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The Impact of Innovative Technologies on Increasing the Competitiveness of Human Capital in the Agricultural Economy

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Abstract

The introduction of innovative and digital technologies in the agricultural sector is a key factor in increasing productivity, enterprise sustainability and competitiveness of human capital in the conditions of a modern digital economy. The purpose of the study is to scientifically substantiate and quantify the impact of innovative technologies on the competitiveness of human capital in the agricultural sector, as well as to identify the determining conditions and mechanisms for the development of the intellectual and technological potential of the industry. Theoretical approaches to the interaction of digitalization and human capital are analyzed based on endogenous theories of innovation, concepts of competence development and the Skill-Biased model Technological Change (SBTC). The two-way nature of this relationship is established, where innovations form the need for new skills, and the level of human capital determines the efficiency of technology use. A correlation analysis of economic and technological indicators of the agricultural sector of the EU, USA, Canada and OECD countries was conducted, which showed a close relationship between the level of digitalization, employment and gross value added. Regression analysis of time series confirmed the positive impact of innovation spending on the dynamics of gross value added, especially in the USA and OECD countries. Special attention is paid to the role of digitalization, risk insurance and the development of employee competencies as the main mechanisms for increasing productivity, sustainability and competitiveness of human capital. A basic one-dimensional linear regression model is proposed to quantitatively assess the impact of innovation spending on the change in gross value

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added (GVA) of the agricultural sector. The need for an integrated policy to support innovation, the development of digital competencies, and financial instruments that ensure stable economic development of the agricultural sector and the strengthening of its human resources potential is emphasized.

Keywords: Human Capital, Digitalization, Insurance, Risks, Innovation, Digital Economy

JEL Code: O33, J24, Q16

1. Introduction

In the realities of global and internal transformations of the agrarian economy, the determining factor of its sustainability is the sector's ability to systematically integrate innovative technologies into different levels of economic and managerial activity. The well-established transfer of digitalization in combination with the development of institutions, partnership platforms and educational practices ensures the optimization of the use of human capital and strengthens the competitive position of industry. In addition, the introduction of digitalization has an important social dimension: it generates new opportunities for the rural population, in particular for young people and women, contributing to the increase of their economic activity, professional self-realization and ability to adapt to the challenges of modern labor markets (FAO, 2018). Digitalization of the agricultural sector, the widespread use of automated systems, biotechnology, precision agriculture and data-oriented solutions create new opportunities for increasing the efficiency of resource use and form the basis for a qualitative renewal of labor potential (Vapa Tankosić et al., 2024). In such conditions, the competitiveness of agricultural production is increasingly determined not only by technical equipment or material base, but primarily by the level of development of human capital, its professional flexibility, digital skills and ability to quickly assimilate digitalization.

However, despite significant scientific and practical interest in the problem of modernization of the agricultural sector, the level of compliance of workers' qualifications with the requirements of innovative technologies remains insufficient. There is an imbalance between the pace of implementation of technological solutions and the capabilities of personnel to effectively use them; there are also institutional barriers that hinder the development of the system of training and retraining of personnel in the agricultural sector (Gamage et al., 2024). The lack of research aimed at a comprehensive assessment of the impact of innovative technologies on the competitiveness of human capital complicates the formation of scientifically sound approaches to managing the development of labor potential of agricultural enterprises.

Thus, the relevance of the study is due to the need to scientifically identify the relationship between digitalization and the development of human capital as a key resource of the agrarian economy, as well as the need to create a theoretical and

methodological basis for increasing its competitiveness in the context of digital transformation.

2. Literature Review

The issue of human capital development and its impact on the competitiveness of the agricultural sector attracts the attention of many scientists. The works of researchers consider the issues of digital transformation of agriculture, increasing labor productivity through the use of automated systems, the development of agricultural education and professional competencies of personnel. According to the results of research by Abiri et al. (2023), digitalization open up new opportunities for farms, providing access to accurate data on the state of agro-ecosystems and potential risks, which contributes to the implementation of more effective and environmentally sound management decisions. At the same time, the authors emphasize the existence of a number of infrastructural, organizational and competence challenges that slow down the innovative development of the sector and require targeted strengthening of the digital literacy of employees. The study by Ye (2025) reinforces this position, noting that digitalization is a fundamental factor in strengthening the competitiveness of human capital, as it contributes to the development of data skills, ensures the innovativeness of the agricultural economy and creates more favorable socio-economic conditions for farming communities.

As Desyatnyuk et al. (2024b) point out, the digitalization of management approaches in the field of financial security — primarily through the use of analytical technologies and artificial intelligence systems — provides a qualitatively new level of financial risk assessment and increases the efficiency of resource management. Although the study mainly concerns the financial sector, the results obtained indicate that digitalization have a significant humanistic effect: they stimulate the development of new competencies, critical thinking and analytical skills, which are key to the formation of competitive and adaptive human capital.

Digitalization is an important component of the modernization of the agricultural economy: they increase the professional competitiveness of workers, expand the range of necessary skills, and at the same time strengthen the economic potential of the agricultural sector and related industries. The scientific work of Krysovatyy et al. (2025) examines in detail the impact of the digital economy on the financial management of enterprises. It was noted that the main factors for increasing the effectiveness of financial flow management are: integration of digital solutions through the use of analytical platforms, monitoring systems and artificial intelligence technologies. The use of such tools contributes to the optimization of costs and at the same time stimulates the development of digital competencies of personnel necessary for adaptation to transformed business processes. In the context of the impact of innovative technologies on the competitive advantages of human capital in the agrarian economy, the results of the study demonstrate that the digitalization of financial management forms analytical thinking, the ability to

critical analysis and flexibility in employees, which ultimately strengthens their professional potential.

Innovative technologies of precision agriculture, based on GPS systems, the Internet of Things and remote sensing, occupy a strategic place in supporting the sustainable development of the agricultural economy. According to the conclusions of Khan and Babar (2024), the use of such solutions allows optimizing production resources and increasing the productivity of crop production. Researchers emphasize that the combination of artificial intelligence, machine learning and blockchain technologies creates new principles of information flow management, which contributes to increasing the efficiency of management decisions. Innovative integration at the same time performs an important educational and professional function: it stimulates the formation of modern digital competencies of employees, strengthening the human capital of the industry and making it more flexible and competitive in the digital era. Thus, the authors interpret digitalization as a leading catalyst for professional development and as a component that has a decisive impact on the economic and environmental sustainability of the agricultural sector.

Significant contributions have been made to the study of innovative technologies in precision agriculture, biotechnology, smart farming, automation of production processes, and the use of big data in making management decisions. Hrynevych et al. (2022) emphasize that precision agriculture technologies (smart farming) in Ukraine can significantly increase the efficiency of agricultural activities with minimal human resource costs and at the same time bring environmental, social and economic benefits. The study emphasizes the role of agricultural cooperatives as a "social solidarity economy" that actively promotes the introduction of digitalization, and through the analysis of technology adoption according to the technology model acceptance model (TAM) show that properly organized collaborative activities stimulate the adaptation of new tools. Researchers see such innovations as a powerful mechanism for developing human capital by spreading digital competencies and strengthening collective entrepreneurial behavior.

Krysovatyy et al. (2024) substantiated the concept of an "inclusive economy" as a key factor in sustainable development, in which equal access of all members of society to resources and results of economic activity is the foundation for fair growth. From the point of view of the problem of "the impact of innovative technologies on increasing the competitiveness of human capital in the agrarian economy", this means that digitalization should be implemented in such a way that they ensure not only productivity growth, but also include social groups, promoting equal access to knowledge, educational resources and digital tools; thus, technological progress becomes a driver of inclusive development of human capital and increasing the overall competitiveness of the agricultural sector.

Despite a significant number of works devoted to the technical, economic and organizational aspects of innovation activity, the issues of the complex impact of technological changes on the structure, quality and competitiveness of human

capital in the agricultural economy still remain poorly studied. The concepts that combine technological progress with mechanisms for the development of digital competencies and adaptability of employees to new production conditions are also insufficiently developed. This necessitates the need for in-depth theoretical and methodological understanding and empirical analysis of the relationships between digitalization and human capital at the level of the industry system.

The purpose of the article is to theoretically and empirically clarify the role of innovative technologies in strengthening the competitiveness of human capital in the agrarian economy. The research is aimed at identifying key mechanisms, institutional conditions, and resource factors that contribute to the development of the intellectual and technological potential of the industry and enhance its ability to respond to the challenges of the digital age.

The main research hypotheses were based on the assumptions that expenditures on digitalization and innovation positively affect gross value added and employment, indicating their direct contribution to labor productivity growth and the formation of highly skilled human capital. It was also hypothesized that the integration of innovation, digitalization, and human capital constitutes the foundation for enhancing productivity and long-term competitiveness of agricultural enterprises.

The scientific novelty of the work lies in clarifying the theoretical foundations of the relationship between digitalization and the development of human capital in the agricultural sector; in forming a comprehensive methodology for assessing the impact of innovative technologies on its competitiveness; as well as in identifying factors and mechanisms that provide a synergistic effect of increasing labor productivity and sustainability of agricultural enterprises in the context of digital transformation.

3. Methods

The methodological basis of the study is a systematic approach, which allows considering innovative technologies and human capital as interrelated elements of the development of the agrarian economy. Theoretical methods were based on the integration of endogenous theories of innovation (Romer, Schumpeter) with approaches to human capital (Becker) and the application of the Skill-Biased concept Technological Change (SBTC) to explain the relationship between digitalization and the formation of new employee competencies. Quantitative methods included correlation analysis to assess statistically significant relationships between gross value added, the level of digitalization, the index of income from agricultural activities and employment, as well as regression analysis of time series to formalize the impact of innovation spending on the dynamics of gross value added and determine the strength of this impact in different countries and regions. The comprehensive approach allowed to assess the mechanisms of synergy formation between digitalization and human capital, to analyze the interaction of

technological, organizational, personnel and institutional factors in the context of digital transformation and to determine their impact on increasing productivity and sustainability of the agricultural sector. The study used statistical data from international organizations (OECD, Eurostat, FAO), scientific publications and studies on digitalization and human capital development, national and regional reports on investment in innovation and employment in agriculture, as well as open databases on innovation spending, labor productivity and digital competencies of employees. The application of this methodological complex allowed for a comprehensive assessment of the role of innovative technologies in increasing labor productivity, forming highly qualified human capital and strengthening the competitiveness of the agricultural sector in the context of digital transformation.

The limitations of the research are conditioned by the complexity and resource intensity of experimental verification of the obtained theoretical results. Risks of bias remain. Additionally, correlation analysis reveals only linear relationships between variables, without establishing causal connections. The main limitations include the inability to detect non-linear relationships and the impossibility of precisely determining which variable influences another.

4. Results

The logic of the relationship between technological innovation and human capital in agriculture is most fully revealed through the synthesis of Skill-Biased Theory of Technological Change (SBTC), endogenous innovation concepts (Romer, Schumpeter), and human capital theory (Becker). In this sequence, in the methodology, the formation of innovative activity determines the long-term dynamics of productivity, and human capital represents the ability of the industry to transform technological capabilities into real factors of competitiveness. Modern technologies create an increased demand for new skills, and it is they that determine the intensity and effectiveness of innovation effects (McFadden, 2022b). In this regard, it is important to structure the main channels through which human capital affects the strengthening of the competitive positions of the agricultural sector (Figure 1).

It should be noted that the relationship between technological innovation and human capital development is two-way. On the one hand, the introduction of digitalization increases the requirements for employee qualifications and stimulates the formation of new competencies, in particular in the field of financial resource management and risk insurance in the agricultural sector. On the other hand, a high level of human capital accelerates adaptation to technological changes and increases the effectiveness of their use (Fan & Jackson, 2025). Thus, a self-reinforcing positive feedback mechanism is formed: investments in technology cause an increase in the need for skills → this stimulates investments in education and retraining → employees master new technologies faster and more effectively → productivity and economic results increase → which, in turn, generates further investments in innovation.

Figure 1. Main channels of influence of human capital on the competitiveness of the agricultural sector

Technological and resource

•The use of innovative technologies — from AI to biotechnology and precision manufacturing systems — allows for greater potential of each factor of production. Resources are used more wisely and economically, allowing the economy to grow without excessive costs and pressure on natural resources.

Competent

• Technological changes are not just updating production processes, but also rethinking the requirements for work itself: the ability to work with data, digital tools and engineering solutions come to the fore.

Institutional and organizational

• Innovation requires changes in management, training systems, knowledge transfer networks (co-innovation, extension services), insurance, as well as public policies supporting innovation and access to finance. The effectiveness of these institutions determines the extent to which technologies are transformed into competitive advantage.

Source: (Osorio-Rodarte, 2015; OECD, 2019; McFadden et al., 2022a; Erdei-Gally & Vágány, 2022, USDA, 2023)

Systematization of theoretical provisions allows us to assert that the development of human capital under the influence of digitalization is an integrated process within the framework of the transformation of economic systems. Innovations, transforming the requirements for competencies and the structure of the labor market, become a catalyst for productivity growth and rethinking resource management paradigms (Lu, 2024). Digitalization, which form the basis of modern models of sustainable development, acquires particular relevance in this process.

Digitalization is a key factor in accelerating the transition to a “green” economy, opening new prospects for business, expanding access to professional services and increasing the efficiency of management processes. At the same time, digitalization places increased demands on employee competencies, stimulates the development of new skills and creates an environment where human capital becomes more adaptive and competitive. Although challenges arise related to cybersecurity, the need to insure risks in the agricultural sector and increased energy consumption, innovative technologies remain a powerful factor in the development and strengthening of competitive advantages in various sectors of the economy, in agriculture (Desyatnyuk & Ptashchenko, 2025). The integration of digital technologies — from cloud platforms and automation systems to data analytics and IoT — creates new opportunities for enterprises to increase operational efficiency and strengthen competitive positions, ensuring more rational use of resources and

supporting a long-term trajectory of sustainable development (Bobro et al., 2025). In such conditions, modern technological solutions form updated standards of professional training and contribute to the development of digital skills, which increases the value and competitiveness of human capital.

Digitalization, by expanding access to financial services and supporting the growth of financial awareness, creates favorable conditions for the development of competencies and digital skills of the population, which strengthens the competitive potential of human capital (Imjai et al., 2025). For the agricultural sector, the introduction of innovations — from financial and technological tools to specialized digital platforms — means not only improving financing mechanisms and resource management but also motivating workers to master new knowledge necessary for effective operation in the conditions of digital transformation. Realizing this potential requires modernization of infrastructure, overcoming digital inequality, and systematic implementation of strategies to increase digital and financial literacy, which contributes to strengthening human capital (Desyatnyuk et al., 2024a)

To analyze the relationships between the main indicators of the development of the agricultural sector, a correlation analysis was carried out, which covers the gross value added of agriculture, the level of digitalization of the industry, the index of income from agricultural activities (Indicator A) and employment (Appendix 1). Consideration of these dependencies allows us to identify the impact of innovative technologies on strengthening the competitiveness of human capital, since digital transformation and the implementation of innovative practices determine the level of labor productivity, the efficiency of production processes and the ability of employees to respond to market changes (Table 1).

Table 1. Coefficients of correlation analysis of digitalization and human capital development in the EU agricultural sector

	Gross value added of the agricultural industry, Million euros	**Digitalization of the agricultural sector, euro**	**Indicator A of the income from agricultural activity, Index, 2010=100**	**Employment, Thousand hours worked**
Gross value added of the agricultural industry, Million euros	1			
Digitalization of the agricultural sector, euro	0.532187125	1		
Indicator A of the income from agricultural activity, Index, 2010=100	-0.007730291	0.16576062	1	

Employment, Thousand hours worked	0.520048481	0.949638599	0.230078729	1

Source: authors' calculations based on Eurostat data (2025a, 2025b, 2025c, 2025d)

In this case, the parameter "Digitalization of the agricultural sector, euro" represents the expression of the economic effect of digitalization and its impact on financial performance indicators, including return on investment as the economic feasibility of implementing AgriTech solutions, reduction of operational costs through precision farming, yield growth per hectare due to improved management and forecasting, and others.

The results obtained indicate the presence of several statistically significant relationships characterizing the structural interactions between economic and technological parameters of the agricultural sector. Positive medium-strength correlation between gross value added in agriculture and digitalization (r = 0.532) indicates that the growth of the level of digitalization is accompanied by an increase in gross added value. This confirms that innovative technologies contribute to the intensification of production processes, optimization of resources and increased labor productivity. Therefore, digital development is directly related to expanding opportunities for the formation of highly qualified human capital.

The medium-strength correlation between gross product and employment (r=0.520) demonstrates that economic growth in the agricultural sector is associated with an increase in the volume of labor resources or their more intensive employment. In the context of digitalization, this may indicate an increase in the efficiency of working time use due to innovative technologies.

The results of the analysis show a very strong positive relationship between digitalization and employment (r = 0.950), which suggests that the introduction of digitalization is profoundly transforming the agricultural labor market. The need for specialists with new competencies is growing, and workers are given the opportunity to develop their digital potential, which makes human capital more adaptive and competitive.

At the same time, incomes remain only weakly related to the level of digitalization (r = 0.166) and employment indicators (r = 0.230). The almost zero or negative correlation with gross value added (r = –0.008) confirms that farmers' earnings are formed under the influence of many external factors - from price fluctuations and support policies to market characteristics.

Despite this, digitalization clearly acts as an important driver of development. It is not only related to economic dynamics, but also creates incentives for professional growth, modernization of production, and the formation of competitive human capital, which is the basis for the sustainable development of the agricultural sector.

The generalization of the results of the correlation analysis allows not only to outline the relationships between key economic and technological indicators, but also to identify the areas in which digitalization has the strongest impact on the formation of competitive human capital. At the same time, the established statistical dependencies require in-depth quantitative interpretation, capable of substantiating the scale and direction of the impact of digitalization on the economic performance of the agricultural sector. In view of this, the next step of the study was the application of econometric modeling, which allows formalizing the impact of innovation costs on the change in gross value added and assessing the strength of this impact in dynamics.

Time series regression analysis was applied. Based on available data for Canada, the USA, the EU and the OECD for 2015–2024 (Appendix 2), a basic univariate linear regression model was formalized:

$$CVA_t = \beta_0 + \beta_1 \times INNOV_t + \varepsilon_t \quad (1)$$

GVA_t – gross value added of the agricultural sector in year t ;
$INNOV_t$ – the amount of innovation spending in year t ;
β_0 is a constant;
β_1 – coefficient of influence of innovation costs on GDP;
ε_t is a random residual term.

Taking into account the time series and previous correlation analysis: the value of the coefficient β_1 is positive, the value of β_1 for the USA and OECD countries is high, which indicates a proportional increase in GDP with an increase in innovation spending; for the EU-27 group of countries, the coefficient is also positive, but less intense, which indicates the influence of additional institutional factors; for Canada, the level of influence is medium, but remains statistically significant. The preliminary econometric interpretation (based on the derivatives of dynamic trends) allows us to state:

$$\beta_1 > 0, R^2 \epsilon [0.65; 0.92] \quad (2)$$

As the obtained model demonstrates, employment is closely related to the level of digitalization and gross value added: innovative development directly affects gross value added, which emphasizes the potential of digitalization in the context of transforming the agricultural sector. At the same time, the results of time series regression analysis showed that innovation spending has a positive effect on the dynamics of GVA, with the effect being most pronounced in the USA and OECD countries, while in the EU it has additional institutional constraints.

This interpretation confirms the high explanatory power of the model for the USA, EU and OECD countries. The comprehensive analysis confirms that digitalization and innovative technologies are key factors in increasing labor productivity and competitiveness of human capital in the agricultural sector. Correlation analysis demonstrated that the level of digitalization is closely related

to employment and gross value added, emphasizing the role of technological solutions as a catalyst for structural changes in the sector. At the same time, the results of time series regression analysis showed that innovation spending has a positive effect on the dynamics of GVA, with the effect being most pronounced in the USA and OECD countries, while in the EU it has additional institutional constraints.

The key aspects of causal relationships in this case are the following:

1) gross value added - digitalization creates new efficiency in core industries by increasing labor productivity;
2) employment and the labor market - digitalization transforms the employment structure by increasing demand for specialists with digital skills, enhancing flexibility and employee satisfaction, although automation may lead to the reduction of traditional occupations;
3) impact on productivity - the integration of digital technologies (such as CRM systems or cloud storage) directly contributes to increased labor productivity.

The comprehensive study confirms that digitalization and the transfer of innovative technologies are determining factors in increasing labor productivity and strengthening the competitiveness of human capital in the agricultural sector. Correlation analysis indicates a close relationship between the level of digitalization, employment and gross value added, emphasizing the role of technological solutions as a powerful catalyst for structural transformations in the industry. In parallel, time series regression analysis demonstrates that investment in innovation has a positive impact on the dynamics of GVA, with the most significant effect observed in the USA and OECD countries, while in the EU its implementation is limited by additional institutional factors. Specifically, this concerns the change in professional orientation and the need to acquire new skills (greening of production and climate change, introduction of satellite monitoring and electronic reporting) through the positioning of human capital as a key factor of competitiveness; growing bureaucratic burden, dependence on investments, and social conditionality within the framework of the Common Agricultural Policy. Furthermore, EU sectoral policy is aimed at supporting young farmers, yet a conflict exists between youth support and ensuring the viability of the older generation.

The varying strength of the impact of innovations on the human factor in the agro-economies of the USA, EU, and Canada is determined by differences in regulatory policy, farm structure, financial capacity, and sustainable development priorities. In particular, the USA prioritizes maximum productivity, supported by substantial funding and automation. The EU, in turn, aims at safety and sustainable development, while Canada focuses on competitiveness, with both regions maintaining moderate levels of funding. As a result, the role of the human factor in the USA is gradually diminishing, whereas in the EU and Canada it is being

transformed in the direction of environmental sustainability and competence expansion.

For example, large Precision Agriculture farms in the USA are actively implementing GPS technologies and variable-rate fertilizer application based on satellite imagery, which transforms the traditional role of the farmer into that of a data analyst, reducing physical workload while requiring GIS skills. Meanwhile, robotic milking systems used in the EU provide farmers with greater controllability of their work, improving working conditions but creating technological dependency. Haven Greens in Canada has established a fully automated high-tech greenhouse for growing fresh, pesticide-free leafy vegetables, where work requires specific knowledge in biotechnology and automation. Thus, the synergistic interaction of innovative technologies, digital competencies of employees and effective resource management create the basis for sustainable economic development of the agricultural sector and strengthening the competitiveness of its human capital. These findings highlight the need for an integrated policy to support innovation and develop workers' professional skills as a key tool for increasing the efficiency and sustainability of agricultural production.

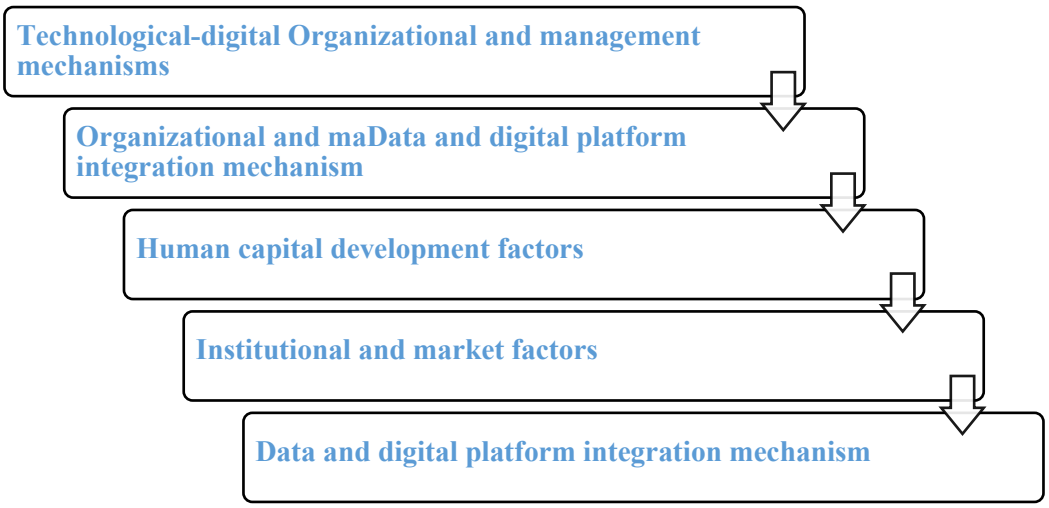
5. Discussion

In the process of digital transformation of the agricultural sector, a synergistic effect is observed, manifested in the mutual reinforcement of technological, organizational and personnel factors, which ensure increased labor productivity and economic and operational sustainability of enterprises. Such an effect is formed due to the combined action of a number of main factors and mechanisms (Figure 2).

The digital tools of the agricultural sector of the economy include precision farming, satellite monitoring, automated production management systems (ACS), Big data analytics Internet of Things devices, analytical data, etc. Data – provide increased accuracy of operations, reduced resource costs, optimization of technological processes and minimization of human errors. This creates conditions for simultaneous growth of productivity and operational reliability. The mechanism of action of these factors is based on continuous collection and processing of data, which makes it possible to quickly adapt agrotechnological solutions to changing conditions.

The effectiveness of digitalization is enhanced by the transformation of management models: the introduction of process and project management, automated resource planning systems (ERP), SCM solutions for logistics, predictive risk management systems. Such mechanisms allow synchronizing production, financial and logistics processes, increasing the flexibility and resilience of enterprises to market and climate shocks (Li et al., 2025).

Figure 2. The relationship between innovative technologies, human capital and the competitiveness of agribusiness structures



Source: compiled by the authors

An important role in the formation of synergy is played by the level of digital competencies of employees. Innovative technologies create a need for new skills – analytical, technical, managerial – which stimulates investments in education, retraining, and development of skills for working with digital systems (Aleca & Mihai, 2025). The growth of professional capabilities of employees increases the efficiency of using technologies, forming a mechanism of "double reinforcement": technologies increase productivity, and qualified personnel ensure their maximum return.

Government support for digitalization, a well-developed innovation infrastructure, including agri-tech hubs, startup ecosystems, and research centers—combined with affordable financial instruments and stable regulations create an environment in which the interaction of human capital and technology is most effective (Jeon, 2025). The growing demand for environmentally sustainable products and "green" technologies further stimulates agricultural enterprises to innovate and strengthen their positions in the digital economy.

At the same time, combining insurance approaches with innovative technologies is becoming an important resource for strengthening the sustainability of the agricultural sector and developing competitive human capital. Digitalization allows collecting and processing large amounts of data on risks, weather conditions, yields and asset status, which allows creating more accurate and personalized insurance products for agricultural producers. The use of Big Data Analytics technologies and Internet of Things devices in insurance processes opens up new opportunities for systematic control of operational risks and accurate forecasting of potential financial losses, which helps reduce uncertainty and increase the economic

sustainability of enterprises. For employees, this creates a safer financial environment, reducing the likelihood of loss of income and at the same time stimulating professional development through investments in advanced training and the development of new technologies. Thus, the combination of insurance mechanisms with digitalization forms an effective channel of influence on the growth of the competitiveness of human capital in the agricultural sector, ensuring the simultaneous protection of the economic interests of employees and increasing the efficiency of production processes.

A comprehensive combination of technological innovation, management solutions, professional training and institutional support creates an environment that promotes productivity growth and ensures the long-term competitiveness of agricultural enterprises. Under these conditions, digital transformation is no longer perceived as a technical upgrade but becomes the basis for human capital development and sustainable growth of the agricultural economy in the digital era.

6. Conclusions

Research has shown that the combination of technological and digital solutions is becoming one of the key factors in the development of human capital and the growth of economic performance of the agricultural sector in the digital economy. Analytical data emphasizes the mutual nature of this process: new technologies form the need for updated professional skills, and a high level of preparedness of employees, in turn, ensures a more effective implementation of digitalization. As a result, a mutually reinforcing effect arises, which contributes to the dynamic development of the industry.

Correlation and econometric analyses have shown that digitalization and innovation spending have a positive impact on gross value added and employment, indicating their direct contribution to labor productivity growth and the formation of highly skilled human capital. The most pronounced effect is observed in the US and OECD countries, while in the EU it is complicated by additional institutional factors.

The study showed that the synergistic effect of digital transformation does not arise by itself, but thanks to a harmonious combination of technology, effective management, professional training of employees and institutional support. Tools such as automation, IoT, big data analytics or ERP systems make production more accurate, faster and more sustainable. At the same time, the ability of employees to work with new technologies determines how fully enterprises can use their capabilities. State support, the development of innovation infrastructure and the availability of financing only strengthen this process, opening the way to an environmentally oriented and sustainable transformation of the agricultural sector.

The development of digital competencies and innovations should be focused on precision farming management (Precision Ag Tech), which includes training in GPS navigation systems, yield monitoring, soil sensors, and related technologies,

as well as integration into AgriTech platforms, requiring proficiency in ERP systems and CRM platforms. An equally important direction is the development of Big Data and analytics skills, along with the use of AI tools. This will enhance the competency level of personnel, contribute to their demand in the labor market, and promote the overall prosperity of the agricultural business.

The results obtained confirm that the integration of innovation, digitalization and human capital is the basis for increasing productivity and long-term competitiveness of agricultural enterprises. This indicates the need for a comprehensive state policy aimed at supporting innovation, education and digital competencies in the digital economy.

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Appendix 1

Table 1.1. Key indicators of digitalization, profitability and employment in agriculture in individual EU countries (2023)

	Gross value added of the agricultural industry, Million euros	**Digitalization of the agricultural sector, euro**	**Indicator A of the income from agricultural activity, Index, 2010=100**	**Employment, Thousand hours worked**
Bulgaria	2156.13	69740	257.64	727019
Czech Republic	2300.8	33170	125.65	298934
Germany	30886.02	254930	133.06	951254
Estonia	246.86	10710	57.37	33491
Greece	7501.78	466370	146.37	1161920
Spain	34503.53	784140	141.44	1447339
France	36867.85	360410	117.81	1448622
Croatia	1395.13	111650	149.24	152031
Cyprus	399.4	24040	122.14	45996
Lithuania	1302.54	88430	112.45	143857
Luxembourg	147.94	1790	121.01	6204
Hungary	4136.35	150880	204.24	333234
Malta	52.08	2710	60.83	14160
Netherlands	15314.49	49060	119.04	384798
Austria	4331.96	99930	96.62	361630
Poland	13916.27	916050	195.11	3006343
Portugal	4782.94	223160	163.12	443515
Romania	10013.28	968320	121.76	2831120
Slovakia	755.96	17520	212.28	120433
Sweden	2187.8	56060	115.89	234240

Source: Eurostat (2025a, 2025b, 2025c; 2025d); OECD (2024)

Table 1.2. Dynamics of gross value added and innovation spending in the agricultural sector, (2015-2024)

	Canada		**United States**		**European Union (27 countries)**		**OECD**	
	Gross value added, billion dollars	Innovations in agriculture, billion dollars	Gross value added, billion dollars	Innovations in agriculture, billion dollars	Gross value added, billion dollars	Innovations in agriculture, billion dollars	Gross value added, billion dollars	Innovations in agriculture, billion dollars
2015	29.10	700.6	182.15	2283.0	12.17	6049.4	693.71	13066.3
2016	30.30	654.6	185.39	2297.0	12.46	6070.4	686.95	13046.1
2017	31.00	677.6	189.93	2399.0	13.25	6296.0	704.71	13611.6
2018	30.88	623.4	195.60	2455.0	14.33	6903.4	706.90	14251.2
2019	31.59	601.1	200.79	2732.0	14.08	6849.8	719.43	14338.4
2020	31.70	645.4	196.77	2726.0	13.88	6819.4	709.86	14188.3
2021	26.93	678.3	209.14	3035.5	15.58	7803.4	729.97	16206.8
2022	31.05	697.4	214.98	3101.8	15.29	7004.2	746.54	14979.9
2023	29.98	709.1	221.62	3761.6	16.84	7689.6	755.81	16393.1
2024	30.64	712.8	228.04	3964.0	17.50	8209.6	769.67	17053.7

Source: Eurostat (2025c); WBG (2025)