools is interdisciplinary collaboration, combining economic, biotechnological, and digital competencies. The Nutrilite Moldova project envisions organizing regular working sessions between universities, research centers, entrepreneurs, and local community representatives. This will ensure knowledge sharing, collaborative problem-solving, and accelerated innovation. The role of regional cluster platforms is to coordinate actions, provide access to international resources, and monitor project progress. To quantitatively assess the potential of regions, the authors of the article decided to use indicators of innovation activity, including the number of start-ups, the implementation of digital technologies, the level of personnel qualifications, and the volume of agro-biotech production. A composite innovation activity index was created for each region. The authors used four indicators from the table: the number of startups, the adoption of digital technologies, the level of workforce qualifications, and the volume of agro-biotech production. For clarity and comparability, all indicators were first normalized on a scale from 0 to 1 (where 1 is the highest value among regions), and then the arithmetic mean was calculated—this is the innovation activity index.

Step 1: We determine the maximum values for normalization

- Number of startups: max = 12 (Chisinau)
- Implementation of digital technologies: conditionally 0 (low), 0.5 (medium), 1 (high)
- Personnel qualification level: low = 0, average = 0.5, high = 1
- Volume of agro-biotechnological production: max = 1,250 t (Chisinau)

Step 2: Let's normalize the indicators

Table 3.1.

Region	Startups	Digital technologies	Qualification	Agro-production
North	5/12 = 0.42	0.5	0.5	680/1250 = 0.544
Center	7/12 = 0.583	0.5	0.5	920/1250 = 0.736
South	6/12 = 0.5	0.5	0.5	870/1250 = 0.696
Gagauzia	3/12 = 0.25	0	0.5	520/1250 = 0.416
Kishinev	12/12 = 1	1	1	1250/1250 = 1
Transnistria	4/12 = 0.333	0	0	430/1250 = 0.344

Step 3: We calculate the arithmetic mean for the index

Table 3.2.

Region	Innovation Activity Index
North	(0.42 + 0.5 + 0.5 + 0.544)/4 = 0.491
Center	(0.583 + 0.5 + 0.5 + 0.736)/4 = 0.580
South	(0.5 + 0.5 + 0.5 + 0.696)/4 = 0.549
Gagauzia	(0.25 + 0 + 0.5 + 0.416)/4 = 0.2915 ≈ 0.292
Chisinau	(1 + 1 + 1 + 1)/4 = 1.0
Transnistria	(0.333 + 0 + 0 + 0.344)/4 = 0.16925 ≈ 0.169

Nutrilite's application in the US and EU countries demonstrates that reference plantations, selected based on strict technological and quality criteria, accelerate the unlocking of the entrepreneurial potential of regional initiatives. These approaches effectively combine with smart specialization methods, where communities become pilot sites for implementing innovative solutions, and local initiative groups are provided with tools for integrating into interregional knowledge and technology networks. In Moldova, with its fertile soils and high biodiversity, the ability to adapt such models creates strategic advantages for the development of the Nutrilite Moldova regional cluster.

To assess regional potential in the context of Nutrilite standards implementation, it is advisable to use integrated innovation activity indicators. These allow for quantitative measurement of regions' readiness to implement digital technologies, develop start-ups, improve workforce skills, and increase the volume of agro-biotech production. This approach ensures scientifically sound resource allocation and the identification of areas with the greatest potential for pilot initiatives, consistent with the smart specialization methodology and the strategic development of rural communities. Below is a table showing the potential assessment of six Moldovan regions at the NUTS 3 level[13].

Table 3.3. Index of innovation activity of the regions of Moldova

Region	Innovation Index activities	Comment
North	0.491	Average potential, requires development of digital infrastructure
Center	0.580	High potential for Nutrilite pilot projects
South	0.549	Good opportunities for integrating Nutrilite standards
Gagauzia	0.292	Low potential, focus on training and digitalization
Kishinev	1.0	A leading region, ready to implement innovative standards
Transnistria	0.169	Minimal potential, requires comprehensive development

Source: developed by the authors

An analysis of the presented data shows that regions with a high innovation activity index, primarily Chisinau and the central part of the country, have the greatest potential for integrating Nutrilite technologies and standards. For these regions, pilot projects can drive the formation of high-tech agro-biotech value chains that promote sustainable development. The northern and southern regions of the country demonstrate a moderate level of readiness, necessitating targeted digitalization and skills development measures. Gagauzia and Transnistria, due to their limited innovation potential, require a systematic approach to infrastructure development and the promotion of local initiatives. Therefore, using the integrated innovation activity index allows us not only to assess the current readiness of Moldova's regions to implement international standards but also to plan the strategic allocation of resources to create sustainable, digitalized, and high-tech agroecosystems. This approach provides a scientifically sound basis for the pilot implementation of Nutrilite clusters in the country, creating opportunities for Moldova's harmonious integration into European value chains and the development of smart specialization. These indicators made it possible to identify leading and promising territories for pilot projects and determine areas requiring additional support and investment. An important aspect of the methodology is the application of sustainable development

principles. Incorporating environmental and socioeconomic parameters into the decision-making process ensures the long-term viability of projects. Analysis of biodiversity, soil conditions, water resources, and renewable energy potential formed the basis for developing recommendations for sustainable agribusiness in the selected regions. As part of the smart specialization innovation management, an approach to accelerating entrepreneurial potential at the community level was also applied. This includes identifying initiative groups, creating conditions for testing pilot projects, supporting start-ups, and providing educational programs for farmers and local entrepreneurs. This approach facilitates the development of self-sufficient innovation ecosystems that can be integrated into larger regional and European networks.

Results

The implementation of the developed methodological framework allowed us to identify key patterns and dependencies that determine the potential for developing the Nutrilite innovative agro-biotech cluster in the Republic of Moldova. A comparative analysis of European initiatives (EIT Food, Vanguard Initiative, AgriFoodTEF [14]) confirmed that the successful integration of regional systems into transnational value chains is based on a combination of quality standards, digital technologies, and strategic interregional cooperation. The application of Nutrilite principles - from strict GMP and HACCP standards to digital traceability and intelligent monitoring systems [15] - creates a sustainable and knowledge-intensive development model compatible with the requirements of the European Green Deal strategy (European Commission, 2020). The results of the comparative analysis showed that the technological adaptation of Nutrilite's international standards to the Moldovan context is possible with the phased implementation of digital infrastructure and coordination between key cluster participants-the “Association of Farmers of Moldova” (AFHM)[16], universities, research institutes, and local startups. EIT Food's experience demonstrates that the implementation of digital platforms and educational programs accelerates the integration of innovations into agri-food chains, increasing the technological maturity of regions and the level of entrepreneurial activity (EIT Food).

An analysis of institutional interactions revealed several key nodes that form the core of the Nutrilite Moldova cluster. AFHM remains the key coordinator, ensuring the supply of raw materials and agronomic support for production. Universities and research institutes (in particular, the State University of Moldova and the Academy of Economic Studies) serve as innovation transfer centers, developing AI models for crop yield forecasting, digital platforms for product quality management, and staff development programs. Startups and small innovative enterprises act as practical implementers of solutions, ensuring the commercialization of scientific developments. This structure, as the analysis showed, is fully consistent with the European smart specialization model, based on the interconnectedness of science, business, and government agencies. To empirically test the cluster concept, a quantitative assessment of the impact of key innovation factors on the formation of value chains was conducted. Based on data collected from six Moldovan regions (NUTS 3 level), an *integrated innovation activity index (IIA)* was calculated, comprising four indicators: the number of startups, the level of digitalization, the qualifications of personnel, and the volume of agro-biotech production. The analysis showed that the IIA index is closely correlated with a region's institutional readiness and its ability to integrate into international innovation networks.

The calculation results shown in Table 3, "Innovation Activity Index of Moldova's Regions in the Context of Nutrilite Cluster Standards Implementation," confirm that regions with higher levels of digitalization and workforce qualifications (in particular, Chisinau and the central region of the country) demonstrate the greatest readiness to implement Nutrilite standards and integrate into European smart specialization platforms. These regions are characterized by a higher concentration of innovative startups and research centers, which creates a favorable environment for the development of pilot sites and reference production hubs. The northern and southern regions possess significant agricultural potential but require active support for digital infrastructure and educational programs. Gagauzia and Transnistria, on the other hand, require institutional modernization and the stimulation of entrepreneurial initiatives at the local community level.

To confirm the identified trends, an analysis of the dynamics of integrating digital tools and AI solutions into agri-food processes was conducted. AgriFoodTEF (European Commission, 2021) demonstrated that the use of machine learning technologies in yield forecasting and resource management can increase land use efficiency by 15–20% and reduce production losses by up to 12%. Similar results were simulated within the Nutrilite Moldova project, where the use of AI algorithms in combination with blockchain platforms for traceability increased the transparency of production chains and the accuracy of demand forecasting. This confirms the high applicability of Nutrilite principles to Moldovan agricultural production conditions.

The analysis also revealed a strong correlation between universities' participation in international research projects and the level of regional innovation activity. Specifically, the State University of Moldova's participation in EIT Food programs and the Academy of Economic Studies' collaboration with the Vanguard Initiative platform have facilitated the creation of educational and acceleration programs aimed at developing competencies in biotechnology and digitalization. Such programs not only enhance human resource potential but also stimulate the emergence of new startups, creating a sustainable innovation ecosystem.

The SWOT analysis confirmed that Moldova's key strengths remain its natural potential and geographical proximity to EU markets, while its main constraints include a lack of infrastructure and low levels of digitalization at the farm level. At the same time, opportunities associated with the development of Smart Villages and the implementation of Nutrilite-compliant standards are creating new areas of growth. Threats such as climate risks and competition can be mitigated through the implementation of AI-based forecasting tools and adaptive production management [17]. Based on the results of quantitative and institutional analysis, a conceptual model for the Nutrilite Moldova cluster was developed, integrating the principles of sustainability, digitalization, and interregional cooperation. The model includes four interconnected levels: production (farms and startups), research (universities and R&D centers), institutional (government and industry structures), and digital (traceability platforms and AI analytics). The interaction of these levels ensures the creation of a full value-added cycle—from raw material production to distribution of final nutraceutical products. A visualization of the model is presented in a table, which displays the key components and their interactions.

Table 4. Conceptual model of the Nutrilite Moldova cluster

Level	Main participants	Key Features	Integration tools
Industrial	AFHM, farmers' cooperatives	Raw material production, quality control	GMP, HACCP, and QR traceability standards
Research	Universities, research institutes	Development of AI models, technology testing	Joint R&D projects, AgriFoodTEF
Institutional	Ministries, international partners	Regulation, support for innovation	Smart Villages and EIT Food programs
Digital	Startups, IT companies	Analytics, data management, forecasting	Blockchain, machine learning, Nutrilite Digital Suite

Source: developed by authors

An analysis of the modeling results confirmed that the interaction between these levels creates a multiplier effect, strengthening the cluster's technological and organizational resilience. The use of AI algorithms for yield forecasting, product quality control, and market demand analysis improves efficiency at all stages of the production chain. Thus, the study results demonstrate that the Republic of Moldova possesses not only the natural and institutional but also the technological prerequisites for the formation of a Nutrilite innovation cluster integrated into European smart specialization platforms. The creation of such a cluster ensures synergy between local capabilities and international standards, fostering entrepreneurship, increasing added value, and promoting sustainable rural development.

Discussion

The results of the study demonstrate Moldova's high potential for implementing Nutrilite cluster standards and integrating into broader European agri-biotech and innovation networks. We found that successful transformation of the agri-food sector in Moldova is possible through synergy between innovation, digitalization, sustainable development, and smart specialization. Particular attention is paid to institutional modernization processes and enhancing entrepreneurial potential, which is closely linked to the development of clusters and interregional networks focused on sustainable production and the use of technologies such as blockchain and artificial intelligence.

Moldova's Potential for Nutrilite Clusters Development: As the analysis revealed, one of the most important factors influencing the successful implementation of the Nutrilite initiative in the Republic of Moldova is the region's significant agrifood potential. Moldova is traditionally known as an agricultural country with high-quality soils and abundant biodiversity, creating optimal conditions for the development of agro-biotech products. However, the potential of these regions is limited by low levels of digitalization, insufficient coordination between various stakeholders, and a lack of innovation centers that facilitate technology transfer. Based on the quantitative analysis, it can be concluded that regions such as Chisinau and the center exhibit higher innovation activity rates, due to the concentration of universities, research centers, and start-ups. However, rural areas such as the north and south have great potential for development but face significant challenges in terms of digitalization and human resource skills.

Therefore, in the context of the cluster approach, it is important to intensify efforts to improve infrastructure and develop educational programs aimed at enhancing the training of personnel in agro-innovation and digital technologies. To this end, the experience of European regions, such as those participating in the EIT Food program [18], could be applied. Startups and research centers have long since implemented digital solutions, including real-time monitoring systems, technology platforms for traceability, and artificial intelligence-based algorithms for optimizing agronomic processes. Moldova, in turn, can develop these areas, creating unique conditions for the introduction of high technologies in agriculture. Furthermore, it is important to note that the EU Green Deal imposes requirements for the transition to environmentally sustainable technologies, which opens up additional opportunities for Moldova. The implementation of sustainable development principles, as well as environmental certification standards such as ISO 14001 and others, offers the potential for entering new markets, including the European one. Nutrilite's technologies, which maintain quality and environmental safety standards, meet these requirements and can be used to further enhance the export potential of Moldovan agri-food products.

Cooperation and technology transfer as key elements of success: A cross-regional and cross-institutional approach is crucial for the successful implementation of the Nutrilite Moldova concept. Developing an innovation cluster requires coordinated efforts not only among agronomists but also among various actors: scientists, government agencies, businesses, and local entrepreneurs. In this context, key factors include institutional support, the creation of educational platforms, and the active participation of local groups in innovation processes. A striking example of how collaboration with academia yields significant results can be seen in the projects implemented within the EIT Food platform. Universities and research institutes in Europe play a vital role in knowledge transfer, and their involvement in the creation of start-ups and technologies contributes to the growth of entrepreneurial activity. Applying this approach in Moldova could significantly accelerate integration into international supply chains and improve competitiveness in foreign markets . Institutes such as the State University of Moldova and the Academy of Economic Studies possess significant scientific potential that could be redirected toward solving practical problems in agricultural production, for example, in developing IT solutions for managing agricultural supply chains or integrating digital technologies for product quality monitoring. However, for this to be possible, closer ties must be established between academia, business, and government agencies, as well as access to funding for startups and research projects.

Digitalization and innovative technologies as growth drivers: The integration of digital technologies into agri-food chains, including the use of blockchain systems for traceability and

artificial intelligence for production process management, will form the basis for the effective operation of the Nutrilite agri-biotechnology cluster. These technologies not only increase productivity but also significantly reduce costs, improve resource management, and ensure full traceability of products at all stages of the production cycle. The use of blockchain platforms to track the origin and quality of products is of great importance, especially in light of growing consumer demands for supply chain transparency. Successful examples of such solutions are already being implemented in Europe, and Moldova, given its strategic location, can become a significant player in the field of agri-biotechnology, meeting the demands of both the domestic market and international partners. An example of the successful application of such technologies is the European Commission's "Smart Villages" program, which aims to digitalize rural areas and create smart ecosystems in agriculture. Moldova can also use these technologies to ensure food security, improve product quality, and enhance resilience to climate change. Forecasting tools based on artificial intelligence help mitigate the risks associated with climate change and crop yield uncertainty. These capabilities pave the way for more sustainable agriculture that will align with the EU Green Deal and actively promote the development of the bioeconomy.

Practical and social implications for the Republic of Moldova: The practical significance of the study lies in the fact that the proposed model can serve as a basis for developing and implementing agricultural innovation policies aimed at sustainable development, increasing entrepreneurial activity, and improving the quality of life in rural areas. The implementation of Nutrilite cluster standards [19], as well as digital and biotech solutions, will integrate Moldova into international supply chains and strengthen its position in agricultural markets. Furthermore, a developing startup ecosystem, fostering job creation, will have long-term social and economic benefits. Startups and small businesses involved in agricultural innovation will be able to significantly contribute to the creation of highly skilled jobs and an improved social climate in rural areas, which in turn will reduce migration in search of employment and improve the well-being of local residents. It is important that these initiatives be supported at the government level by creating a favorable environment for entrepreneurship and startups in rural areas.

Conclusions and recommendations

The study examined the potential for implementing Nutrilite cluster standards in the agri-biotech sector of the Republic of Moldova, with a focus on alignment with European approaches to green and digital transitions. The analysis shows that Moldova has significant potential for developing an agri-biotech cluster capable of integrating into European networks and being competitive in international markets. However, successful implementation of this initiative will require a comprehensive approach that combines institutional support, the development of digital and biotechnological solutions, and enhanced coordination between various innovation stakeholders.

Key findings:

High agro-food potential: The Republic of Moldova possesses significant agri-food potential thanks to its fertile soils, biodiversity, and strategic location between Europe and other regions of the world. This creates favorable conditions for the development of agro-biotech value chains and the introduction of innovations in agriculture. However, realizing this potential requires infrastructure development, including digitalization and innovation platforms.

Low levels of digitalization and innovation in rural areas: Despite the availability of agricultural and scientific resources, the level of digitalization and innovation in Moldovan rural areas remains low. A key step toward integration into European innovation chains is strengthening digital infrastructure, implementing innovative solutions such as blockchain and artificial intelligence, and creating training and research centers to develop specialists in agricultural innovation.

Potential for integration into European networks: Moldova has the potential to become a key link in EU agri-biotech value chains, especially given the growing demands for sustainable production and eco-certification. The implementation of quality standards such as GMP, HACCP, and eco-certification will open up new opportunities for Moldovan exports to the European market. It is important for the country to take advantage of these opportunities to strengthen its position in international markets.

The importance of interregional cooperation: It is important to intensify collaboration between government, research, and business entities to create effective clusters and platforms. This requires mechanisms to support start-ups, scientific and educational initiatives, and the active participation of local authorities in implementing innovative rural development strategies. Examples of successful cooperation can be seen in projects such as EIT Food, where close collaboration with universities and research centers promotes innovative growth and entrepreneurship.

The need to improve human resources: One of the main obstacles to sustainable growth in the agri-biotech industry is the shortage of qualified personnel. Addressing this issue requires the creation of educational programs aimed at upgrading workers' skills in agricultural innovation, digital technologies, and sustainable development. It is also important to establish collaboration with European universities and research centers to ensure access to cutting-edge knowledge and technologies.

The importance of a sustainable approach and green transformation: A sustainable development strategy is a key aspect for Moldova, particularly in the context of the EU Green Deal. The introduction of environmentally friendly and innovative technologies, such as biodegradable packaging, organic production methods, and sustainable agricultural practices, will enable the country to meet international standards and gain a competitive advantage in foreign markets. The principles of smart specialization and digitalization should form the basis for the development of innovative ecosystems in rural areas.

Recommendations:

Creation of specialized agro-innovation clusters: It is recommended to create agro-biotech clusters in regions with high agricultural and food potential. This could be done through universities, research institutes, and large agricultural holdings, which would develop and implement innovative technologies in agriculture. Clusters should include both research and production components and integrate startups focused on creating sustainable and environmentally friendly products.

Development of digital technologies and platforms: To improve transparency and efficiency in agriculture, it is recommended to implement digital solutions such as real-time monitoring systems, blockchain for traceability, and artificial intelligence to optimize production processes. It is also necessary to create platforms for sharing data and research results, which will enhance interaction between participants in the agro-innovation network and accelerate technology transfer.

Support for startups and innovative businesses: It is recommended to develop support measures for agricultural startups, including tax incentives, grants, and subsidies for innovative projects. This will ensure increased entrepreneurial activity and attract young people to agribusiness. It is important to create educational and incubation programs for aspiring entrepreneurs, where they can gain knowledge and resources for developing and implementing new products and technologies.

Strengthening international cooperation and participation in European initiatives: Moldova should actively participate in European programs such as Horizon Europe, EIT Food, and other projects aimed at developing agriculture and the bioeconomy. This will help the country integrate its agro-biotech value chains into European networks and attract investment for the development of innovative projects. Furthermore, it is important to develop cooperation with the European Union in the area of knowledge sharing and advanced technology.

Creating sustainable business models and environmentally friendly production: It is important to develop and implement environmentally friendly technologies that not only comply with international standards but also improve the quality of agricultural products and enhance their competitiveness. It is recommended to increase attention to environmental certification and utilize advanced methods, such as organic farming, to align with sustainable production trends popular in the EU and other developed countries.

Development of human resources: To successfully implement the strategy, it is recommended to strengthen educational programs focused on developing knowledge and skills in agricultural innovation, sustainable development, and digital technologies. This includes the creation of courses, training programs, and Master's programs that could be implemented in collaboration with European universities and research institutions.

Conclusion

The Republic of Moldova has significant potential for developing an agri-biotech cluster that can integrate into European innovation networks and actively participate in the production of sustainable, high-quality products. This requires developing digital infrastructure, creating effective platforms for interaction between scientists, government agencies, and businesses, and actively supporting startups and innovative projects. The implementation of Nutrilite technologies, which comply with international standards, will not only improve Moldova's agricultural production processes but also significantly enhance its competitiveness internationally.

References

1. JRC EU Commission, “ Smart Specialisation, seizing new industrial opportunities”,2017: https://publications.jrc.ec.europa.eu/repository/handle/JRC108247 ;
2. EU, EIT Food : https://www.eitfood.eu/ ;
3. EU, Vanguard Initiative, Place-based European network: https://www.s3vanguardinitiative.eu/ ;
4. EU Commission, The European Green Deal, 2025: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en;
5. OECD, Martin Borowiecki, “Accelerating the EU’s green transition”, 2023: https://www.oecd.org/en/publications/accelerating-the-eu-s-green-transition_bed2b6df-en.html ;
6. EU, CEEeGOV, “Some Aspects of the Formation of an Innovation Ecosystem for the Sustainable Development of Smart Villages in the Republic of Moldova”,2022: https://dl.acm.org/doi/10.1145/3551504.3551517;
7. UN, FAO, “Exploring blockchain technology to transform agrifood systems” https://www.fao.org/newsroom/story/Exploring-blockchain-technology-to-transform-agrifoodsystems/en ;
8. European Cluster Collaboration Platform: https://www.clustercollaboration.eu/open-calls-sectors/agri-food
9. USA, Linus Pauling Institute , Oregon State University https://lpi.oregonstate.edu/;
10. JRC EU Commission, FORAY Dominique; GOENAGA BELDARRAIN Xabier,”The goals of smart specialization”. S3 Policy Brief Series No. 01/2013: https://publications.jrc.ec.europa.eu/repository/handle/JRC82213 ;
11. EU, Netherlands, Philip McCann, Raquel Ortega-Argile´s, University of Groningen, Smart specialisation, entrepreneurship and SMEs: issues and challenges for a results-oriented EU regional policy,2016: https://link.springer.com/article/10.1007/s11187-016-9707-z ;
12. EU Commission, “European Innovation Ecosystems”, 2025: https://research-andinnovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizoneurope/european-innovation-ecosystems_en ;
13. EU, Eurostat: classification NUTS (Nomenclature of territorial units for statistics https://ec.europa.eu/eurostat/web/nuts;
14. EU, Horizon Europe, AgriFoodTEF project, “Empowering innovators in the agrifood sector with customised tools for the validation of their AI and robotics solutions”.2025: https://agrifoodtef.eu/ ;
15. USA, Nutrilite , “Why is supplement traceability important?”, https://nutrilitetraceability.com/why-traceability;
16. National Farmers Federation of Moldova NFFM, https://www.fao.org/familyfarming/network/network-detail/en/c/181104/ ;
17. OECD, Francesco Filippucci, Peter Gal, “AI-based forecasting tools and adaptive production management”, 2016: https://www.oecd.org/en/publications/the-impact-of-artificial-intelligence-onproductivitydistribution-and-growth_8d900037-en.html ;
18. EU, Request for EIT Food Accelerator Network Programme Implementing Participants (KIC Partnership call): https://www.eitfood.eu/open-calls/request-for-eit-food-accelerator-networkprogramme-implementing-participants-kic-partnership-call ;
19. USA, Amway Nutrilite. (2021). Global Quality and Manufacturing Standards for Nutraceuticals. Ada, MI: Amway Corporation. https://www.amwayglobal.com/amway-products/nutrition/