

ISSN: 2221-1055
E-ISSN: 2413-2322

Національний науковий центр «Інститут аграрної економіки»

ЕКОНОМІКА АПК

Міжнародний науково-виробничий журнал

Заснований у 1994 році
Випускається 6 разів на рік

Том 32, № 4

Київ – 2025

Рік заснування: 1994

*Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Національного наукового центру «Інститут аграрної економіки»
(протокол № 9 від 29 серпня 2025 р.)*

**Рішення Національної ради України
з питань телебачення і радіомовлення № 1498,
протокол № 15 від 09.05.2024.
Ідентифікатор медіа – R30-04656.**

Журнал входить до Переліку наукових фахових видань України
Категорія «А». Спеціальності: C1 (051) – Економіка, D1 (071) – Облік і оподаткування,
D2 (072) – Фінанси, банківська справа, страхування та фондовий ринок, D3 (073) – Менеджмент,
D7 (076) – Підприємництво та торгівля
(наказ МОН України від 24 лютого 2025 року № 349)

**Журнал представлено у міжнародних наукометричних базах даних,
репозитаріях та пошукових системах:** Google Scholar, Фахові видання України, Національна
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Index, EuroPub, Dimensions, University of Oslo Library, University of Hull Library, Search Oxford Libraries
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ISSN: 2221-1055
E-ISSN: 2413-2322

National Scientific Centre “Institute of Agrarian Economics”

EKONOMIKA APK

Founded in 1994
Published six times per year

Volume 32, No. 4

Kyiv – 2025

Year of foundation: 1994

*Recommended for printing and distribution
via the Internet by the Academic Council
of the National Scientific Centre "Institute of Agrarian Economics"
(Minutes No. 9 of August 29, 2025)*

**Decision of the National Council
of Television and Radio Broadcasting of Ukraine No. 1498,**
Minutes No. 15, dated 09.05.2024.
Media identifier – R30-04656.

Journal is included in the List of Scientific professional publications of Ukraine
Category "A". Specialties: 0311 – Economics, 0411 – Accounting and Taxation, 0412 – Finance, Banking and Insurance, 0413 – Management and Administration, 0416 – Wholesale and Retail Sales
(Order of the Ministry of Education and Science of Ukraine No. 349 dated February 24, 2025)

**Journal is presented international scientometric databases, repositories
and scientific systems:** Google Scholar, Professional publications of Ukraine, Vernadsky National Library of Ukraine, Crossref, AGRIS, German Union Catalogue of Serials, Econlit, ECONBIZ, UCSB Library, ZBW, WorldCat, JournalFinder, EZB, Litmaps, Ulrichsweb Global Serials Directory, InfoDase, PBN, UBL, COPE, TIB, I2OR, BASE, ERIH PLUS, EBSCO, Open Ukrainian Citation Index, EuroPub, Dimensions, University of Oslo Library, University of Hull Library, Search Oxford Libraries Online, European University Institute, Cambridge University Library, Scopus

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UDC 338.1:339.564:637.5(477)

Prospects for the transformation of grain exports into livestock development as a scenario for the economic growth of the Ukrainian agricultural sector in the postwar period

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► **Abstract.** The purpose of this study was to substantiate the scenario of transformation of grain exports into the development of beef cattle and pig breeding as high value-added products with the corresponding definition of an indicative positive impact on the Ukrainian economy. The study employed the following methods: comparative analysis, statistical, tabular, calculation and design, abstract-logical, as well as trend extrapolation tools. The study found a trend of increasing concentration of raw materials in Ukraine's agricultural exports – 85%. The share of grain in total exports was almost 25%. Further growth in grain exports was becoming an issue for the internal and external markets. Therewith, export earnings from meat sales continues to be insignificant at 3-4%, while beef and pork production was steadily declining. The factual consumption of beef and veal meat by the population was almost 6 times lower than the rational norm, and pork – 1.5 times. It was found that the high concentration of raw materials in Ukrainian agricultural exports leads to significant annual losses of export earnings, potential jobs, and a decrease in the country's GDP. The forecast benchmarks for the parameters are to increase beef production to 1 million tonnes and pork production to 2 million tonnes per year. The total projected demand for grain to produce the specified

► **Suggested Citation:** Lupenko, Yu., Cheremisina, S., Mogylova, M., Balan, O., & Gutsul, T. (2025). Prospects for the transformation of grain exports into livestock development as a scenario for the economic growth of the Ukrainian agricultural sector in the postwar period. *Ekonomika APK*, 32(4), 10-21. doi: 10.32317/ekon.apk/4.2025.10.

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volumes of beef and pork was 12.94 million tonnes per year (wheat – 5.51 million tonnes, maize – 5.59 million tonnes, barley – 1.84 million tonnes). The calculations proved that the use of certain volumes of wheat, maize, and barley for fattening animals for meat production rather than export would increase Ukraine's export earnings by 12.6% (or by USD 1.23 billion per year). The study found that Ukraine's GDP could grow by UAH 525.6 billion or USD 12.5 billion. The practical findings of this study enable an objective assessment of the scenario of transformation of the grain market structure with the corresponding determination of the forecast parameters for increasing export earnings and added value for the Ukrainian economy, which may be useful for government agencies in predicting the areas of post-war recovery of the country's agricultural sector

► **Keywords:** grain market; commodity exports; import dependence; beef cattle and pig products; added value; economic effect

► Introduction

Ukraine has always been an agrarian country. According to the Official Website of the State Statistics Service of Ukraine (n.d.), before the war, the share of agricultural exports was 40.7% (USD 27.7 billion). In 2022, this figure increased to 53% (USD 23.4 billion), and in 2023 it exceeded 60% of the country's total exports. However, the problem of excessive concentration of raw materials in agricultural exports has been a topic of debate among the academic community and sectoral authorities for a long time. This issue became especially acute during the war, in the face of extraordinary geopolitical, economic, organisational, and logistical challenges. In 2021, the share of grain in Ukraine's total exports was 18.1%. During the full-scale war, these relative figures increased considerably. Thus, in 2022, the export share of grain crops increased to 20.6%, and in 2023 – to 23%. In 2024, the export revenue from grain sales exceeded USD 9.4 billion. Its share in total exports was 22.6%.

According to S. Cheremisina *et al.* (2025), only 20-25% of the total grain volume is used for domestic consumption. The rest is exported to foreign markets. However, in 2022-2024, grain production became a problem for both the internal and external markets. Therefore, agricultural producers should not only look for channels and markets for their products, but also ensure the processing of their raw materials, which will help to increase the level of profit from their sales. Agricultural products only become a full-fledged commodity if they are sold on the external market as a highly processed product with high added value, which brings a much greater amount of income.

Solving the problems of optimising the grain market, namely, reducing the concentration of grain crops in agricultural exports, allocating part of the grain to expand the capacity of the markets for beef cattle and pig products, and achieving an increase in export earnings and added value for the Ukrainian economy are all relevant. The issues of organisational, economic, and logistical challenges faced by Ukrainian grain exports since the beginning of the full-scale war, and the substantiation of the areas of development of the meat market as a product with high added value have been the subject of research by many scholars.

Y. Voloshchuk & O. Shedlovska (2024) focused their research on the need to find mechanisms for the strategic development of the grain market of Ukraine. The researchers conducted a thorough analysis of the problems and challenges faced by both the internal and global grain markets. The monitoring of current market developments in the grain market allowed the researchers to identify priority areas for the strategic development of the Ukrainian

grain market in the context of current geopolitical and economic challenges. The major driver of the post-war economic recovery is to increase the investment attractiveness of agricultural enterprises and increase exports of high value-added products.

V. Budziak & O. Budziak (2024) studied the complex of problems faced by the Ukrainian meat market during the war. The researchers formulated a hypothesis that regulating the production of certain types of animal meat and stimulating their exports under martial law can increase the profitability of livestock farming and its further development. A. Sakhno & I. Salkova (2021) focused on the production and consumption of meat and meat products in Ukraine. The researchers identified the key changes in meat supply and demand, the density and vector of the relationship between consumption and the factors that determine it. The study reported a strong cause-and-effect relationship between meat consumption and supply in Ukraine. The researchers focused on the decline in household incomes, reduced supply, and positive dynamics of meat prices as priority factors.

O. Svitovyi (2021) thoroughly analysed the current state of grain production and the key products of its processing. The presented practical recommendations for improving the management of production and marketing of grain and its processed products in the context of maximising added value are of considerable interest. The researcher emphasised the need to expand the range of finished grain products and increase exports of grain products. This will contribute to the growth of added value and increase the country's export potential.

O. Yurchenko *et al.* (2024) studied the current state of pig production in Ukraine. The researchers assessed the direct losses of industrial pig production as a result of the hostilities and identified the major problems of the functioning and further development of the pork market. The researchers suggested that the short-term task is to increase pork production and expand export markets. The development of pig production is linked to state support and optimisation of the grain market in Ukraine.

D. Sedikov & I. Sedikova (2023) noted that Ukraine has significant prospects for the development of the market for deeply processed grain products with high added value. The researchers addressed the problem of the raw material nature of Ukrainian exports (almost a quarter of which is grain). They analysed the areas of deep grain processing and production of high value-added products that are in demand in the internal market and have prospective export potential.

O. Nechyporenko *et al.* (2024) identified the state and trends of beef production in the world and Ukraine. The researchers focused on possible scenarios for the development of the beef market, considering the reality of international economic integration. The policy of expanding beef exports from Ukraine to countries with which regional trade agreements were concluded, especially regarding the production of kosher and halal products, is considered promising. D. Enahoro *et al.* (2021) investigated the problems of livestock development in developing countries. The researchers examined the current state of meat trade and presented plausible forecasts for the future, highlighting the effects of animal diseases on current and future trade dynamics.

M. Ijaz *et al.* (2021) studied the global negative impact of the COVID-19 pandemic on global production, supply chains, and meat prices. The researchers argued that integration between all stakeholders in the meat industry is essential for the resilience of the industry's supply chain to handle such disruptive conditions that may arise in the future. G.K. Dambaulova *et al.* (2022) identified the export potential of the pork market in Kazakhstan and predicted the key indicators of its development. The researchers foresaw positive prospects for expanding pork production in the country and gradually entering foreign markets, particularly China and Russia.

G. Mateos *et al.* (2024) thoroughly assessed the current situation and future prospects for pork production in the EU. The study noted that in the short term, pork production in the EU is expected to decline. To maintain the performance of the pig industry, the researchers proposed the gradual implementation of such strategies as ensuring proper maintenance of meat quality for export markets, improving animal disease control, and intensifying the introduction of technological innovations in the pork production process.

Mentioned studies focus on the negative impact of a full-scale war on grain exports from Ukraine, destructive changes in grain export logistics, and the need to find alternatives to grain exports, namely the use of part of grain export flows in meat production. However, the existing research lacks elements of calculation and design to determine the volumes of grain (wheat, maize, and barley) necessary to produce the forecast parameters of pork and beef and to calculate the incremental effect on the Ukrainian economy. The purpose of this study was to develop a mechanism for optimising the grain market aimed at reducing the export burden and assessing the potential effect on the agricultural economy of Ukraine.

► Materials and methods

The study employed a series of methods of scientific cognition. The method of comparative analysis was used for analytical monitoring of the dynamics of indicators of raw material concentration in the export of agri-food products and retrospective monitoring of indicators of production and consumption of beef, veal, and pork in Ukraine. The calculation-constructive method was employed to determine the indicators of import dependence of the beef, veal, and pork markets. Statistical method was used to determine the required volumes of grain (wheat, maize, and barley) required to produce forecast parameters for expanding the capacity of the markets for beef cattle and pig products.

The methodological tools of trend extrapolation were comprehensively applied to determine the real trends in the reduction of livestock in beef cattle and pig production. Using the tabular method, the study illustrated the identified forecast indicators of optimisation of the grain market structure and parameters of increasing export earnings and added value for the Ukrainian economy. The abstract and logical method was applied to formulate conclusions.

The conceptual features of the study included the substantiation of the areas of optimisation of the structure of the grain market of Ukraine with the corresponding definition of indicators of raw material concentration in the export of agri-food products; determination of indicators of import dependence of beef and pork markets; calculation of the volumes of grain (wheat, maize, and barley) required to produce forecast parameters for expanding the capacity of the markets for beef cattle and pig products; determination of forecast parameters for increasing export earnings and added value for the economy of Ukraine.

The study was based on the dynamics of statistical and calculated data for 2010-2024. To establish the scale of the reduction in production and consumption of beef, veal, and pork, the retrospective dynamics of the relevant indicators for 1990-2024 was chosen. The corresponding forecast calculations of the parameters of expansion of beef and pork markets, reduction of the export burden of the grain market, and increase in export earnings and added value for the Ukrainian economy were calculated for the period up to 2030. The empirical basis of the study was the data from the Official website of the State Statistics Service of Ukraine (n.d.a; n.d.b; n.d.c).

The indicator of raw material concentration in Ukraine's agricultural exports was determined according to the following formula:

$$AP_{si} = \frac{RAG_{exi}}{AG_{exi}} \cdot 100\%, \quad (1)$$

where AP_{si} – the share of exports of agricultural raw materials in the i^{th} period, %; RAG_{exi} – the export of agricultural raw materials in the i^{th} period, billion USD; AG_{exi} – the total export of agricultural products in the i^{th} period, billion USD.

Share of exports of high value-added agricultural products:

$$AP_{si} = \frac{PF_{exi}}{AG_{exi}} \cdot 100\%, \quad (2)$$

where AP_{si} – the share of agricultural products in the total structure of exports in the i^{th} period, %; PF_{exi} – the exports of finished food products for the i^{th} period, USD billion.

The ratio of exports of raw materials to finished agricultural products was calculated using the following formula:

$$Rc_i = \frac{RAG_{exi}}{PF_{exi}}. \quad (3)$$

The import-export coverage ratio for the beef and pork markets was calculated using the following formulas:

$$IEbm_i = \frac{Bex_i}{Bi_i}, \quad (4)$$

where $IEbm_i$ – the import-export coverage ratio in the beef market in the i^{th} period; Bex_i – the volume of beef exports in the i^{th} period, thousand tonnes; Bi_i – the volume of beef imports in the i^{th} period, thousand tonnes;

$$IEpm_i = \frac{Pex_i}{Pi_i}, \quad (5)$$

where $IEpm_i$ – the coefficient of import coverage of exports in the pork market in the i^{th} period; Pex_i – the volume of pork exports for the period, thousand tonnes; Pi_i – the volume of pork imports in the i^{th} period, thousand tonnes.

The dynamics of the level of self-sufficiency of the beef and pork markets in Ukraine was estimated using the following formulas:

$$IBm_i = \frac{Bi_i}{VDbc_i}, \quad (6)$$

where IBm_i – the import dependency ratio of the beef market in the i^{th} period; $VDbc_i$ – the volume of domestic beef consumption in the i^{th} period, thousand tonnes;

$$IBp_i = \frac{Pi_i}{VDpc_i}, \quad (7)$$

where IPm_i – the import dependence ratio of the pork market in the i^{th} period; $VDpc_i$ – the volume of domestic pork consumption in the i^{th} period, thousand tonnes.

The volumes of grain (wheat, maize, and barley) required to produce the forecast parameters for expanding the capacity of the beef cattle and pig markets were determined by the following structures:

1) total estimated need for concentrated feed to produce 1 kg of beef, kg of feed units: 1.3 (wheat) + 1.5 (maize) + 0.5 (barley) + 1.6 (feed maize meal) + 0.7 (feed wheat meal) + 0.4 (milling waste) = 6 kg of feed units;

2) total estimated need for concentrated feed to produce 1 kg of pork, kg of feed units: 0.9 (wheat) + 1.44 (maize) + 0.81 (barley) + 0.68 (feed maize meal) + 0.23 (feed wheat meal) + 0.45 (milling waste) = 4.5 kg of feed units.

These parameters were calculated using the Order of the State Statistics Committee of Ukraine No. 18 (2008). The forecast parameters of feed demand in terms of grain were calculated using the following formula:

$$Gn_n = \frac{Ft_j}{Fu_j}, \quad (8)$$

where Gn_n – the demand for the n^{th} type of grain, kg; Ft_j – the demand for the j^{th} type of feed for the production of 1 kg of beef (pork), kg of feed units; Fu_j – the content of feed units in 1 kg of the j^{th} type of feed, kg of feed units.

Next, the need for a specific type of grain to produce 1 kg of beef (pork) is determined as the corresponding sum of feed types, depending on the type of grain they are produced from – wheat, maize, and barley:

$$Gn_w = \sum_{j=1}^n \frac{Ft_j}{Fu_j}, \quad (9)$$

where Gn_w – the demand for wheat grain to produce 1 kg of beef (pork), kg; n – the number of types of feed produced from wheat;

$$Gn_c = \sum_{j=1}^n \frac{Ft_j}{Fu_j}, \quad (10)$$

where Gn_c – the demand for corn grain to produce 1 kg of beef (pork), kg; n – the number of types of feed produced from maize;

$$Gn_b = \sum_{j=1}^n \frac{Ft_j}{Fu_j}, \quad (11)$$

where Gn_b – the demand for barley grain to produce 1 kg of beef (pork), kg; n – the number of types of feed produced from barley.

The total amount of grain for beef production is determined by the following formula:

$$Vb = \sum (Gn_w + Gn_c + Gn_d) \cdot Fb_{prod}, \quad (12)$$

where Vb – the volume of grain to produce the forecast annual volume of beef, million tonnes; Fb_{prod} – the forecast of beef production, million tonnes per year.

The total volume of grain for pork production is determined by the following formula:

$$Vp = \sum (Gn_w + Gn_c + Gn_d) \cdot Fp_{prod}, \quad (13)$$

where Vp – the volume of grain to produce the forecast annual volume of pork, million tonnes; Fp_{prod} – the forecast of pork production, million tonnes per year.

The calculation of the added value from the use of grain in Ukraine for fattening and selling beef is determined according to the following formula:

$$AdV = ((Fb_{prod} \cdot P_{bf}) + (Fp_{prod} \cdot P_p)) - (Gn_w \cdot P_w + Gn_c \cdot P_c + Gn_b \cdot P_b), \quad (14)$$

where AdV – the value added, UAH million; P_{bf} – the price of a tonne of beef, UAH; P_p – the price of a tonne of pork, UAH; P_w – the price of a tonne of wheat, UAH; P_c – the price of a tonne of maize, UAH; P_b – the price of a tonne of barley, UAH.

► Results and discussion

Over 2010–2024, the share of agricultural products in Ukraine's total exports tripled, from 19.3% in 2010 to 59.1% in 2024, a trend that intensified during the war (Cheremisi-na *et al.*, 2025). Thus, according to the Official Website of the State Statistics Service of Ukraine (n.d.), this indicator was 40.7% in 2021, increased to 53% in 2022, to 60.8% – in 2023, and decreased by 1.7% in 2024 (Table 1). A stable trend in Ukrainian agricultural exports is the high concentration of raw materials. Thus, during the analysed period, the share of raw agricultural exports increased by 10.7% – from 74.1% in 2010 to 84.8% in 2024. Therewith, the share of processed food products in the structure of agricultural exports has been steadily declining – from 25.9% in 2010 to 15.2% in 2024. The ratio of exports of raw materials to finished products almost doubled over the analysed period – from 2.87 to 5.57, i.e., USD 1 of exports of processed agricultural products accounts for USD 5.6 of exports of raw materials.

Table 1. Dynamics of raw material concentration in agri-food exports

Indicator	2010	2015	2020	2021	2022	2023	2024
Share of agricultural products in total exports, %	19.3	38.2	45.1	40.7	53.0	60.8	59.1
Exports of agricultural products – total, billion USD	9.94	14.56	22.18	27.71	23.39	22.0	24.7
Including:							
raw material exports	7.37	12.09	18.66	23.77	20.75	18.57	20.94
share, %	74.1	83.0	84.1	85.8	88.7	84.4	84.8
export of processed products	2.57	2.47	3.52	3.94	2.64	3.43	3.76
share, %	25.9	17.0	15.9	14.2	11.3	15.6	15.2

Table 1, Continued

Indicator	2010	2015	2020	2021	2022	2023	2024
ratio of exports of raw materials to finished goods	2.87	4.89	5.30	6.03	7.86	5.41	5.57
Grain exports, billion USD	2.47	6.06	9.41	12.34	9.11	8.31	9.42
Including:							
wheat	0.91	2.24	3.60	5.07	2.68	2.94	3.74
maize	0.79	3.0	4.88	5.89	5.93	4.97	5.07
share of grain in agricultural exports, %	24.8	41.6	42.4	44.5	38.9	37.8	38.1
share of wheat and maize in grain exports, %	68.8	86.5	90.1	88.8	94.5	95.2	93.5
Meat exports, billion USD	0.09	0.38	0.65	0.85	0.92	0.89	1.05
Including:							
beef and veal	0.046	0.084	0.084	0.12	0.069	0.086	0.079
pork	0.003	0.055	0.006	0.007	0.0005	0.003	0.008
share of meat in agricultural exports, %	0.9	2.6	2.9	3.1	3.9	4.0	4.2

Source: based on State Statistics Service of Ukraine (n.d.a; n.d.b; n.d.c)

One of the major export commodities is grain. During the analysed period, its share in the structure of agricultural exports increased from 24.8% in 2010 to 38.1% in 2024. In 2023, the share of grain in the overall structure of Ukrainian exports reached its five-year high, exceeding 23%. Wheat and maize are consistently dominant by type of grain, with their share in grain exports increasing from 68.8% to 93.5% over the analysed period. At the same time, export earnings from meat sales continue to be insignificant. During the analysed period, they did not exceed USD 1 billion, and their share in total agricultural exports was 3-4%. Chicken continues to be the primary meat export product, while annual exports of beef, veal, and pork do not exceed USD 100 million, which is 0.4% of the agricultural export structure.

The high concentration of raw materials in Ukrainian agricultural exports leads to considerable price disparities between raw materials for agricultural exports and processed raw materials into high value-added products. This causes not only significant annual losses in export earnings, but also potential job losses and a decline in the country's GDP. It was found that during the war, the share of grain exports from Ukraine in total production increased significantly. Thus, while in 2021 this figure was 62.4%, in 2023 it increased to 75%, and in 2024 it exceeded 96%. It was determined that on average, in 2022-2024, grain exports accounted for 73.5% of total production, while domestic consumption did not exceed 25%. However, the full-scale war led to a series of organisational, economic, and logistical challenges faced by Ukrainian grain exports. As a result, grain production is becoming problematic for both the internal and European markets.

Ukrainian producers have suffered substantial losses due to the catastrophic rise in the price of fuel, fertilisers, other inputs to the production process and logistics costs. However, the internal and external price situation for grain is not conducive to the efficient reproduction of production processes by rural producers. As for the problems of foreign markets, the reorientation of grain logistics flows from sea routes to Asia and Africa to the EU has led to a marked decline in grain prices in Europe. The fundamental reason for this is clearly a significant imbalance in the comparison of a set of indicators of agricultural production in Ukraine and the EU countries – the quality of land resources, labour costs, cost structure, and economies of scale.

The problem of finding ways to reorient the raw material orientation of Ukraine's agricultural sector towards processing raw materials and creating high value-added products has become particularly acute during the full-scale war. The search for channels, logistics routes for export, and new markets for agricultural products is not the way forward for the effective post-war recovery of Ukrainian agriculture. Gradually increasing the level of processing of domestic products, aimed at creating high value-added goods, will not only bring more income to producers, but also contribute to sustainable GDP growth. One of these intermediate areas is the revival and gradual development of Ukrainian beef cattle and pig breeding. An analysis of the retrospective dynamics of statistical data on the state of these components of the Ukrainian meat market shows a steady downward trend in both absolute production and relative consumption indicators (Table 2).

Table 2. Retrospective dynamics of production and consumption of beef, veal, and pork

	1990	2000	2010	2015	2020	2021	2022	2023	2024
Production in slaughter weight, thousand tonnes									
beef and veal	1,985.4	754.3	427.7	384.0	345.4	310.5	268.4	256.9	244.5
pork	1,576.3	675.9	631.2	759.7	697.2	724.0	658.7	638.2	672.1
Production per 1 person, kg									
beef and veal	38.3	15.3	9.3	8.9	8.2	7.5	7.8	7.6	7.2
pork	30.4	13.8	13.8	17.8	16.8	17.6	19.4	18.8	19.7

Table 2, Continued

	1990	2000	2010	2015	2020	2021	2022	2023	2024
Consumption per 1 person, kg									
beef and veal	32.4	13.2	9.8	8.1	8.1	7.3	7.0	6.2	6.0
pork	19.2	10.3	18.0	18.1	18.8	19.9	19.5	19.3	19.4
Production to consumption ratio indicator									
beef and veal	1.18	1.16	0.95	1.10	1.01	1.03	1.11	1.23	1.18
pork	1.58	1.34	0.77	0.98	0.89	0.88	0.99	0.97	1.2

Source: based on State Statistics Service of Ukraine (n.d.a; n.d.b; n.d.c)

During the analysed period, beef and veal production decreased by almost 8 times, and pork production by 2.5 times. The respective relative indicators of production and consumption per capita decreased by 5.3 and 5.4 times for beef cattle products, and by 1.7 times for pork meat, respectively (the indicator of pork consumption per capita did not change – within 18–19 kg). It was found that the factual consumption of beef and veal meat by the population was almost 6 times lower than the rational norm, and pork – 1.5 times.

The key synergistic reasons for this decline in consumption of these types of meat include the low purchasing power of the Ukrainian population and the catastrophic decline in the number of livestock. Thus, since independence, the number of cattle has decreased by 11 times (from 24.6 million heads in 1991 to 2.2 million heads in 2024), fattening calves by 22 times (from 1.4 million heads to 0.6 million heads), and pigs by 4 times (from 19.5 million heads to 5.1 million heads). Considering the existing trends, the selected trend equations formally describe them as follows:

► the number of fattening calves by 2029 may further decrease by 35% to 362 million heads ($y = -0.5136x^3 + 3,113.6x^2 - 6E + 06x + 4E + 09$; $R^2 = 0.978$);

► the number of pigs by 2029 may decrease by 14% to 4.4 million heads ($y = -4,597.4\ln(x) + 21,337$; $R^2 = 0.934$).

Most of the added value generated by the country's economy is generated in foreign trade. Therefore, the most promising areas for the post-war development of Ukraine's agricultural sector are to direct agricultural production capacities to occupy and expand new market niches. According to the forecast indicators of the Organisation for Economic Co-operation (OECD) FAO, global pork consumption will gradually increase and may reach 16.5 million tonnes by 2030 (Hopka, 2023). If, according to 2022 data, global trade in pork products was 11 million tonnes, it is reasonable to assume that by 2030, the annual

increase in consumption will average 2 million tonnes. At the same time, the gradual decline in the number of pigs in the EU is a stable trend. Rising environmental standards and the development of policies to minimise the negative environmental impact of pig production processes are leading to subsidies for the closure of pig farms in EU countries. Accordingly, a promising market niche is opening for Ukrainian agribusiness – bringing annual pork production to 2 million tonnes in slaughter weight and a corresponding increase in livestock. The cross-sectoral programme New Pig Farming 2025 (2020), initiated in 2020, envisages a gradual increase in the number of pigs to the 1991 level of 20 million, which is 4 times greater than the factual level. Pig farming in the post-war perspective of the development of the agricultural sector of the economy can be a truthful way to gradually solve the problems of grain exports.

As for the perspective parameters of modelling the development of the beef and veal market as products with higher added value, the priority should be to expand the capacity of the internal market to ensure that consumption by the population meets the rational standards of 32.4 kg per person per year. Thus, the expansion of the domestic beef, veal, and pork market will contribute to its price stabilisation and the formation of a significant export potential of the beef cattle and pig industries. Thus, in 2021, beef and pork prices increased by 22.3% and 7.5%, respectively, in 2022, the price increase was 3.9% and 36%, in 2023 – 18.9% and 15.4%, and in 2024 – 13.1% and 3.4%. During the war, consumer prices for beef increased by 55.6%, from UAH 182.84 UAH/kg to UAH 284.53 UAH/kg, and for pork by 48.5%, from UAH 123.75 UAH/kg to UAH 183.31 UAH/kg. This is despite a steady decline in household incomes and purchasing power. During the analysed period, imports of beef and veal decreased by 26.6% (from 3.68 to 2.7 thousand tonnes), and pork by 48 times (from 108.6 to 2.3 thousand tonnes) (Table 3).

Table 3. Retrospective dynamics of import dependence indicators for beef, veal, and pork markets

	2010	2015	2020	2021	2022	2023	2024	For the period up to 2030	2024 as % of 2010
Import, thousand tonnes									
beef and veal	3.68	1.16	2.07	2.79	1.1	2.3	2.7	0.5	73.4
pork	108.6	3.69	28.02	40.65	46.9	12.99	2.27	1.5	2.1
Export, thousand tonnes									
beef and veal	13.39	32.06	24.42	27.21	15.4	21.3	19.46	150.5	145.3
pork	0.61	27.17	2.9	3.81	0.3	0.9	3.2	1,151.5	524.6
Import-export coverage ratio									
beef and veal	3.64	27.64	11.80	9.75	14.00	9.26	7.21	300	198.1
pork	0.01	7.36	0.10	0.09	0.01	0.07	1.41	767	141

Table 3, Continued

	2010	2015	2020	2021	2022	2023	2024	For the period up to 2030	2024 as % of 2010
Domestic food consumption, thousand tonnes									
beef and veal	447	347	337	299	238	211	204	850	45.6
pork	825	775	786	824	702	667	671	850	81.3
Import dependence indicator, %									
beef and veal	0.82	0.33	0.61	0.93	0.46	1.09	1.32	0.06	0.5
pork	13.16	0.48	3.56	4.93	6.68	1.95	0.34	0.18	-12.8

Source: based on State Statistics Service of Ukraine (n.d.a; n.d.b; n.d.c)

Exports of these types of meat increased by 1.5 and 5.2 times, respectively. The import-export coverage ratios for beef and veal meat increased by a factor of 2, from 3.64 in 2010 to 7.21 in 2024, while for pork these indicators increased significantly, from 0.01 to 1.41, but were still insufficient. Therewith, the absolute and relative indicators of meat exports as a high value-added product stayed extremely low. In pre-war 2021, exports of beef and veal amounted to 27.21 thousand tonnes or 8.8% of total production, while pork exports were much lower – 3.81 thousand tonnes or 0.5% of production. During the war, export flows of beef cattle and pig products deteriorated to 5.7 thousand tonnes and 8.3% for beef and veal, and to 0.05 thousand tonnes and 0.14% for pork.

The determined indicators of import dependence of the beef cattle and pig production markets indicate an extremely low (within 1%) dependence on imports of Ukrainian beef and veal markets and a decrease in this indicator

for pork by 12.8% – from 13.2% in 2010 to 0.34% in 2024. If annual pork production is increased to 2 million tonnes in slaughter weight, and beef and veal production to a promising 1 million tonnes, the relevant indicators of import dependence and available export potential can reach the following parameters. If the consumption of beef and pork is brought to the factual poultry consumption rate of 25 kg per person per year, domestic consumption will increase to 850 thousand tonnes, respectively. Therewith, Ukraine can export 150.5 thousand tonnes of beef and veal and almost 1.2 million tonnes of pork annually. The respective import dependence indicators will decrease to a minimum of 0.06% and 0.18%. To determine the required volumes of grain (wheat, maize, and barley) required to produce the forecast parameters for expanding the capacity of the markets for beef cattle and pig products, the study used the established statistics of the retrospective dynamics of feed consumption per unit of livestock production (Table 4).

Table 4. Feed consumption per unit of livestock meat production, feed units

Indicators	2010	2015	2019	2020	2021	2022	2023	
Per 1 kg of cattle gain								
Feeds of all kinds	15.69	14.80	13.95	12.84	13.17	12.55	12.50	Forecast parameters of demand in terms of grain, kg for the period up to 2030
including concentrated	4.47	4.93	6.65	6.12	6.15	5.87	6.09	
types of concentrated feed from grain crops	Content of feed units per 1 kg of feed			Estimated demand for concentrated feed, feed units				
soft wheat	1.28			1.3				
maize	1.33			1.5				
barley	1.15			0.5				
feed maize meal	1.33			1.6				
feed wheat meal	1.12			0.7				
flour milling waste	0.63			0.4				
Total	X			6.0				
Per 1 kg of pig gain								
Feeds of all kinds	5.98	4.46	4.84	4.79	4.60	4.44	4.31	Forecast parameters of demand in terms of grain, kg for the period up to 2030
including concentrated	5.71	4.34	4.80	4.75	4.56	4.41	4.28	
types of concentrated feed from grain crops	Content of feed units per 1 kg of feed			Estimated demand for concentrated feed, feed units				
soft wheat	1.28			0.9				
maize	1.33			1.44				
barley	1.15			0.81				
feed maize meal	1.33			0.68				
feed wheat meal	1.12			0.23				
flour milling waste	0.63			0.45				
Total	x			4.50				

Source: based on State Statistics Service of Ukraine (n.d.a; n.d.b; n.d.c), Order of the State Statistics Committee of Ukraine No. 18 (2008)

Based on the average consumption of concentrated feed per 1 kg of beef and veal production of 6.0 feed units, the forecasted demand for particular types of grain crops is 2.28 kg of wheat, 2.33 kg of maize, and 0.43 kg of barley. The average feed consumption to produce 1 kg of pork is 4.5 feed units. Therefore, the determined feed requirement

in terms of grain is as follows: wheat – 1.62 kg per 1 kg of pig gain, maize – 1.59 kg, barley – 0.7 kg. The total projected demand for grain to produce the specified volumes of beef and pork is 12.94 million tonnes per year. Of these, wheat is 5.51 million tonnes, maize is 5.59 million tonnes, and barley is 1.84 million tonnes (Table 5).

Table 5. Forecast indicators for optimising the structure of the Ukrainian grain market

Types of grain crops	Production, million tonnes			Exports, million tonnes			Projected grain demand for meat production, million tonnes			Forecast of grain export volumes, million tonnes*	Export load indicator, %		
	2022	2023	2024	2022	2023	2024	beef and veal	pork	total		factual 2023	factual 2024	forecast*
Wheat	20.7	21.6	22.4	11.2	16.2	20.7	2.28	3.24	5.51	10.5	75.0	92.4	48.8
Maize	26.2	31.0	26.9	24.9	26.4	29.6	2.33	3.26	5.59	21.4	85.2	110.0	76.3
Barley	5.6	5.5	5.3	2.1	2.2	3.4	0.43	1.41	1.84	0.7	40.0	64.2	13.3
Total	52.5	58.1	54.6	38.2	44.8	53.7	5.04	7.91	12.94	32.6	x	x	x

Notes: *the average values of grain export production indicators for 2022-2024 were used to calculate the forecast indicators

Source: based on State Statistics Service of Ukraine (n.d.a; n.d.b; n.d.c)

The annual demand for grain for fattening and production of beef and veal is 5.04 million tonnes, and for pork production – 7.91 million tonnes. This will result in a certain optimisation of the grain market structure in Ukraine. If certain volumes of wheat, maize, and barley are used to feed animals for meat production rather than for export, the relevant indicators of the market's export load will decrease significantly. Thus, in 2023, 75% of the total wheat production was exported, while the figure for maize exceeded 85% and barley – 40%. In 2024, grain exports exceeded the pre-war figures of 2021, and the export load indicators reached record levels: wheat – 92.4%, maize – 110.0% (including last year's balances), barley – 64.2%. The reorientation of grain exports to internal production of high value-added meat products will reduce these export load indicators for grain crops to 48.8%, 76.3%, and 13.3%, respectively.

Therefore, the effective parameter of the grain market optimisation will be a decrease in annual grain exports by 28.4% on average (from 45.6 million tonnes to 32.6 million tonnes). In terms of the main export crops, this reduction will be 34.5% for wheat (from 16.0 million tonnes to 10.5 million tonnes), 20.7% for maize (from 27.0 million tonnes to 21.4 million tonnes), and 73.1% for barley (from 2.6 million tonnes to 0.7 million tonnes). It was found that such a decline in grain exports, with a corresponding possible increase in beef and pork exports, will not be reflected in a reduction in export earnings. If, according to the data of 2024, export earnings from the sale of grain and beef and pork meat amounted to USD 9.5 billion, the optimisation of the agricultural structure will not affect the export earnings. Optimising the structure of the agricultural market will help to increase this figure to USD 10.7 billion (or 12.6%) (Table 6).

Table 6. Forecast parameters for the increase in export earnings and added value for the Ukrainian economy, UAH million/USD million

Product types	Production, million tonnes		Exports, million tonnes		Exports, million USD		Cost of grain for meat production, UAH million	Cost of meat, UAH million	Value added, UAH million
	2024	Forecast	2024	Forecast	2024	Forecast			
Wheat	21.6	–	20.7	10.5	3,736.3	1,940.7	40,012.1	x	x
Maize	31	–	29.6	21.4	5,072.4	4,314.8	42,063.9	x	x
Barley	5.5	–	3.4	0.7	557.3	115.5	12,123.9	x	x
Beef and veal	0.24	1	0.019	0.15	79	943.4	36,922.9	260,150	223,227.1
Pork	0.67	2	0.003	1.15	7.98	3,373.3	57,277.1	359,620	302,342.9
Total					9,452.98	10,687.7	94,200.0	619,770	525,570
					+1,234.7 USD million				or 12,513.5 USD million

Source: based on State Statistics Service of Ukraine (n.d.a; n.d.b; n.d.c)

It was found that the amount of added value, which is the newly created value acquired by grain crops used for meat production in the process of passing the chain from producer to end consumer, will amount to UAH 525.6 billion or USD 12.5 billion. In contrast to the findings of L. Pobochenko *et al.* (2023), who suggested that it is the

raw grain exports that are most promising, it is necessary to intensify processing and transform grain flows into high value-added products.

The findings of Yu. Haida & B. Shainiuk (2023), who made an indicative assessment of the significant potential of the global grain market, the growth of supply volumes

due to increased production by the world's largest exporters – Australia, Argentina, Canada, and the United States, confirmed the findings of the present study that a decrease in grain exports from Ukraine will not affect global food security. The authors of the present study agree with the opinion of M. Constantin *et al.* (2023) that a sound policy of transforming raw grain exports into exports of high value-added agri-food products will contribute to the sustainability, competitiveness, and efficiency of the country's agriculture.

O. Hromyk & O. Semenda (2023) focused on the steady growth of the capacity and export potential of the chicken meat market in Ukraine. The researchers noted that chicken production currently has a series of competitive advantages, the key among which is affordability compared to other types of meat products. Consumption of chicken is growing, while that of pork and beef is declining. It is worth agreeing with the researchers' conclusions on the need to introduce mechanisms for the development of other livestock sectors, such as beef cattle and pig production. The findings of O. Skydan *et al.* (2024) are quite interesting for the methodology and practice of post-war agricultural development in Ukraine. The researchers' model of a cybernetic management system in the agricultural sector of the economy, aimed at gradually increasing the production of high value-added products and reducing the raw material export dominance in the context of EU integration, should be supported.

N. Sansika *et al.* (2023) conducted a thorough investigation of the effects of economic globalisation on agriculture in the context of the dynamics of value added and income levels of countries. The researchers employed a multifactorial approach to determine the impact of economic globalisation on the dynamics of value added in agriculture, including production consumption of resources, employment, exports, imports, exchange rates, investment activity, etc. It is reasonable to agree with the researchers' conclusions that the priority influence on the positive dynamics of value added in agriculture in developing countries is exerted by the level of employment, the national currency exchange rate, and foreign investment.

The findings presented by T. Melembe *et al.* (2021) are quite interesting for the development of a policy of post-war optimisation of Ukraine's agricultural sector in the context of reducing the concentration of raw materials in exports. The researchers found a correlation between the level of profitability of grain and livestock farmers and the degree of further processing of their products. It is worth supporting the researchers' research conclusions that extension policies, training, and information on value addition and agro-processing of raw materials can increase the profitability and strengthen the food security of South African farmers. S. Bonardi *et al.* (2021) studied and systematised EU food legislation on risk reduction and quality assurance requirements for meat, particularly pork. The researchers emphasised the need to further increase the requirements for meat products imported to the European market. It was proposed to increase the transparency of forward and backward communication in the pork production chain.

P. Greenwood (2021) focused on assessing beef production in countries around the world. The researcher

argues that sustainable beef production requires high efficiency and productivity on the farm, as well as efficient value chains, which is required by the target market. It was emphasised that technological digitalisation would help to increase the productivity and efficiency of beef production. It accelerates the flow of information about the environment and cattle productivity and can improve the set of performance indicators in the beef industry.

Understandably, production processes in beef cattle and pig production involve certain technological costs, but the process itself gives the product additional consumer qualities and increases the price of the product (Bondarenko *et al.*, 2023). The primary factors that determine the value added are the processing of raw materials, the structure of the product range, and the quality of the product. At the same time, the creation of added value in such production chains as 'grain – cattle – meat' and 'grain – pigs – meat' should become a promising area for the post-war restructuring of Ukraine's agrarian economy.

Thus, the reorientation of Ukrainian agriculture from total grain exports to the expansion of the internal market for beef cattle and pig products is an extremely promising area for post-war economic recovery. Therewith, the dynamics of global beef and pork prices create real opportunities to generate added value not only domestically but also to increase the corresponding export flows. However, the effective development of beef cattle and pig farming requires government support and logistical expansion of sales markets.

For example, the European markets are attractive due to their proximity, favourable pricing policies, and the long-standing experience of cooperation. However, the integration path to the European consumer is becoming increasingly challenging for Ukrainian agricultural products. The EU government pursues a tough protectionist policy to safeguard its producers. This is a consistent practice of introducing quota restrictions, expanding the list of environmental and phytosanitary requirements, and tightening European standards not only for the quality of finished products but also for the entire technological chain of their production (cultivation).

Therefore, the European market for Ukrainian beef and pork has limited prospects (Matviichuk *et al.*, 2024). Based on the statistics of consumption of different types of meat in European countries according to V. Budziak & O. Budziak (2024), it is advisable to choose countries with the lowest consumption of beef and pork meat per capita for logistical export targets. For example, the markets of such countries as Moldova, Romania, Bulgaria, Latvia, Lithuania, and Slovakia, where beef consumption per capita does not exceed 6 kg per year, may be quite accessible to Ukrainian beef producers. For promising pork export destinations, Ukraine can focus on such countries as Albania, Bosnia and Herzegovina, North Macedonia, and Greece. These countries have the lowest pork consumption in Europe – up to 15 kg per person. Outside of Europe, the most promising markets are typically the Middle East (Saudi Arabia, the United Arab Emirates, Turkey, and China). It is also necessary to search for and cover new markets, which could potentially be the countries of Southeast Asia – Thailand, Malaysia, Indonesia, Singapore, the Philippines, Vietnam, and others.

The conducted study correlates with the principal perspective scenarios contained in the Resolution of the Cabinet of Ministers of Ukraine No. 76-p (2025). The implementation of this programme is aimed at ensuring the progressive development of Ukraine's livestock sector and expanding the use of crop products (including grain) to increase beef and pork production as high value-added products. The result of the conducted study is the development and practical testing of a methodical calculation and design algorithm for post-war optimisation of the grain market of Ukraine, which, unlike the existing ones, comprehensively covers forecasting the parameters of expansion of the markets for beef cattle and pig products, determining indicators of reducing the export burden of the structural components of the grain market and parameters for increasing export earnings and added value. The conducted study is valuable for government agencies in strategic planning and forecasting the parameters of increasing the efficiency of grain production and livestock development as priority areas of economic growth in the agricultural sector of Ukraine in the post-war period.

► Conclusions

The study found that a stable trend in Ukrainian agricultural exports is a high concentration of raw materials rather than finished food products. The share of raw agricultural products is 85%, while exports of processed products do not exceed 15%. In the overall structure of Ukrainian exports, the share of grain exceeds 23%. The increase in grain exports from Ukraine creates problems for European farmers. Therewith, export earnings from meat sales continue to be insignificant at 3-4%. Between 1990 and 2024, beef and veal production decreased by almost 8 times, and pork production by 2.3 times. It was found that the factual consumption of beef and veal meat by the population is almost 6 times lower than the rational norm, and pork – 1.5 times. The study showed that, under current trends, the number of fattening calves could further decrease by 35% to 362 million heads by 2029, and the number of pigs could decrease by 14% to 4.4 million heads.

The high concentration of raw materials in Ukraine's agricultural exports leads to significant annual losses in

export revenues, potential jobs, and a decline in the country's GDP. A possible scenario for increasing the level of agricultural processing is to channel part of grain exports into the production of livestock products, such as beef and pork. The forecast benchmarks for increasing beef production are to expand the capacity of the domestic market to ensure that consumption by the population meets the rational standard of 32.4 kg per person per year. Growth in global pork consumption opens a corresponding market niche for Ukrainian farmers, estimated at 2 million tonnes of meat per year.

The total projected need for grain to produce the specified volumes of beef and pork is 12.94 million tonnes per year (wheat – 5.51 million tonnes, maize – 5.59 million tonnes, barley – 1.84 million tonnes). Calculations proved that the use of certain volumes of wheat, maize, and barley to fatten animals for meat production rather than for export will significantly reduce the export load of the market: wheat – from 75% to 48.8%, maize – from 89% to 76.3%, barley – from 47% to 13.3%. Annual grain exports are forecast to decline by 28.4% (from 45.6 million tonnes to 32.6 million tonnes). The decline in grain exports, with a corresponding possible increase in beef and pork exports, will increase Ukraine's export earnings by 12.6% (from USD 9.5 billion to USD 10.7 billion). The key result of the study lies in determining the amount of added value that would be created by directing part of grain exports to beef and pork production. The study found that the gross domestic product of Ukraine could increase by UAH 525.6 billion or USD 12.5 billion. Further research will focus on determining the volume and sources of financing for the transformation of grain exports into the development of livestock production and grain processing.

► Acknowledgements

None.

► Funding

None.

► Conflict of Interest

None.

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Перспективи трансформації зернового експорту у розвиток тваринництва як сценарій економічного зростання аграрного сектору України в повоєнний період

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► **Анотація.** Метою дослідження було обґрунтування сценарію трансформації зернового експорту у розвиток м'ясного скотарства та свинарства, як продукції з високою доданою вартістю із відповідним визначенням індикативного позитивного впливу на економіку України. Було використано такі методи: порівняльного аналізу, статистичний, табличний, розрахунково-конструктивний, абстрактно-логічний, а також інструментарій екстраполяції тренду. Встановлено тенденцію зростання концентрації сировини в аграрному експорті України – 85 %. Частка зерна в загальному експорті продукції склало майже 25 %. Подальше нарощування зернового експорту стало проблемою для внутрішнього та зовнішнього ринку. Разом з тим експортні надходження від продажу м'яса залишилися незначними – 3-4 %, а виробництво яловичини та свинини стійко скорочується. Фактичне споживання населенням м'яса яловичини та телятини майже в 6 разів нижче за раціональну норму, свинини – в 1,5 раза. Визначено, що висока концентрація сировини в українському експорті аграрної продукції призводить до значних щорічних втрат експортної виручки, потенційних робочих місць та зменшення ВВП країни. Прогнозними орієнтирами параметрів збільшення виробництва яловичини до 1 млн т, свинини – до 2 млн т на рік. Визначено загальну прогнозу потребу в зерні для виробництва визначених обсягів яловичини та свинини – 12,94 млн т на рік (пшениці – 5,51 млн т, кукурудзи – 5,59 млн т, ячменю – 1,84 млн т). Розрахунками доведено, що спрямування визначених обсягів пшениці, кукурудзи та ячменю не на експорт, а на відгодівлю тварин для виробництва м'ясної продукції, сприятиме збільшенню експортних надходжень в Україну на 12,6 % (або на 1,23 млрд дол США на рік). Визначено, що ВВП України може зрости на 525,6 млрд грн. або 12,5 млрд дол США. Практичні результати дослідження дозволяють об'єктивно оцінити сценарій трансформації структури зернового ринку із відповідним визначенням прогнозних параметрів збільшення експортних надходжень та доданої вартості для економіки України, що може бути корисним для урядових органів при прогнозуванні напрямів повоєнного відновлення аграрного сектору країни

► **Ключові слова:** зерновий ринок; сировинний експорт; імпортозалежність; продукція м'ясного скотарства та свинарства; додана вартість; економічний ефект



UDC 636.5

Activation of innovative development of poultry farming and meat livestock farming industries on the food market of Ukraine

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► **Abstract.** This article studied the peculiarities of integrating innovative technologies into poultry farming and meat livestock farming – essential elements of the Ukrainian food market. The goal was accomplished through the contextual analysis of industry reports, examination of the European legislation, and assessment of the Ukrainian poultry and meat production segments in terms of the Food Demand Index, Food Supply Index, and Regional Trade Development Index. Despite the military time turbulence, the Ukrainian meat production industry stood resilient and demonstrated potential for sustainable development, with poultry accounting for 56.3% of the total segment. However, integration of the Ukrainian meat production into the European segment remained modest, despite 38,481 TRACES NT certificates obtained: in 2024, the share of poultry exports decreased by 37.2% compared to 2023. The econometric analysis revealed a statistically significant relationship between innovation and output in the national meat production segment, with 66.4% variations in annual poultry and beef consumption attributed to innovative technologies. Connection was also discovered between the use of innovative technologies and reduced production cost, as well as between innovative approaches and an adherence to sustainable development practices. The integration of innovative technologies was not uniform throughout the country: the central regions of Kyiv and Vinnytsia had the highest innovation rankings, with the potential of receiving integral index values of up to 8.13. It was

► **Suggested Citation:** Khakhula, B., Semysal, A., Shepel, T., Shchebel, A., & Shtymak, I. (2025). Activation of innovative development of poultry farming and meat livestock farming industries on the food market of Ukraine. *Ekonomika APK*, 32(4), 22-34. doi: 10.32317/ekon.apk/4.2025.22.

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further discovered that the use of technologies could facilitate rational allocation of resources: one robot can serve up to 70 animals, hence, free human resources to address more technological tasks. The obtained findings could be used to increase performance effectiveness, enhance competitiveness, and support sustainable development of the Ukrainian food market

► **Keywords:** innovative technologies; cattle breeding industry; econometric dependence; supply chain; fuzzy modelling

► Introduction

Military operations in Ukraine and limited access of Ukrainian producers to resources have a negative impact on the production of agricultural products in all regions of the country and might trigger a range of food security issues. Moreover, the threat remains relevant to all segments of the national agricultural sector, including poultry farming and meat livestock farming. The existing threat might be reduced through the introduction of innovative solutions to the Ukrainian food market with an aim to allocate resources, cut costs, restructure logistics chains, and maintain sustainable development. Nevertheless, integration of technology into specific food market segments remains an under-researched issue, which indicates relevance of the selected topic.

Z. Hussain *et al.* (2025) acknowledged that the global food market has undergone major transformations to meet evolving customer preferences and growing demand for sustainable development. The authors further stressed that the growing use of technology has become an integral element of this change process and pointed to a range of technological advances in the field. The study of S. Kimani (2024) stressed the relationship between the integration of innovation in specific sectors, including crop breeding, enhanced productivity, and food availability. Considering this relationship, the researcher concluded that innovative development might become the key to fighting food insecurity in some areas, for example, Sub-Saharan Africa. K. Malec *et al.* (2024) discovered that investments in agricultural innovation preconditioned an increase in food security. Similar to Z. Hussain *et al.* (2025), the authors asserted the relationship between innovations and food security was moderated by the productivity growth. E.D. Farsani *et al.* (2024) examined 36 academic sources and detected eight factors preconditioning innovation in agriculture – human capital, research, institutional frameworks, market sophistication, infrastructure, knowledge and technology outputs, and creative and innovative endeavours. The cited sources emphasised the role of innovation in sustainable development of the agricultural sector and solution of pressing socio-economic problems.

Several studies, including the research of J.N. Ocran (2025) underlined the significance of innovation for poultry and meat livestock farming. The cited researcher, in particular, studied the use of artificial intelligence (AI) tools in livestock and poultry production. The author concluded that AI tools transformed traditional animal husbandry practices by improving animal welfare, enhancing performance efficiency, and supporting animal farms' sustainability. S. Wongtangintharn *et al.* (2025) stressed that the use of innovative approaches and tools might facilitate the effective integration of certain national agricultural segments, for instance, Thai, into the global food market.

The experts argued such integration was possible due to the use of innovative technologies, like precision-farming and AI-driven systems, to support strategic decision-making and ensure alignment with international food market standards. V. Beck *et al.* (2024) examined the role of innovative technologies in transforming livestock and meat value chains. The authors argued that innovative tools, for example, big data analytics, enhanced value chains' efficiency through product variation and horizontal diversification. R.B. Bist *et al.* (2024) stressed the significance of innovative technologies for promoting poultry welfare and increasing the segment's competitiveness. The cited experts argued that these goals were accomplished through the integration of technology into resource allocation, nutrient recycling and promotion of climate-smart agricultural practices. C. Krampe *et al.* (2024) assessed the role of innovative technologies through a comparative analysis of 367 pig and dairy farmers in three European countries – Finland, the Netherlands, and Spain. Based on collected data, those researchers concluded that farmers used innovative technologies, including digital tools, to manage their data, monitor farm animals, and share information with value-chain actors to optimise business innovation and certification. The collected evidence suggested that the integration of innovative technologies into strategic planning and business management processes can transform poultry and meat livestock farming to enhance the segment's performance and increase its competitiveness (Taishykov *et al.*, 2025).

Despite sufficient research in the field, specific national contexts, including Ukrainian remain a relatively unexplored terrain. Little was known about maintaining innovative development of poultry and meat livestock farming under the martial law and associated limitations. Considering the detected gap, this paper studied the peculiarities of activating innovation in Ukrainian poultry and meat livestock farming. The goal was accomplished through examining the factors shaping the integration of innovative tools in the selected segments, assessing hindrances to the integration process, and proposing strategies to overcome them.

► Materials and methods

This research relied on the data of 2021-2024 retrieved from the industry reports of the OECD-FAO Agricultural Outlook 2024-2033 (2024), State Statistics Service of Ukraine (2024), Data browser (n.d.), Statistics (n.d.). Also, it was analysed data from sources M. Bogonos *et al.* (2024), V. Afanasyev *et al.* (2024), I. Guzhva (2025). The data was used to assess the state of poultry and meat livestock farming in the Ukrainian regions: Dnipropetrovsk, Kyiv, Kirovohrad, Mykolaiv, Odesa, Kharkiv,

Vinnitsia, Volyn, Zhytomyr, Lviv, Poltava, Rivne, Sumy, Ternopil, Khmelnytskyi, Cherkasy, Chernivtsi, Chernihiv, Zakarpattia, and Ivano-Frankivsk. In addition to industry reports, the following pieces of European legislation were examined: Commission Delegated Regulation (EU) No. 2021/1374 (2021), Regulation (EU) of the European Parliament and of the Council No. 2022/870 (2022), Commission Delegated Regulation (EU) No. 2023/2652 (2023).

The data from Yu. Lupenko *et al.* (2021), T. Nakelse & E. Dennis (2024), and J. Rittirong *et al.* (2024) was used to create a system of indicators to assess innovative development of the poultry and meat livestock industries in the food market: food demand index (I_{dem}) – characterised the level of meeting consumer needs in poultry and meat livestock products, provided that the financial activity of agribusiness entities increased and capital was invested in innovative technologies; food Supply Index (I_{offer}) – characterised the level of production capabilities and the degree of market saturation with poultry and meat livestock products, its competitive positions in production and sale using innovative technologies, in time space; Regional Trade Development Index ($I_{reg,trade}$) – determined opportunities for the sale of poultry and meat livestock products produced and sold using innovative technologies through trade networks, provided an opportunity for producers to reduce sales costs due to the volume of product batches. When forming a dependence between the indicators, a mathematical equation was determined to find the integral indicator of innovative development of the poultry and meat livestock industries in the food market ($I_{reg,market}^{in}$):

$$I_{reg,market}^{in} = v_{i1} \times I_{i1} + v_{i2} \times I_{i2} + \dots + v_{in} \times I_{in},$$

$$\text{or } I_{reg,market}^{in} = UNa_{i1} + UNa_{i2} + \dots + UNa_{in}, \quad (1)$$

where v_{i1}, v_{i2}, v_{in} – the weight of each i -th indicator of innovative development of the poultry and meat livestock industries in the food market; I_{i1}, I_{i2}, I_{in} – indicators of innovative development of the poultry and meat livestock industries in the food market; $UNa_{i1}, Na_{i2}, UNa_{in}$ – weighted normalised assessment of each individual i -th indicator of innovative development of the poultry and meat livestock industries in the food market. Whereas, UNa_{in} was calculated by the formula:

$$UNa_{in} = Na_{in} \times v_{in}, \quad (2)$$

where Na_{in} – normalised estimate per person of the i -th indicator of innovative development of the poultry and meat livestock industries in the food market. In this case, (Na_{in}) was calculated by the formula:

$$Na_{in} = \frac{I_{in} \times 10}{I_{i,max}}, \quad (3)$$

where I_{in} – indicator per capita of the i -th indicator of innovative development of the poultry and meat livestock industries in the food market; Na_{in} – the maximum indicator per capita of the i -th indicator of innovative development of the poultry and meat livestock industries in the food market, which was found empirically through a comparison of all indicators of the i -th indicator in a specific region. To determine the mathematical dependence between the indicators, correlation-regression analysis was used:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}}. \quad (4)$$

The correlation coefficient ranged from $-1 \leq r$ to $\leq +1$ indicating statistically significant negative and statistically significant positive correlation, respectively. The formula was used to calculate the correlation between the trade development indicator and the demand indicator, as well as between the demand indicator and the supply indicator. If the obtained results showed a close correlation between the indicators, then the importance of these indicators was determined:

$$v_i = \frac{r_i}{\sum r_i + r_2 + \dots + r_n}, \quad (5)$$

where v_i – the weight of the i -th indicator of the innovative industries of poultry farming and meat cattle breeding in the food market; r_i – the correlation of the i -th indicator of the innovative industries of poultry farming and meat cattle breeding in the food market; $r_i + r_2 + \dots + r_n$ – the sum of the possible calculated correlations. The logarithmic function was used to assess the structure of the poultry meat food supply in Europe in 2021-2024; compare the structure of food supply of poultry and beef in the Ukrainian, European, and global markets; detect the econometric relationship between the trade development indicator and the food supply indicator of the Ukrainian meat market since 2021:

$$y = a \cdot \ln(x) + b, \quad (6)$$

where $\ln(x)$ – natural logarithm (logarithm base a); a – coefficient controlling the steepness, and b – y -intercept.

The forecast assessment of the integral index was carried out on the basis of accounting data and non-financial reporting on the signs of a stable state of innovative development of entities in the poultry farming and meat cattle breeding industries considering a sufficient retrospective of indicators for constructing fuzzy-multiple parameters by weight indicators not as a fuzzy logic by a sample of factors, but as a convolution of the current levels of these factors in the interval from 0 to 1, taking into account stability states. In the reverse order, the sign of the crisis of innovative development of industries changes (very low, low, medium, high and very high). The fuzzy set methodology was described using the composition of individual indicators $X = \{X_i\}$, which most closely corresponded to the assessment objectives: X_1 – innovation autonomy coefficient; X_2 – innovation provision coefficient with own funds; X_3 – intermediate innovation coefficient; X_4 – innovation coefficient by cash flows; X_5 – innovation turnover in the operating cycle; X_6 – profitability of operating activities. Basic sets were introduced, which were explained as follows: a) a complete set of states Q_i by industry entities; b) a set Q_i of levels of the crisis of innovative development W ; c) for an arbitrarily separate indicator X_i a set of its values P_i .

A universal factor for the variables q, p and w was the interval from 0 to 1, and the factor of the values involved the sets $Q = \{Q_1, Q_2, Q_3, Q_4, Q_5\}$, $P = \{P_1, P_2, P_3, P_4, P_5\}$ and $W = \{W_1, W_2, W_3, W_4, W_5\}$ respectively. The sets of the linguistic variable “State of innovative development of the subject of the industry” were divided into five fuzzy subsets that will intersect. These subsets had the following form (four corner points of the trapezoid): $Q_1 = (0; 0; a_1; a_2)$; $Q_2 = (a_1; a_2; a_3; a_4)$; $Q_3 = (a_3; a_4; a_5; a_6)$; $Q_4 = (a_5; a_6; a_7; a_8)$; $Q_5 = (a_7; a_8; 0; 0)$. Each subset had its own membership function $\mu(X)$, with trapezoidal membership functions being the most commonly used in this case. The one-to-one

correspondence of the linguistic variables “State of innovative development of the subject of the industry” and

“Sign of the crisis of the innovative development of the subject of the industry” was given in Table 1.

Table 1. Correspondence of linguistic variables Q_i and W_i

Value of the variable Q_i – “State of innovative development of the industry entity”	Value of the variable W_i – “Sign of crisis of innovative development of the industry entity”
Unstable boundary (Q_1)	Highest (W_1)
Low stability state (Q_2)	High (W_2)
Medium stability state (Q_3)	Average (W_3)
Sufficient stability state (Q_4)	Low (W_4)
Very stable boundary (Q_5)	Very low (W_5)

Source: based on The European Union officially abolished tariffs on Ukrainian goods (2022), E.S. Aljohani *et al.* (2024), K.M. Kang *et al.* (2024)

The method of the fuzzy-multiple approach took into account the relationship between the forecast of the steady state of innovative development of the poultry and meat livestock industries with their probabilistic crisis, and the developed model was characterised by flexibility and adaptability to changing environmental conditions, where it was possible to rank the regions of the country by the value of the integral index.

► Results

The production of poultry and meat products is one of the leading areas in solving the food security problems and providing the population of Ukraine with high-quality dietary protein. Based on the analysis of trends in the Ukrainian and European food markets since 2021, it was

important to timely determine the vector of the poultry and meat industries' revival. First, even in European countries, producers need to focus on the demand of various population groups with different income levels, including low ones. Second, certain trends have been identified in the dynamics and structure of the global meat consumption towards an increase in the share of poultry meat. This has had a particularly noticeable impact on the structure of meat consumption in the European countries. Third, in non-European countries, the share of cheaper meat production was increasing, namely poultry and pork meat have an advantage, and the most expensive was cattle meat (Diachenko, 2020). The historical overview of the meat market emergence, development, and major actors was shown in Figure 1.

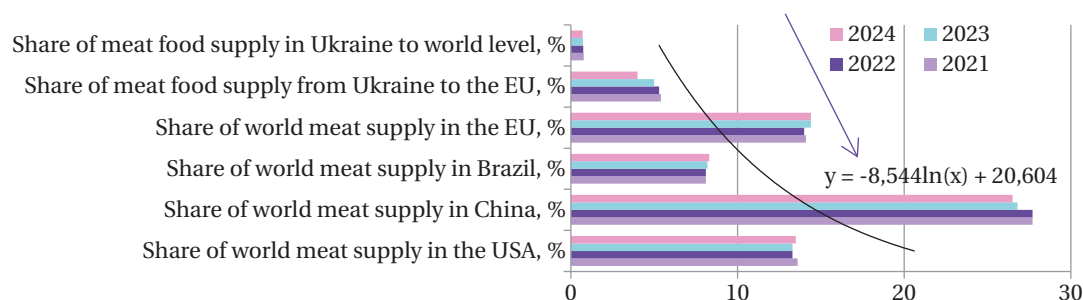


Figure 1. Share of meat food supply in the EU and Ukraine from the world level for 2021-2024

Source: based on OECD-FAO Agricultural Outlook 2024-2033 (2024), State Statistics Service of Ukraine (2024), P. Pyvovarov & O. Rozhkov (n.d.)

The provided figure suggested that 26.5% of the global meat supply was contributed by China, while 16.6% were due to the USA – these two countries have been obtaining the largest shares of the world meat supply since 2021. In the analysed period, Ukraine's contribution to the global food market remained relatively low, but showed minor fluctuations; as for the country's share in the European food market, it was identified as modest. A logarithmic trend line suggested a gradual decline in Ukraine's relative share over the observed period, reflecting ongoing challenges amid external pressures, including economic crisis and functioning in wartime mode. The structure of the food supply of poultry meat in Ukraine differed from the EU countries. As seen from Figure 2, Ukraine has a significantly higher share in poultry (50.8%) compared to the EU (30.5%) and the global average. However, Ukraine's beef supply share of 16% lags slightly behind the European (16.5%) and the world average. Logarithmic trend lines showed a steeper upward

trend for Ukraine in poultry production, suggesting accelerated growth in this segment. Based on the figure, Ukraine specialised in poultry, while beef production remained more aligned with broader regional and global patterns.

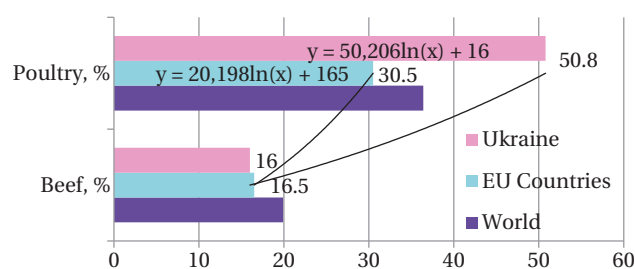


Figure 2. Structure of food supply of poultry and beef in the markets of Europe and Ukraine in 2024

Source: based on the OECD-FAO Agricultural Outlook 2024-2033 (2024), P. Pyvovarov & O. Rozhkov (n.d.)

The growing Ukrainian share in the global poultry meat supply has become possible due to changes in the EU legislation, according to which batches of poultry and beef intended for human consumption can be imported into the EU only from enterprises approved by the State Food and Consumer Protection Service. As a part of its European integration strategy, Ukraine has switched in 2024 to using TRACES NT – the online platform of the European Commission for certification and support of export, import, and transit of animals, products of animal and plant origin, food, feed – which has significantly simplified the formal procedures for the export and transit of food products to the EU territory, when crossing the state border (The right to export livestock products to the EU..., 2025). As of 2023, specialists of the territorial bodies of the State Service for Food Safety and Consumer Protection were able to issue 20 types of certificates in TRACES NT, which allowed significantly shortening the issuance procedures and reducing the burden on exporters (Trusova *et al.*, 2023). In 2024, 38,481 certificates were issued using TRACES NT for goods sent to or through the EU territory, including 18,649 certificates for import into the EU, and 19,832 certificates for transit.

Commission Delegated Regulation (EU) No. 2021/1374 (2021) laying down specific hygiene requirements for food of animal origin provided for new possibilities adapted to the 2025 and to address the identified problems regarding the sale of poultry and meat products on the food market. Among other aspects, the main changes were relevant to the following aspects: the meat of ungulates criteria was introduced to avoid possible problems during transportation, regulating the slaughter of a small number of animals on the farm; “approval of a veterinarian” was replaced by “official veterinarian”; the food donation requirements were established for the freezing of meat of ungulates, poultry and lagomorphs in retail trade if they were intended for donation.

Regulation (EU) of the European Parliament and of the Council No. 2022/870 (2022) had supplemented the opportunities available to Ukrainian exporters under the Association Agreement between Ukraine and the EU. This decision, among other things, suspended all tariff quotas for agricultural products, which had become an incentive for Ukrainian producers. The liberalisation of trade relations, in turn, implied that Ukraine will comply with

European rules: the origin of goods and relevant procedures within the framework of the Association Agreement, refraining from any new restrictions on imports from the EU, Ukraine's respect for democratic principles, human rights and fundamental freedoms, the rule of law, and the fight against corruption. These new rules will help Ukrainian producers and exporters withstand the burden of war and strengthen their positions on the European market.

As explained by Yu. Lupenko *et al.* (2021), the poultry and meat livestock industries of Ukraine, despite the instability of innovative activity, were trying to integrate advanced developments and adapt them to their own production. J. Rittirong *et al.* (2024) suggested that the emphasis was on the use of innovative and energy-renewable technologies utilising solar energy, wind energy, biogas plants, rational and efficient use of feed and improving its quality, the introduction of energy-saving and intensive technologies, modernisation, technical re-equipment and automation of the feeding process. Researchers T. Katkova & Y. Kravchik (2022) noted about the impact of the introduction of digital technologies at enterprises on production efficiency. Strategic task in the field of animal sciences involved the creation of intelligent farms, where the feeding processes and livestock management were combined. In meat livestock, an essential example and one of the basic concepts of Smart Farm involved the use of robotic animal feeding boxes, which encompassed the principles of building a balanced farm and fit the environmental requirements of safe production. The main working element of the robotic feeding system was a multifunctional manipulator, designed according to the principle of a human hand, which ensured the feeding process, regardless of the various shapes and locations of feed objects; for example, one robot was capable of serving an average of up to 70 animals (Ibatullin *et al.*, 2022). The mentioned approach allowed for equally effective control of many other technological factors in both large and small farms with an aim of enhancing animal productivity. Despite the martial law-related limitations, the introduction of innovative technologies in the beef cattle breeding segment preconditions an increase in the supply of products to the food market. This was evidenced by the data on the grouping of regions by the number of cattle per 100 hectares of agricultural land (Table 2).

Table 2. The impact of the density of livestock in beef cattle breeding on the volume of food supply of beef produced using innovative technologies in 2024

Indicators	Group of regions by number of livestock of meat cattle per 100 hectares of agricultural land			Total
	I	II	III	
	to 10	10.1-20	20.1 and more	
Number of regions in the group	8	10	2	20
Average livestock density by group, head	6.7	13.5	30.6	10.1
Food supply of beef using innovative technologies per capita, kg	5.6	12.6	15.7	8.8
Food supply of beef using innovative technologies per 100 hectares of agricultural land, kg	6.7	13	46.1	10.2
Beef consumption per capita, kg	7.2	10.8	11.1	8.1

Note: group I regions: Dnipropetrovsk, Kyiv, Kirovohrad, Mykolaiv, Odesa, Kharkiv; group II regions: Vinnytsia, Volyn, Zhytomyr, Lviv, Poltava, Rivne, Sumy, Ternopil, Khmelnytskyi, Cherkasy, Chernivtsi, Chernihiv; group III regions: Zakarpattia, Ivano-Frankivsk

Source: based on Organisation for Economic Co-operation and Development (2024), M. Bogonos *et al.* (2024)

According to the Table 2, for every 1% increase in beef cattle density, the food supply of beef produced with innovative technologies grows by 0.7% per person and by 0.9% per unit of land area. It was discovered that an enhancement in the livestock contributes to a statistically significant increase in the use of organic fertilisers, improvement of soil fertility and obtaining environmentally friendly agricultural raw materials. Thus, with an increase in the density of beef cattle per 100 hectares of agricultural land from 6.7 to 30.6 heads, the manure yield per 1 hectare of arable land increases by 7.8 times, respectively. Therefore, in regions, where livestock density was low – fewer than 10 heads per 100 hectares of agricultural land (specifically 6.7 heads) – there was a need to implement innovative measures to boost meat production and strengthen the country's food potential. The production of poultry meat was among the essential components contributing to the meat market supply in Europe. Commercial value was mainly represented by chickens, turkeys, ducks, or geese. Chickens have become the most widespread among domestic birds in Europe; the share of their meat has exceeded 85% of the total poultry meat production for more than 20 years (Fig. 3).

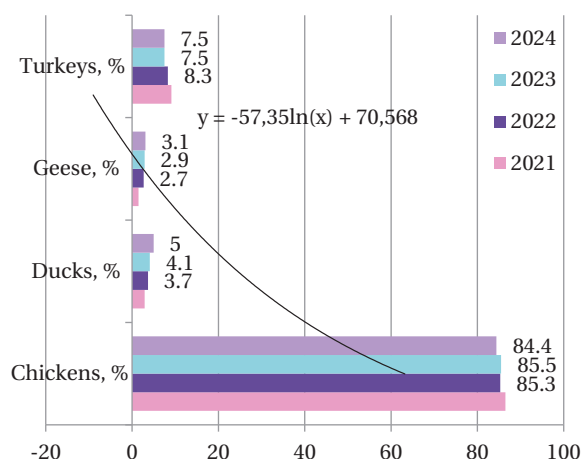


Figure 3. Structure of poultry meat food supply in Europe for 2021-2024

Source: based on Statistics (n.d.), State Statistics Service of Ukraine (2024), Data browser (2024)

The Figure 3 suggested that chicken meat production had remained the main segment of the European poultry meat supply chain. However, there was noticed a slight decrease in the share of this particular segment of the European poultry meat market – from 85.3% in 2021 to 84.4% in 2024. Decrease was also seen in the production of turkey meat – from 8.3% to 7.5%. However, upward trends were identified in the production of duck and goose meat – from 3.7% in 2021 to 5% in 2024 and from 2.7% in 2021 to 3.1% in 2024, respectively. Therefore, it was concluded that the European poultry meat supply had undergone some changes since 2021.

As of 2024, the poultry meat market in Ukraine remained among the key segments of the agricultural sector (State Statistics Service of Ukraine, 2024). Although the Russian military aggression against Ukraine had significantly affected the industry, especially in areas with major production facilities, most large producers could

resume operations, and the market was gradually stabilising. The poultry meat market was showing positive changes by adapting to new conditions, in particular, through support from state and international programmes contributing to the restoration of the agricultural sector. The Ukrainian products were in demand in foreign markets, in particular in the EU and the Middle East, which added opportunities for export. However, the share of exports in total production decreased to 37.2% in 2024 compared to 2023 (Afanasyev *et al.*, 2024). Considering the structure of meat production in Ukraine using modern innovative technologies, the largest share (56.3%) fell on the poultry industry (BDO in Ukraine on poultry farming..., 2024). However, during military operations, poultry farms in regions, where innovations were actively implemented and production had increased still experienced negative impacts on their efficiency (Fig. 4).

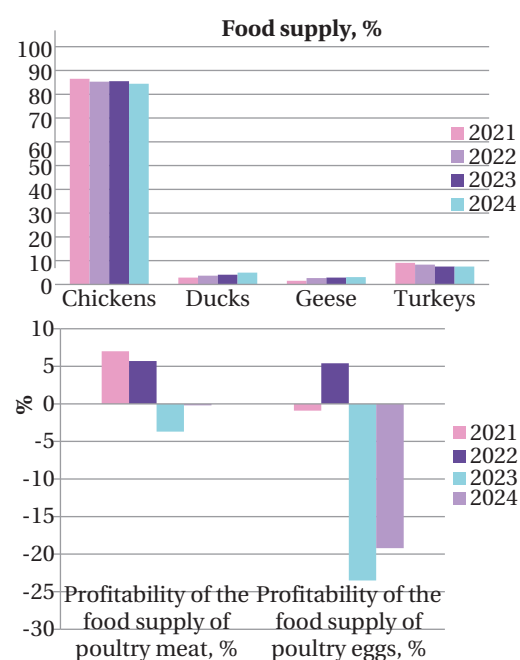


Figure 4. Efficiency of food supply in the poultry industry of Ukraine by innovative technologies in 2021-2024

Source: based on BDO in Ukraine on poultry farming: Market status, forecasts and opportunities for export (2024), V. Afanasyev *et al.* (2024)

Logistics in the poultry industry since February 24, 2022 has faced challenges due to the disruption of traditional transport routes, in particular in the South and East of Ukraine. At the same time, Ukrainian producers were actively using western border crossings and alternative routes through European countries, which allowed maintaining stability in the supply of products. However, poultry meat prices in Ukraine remained below the world level, which helped maintaining demand in both domestic and foreign markets. To a large extent, the formation of meat prices was influenced by the ratio of supply and demand for it and the solvency of the population. In 2021-2024, average prices across all sales channels changed significantly – to USD 1,578 per ton of poultry meat in live weight, or 2.1 times compared to 2021. Poultry meat sales prices by region of Ukraine were presented in Figure 5.

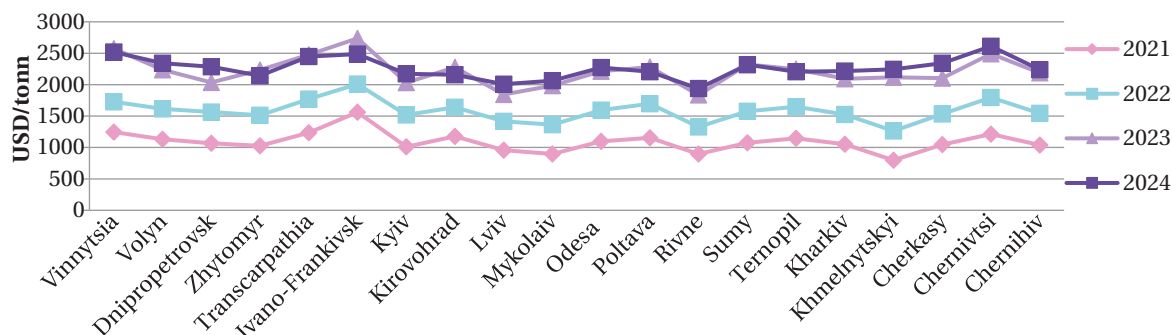


Figure 5. Selling price of 1 ton of poultry meat for 2021-2024

Source: based on BDO in Ukraine on poultry farming: Market status, forecasts and opportunities for export (2024), Organisation for Economic Co-operation and Development (2024), M. Bogonos *et al.* (2024)

Innovative technologies in the poultry industry continued to develop, despite safety challenges and economic hurdles. Large enterprises tend to modernise equipment, optimise production processes, and introduce new approaches and tools, including automation, to increase efficiency and reduce costs (Samoichuk *et al.*, 2016). One example suggested that work on poultry farms was a labour-intensive and monotonous process, which involved cleaning and disinfection, egg collection, and other operations, and that can be intensified and automated with the help of robots (Sychoy *et al.*, 2024). The use of robots allowed

cleaning and disinfecting poultry houses and created a map indicating the places, where the work is or was being performed. A constantly moving robot encouraged birds to move and teaches chickens not to lay eggs on the floor. In addition, the robot worked autonomously, constantly emits light and, if necessary, produced sounds or music. Another important aspect was the movement towards biosecurity of the farm, as human contact with birds was reduced. The econometric dependence of the innovative development indicators of the poultry and meat livestock industries in Ukraine was determined (Table 3).

Table 3. Data for determining the econometric dependence between the indicators of innovative development of the poultry and meat livestock industries of Ukraine

Years	Volume of retail turnover of poultry and beef by brand technologies, USD thousand	Volumes of consumption of poultry, thousand tons	Volumes of consumption of beef, thousand tons	Volume of food supply of poultry by innovative technologies, thousand tons	Volume of food supply of beef by innovative technologies, thousand tons
2021	148,301	2,112	1,874	2,517.8	2,047.8
2022	155,528	2,184	2,074	2,762.8	2,298.5
2023	246,604	2,178	2,178	2,809.4	2,244.7
2024	198,227	2,070	2,277	2,747	2,369.4

Source: based on M. Bogonos *et al.* (2024), T. Nakelse & E. Dennis (2024), Organisation for Economic Co-operation and Development (2024)

The econometric dependence and consequences of the correlations between the trade development indicator and the demand indicator were demonstrated in Figure 6. The graph illustrated a statistically significant relationship, suggesting that shifts in demand were closely associated

with changes in trade dynamics. This correlation implied that an increase in consumer or market demand may serve as a driving force behind trade expansion. Understanding this interdependence helped to better predict economic outcomes and formulate responsive trade policies.

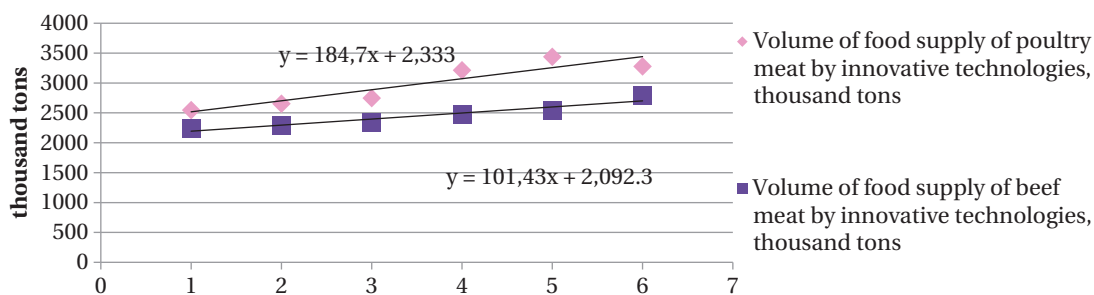


Figure 6. Econometric relationship between the trade development indicator and the food supply indicator of poultry and beef in Ukraine on average for 2021-2024

Source: based on P. Pyvovar & O. Rozhkov (n.d.), M. Bogonos *et al.* (2024)

The econometric dependence and effects of the correlations between the demand indicator and the supply indicator were demonstrated in Figure 7. The figure revealed a clear interrelationship, where changes in demand were closely mirrored by adjustments in supply levels.

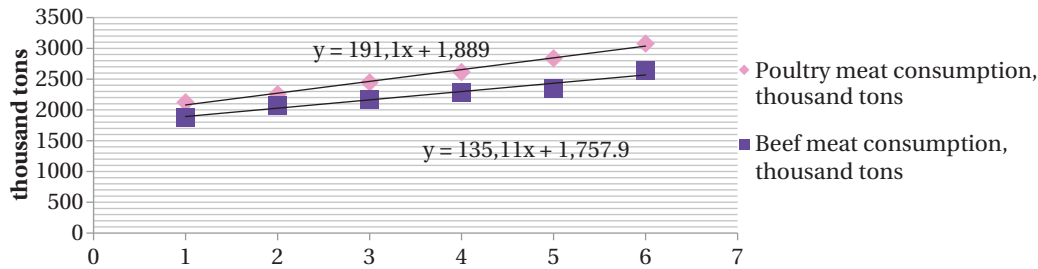


Figure 7. Econometric relationship between the demand indicator and the food supply indicator for poultry and beef in the markets of Ukraine on average for 2021-2024

Source: based on V. Afanasyev *et al.* (2024), P. Pyvovar & O. Rozhkov (n.d.), M. Bogonos *et al.* (2024)

At the same time, linear variables of poultry and beef consumption volume changed the annual production volume of products through the use of innovative technologies by 42.9%, respectively. The econometric dependence

and consequences of correlations between the food supply indicator and the trade development indicator (retail turnover of poultry and beef by brand technologies in 2021-2024) were shown in Figure 8.

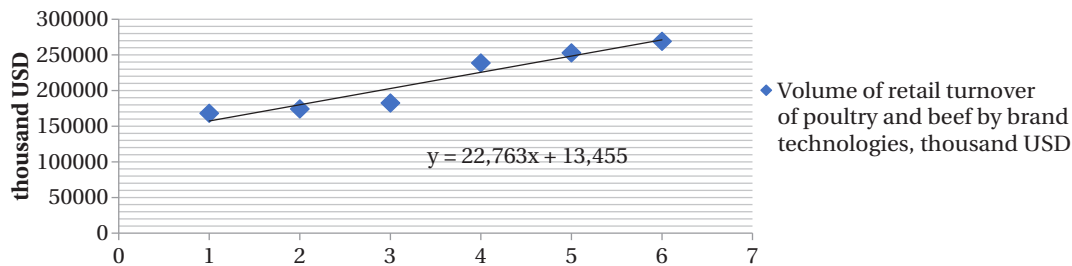


Figure 8. Econometric relationship between the food supply indicator and the trade development indicator in the poultry and beef market in Ukraine on average for 2021-2024

Source: based on Statistics (n.d.), V. Afanasyev *et al.* (2024), State Statistics Service of Ukraine (2024)

The linear regression model indicated that variations in poultry and beef consumption volumes explain 66.4% of the variance in annual meat production levels based on innovative technologies ($R^2=0.664$). The weight of each indicator of innovative development of the poultry and beef industries in the food markets of poultry and beef (v_i) will be as follows:

$$v_{reg.trade} = \frac{0.45}{1.93} = 0.23; v_{dem} = \frac{0.66}{1.93} = 0.34; v_{offer} = \frac{0.82}{1.93} = 0.42, \quad (7)$$

$$\sum r = 0.45 + 0.66 + 0.82 = 1.93. \quad (8)$$

The calculation of each individual indicator of innovative development of the poultry and beef industries in the food markets of poultry and beef, on average per person, allows determining the reference region for each indicator, namely:

1. $v_{dem}^{max} = 30.2$ kg – Dnipropetrovsk region (Southern region) ≈ 10 points.
2. $v_{offer}^{max} = 298.58$ kg – Vinnytsia region (Central region) ≈ 10 points.
3. $v_{reg.trade}^{max} = 14294.37$ thousands USD – Kyiv region and Kyiv city (Central region) ≈ 10 points.

The mathematical expression for calculating the normalised score of each of the three indicators for the i -th

region will be calculated as follows:

$$Na_{dem}^i = \frac{I_{dem}^i \times 10}{30.2}; Na_{offer}^i = \frac{I_{offer}^i \times 10}{298.58};$$

$$Na_{reg.trade}^i = \frac{I_{reg.trade}^i \times 10}{14,294.37}. \quad (9)$$

The calculation of the weighted normalised score of each of the three indicators for the i -th region will be as follows:

$$UNa_{dem}^i = Na_{dem}^i \times 0.34; UNa_{offer}^i = Na_{offer}^i \times 0.42;$$

$$UNa_{reg.trade}^i = Na_{reg.trade}^i \times 0.23. \quad (10)$$

Taking into account the previous calculations, a mathematical model of an integral indicator of innovative development of the poultry and meat livestock industries in the food markets of poultry and beef has been formed:

$$I_{RMD}^i = \sum UNa_{dem}^i + UNa_{offer}^i + UNa_{reg.trade}^i, \quad (11)$$

where – separate i -th region in the food market of poultry and beef in the country.

The calculation of the integral index of innovative development in the poultry and meat livestock industries among the food markets of the Central, Northern, Southern and Western regions of Ukraine was shown in Figure 9.

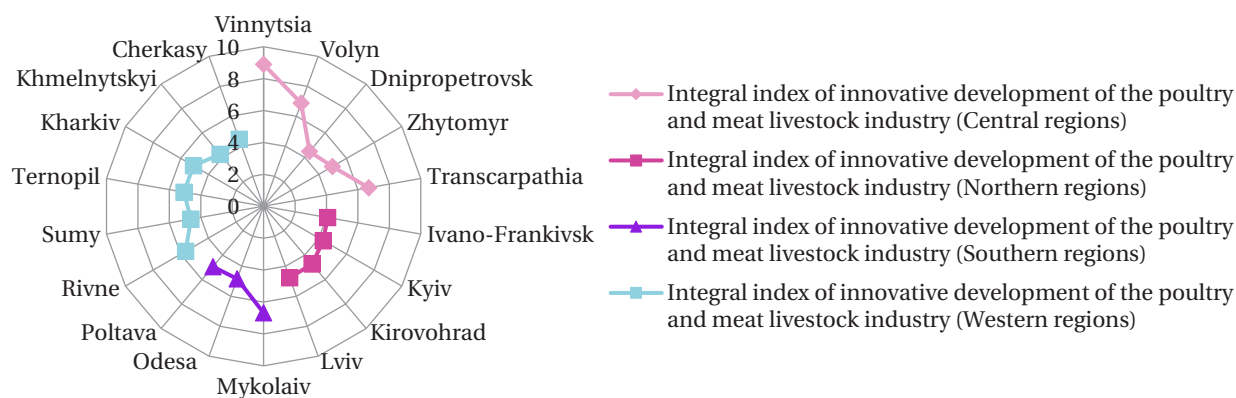


Figure 9. Integral index of innovative development of poultry farming and meat cattle breeding industries among the Central, Northern, Southern and Western regions of Ukraine on average for 2021-2024

Source: calculated by the authors

Regions with the highest poultry and beef consumption were the most attractive for producers. Conversely, the highest degree of market competition was observed in regions, where food products were widely supplied using innovative technologies. However, in these particular regions, the supply of such products surpassed the level of consumption. Accordingly, the lowest prices for products were observed, which, in turn, also stimulated the consumption of poultry and beef among other types of meat. The central region of Ukraine was the first in the rating for innovative development of the poultry and meat livestock industries, as it included two regions at once – Vinnytsia region as the leader in the volume of food supply of poultry and beef using innovative technologies, and Kyiv region being the leader in the volume of retail trade. The predictive assessment of the signs of a stable state of innovative development of entities in the poultry and meat cattle industries of the Central region of Ukraine took into account sufficient retrospective of indicators of the financial component in business entities to construct fuzzy-multiple parameters by weight indicators (Fig. 10).

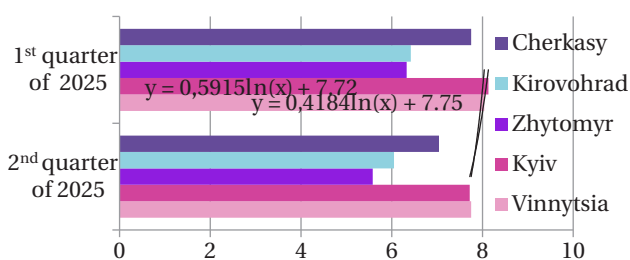


Figure 10. State of innovative development of poultry and meat cattle breeding entities in the Central regions of Ukraine for the 1st-2nd quarter of 2025

Source: based on I. Guzhva (2025), P. Pyvovar & O. Rozhkov (n.d.)

The results suggested that in the first quarter of 2025, only 52 business entities from three regions of the Central part of Ukraine – Vinnytsia, Kyiv, and Cherkasy – had a sufficiently stable state of innovative development of the poultry and meat livestock industries – 7.75; 7.72;

7.04, respectively. Among the regions in the central part of Ukraine, two regions – Vinnytsia and Kyiv regions – retained their leading positions in the food market. For the second half of 2025, a significant application of the financial component of the innovative development of the poultry and meat livestock industries was planned, where business entities in these regions were actively adapting to the European market requirements for meat products. Such adaptation made it possible to increase the index to a very stable state through the regulation of strategic positions and strengthening of competitive advantages within the values of 8.04 and 8.13, respectively.

Thus, establishing a stable trajectory of innovative development over time and determining optimal conditions for its support in the poultry and meat livestock industries can shift the balance of influencing factors. Depending on the time dimension, the state of innovative development may follow one of three possible scenarios: a decline, a stable level, or a growing equilibrium. Accordingly, changes in innovative development were likely to occur gradually, influenced by moderate structural adjustments in financial components – particularly under the most favourable scenario, which assumed successful mitigation of the post-war crisis in the poultry and meat livestock sectors.

► Discussion

Among the key ideas introduced in this paper, one was about the growing global demand for poultry and meat and the role of technology in addressing it. The idea was, for instance, reflected in Figure 1 of this paper comparing the share of meat supply in Ukraine, the EU, Brazil, China, and the USA. The case of Ukraine also illustrated that integration into the European or global market was connected with the need to increase meat production volumes. Several examples introduced in the paper suggested that Ukraine had already made a step toward integrating innovative approaches to meat production by, for example, using robots to clean chicken coops, make chickens move, and control the hatching of eggs so to increase production volumes. The significance of technology in maintaining or growing the volume of meat production was further confirmed in previous studies, including A. Suychinov *et al.* (2024). While using Slovakia as

a context, the cited experts acknowledged the significance of AI-powered strategies, including precision biotechnology, for addressing consumer needs in certain amount of meat. The study of the researcher was considered relevant to the this research, considering economic, cultural, and other similarities between the Ukrainian and Slovak contexts. Some consistency was also detected between the study of Q. Sun *et al.* (2025) and this research, since both examined the use of innovative strategies and tools in growing meat production volume. The study of Chinese meat production context allowed Q. Sun *et al.* (2025) to conclude that the integration of AI agents into supply chain management and intelligent control systems leads to a 26.89% increase in overall profits. The work of scientist was relevant to this study because according to the above cited data, Chinese agricultural segment accounts for around one-third of the global meat production. The data meant that Chinese farmers had accumulated sufficient experience in the meat production segment, which can be partly or completely adapted to the Ukrainian context. Another reason was that the study of Q. Sun *et al.* (2025) introduced strategies to increase overall profits without compromising production quality standards; and the obtained insights might be partly integrated into the Ukrainian agrarian segment striving to maintain resilience amidst the war-era turbulence.

This paper also elaborated on the idea that integrating the Ukrainian agrarian segment into the European food market implied an adherence to the EU production standards and quality requirements. This idea, which was examined in the context of the EU legislative acts, rests on the assumption that customers tend to buy foods produced in compliance with universal quality, ethics, and sustainability requirements (Karatieieva *et al.*, 2024). In this regard, there was noticed a consistency between this research and the study of P. Castellani *et al.* (2025) examining customers' motivation for purchasing lab-grown meat. Experts discovered that, while the relationship between the perceived higher environmental sustainability and customers' intention to buy lab-grown meat remained unclear, peculiarities of the meat production process still play an essential role in a purchasing decision-making process. A partial consistency was found between the work of P. Castellani *et al.* (2025), focused on the lab-grown meat production, and this work exploring the peculiarities of sustainable poultry and meat production in the context of technological advances. The idea of using technology for sustainable meat production was also explored by L. Woelken *et al.* (2024), who interviewed 11 experts to detect the factors shaping the cultivated meat production. Based on the interview data, the experts argued that the use of innovative practices lowers production costs and cultural barriers. The latter effect of particularly important for the Ukrainian agrarian segment seeking flexibility as a way to navigate the turbulent market, stay competitive, and maintain sustainable development.

This paper further took an in-depth look into the role of technology in cutting costs of meat production, since this strategic goal was considered relative in the Ukrainian context. Lowering costs and toxicological evaluation of meat not only helps to maintain an adequate standard of living for the population affected by the war, but also

to stay competitive, while integrating into the European and global market (Tkachuk *et al.*, 2023). The idea of a relationship between technology and meat production cost was confirmed in previous research, including the work of A. Samad *et al.* (2024). The authors argued that the use of technology can cut costs by producing restructured meat with increased shelf life. Despite some consistency noticed, it was worth stressing that compared to the present research, the study of this researchers had a considerably narrower focus on restructured meat, the pricing features of which might be somewhat different from the pricing features of the traditional meat production. Logical parallels were also drawn between this research and the study of Y. Deng *et al.* (2024) exploring the use of technology in processing of rabbit meat. Scientists argued that innovative tools might be applied in such critical processes as deodorisation, texture adjustments, and water retention, where any transformation was closely related to the end-product price. In spite of existing similarities, it should be stressed that this study and the research of Y. Deng *et al.* (2024) differed in their focus, which might affect the transferability of obtained results. L.K. Hernandez-Murillo & F. Galan-Mendez (2024) argued that integrating technology into meat production and processing processes can cut costs through the adoption of sustainable practices. As explained by this researchers, advances in thermal and non-thermal treatments increase productivity, yield, and quality, while ensuring effective allocation of available resources. The study extended the scope of the present discourse by elaborating on the strategies to cut costs in the meat processing, which follows immediately after the meat production process. Hence, most obtained results found their confirmation in previous research studies, which meant this work has fit into the already existing academic discourse. This paper, however, had also made its own contribution to the field due to its specific focus on the poultry and meat production segment of the Ukrainian food market. While exploring the Ukrainian context, this paper had provided insights into maintaining competitiveness and sustainable development of certain economic segments amidst turbulence.

► Conclusions

The research revealed that the Ukrainian poultry industry was gradually stabilising despite the war-caused disruptions. As of 2024, poultry accounted for 56.3% of the total meat production in Ukraine, indicating its dominant role in the sector. The export capacity remained resilient, with 38,481 TRACES NT certificates issued for goods exported or transited through the EU. However, the share of poultry exports had decreased to 37.2% since 2021, reflecting wartime limitations and market shifts. Econometric analysis confirmed a strong relationship between innovation and output: variations in poultry and beef consumption volumes explained 66.4% ($R^2 = 0.664$) of the variance in annual meat production through innovative technologies. Additionally, every 1% increase in livestock density per 100 hectares resulted in a 0.7% rise in per capita beef supply and a 0.9% increase per land unit. The data also suggested a positive ecological outcome, with manure yield per hectare increasing 7.8 times as livestock density rose from 6.7 to 30.6 heads.

The study also identified regional leaders in innovation: central regions, especially Vinnytsia and Kyiv, ranked the highest in terms of food supply, retail trade, and overall innovative development index. The analysis further highlighted the role of robotic automation, AI-driven livestock monitoring, and smart farming systems in transforming both large-scale and smallholder operations. For instance, robotic feeding systems can serve up to 70 animals per robot, enhancing productivity and aligning with EU biosecurity standards. Hence, innovation in Ukraine's poultry and meat livestock industries was not only feasible, but also vital for economic recovery, food sovereignty, and international competitiveness. Strategic investments, coupled with regulatory alignment and region-specific support, can ensure a sustainable and resilient future for the sector. Limitations of the study include restricted access to primary

data from regions directly impacted by military actions, which may affect the representativeness of some regional comparisons. Future research should explore the long-term effects of technology adoption on cost-efficiency and environmental sustainability in meat production under martial law conditions, with a focus on modelling different integration scenarios into the European food market.

► Acknowledgements

None.

► Funding

None.

► Conflict of Interest

None.

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Активізація інноваційного розвитку птахівництва та м'ясного тваринництва на продовольчому ринку України

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► **Анотація.** У цій статті досліджено особливості впровадження інноваційних технологій у птахівництві та м'ясне тваринництво – важливі елементи українського продовольчого ринку. Мета була досягнута шляхом контекстуального аналізу галузевих звітів, вивчення європейського законодавства та оцінки сегментів птахівництва та м'ясного виробництва України з погляду індексу попиту на продовольство, індексу пропозиції продовольства та індексу розвитку регіональної торгівлі. Незважаючи на військову кризу, українська м'ясна промисловість продемонструвала стійкість та потенціал для сталого розвитку, причому птахівництво становило 56,3 % від загального сегмента. Однак інтеграція українського м'ясного виробництва в європейський сегмент залишалася скромною, незважаючи на отримання 38481 сертифікатів TRACES NT: у 2024 році частка експорту птиці зменшилася на 37,2 % порівняно з 2023 роком. Економетричний аналіз виявив статистично значущий зв'язок між інноваціями та обсягом виробництва в національному сегменті м'ясопереробної промисловості, причому 66,4 % коливань у річному споживанні птиці та яловичини пов'язані з інноваційними технологіями. Також було виявлено зв'язок між використанням інноваційних технологій і зниженням виробничих витрат, а також між інноваційними підходами і дотриманням принципів сталого розвитку. Інтеграція інноваційних технологій не була однаковою по всій країні: центральні регіони Києва та Вінниці мали найвищі рейтинги інноваційності, з потенціалом отримання інтегральних значень індексу до 8,13. Крім того, було виявлено, що використання технологій може сприяти раціональному розподілу ресурсів: один робот може обслуговувати до 70 тварин, що звільняє людські ресурси для виконання більш технологічних завдань. Отримані результати можуть бути використані для підвищення ефективності діяльності, посилення конкурентоспроможності та підтримки сталого розвитку українського продовольчого ринку

► **Ключові слова:** інноваційні технології; галузь скотарства; економетрична залежність; ланцюг постачання; нечітке моделювання



UDC 338.432:330.341.1:502.33

Models of innovative and investment development of farms in the context of ecological economics

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► **Abstract.** This work was aimed at analysing modern approaches to the development of farms through the lens of innovation and investment, as well as examining the impact on sustainable development and the environmental aspects of the economy. The study explored the concept of sustainable development in the agricultural sector, particularly in the context of Ukraine, where there was significant potential for its implementation due to the presence of fertile land and favourable climatic conditions. It was found that capital investment in the agricultural sector decreased to UAH 12.6 billion in 2023, followed by a slight increase to UAH 15.2 billion in 2024. The research highlighted the need to move away from traditional agriculture based on chemical fertilisers and pesticides towards sustainable methods, such as organic farming, bioenergy, and precision agriculture, which allowed for resource optimisation and a reduction in negative environmental impact. In particular, spending on environmental protection in agriculture increased to UAH 1,007.3 million in 2023, indicating greater attention to the restoration of natural resources. It was revealed that the main barriers to the implementation of sustainable practices remained the low level of digitalisation, insufficient financial support, and institutional constraints. Based on the results obtained, several promising areas for development were identified, such as the expansion of the circular economy, the implementation of precision agriculture, and the stimulation of investment in renewable energy sources. The findings emphasised the need for active state support, the creation of a favourable investment environment, and the development of scientific research to ensure the sustainable development

► **Suggested Citation:** Chupryna, N., Loza, S., Nekrasova, O., Kobenko, Yu., & Volianskyi, V. (2025). Models of innovative and investment development of farms in the context of ecological economics. *Ekonomika APK*, 32(4), 35-45. doi: 10.32317/ekon.apk/4.2025.35.

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of the agricultural sector. Strategies aimed at improving infrastructure, preserving natural resources, and increasing the efficiency of agricultural production could serve as the foundation for the creation of a resilient agricultural system capable of adapting to global challenges such as climate change and population growth

► **Keywords:** green technologies; precision agriculture; bioenergy; agricultural sector of Ukraine; state support

► Introduction

The development of the agricultural sector within the modern economy has been closely linked to the adoption of innovative approaches and the attraction of investment – key factors in ensuring its long-term sustainability and global competitiveness. This has necessitated a comprehensive reassessment of traditional farming methods in favour of innovative solutions capable of adapting the sector to evolving market and climate conditions. In this context, farms have become not only key producers of agricultural goods but also active participants in innovation and investment processes that account for economic, environmental, and social aspects of development. This approach has become particularly relevant in the face of global climate change, rapid land degradation, population growth, and the resulting increase in demand for environmentally friendly products.

One of the major challenges faced by farms in this process has been the insufficient funding for modern innovative technologies aimed at the efficient and rational use of natural resources. Combined with imperfect investment incentive mechanisms, limited access to financial instruments, and the weak integration of environmental principles into farm development strategies, this has hindered the adaptation to current market conditions. In particular, the absence of a systematic approach to innovation-driven investment development has created barriers to the adoption of modern technologies that not only increase efficiency but also minimise negative environmental impacts.

The theoretical framework for research in this area has been shaped by the concepts of sustainable development, ecological economics, and innovation management. The concept of sustainable development has focused on ensuring balanced economic growth, social well-being, and environmental preservation for future generations. Ecological economics has emphasised the integration of environmental protection measures into all areas of economic activity, including agriculture (Naumenkova *et al.*, 2024). Innovation management, in turn, has offered effective tools for the implementation of cutting-edge technologies that contribute to the optimisation of production processes and enhancement of the environmental safety.

In the context of researching innovation and investment development in farming, significant contributions have been made by various scholars, whose work has laid both the theoretical and practical foundations for analysing this topic. Notably, R.R. Danda (2023) highlighted the importance of technological innovations in enhancing the competitiveness of farms, emphasising that the integration of novel solutions into production reduces costs and optimises resource use. O. de Oca Munguia *et al.* (2021) stressed that innovation drives economic progress and that its application in agriculture transforms traditional land use methods into high-efficiency systems. V. Shcherbak & B. Shovkopyas (2023) explored mechanisms for attracting investment

into farms, focusing on the need to develop financial instruments accessible to small and medium-sized enterprises. The authors argued that effective financing stimulates both economic growth and the adoption of environmentally safe technologies. Meanwhile, J.F. Velasco-Muñoz *et al.* (2021) expanded on the principles of ecological economics, underscoring the importance of implementing circular economy practices in farming. The research stressed the need to shift from extensive to rational resource use. P. Yukhymenko *et al.* (2021) concentrated on the role of public policy in the development of farms, indicating that subsidies and tax incentives could be important drivers for investment in sustainable development. K. Pawlak & M. Kołodziejczak (2020) studied the role of institutions in ensuring a stable economic environment that supports farm development, emphasising the importance of conditions for long-term agricultural planning. M.M. Maja & S.F. Ayano (2021) pointed out that the economic development of agriculture is closely tied to demographic processes and that innovation in this sector can address food security challenges. H. Saleh *et al.* (2020) highlighted the importance of human capital in implementing innovations, noting that educational programmes and professional training for farmers are vital for the effective use of new technologies. R. Henry's (2020) study showed that agricultural intensification through innovation is an effective response to the rising demand for food products, particularly under conditions of limited natural resources. Finally, D. Pauschinger & F. Klauser (2022) emphasised that the adoption of digital technologies in farming, such as monitoring and data analysis systems, boosts productivity and reduces environmental pressure.

Thus, the research conducted by these authors demonstrates the diversity of approaches to the innovation and investment development of farms to ensure the sustainability, economic efficiency, and environmental responsibility. Despite the considerable academic interest in this area, several important aspects remain underexplored. Specifically, mechanisms for integrating environmental innovations into the business models of farms, with regard to regional specificities, have not been sufficiently studied. The relationship between the use of innovative technologies and the reduction of environmental pressure, as well as the role of public policy in encouraging the adoption of such technologies, also requires further investigation.

The aim of this study was to identify models for innovation and investment development in farms that ensure the effective implementation of environmentally oriented technologies and the creation of a resilient economic and ecological system in the context of current challenges. The objectives included analysing the current state of innovation and investment development in Ukrainian farms, identifying the factors influencing the investment attractiveness of environmental projects in agriculture, and developing recommendations for strengthening these efforts.

► Materials and methods

To study the sustainable development of Ukraine's agricultural sector in the context of ecological economics and innovation management, a comprehensive approach was used, incorporating several analytical methods. Statistical data obtained from the State Statistics Service of Ukraine (2023) served as the main source for analysing the economic situation in the agricultural sector. These data included indicators of production, capital investments, environmental protection expenditures, and other economic indicators that enabled the assessment of the state and trends in the development of the agricultural economy under sustainable development conditions. The study used statistical data from 2020 to 2023, as this period allowed for an evaluation of current sectoral development trends, while data for 2024 had not yet been published at the time of analysis. However, this does not apply to capital investments in agriculture, forestry and fisheries (State Statistics Service of Ukraine, n.d.). A comparative analysis method was applied to assess changes in the agricultural economy against the backdrop of climate change, the political situation, and external influences.

One of the main aspects of the work involved researching the implementation of innovative technologies in the agricultural sector, particularly precision farming, bioenergy, and organic agriculture. The research methodology also included exploring the potential for innovation integration into the production processes of agricultural enterprises. In particular, it analysed which technologies were the most promising for different regions of Ukraine under resource constraints and the need to preserve natural resources. This allowed for the assessment of which investment models were the most effective for the development of the agricultural sector and identified the barriers to large-scale innovation implementation. To analyse investment opportunities, methods for evaluating the investment attractiveness of agricultural enterprises were used, along with assessments of the economic efficiency of implementing "green" technologies.

Additionally, an analysis of government policy in the agricultural sector was conducted, focusing on the funding of scientific research, state programmes, and subsidies for farmers engaged in organic farming or using renewable energy sources. This analysis revealed key issues and opportunities for improving state support for sustainable development in the agricultural sector. The policy analysis method was used, involving the study of existing government initiatives and the effectiveness in the context of sustainable agricultural development. Another important stage of the study involved examining the environmental aspects of agricultural production. An ecological analysis method was used to assess the environmental impact of different forms of agricultural production. This included analysis of environmental protection expenditures, the use of biological and chemical pest control agents, and methods for preserving biodiversity on agricultural lands.

The effectiveness of sustainable practices in the agricultural sector was evaluated using a cross-country comparison method. Compared to other countries such as the Netherlands, Switzerland, Germany, Poland, and the USA, Ukraine's potential for developing organic farming,

bioenergy projects, and precision agriculture was analysed. The selection of countries for comparison was based on the experience in implementing sustainable agricultural practices and the level of sectoral development. For this comparison, international reports and studies were used. This comparison helped identify weaknesses and prospects for developing innovation management in Ukraine's agricultural sector.

► Results

The concept of sustainable development has become one of the central ideas in modern economic, environmental, and social policy. Its primary aim is to ensure a balance between three key pillars: economic growth, environmental preservation, and social well-being. This concept holds that the planet's resources must be utilised in such a way that current needs are met without compromising the ability of future generations to meet the own needs (Ruggerio, 2021). The agricultural sector plays a vital role in realising the principles of sustainable development, as it is directly linked to the use of natural resources such as soil, water, biodiversity, and energy. Traditional farming methods, focused on maximising production, often lead to resource depletion, land degradation, and pollution of water and air. As a result, these approaches not only pose environmental threats but also undermine the long-term productivity of the agricultural sector itself (Harwood, 2020).

Sustainable agriculture involves a shift towards methods that prioritise environmental safety, social responsibility, and economic efficiency. For example, the implementation of precision farming technologies enables the efficient use of fertilisers and pesticides, thereby reducing the environmental impact (Tkachenko & Tykha, 2020). Organic farming is gaining popularity due to its ability to maintain soil fertility and support biodiversity. One of the key principles of sustainable development is the efficient use of resources. In the agricultural context, this means optimising water use through drip irrigation systems and rehabilitating degraded lands using reclamation technologies (Stephens *et al.*, 2020). In addition, growing attention is being paid to the use of renewable energy sources such as biogas plants, solar panels, and wind turbines, which can be integrated into farming operations.

Sustainable development also encompasses social aspects. The agricultural sector should provide decent working conditions, support employment in rural areas, and strengthen local communities. This is crucial not only for social stability, but also for preserving the cultural and economic potential of rural regions. The concept of sustainable development offers a pathway toward creating a resilient agricultural system that ensures food security, conserves natural resources, and contributes to socio-economic development (Rexhepi *et al.*, 2024). In the long term, this is the only viable approach to preserving the viability of the agricultural sector and ensuring its adaptation to global challenges such as climate change, population growth, and resource scarcity.

Ecological economics is a fundamental component of sustainable development, combining economic, social, and environmental aspects to create a resilient system of production and consumption. In the context of farming, ecological economics plays a critical role, as this sector is

heavily reliant on natural resources and significantly impacts ecosystems. The primary goal of ecological economics is to integrate environmental principles into economic activities to strike a balance between production needs and ecological constraints (Prokopowicz, 2020). Farms guided by ecological economic principles emphasise the rational use of natural resources. This involves moving away from extensive agriculture, characterised by land exhaustion and excessive chemical use, towards integrated systems that consider resource renewability. For instance, organic farming methods reduce reliance on synthetic fertilisers and pesticides, helping to preserve soil fertility and reduce water and air pollution (Shuvar *et al.*, 2022).

Ecological economics also promotes the implementation of circular models on farms, which focus on minimising waste and reusing resources. Practices such as composting organic waste or using biogas systems to process agricultural residues allow farms to significantly reduce the environmental footprint and lower energy costs (Andreitsev *et al.*, 2024). Another important aspect is the economic valuation of natural resources. Ecological economics offers methods to account for the value of ecosystem services such as air purification, water cycle regulation, and biodiversity maintenance (Xia & Ruan, 2020). This approach helps farms recognise the real value of natural capital, encouraging more responsible environmental stewardship. Beyond technological solutions, ecological economics places emphasis on social factors. Sustainable farms create jobs, reduce rural outmigration, and contribute to the development of local communities (Washington & Maloney, 2020). For example, using environmentally friendly approaches can increase demand for high-value-added products such as organic goods or locally produced items, which in turn strengthens rural economies.

The relevance of ecological economics to farming also lies in its capacity to help adapt to climate change (Brych *et al.*, 2023). Measures such as reducing greenhouse gas emissions through low-carbon technologies or establishing agroforestry systems that limit soil erosion exemplify this adaptation. These initiatives help farms become more resilient to climate risks such as droughts, floods, and extreme temperatures (Tkachenko & Voronin, 2024). Government policy plays a vital role in the implementation of ecological economics principles. Incentivising farmers through financial tools – such as subsidies for green technologies or tax benefits for reducing environmental impacts – serves as a strong motivator for adopting sustainable models. Educational programmes that raise farmers' awareness about the benefits of eco-friendly solutions and the long-term impact on farm productivity are equally important.

Innovation management is a powerful tool enabling farms to enhance production efficiency, respond to market challenges, and ensure sustainable development. At its core, innovation management involves adopting new technologies, management practices, and organisational

solutions aimed at optimising resource use, reducing costs, and boosting competitiveness. In agriculture, innovation management plays a pivotal role in securing productivity (Gama & Magistretti, 2023). One example is the use of precision agriculture technologies. Tools such as GPS navigation, soil moisture sensors, drones for crop monitoring, and data analysis software allow farms to plan production processes more accurately. This significantly reduces spending on fertilisers, water, and pesticides, while also minimising environmental impact (Sharma *et al.*, 2020).

Another key area of innovation management is digitalisation. The integration of modern information technologies, such as cloud platforms, mobile farm management apps, and automated data collection systems, allows farmers to control every stage of production more effectively. For example, software can analyse data on weather conditions, soil status, and crop needs, providing real-time recommendations (Abbasi *et al.*, 2022). Innovation management also includes the introduction of biotechnologies, which enhance the quality and productivity of crops. The use of biological pest control agents or genetically modified drought- and disease-resistant varieties ensures high yields even under unfavourable climatic conditions.

Furthermore, building energy resilience is a key aspect of innovation management. Renewable energy sources such as solar panels, wind turbines, and biogas plants are becoming increasingly popular on farms. These technologies help reduce reliance on traditional energy sources, lower greenhouse gas emissions, and cut energy costs. Innovation management also contributes to optimising logistics and product distribution. With tools like e-commerce platforms, direct-to-consumer sales channels, and digital marketing, farms can expand the market reach, reduce dependence on intermediaries, increase profitability, and establish direct connections with end consumers.

Human capital development is a crucial component of innovation management. Training farmers in modern technologies, expanding the knowledge of sustainable practices, and strengthening innovation competencies enable faster adoption of advanced solutions. Educational programmes, training sessions, partnerships with research institutions, and the exchange of best practices lay the foundation for the effective use of innovative tools (Khoshmaram *et al.*, 2020). Farms in Ukraine play an important role in ensuring food security, boosting export potential, and supporting the country's economic stability. However, the current state of innovation and investment development in the sector is uneven, influenced by both external and internal factors. On the one hand, Ukraine possesses significant natural potential for agricultural development, including fertile soils and a favourable climate. On the other hand, a range of economic, technological, and institutional barriers hinders the full-scale adoption of innovations and investment attraction. Table 1 presents the economic accounts of the agricultural sector.

Table 1. Economic accounts of agriculture in Ukraine for 2018-2023, UAH billion

No.	Types/groups of products/activities	2020	2021	2022	2023
1	Cereal crops	309.7	538.9	334.1	320
2	Industrial crops	209.9	393.1	294.3	310.5
3	Fodder crops	10.4	13.9	11.7	12.2
4	Vegetable crops	49.2	59.7	83.2	91

Table 1, Continued

No.	Types/groups of products/activities	2020	2021	2022	2023
5	Potato	60.9	61.2	54.2	55.5
6	Fruits, berries, grapes	26.8	28.8	24.1	26
7	Other crop products	3.5	4.6	9.5	10.3
8	Crop production output as a whole	670.4	1,100.2	811.1	825.5
9	Livestock (raising of farm animals)	110.4	127.9	136.6	140
10	Livestock products	93.6	109.7	107	108.3
11	Livestock production in general	203.9	237.6	243.6	248.3
12	Agricultural product output	874.4	1,337.8	1,054.7	1,073.8
13	Agricultural services output	13.5	21.6	14.9	15.5
14	Agricultural production output	887.8	1,359.4	1,069.6	1,089.3
15	Output of non-agricultural integral secondary activities	5	7.1	4.4	4.6
16	Agricultural output	892.9	1,366.5	1,073.9	1,093.9
17	Intermediate consumption	511.5	789.6	637	645
18	Gross value added	381.4	576.8	437	448.9

Source: based on State Statistics Service of Ukraine (2023)

The year 2021 marked a peak in agricultural production, driven by favourable weather conditions and increased exports of grain and industrial crops. However, in 2022, production declined due to the negative impact of the war, which led to a reduction in cultivated land areas, logistical difficulties, and limited access to financing. In 2023, the sector showed signs of partial recovery. Although output of grain and industrial crops slightly decreased compared to 2021, there was an increase in the production of vegetables and potatoes, indicating the adaptation of farms to the new conditions. Despite these changes, the gross value added by agriculture has remained at pre-war levels, underscoring the importance of innovation-driven investment to improve production efficiency. Recovery of the sector requires the implementation of modern technologies, enhancement of infrastructure, and attraction of investment – especially into environmentally oriented projects. The low level of investment in science and innovation presents

a significant barrier to the adoption of modern technologies that could enhance production efficiency, ensure environmental sustainability, and help farms adapt to climate change. Insufficient funding makes it impossible to develop large-scale innovative projects, which require considerable resources and long-term research. The development of Ukraine's agricultural sector demands a fundamental reassessment of approaches to financing scientific research. The key task is not only to increase expenditure but also to ensure its effective allocation. This can be achieved through the attraction of private capital, partnerships with international organisations, and the integration of innovation into the sector's strategic development programmes. To ensure the sustainable development of the agricultural sector, it is essential to invest in the modernisation of technical infrastructure, the introduction of innovative technologies, and the improvement of production efficiency. Table 2 presents capital investments in agriculture, forestry, and fisheries.

Table 2. Capital investments in agriculture, forestry, and fisheries for 2020-2024, UAH million

Year	2020	2021	2022	2023	2024 (January-September)
Volume of capital investments	36,442.1	49,127.4	32,604	31,641.9	31,821.7
Investments in tangible assets	35,756.7	48,198.6	32,099.7	30,644.3	30,896.9
Of them					
Residential buildings	64.8	99.2	65.6	159.5	38.8
Non-residential buildings	6,735.8	7,485	4,937.9	4,609.8	4,112.3
Engineering structures	1,656.9	2,655.1	1,793.6	2,054.9	1,349.8
Machinery, equipment, and inventory	18,188	24,978.2	15,751.8	12,554	15,156.9
Vehicles	4,868	7,598	5,074.5	5,798.7	5,827.5
Earth	126.7	149.7	68	81.5	1,131.4
Long-term biological assets of crop and livestock production	3,765.4	4,698.5	4,022	4,860.2	2,879.2
Other tangible assets	351.1	534.9	386.3	525.6	401
Investments in intangible assets	685.4	928.8	504.3	997.7	924.9
Of them					
Software and databases	33.9	85.2	53.8	80.2	71.5

Source: based on State Statistics Service of Ukraine (n.d.)

The bulk of investment continues to be directed towards tangible assets, particularly machinery, equipment, and tools. However, the share has also decreased: in 2023, investment stood at UAH 12.6 billion, with a modest increase to UAH 15.2 billion in 2024. Investment

in non-residential buildings and engineering structures remains low, indicating a slowdown in infrastructure expansion. The reduction in investments in long-term biological assets to UAH 2.8 billion in 2024 reflects high risks in livestock and crop production. Meanwhile,

investments in intangible assets, such as software, remain negligible, signalling insufficient digitalisation within the sector. Overall, to revitalise and develop the agricultural sector, it is essential to stimulate investment in innovation, infrastructure, and digital technologies, which would enhance the competitiveness of farming enterprises and the resilience to challenges.

One of the most significant issues remains the insufficient level of financing for farms. Small and medium-sized farming businesses often face limited access to credit due to high interest rates, low financial capacity, and limited state support. Many farms, in particular, are unable to invest in modern technologies that are fundamental to innovative development. The state of innovation implementation also depends on the level of technical equipment available to farmers. Despite the availability of modern technologies – such as drones, precision farming systems, and automated management platforms – the adoption remains limited. The main reasons for this include the high cost of equipment, a lack of awareness among farmers regarding the benefits of new technologies, and a shortage of technical support at the local level.

At the regional level, there is a marked disparity in the development of farming enterprises. In the southern and central regions, where large agricultural holdings are concentrated, innovative solutions are adopted more actively.

In contrast, in the western and northern regions, where small and medium-sized farms dominate, innovation and investment activity is significantly weaker. This disparity is driven not only by differences in financial capacity but also by unequal access to modern knowledge, technologies, and infrastructure. While government support is aimed at stimulating farm development, it remains insufficient. Funding programmes, such as compensation for the cost of agricultural machinery or support for organic production, do exist, but the coverage is limited. Moreover, complex procedures for obtaining subsidies and grants hinder farmers' access to these resources.

A noteworthy aspect of the current situation is the growing interest in environmentally-oriented production. Ukrainian farmers are gradually beginning to recognise the advantages of organic farming, renewable energy sources, and environmental protection practices. However, the implementation requires substantial investment and training, posing yet another challenge for small and medium-sized enterprises. Regarding the investment climate, foreign investors have shown interest in cooperating with Ukrainian farms, particularly in organic production and the use of renewable energy. However, the unstable economic situation, war, and regulatory constraints create risks that deter investment. Table 3 presents environmental protection expenditures in agriculture.

Table 3. Environmental protection expenditures in agriculture, forestry, and fisheries for 2021-2023, million UAH

Year	2020	2021	2022	2023
Current expenses	373.4	479.4	412.4	1,007.3
Air protection and climate change issues	–	12.7	11.9	29.1
Waste water treatment	–	11	7.5	14.1
Waste management	–	19.2	16.2	15.1
Protection and rehabilitation of soil, groundwater, and surface water	–	11.1	12.8	680.7
Other measures	–	425.3	363.9	268.3

Source: based on State Statistics Service of Ukraine (n.d.)

Expenditures on environmental protection in agriculture, forestry, and fisheries demonstrate important dynamics, reflecting certain shifts in environmental policy priorities. In 2020, total spending amounted to UAH 373.4 million. By 2023, this had risen significantly to UAH 1,007.3 million, likely due to the implementation of large-scale natural resource rehabilitation programmes. The most substantial increase was observed in expenditures on the protection and rehabilitation of soils and both groundwater and surface water: from UAH 12.8 million in 2022 to UAH 680.7 million in 2023. This indicates a growing recognition of land degradation as a critical issue for the agricultural sector. At the same time, expenditures on air protection, wastewater treatment, and waste management remain relatively low, suggesting insufficient attention to these areas.

Amid global challenges related to natural resource degradation, climate change, and growing demand for environmentally friendly products, the development of farming in Ukraine requires innovative and investment-driven approaches. In the context of ecological economics, which aims to balance economic growth with environmental preservation, farmers must adapt the production processes, adopt advanced technologies, and actively attract investment. This will ensure the sector's sustainability,

minimise environmental risks, and enhance competitiveness. A key area for improving innovation-investment models is the adoption of circular economy principles. This involves resource reuse and minimisation of waste. For instance, organic livestock waste can be converted into biogas or compost, providing farms with energy independence and improving soil quality. A successful example of such practices can be found in Europe, particularly in the Netherlands, where farmers widely utilise biogas facilities (Westhoek & Boezeman, 2024). As of 2025, this direction is still developing in Ukraine, but the government should encourage farmers through grants, tax incentives, or subsidies to implement such solutions.

Another crucial element is the development of precision agriculture. The use of drones, sensors, and satellite technologies enables farmers to collect data on field conditions, soil moisture, and plant disease levels. This allows for precise application of fertilisers and pesticides, reducing costs and minimising environmental impact. For example, farmers in the USA actively use automatic tractor control systems, which not only save fuel but also improve productivity (The self-driving tractor..., 2025). In Ukraine, as of 2025, such technologies are increasingly being adopted, but the technologies remain largely accessible only to large farms due to the high cost.

Organic farming also represents a promising direction. Ukraine has significant potential in this area thanks to fertile soils and favourable climatic conditions. However, to expand the area under organic cultivation, government support is needed in the form of certification programmes, grants, and assistance in accessing international markets. Switzerland is a leader in organic farming due to its well-designed government policy and broad support for farmers (Organisation for Economic Co-operation and Development, 2023). In Ukraine, as of 2025, there are successful examples of organic production, but it has yet to become widespread.

Environmentally focused infrastructure investments are also of great importance. For example, implementing drip irrigation systems can significantly reduce water use and increase crop yields. This is especially relevant for southern regions of Ukraine, which suffer from water shortages. Other investments could include building modern logistics centres for produce storage, helping reduce harvest losses and maintain quality. Bioenergy is another strategic area for development. Farmers can install solar panels, wind turbines, or biogas plants to supply farms with alternative energy. In Germany, for example, farmers widely use biogas systems, allowing the farmers to sell surplus energy to the national grid, creating an additional income source (Park & Grundmann, 2025). In Ukraine, as of 2025, this area is still emerging but holds significant potential for scaling up.

State involvement is crucial to support innovative and investment-driven development. It should create a favourable investment climate through a stable legal framework, tax incentives for green projects, and access to concessional financing. Furthermore, public-private partnerships should be promoted to attract foreign investment and cutting-edge technologies. For instance, Poland has successfully established agritech hubs like the Poznań Science and Technology Park, which bring together research institutions, agricultural companies, and start-ups to drive innovation in agriculture. Creating similar hubs in Ukraine could accelerate agrotechnology development and boost the sector's competitiveness.

In conclusion, improving innovation-investment development models for farms within the framework of ecological economics is an integral part of sustainable agricultural development in Ukraine. The integration of modern technologies, development of the circular economy, bioenergy, and organic farming, as well as support from the state and international partners, will ensure farm sustainability, improve efficiency, and minimise environmental impact. These models will contribute not only to economic growth but also to building an environmentally responsible agricultural sector, laying the foundation for Ukraine's future development.

► Discussion

The study of sustainable development in Ukraine's agricultural sector within the context of ecological economics and innovative management has shown that, despite considerable potential, this sector faces a number of challenges that require resolution at both policy and practical levels. Barriers to the implementation of innovations, environmentally friendly technologies, and sustainable practices were identified, encompassing both economic and social aspects. This underscores the need for a comprehensive

approach to ensure sustainable agricultural development. Analysis of results indicates that infrastructure for large-scale implementation of precision farming in Ukraine is insufficiently developed. GPS navigation technologies, drones, and data analysis for resource optimisation are already actively used in some regions of Ukraine, but the prevalence is still not widespread enough to mark a mass shift to these innovations (Remeshevska *et al.*, 2021; Horbal & Makarova, 2023). This is due both to the high initial costs of adopting such technologies and the lack of adequate qualifications among farmers. Similar problems are observed in other developing countries, but in Ukraine, these problems are more pronounced due to economic instability and uncertainty in agricultural policy. In the work, K. Takahashi *et al.* (2020) examined the impact of modern agricultural technologies on farming efficiency, particularly the use of drones, GPS navigation, automated control systems, and other innovative solutions that form the basis of precision farming. The authors noted that such technologies significantly reduce production costs and increase yields through precise monitoring of soil and crop conditions, allowing timely responses to changing environments. Y. Hu *et al.* (2022) also highlighted that economic benefits increase with the adoption of innovative technologies, but successful implementation requires substantial financial support for agricultural enterprises. Current findings align with the authors' conclusions about the importance of precision farming technologies. However, the current study focuses more on the environmental aspects and identified implementation barriers, which are less emphasised in the cited works.

Analysis of state policy in the agricultural sector revealed a significant issue – the low effectiveness of government programmes supporting sustainable agricultural development. Although programmes for supporting organic farming, bioenergy development, and environmentally friendly technologies exist, these technologies often suffer from limited funding and poor implementation at the local level (Romankiewicz *et al.*, 2023). This suggests a need to revise national agricultural policy and increase investment in sustainable farming development. Similar conclusions were drawn in studies from other countries, where government support proved critical for implementing innovative agricultural technologies. J. Streimikis & T. Baležentis (2020) analysed the effectiveness of sustainable development support programmes in the agricultural sector, noting that many fail to achieve the goals due to political instability and insufficient funding. The authors proposed optimising existing programmes and increasing financial support for ecological initiatives. These results align with current findings on the ineffectiveness of state programmes and the importance of boosting investment in sustainable agricultural development. While the authors stressed the need for policy reforms, the current study emphasised economic and social barriers.

T. Havemann *et al.* (2022) explored the potential for attracting private investment in sustainable agriculture and assessed the role of state support programmes. The authors argued that attracting investors effectively is only possible under stable economic conditions and with a favourable investment climate. The conclusions align with current findings regarding the importance of state

funding for sustainable development of the agricultural sector. However, the present study focuses more on specific economic and social barriers impeding sustainable practices, while the authors place greater emphasis on state mechanisms and the role of the private sector.

Regarding environmental aspects, the research confirms the importance of transitioning to organic farming and preserving biodiversity. In this context, programmes supporting environmentally friendly production and rural enterprises that operate according to sustainable standards play a significant role (Rudavska *et al.*, 2023). However, the study showed that only a small proportion of agricultural enterprises in Ukraine are currently ready to transition to organic farming, primarily due to the high costs of certification and production process organisation. H. Aghasafari *et al.* (2020) focused on the state of organic farming, noting that although it holds great potential, development is hampered by high certification costs and an uncertain organic product market. Z. Ferdous *et al.* (2021) also noted that only some farmers can afford to switch to organic farming due to limited financial capacity, creating barriers to widespread adoption despite long-term ecological and economic benefits. The authors' findings align with current results, particularly concerning the importance of organic farming development and the obstacles to its widespread adoption. While the authors concentrated more on the technical aspects, the current study focuses on how these barriers affect sustainable development.

Another important issue is the lack of proper infrastructure for developing bioenergy in the agricultural sector. Bioenergy projects have considerable potential in Ukraine, given the country's rich resources for bioenergy production (Borysiak *et al.*, 2022). However, there are currently no effective mechanisms for advancing this field. International experience shows that agricultural bioenergy can be effective only through close cooperation between government institutions, the private sector, and research organisations. A. Bharti *et al.* (2021) explored the potential of bioenergy in agriculture, highlighting the use of biomass for energy production as a way to reduce reliance on traditional energy sources and lower energy costs in farming. However, A. Abdullah *et al.* (2021) stressed that the lack of infrastructure and investment creates serious barriers to the development of bioenergy technologies, limiting the wide-scale adoption in agriculture. The authors' findings reflect aspects of the current study, particularly the importance of developing bioenergy. Nevertheless, the present research places more emphasis on environmental aspects rather than the economic and infrastructural challenges. M. Qaim (2020) examined the influence of international organisations and foreign investment on the development of sustainable agriculture. The author noted that international programmes and funds play a crucial role in financing ecological initiatives, but the effectiveness is limited by the country's political and economic situation. While the author emphasises the role of international investors, the current study focuses more on domestic economic barriers and policy. The author draws attention to external factors that could help implement sustainable practices.

The analysis also confirmed that developing sustainable agriculture in Ukraine requires significant

enhancement of educational programmes for farmers and infrastructure to support innovations. This includes creating advisory centres, access to modern agricultural technologies, and a more active role for local authorities in implementing national initiatives at the local level. E. Raji *et al.* (2024) studied challenges in sustainable agriculture development, particularly stressing the need for improved educational programmes for farmers and the development of relevant infrastructure to support innovative initiatives in the agricultural sector. The authors highlighted the importance of advisory centres to help small and medium-sized farmers navigate rapid changes in agriculture and adapt to new technological demands. The current findings confirm the importance of these aspects, as effective implementation of innovative technologies is impossible without proper training and infrastructure support at the local level. In conclusion, although Ukraine's agricultural sector has significant potential for sustainable development, achieving this requires substantial changes in state policy, financing, infrastructure, and education. The implementation of innovative and environmentally friendly technologies, support for organic farming, and bioenergy development can become the main drivers of sustainable growth in the country's agricultural sector.

► Conclusions

The research results showed that sustainable development in agriculture includes the implementation of innovative technologies such as precision farming, organic production, and the use of renewable energy sources. The use of organic farming methods contributes to the preservation of soil fertility and the maintenance of biodiversity. For example, in Ukraine in 2021, spending on environmental protection in the agricultural sector amounted to UAH 479.4 million, but due to crisis conditions related to the war, in 2022 this decreased to UAH 412.4 million. In 2023, this spending increased again, reaching UAH 1,007.3 million, indicating growing attention to the issue of environmental sustainability.

In 2023, the volume of capital investment in the agricultural sector amounted to UAH 12.6 billion, but even so, investment in infrastructure and digital technologies remains low, particularly in intangible assets such as software, which continue to be at a low level. This indicates limited digitalisation in agriculture, which is an important factor in increasing the efficiency and resilience of agricultural enterprises. Nevertheless, Ukrainian farmers are gradually beginning to adopt new environmental practices. Thus, in 2023, there was an increase in spending on soil and water resource protection, which indicates a growing interest in sustainable and environmentally safe farming methods. However, for further development, it is important to increase public funding for scientific research, encourage investment in innovative technologies, and modernise infrastructure.

Therefore, to ensure the sustainable development of Ukraine's agricultural sector, it is necessary to increase investment in innovation and infrastructure, as well as to support the implementation of new environmentally oriented technologies. The active role of the state in creating favourable conditions for investment, including through tax incentives and subsidies, as well as the development of

public-private partnerships, is key to the successful transformation of the agricultural industry. A limitation of the study is the lack of available data due to the impact of the war on economic indicators and limited funding in the agricultural sector. Further research should focus on a deeper analysis of the effectiveness of sustainable technologies in agricultural production and the role of state support in the development of innovation.

► Acknowledgements

None.

► Funding

None.

► Conflict of Interest

None.

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Моделі інноваційно-інвестиційного розвитку фермерських господарств у контексті екологічної економіки

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► **Анотація.** Дана робота була направлена на аналіз сучасних підходів до розвитку фермерських господарств через призму інновацій та інвестицій, а також вивчення їхнього впливу на сталий розвиток та екологічні аспекти економіки. У роботі досліджувалась концепція сталого розвитку в аграрному секторі, зокрема в контексті України, де є значний потенціал для її впровадження через наявність родючих земель і сприятливих кліматичних умов. Було встановлено, що капітальні інвестиції в агросектор скоротилися у 2023 році до 12,6 млрд грн, з подальшим незначним зростанням до 15,2 млрд грн у 2024 році. Дослідження підкреслило необхідність переходу від традиційного сільського господарства, що базується на хімічних добривах та пестицидах, до сталих методів, таких як органічне землеробство, біоенергетика та точне землеробство, що дозволяє оптимізувати використання ресурсів та зменшити негативний екологічний вплив. Зокрема, витрати на екологічний захист у сільському господарстві у 2023 році зросли до 1007,3 млн грн, що вказує на підвищену увагу до відновлення природних ресурсів. Виявлено, що ключовими бар'єрами на шляху впровадження сталих практик залишаються низький рівень цифровізації, недостатність фінансової підтримки та інституційні обмеження. На основі отриманих результатів визначено перспективні напрямки розвитку, такі як поширення циркулярної економіки, впровадження точного землеробства та стимулювання інвестицій у відновлювані джерела енергії. Отримані дані підкреслили необхідність активної державної підтримки, створення сприятливого інвестиційного середовища та розвитку наукових досліджень для забезпечення сталого розвитку аграрного сектору. Стратегії, спрямовані на покращення інфраструктури, збереження природних ресурсів і підвищення ефективності аграрного виробництва, можуть стати основою для створення стійкої аграрної системи, що адаптується до глобальних викликів, таких як зміна клімату та зростання популяції

► **Ключові слова:** зелені технології; точне землеробство; біоенергетика; аграрний сектор України; державна підтримка



UDC 332.1:004.77:338.43

Use of financial technologies to increase transparency of agricultural market

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► **Abstract.** The study aimed to analyse the role of financial technologies in increasing transparency in the agricultural market and determine the potential to address key issues in the sector. The study examined the effectiveness of financial technologies such as blockchain, digital platforms, peer-to-peer (P2P) lending, InsurTech and RegTech in increasing the transparency of the agricultural market and optimising agricultural processes. The study determined that the introduction of financial technologies significantly improves the transparency of the agricultural market, reducing opportunities for corruption and price manipulation. The use of blockchain technologies in agricultural transactions ensures data integrity and transparency in the supply chain, which can be used to trace the origin of products, reducing the risk of fraud. Digital platforms for agricultural trading enable farmers to interact directly with buyers, which ensures fair market prices and eliminates the role of intermediaries, reducing costs. The analysis showed that FinTech solutions, such as P2P lending, enable farmers to obtain financing on more favourable terms, which makes it easier for small and medium-sized agribusinesses to access credit. Innovative risk insurance solutions, such as InsurTech, using satellite data to assess climate threats, can be used to respond quickly to natural disasters and minimise losses. The study also confirmed that the use of big data and artificial intelligence technologies enables accurate forecasting of yields and demand for agricultural products, making the agricultural sector more predictable and sustainable. Thus, FinTech technologies help to optimise financial flows and reduce risks in the agricultural sector

► **Keywords:** blockchain; digital platforms; P2P lending; InsurTech; risk insurance; artificial intelligence

► **Suggested Citation:** Shebanina, O., Kormyshkin, Iu., Drobitko, A., & Potryvaieva, N. (2025). Use of financial technologies to increase transparency of agricultural market. *Ekonomika APK*, 32(4), 46-57. doi: 10.32317/ekon.apk/4.2025.46.

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► Introduction

The agricultural sector is one of the main components of the economy of many countries, including Ukraine, and its development directly affects food security and economic stability. However, the sector faces numerous challenges, such as market opacity, corruption risks, lack of access to finance for small and medium-sized farmers, and inefficient management of agricultural resources. In this context, financial technologies (FinTech) can make a significant difference by increasing transparency, making financial services more accessible and reducing risks. Innovations in blockchain technology, digital platforms, peer-to-peer (P2P) lending, risk insurance and the use of artificial intelligence can make the agricultural sector more efficient, resilient and open.

The problem of transparency and efficiency of the agricultural market remains relevant in many countries, as many farmers and agrarians face difficulties in obtaining financing, as well as high risks associated with climate change and natural disasters (Babash *et al.*, 2025). S. Menon & K. Jain (2021) highlighted how blockchain technologies can ensure transparency of transactions in agriculture by tracking the supply chain of products. Reduction of the risks of data falsification and abuse was achieved using distribution ledgers. O.O. Ajayi *et al.* (2024) highlighted that digital platform have contributed to reducing farmers' dependence on intermediaries, leading to more transparent and efficient trading. Such platforms also provide fairer prices for the products by reducing transaction costs. Z. Chen *et al.* (2021) emphasised the importance of using automated data collection systems to forecast prices and demand for agricultural products. The study also highlighted that accurate analytical tools can reduce the economic risks of farmers. M. Soekarni *et al.* (2024) studied the benefits of P2P lending for small farmers who usually did not have access to traditional finance. This reduced interest rates and facilitated the process of obtaining loans. F. Rufaidah *et al.* (2023) analysed how financial technologies have helped reduce barriers to investment in the agricultural sector. The study also emphasised the importance of digital platforms for raising funds from a variety of investors.

K. Bezas & F. Filippidou (2023) studied the role of artificial intelligence in the agricultural sector, in particular in creating accurate yield forecasts. The study also noted that artificial intelligence (AI) can help farmers plan production efficiently and optimise the use of resources. B. Sheehan *et al.* (2023) explored the potential of using Insurance Technology (InsurTech) to reduce the risks associated with natural disasters such as droughts and floods. The speed of insurance payments accelerate recovery from losses. L. Grassi & D. Lanfranchi (2022) addressed the use of Regulatory Technology (RegTech) to automate the monitoring of land transactions. This reduced the level of raider attacks and abuses in land issues. N. De la Peña & O.M. Granados (2024) highlighted the importance of open data in the agricultural sector, which helped to reduce information asymmetry between market participants. Access to this data facilitated planning for farmers and ensured equal access to markets. M. Kumarathunga *et al.* (2022) studied the role of digital currencies and stablecoins in international agribusiness payments, which reduced the cost of foreign exchange transactions. The use

of such currencies for transactions between international partners ensured speed and security.

In summary, existing research reveals the importance of financial technologies for increasing agricultural market transparency, but many aspects, such as the impact on small farms, regulation of digital platforms, and adaptation of technologies to the specific conditions of different countries, require further study. The study aimed to examine the role of FinTechs in the agricultural market, analyse their impact on improving transparency, reducing corruption risks optimising financial flows, and identify potential areas for the development of these technologies in agriculture.

Research objectives:

1. To consider the main mechanisms for using digital financial instruments to reduce corruption risks in the agricultural sector.

2. To assess the effectiveness of these technologies in optimising financial flows between farmers, suppliers and consumers.

3. To identify the prospects for the development of FinTech in agriculture in the context of current economic challenges.

► Materials and methods

The study analysed how various digital tools and platforms can address the many challenges faced by the sector. The study examined the effectiveness of financial technologies such as blockchain, digital platforms, agri-finance through P2P lending, InsurTech and RegTech in addressing issues of transparency, anti-corruption, access to finance and optimisation of agricultural processes. The study also examined successful examples of the use of FinTech solutions in the agricultural sector of different countries. For the analysis, countries that are actively implementing digital financial technologies in the agricultural sector and demonstrate positive results of application were selected. For example, platforms such as AgriLedger (n.d.) (UK), Agri Marketplace (n.d.) (Portugal) and Hectare Trading (n.d.) (UK) have demonstrated how modern technologies can help increase supply chain transparency, optimise trade processes and facilitate farmers' access to finance. In the United States and Australia, blockchain-based platforms, such as GrainChain (n.d.) and AgriDigital (n.d.), have significantly increased the efficiency of agricultural trade by providing instant payments and transparency in transaction processes. These countries have developed infrastructure for digital payments and regulatory support for FinTech initiatives. Indonesia was chosen due to the active use of Big Data and blockchain in agriculture. The HARA (n.d.) platform helps to collect and analyse agricultural data, which enable informed management decision-making and increase productivity. Kenya, as one of Africa's leaders in FinTech, was included in the study because of its successful application of digital financial solutions for small farmers. The Farmdrive (n.d.) platform uses FinTech to analyse farmers' data, providing them with access to credit and promoting financial inclusion.

In addition, innovative Ukrainian projects such as AgriChain (n.d.), SmartFarming (n.d.) and Kernel (n.d.), which actively use digital platforms to automate agricultural processes and facilitate farmers' access to finance, were studied. All these projects are aimed at reducing costs

and increasing transparency in the agricultural sector of Ukraine, which is an important factor in the development of the national economy and stimulating investment in agriculture. To assess the effectiveness of FinTech solutions in Ukraine, a comparative analysis was conducted with the practices of other countries. The comparison was based on key indicators, such as the level of digitalisation of the agricultural market, access to finance for farmers, the spread of blockchain technologies in the land registry and agricultural transactions, and the impact of FinTech solutions on reducing operating costs. The study also addressed government support for the implementation of digital solutions, the investment attractiveness of the sector, and the availability of regulatory mechanisms that promote the development of financial technologies.

The study analysed the use of blockchain technologies for agricultural transactions in Ukraine to assess their effectiveness in increasing transparency and reducing corruption risks (Iermakova *et al.*, 2022). Digital platforms for agricultural trading, such as AgroTrade, FarmMarket, CropBuy, AgriConnect, and RuralMarket, were also studied to help optimise the purchase and sale processes and eliminate intermediaries (Prikhodko *et al.*, 2022). Particular attention was paid to the dynamics of the growth of financing through P2P lending for farmers to assess its impact on the availability of financial resources for farmers (IMARC Group, n.d.). In addition, the development of FinTech in agriculture at the global level was studied to compare the implementation of financial technologies in Ukraine and other countries and identifying key factors for the successful use of FinTech solutions in this area (Peng *et al.*, 2023). One of the key aspects of the research was the study of technological solutions that can ensure transparency at all stages of agricultural production, from production to sales. The use of blockchain technologies to guarantee the integrity of transaction data, track product supply chains and register land ownership was addressed.

► Results

The agricultural sector is an important component of any country's economy, but it faces several challenges that make it difficult to operate efficiently and transparently. One of the most pronounced is asymmetry of information when market participants do not have equal access to data on prices, supply and demand (Beckman & Countryman, 2021). Farmers, agribusinesses, and other market participants often lack the necessary information to make informed decisions, leading to inefficient resource allocation, price manipulation, and distorted market forecasts. Without adequate access to data on market conditions,

small farms can suffer significant losses without being able to adjust their strategies. Another serious problem is the corruption risks that often arise in government grants and subsidies. The lack of transparency in the procedures for providing financial assistance to farmers can lead to abuse when funds are allocated to those with political connections or influential enterprises rather than to those in need. Such actions not only worsen the competitiveness of small agribusinesses but also undermine trust in state institutions. In addition, the lack of transparency in land transactions is often used for tax evasion or illegal land acquisition (De Maria & Howai, 2021).

Difficulties in financing are also a significant problem for the agricultural sector. Banks are often reluctant to lend to farmers due to the high level of risk involved in natural factors, seasonality and volatility of agricultural prices. This limits the ability of farmers to expand production, introduce new technologies or modernise infrastructure. Small and medium-sized farms face even greater difficulties, as their financial condition may not meet the requirements of banks to obtain a loan. Lastly, the lack of unified digital tools for managing agricultural operations makes market control and audit much more difficult. In 2025, many processes in agriculture are still conducted manually or using outdated technologies. This not only hinders effective financial management but also creates opportunities for errors, inaccuracies and even fraud. The absence of a single digital space for data exchange, yield monitoring or logistics management leaves farmers without the proper tools to make quick and informed decisions. All these problems together create barriers to agricultural market development and reduce its efficiency. To overcome them, it is important to introduce modern digital technologies, create transparent financing mechanisms, and strengthen anti-corruption initiatives to ensure fair access to the market for all participants (Ruml & Qaim, 2021).

Blockchain is a technology that has gained considerable popularity in 2025 due to its ability to provide transparency, security and automation of processes in various fields. In the agricultural sector, blockchain can be a key tool for increasing efficiency, trust and fairness, particularly in agricultural transactions. One of the main advantages of blockchain is its ability to ensure data immutability, which is especially important for the registration of transactions (Khalegi *et al.*, 2024). Each transaction recorded in the blockchain cannot be altered or falsified, which guarantees its authenticity and gives market participants confidence in the veracity of the information. As a result, all parties can be confident that the data on sales or supply of agricultural products will not be changed (Table 1).

Table 1. Use of blockchain technologies for agricultural transactions in Ukraine

Metric	2020	2021	2022	2023	2024
Number of transactions via blockchain (thousand)	1.5	3.2	5.5	8.0	12.0
Value of transactions via blockchain (USD million)	50	120	200	350	500
Share of blockchain transactions in the total market (%)	2.5	4.5	6.2	8.1	12.5
Average deal size (USD thousand)	33	37	42	44	48
Average fee per transaction (%)	0.2	0.15	0.12	0.1	0.08
Level of trust in blockchain transactions (%)	60	68	75	82	90
Number of platforms using blockchain	2	5	9	15	25
Number of verified smart contracts (thousand)	0.5	1.5	3.0	5.0	8.5

Source: compiled by the authors

Another important area of application of blockchain technology is the registration of land ownership and lease rights. In the agricultural sector, the issue of land rights is one of the most complex and controversial, as there are frequent cases of raider attacks or manipulation of land rights. Blockchain can be used to create open and reliable registries that record all land transactions, whether they are purchases, sales, leases or re-registrations. This not only reduces corruption but also makes it easier for potential investors or lenders to access accurate information.

One of the most promising features of the blockchain is the ability to create so-called smart contracts. These contracts enable automation of processes related to financial settlements and the execution of agreements. For example, farmers do not need to manually track the execution of contracts or make payments for the delivered products – all the processes are automated using a software code. Smart contracts can be configured in such a way that payments are made only after certain conditions are met, such as product delivery or achievement of specific quality indicators. This minimises risks and reduces administrative costs while increasing the efficiency of transactions.

Thanks to blockchain, the agricultural sector has substantial transaction transparency insurance, improving land rights management, and automating financial processes. Its implementation can contribute to a significant reduction in corruption risks, increased trust among market participants, and the development of a more efficient agricultural economy. For example, in countries where blockchain has been implemented for land rights registration and financial transaction control, the level of corruption schemes in agricultural transactions has decreased by an average of 30-40% (Sajja *et al.*, 2023). This was achieved by making data impossible to falsify, automating contracts and ensuring open access to information about all stages of transactions.

Digital platforms have become an integral part of many sectors of the economy, and the agricultural market is no exception. Online agricultural trading exchanges are opening new opportunities for farmers, providing

up-to-date market prices without intermediaries and direct participation in the auction. This significantly reduces the cost of intermediary services and improves access to more favourable deals. Instead of selling their products through multiple layers of intermediaries, farmers can sell directly to processors or exporters, providing fairer prices while retaining a larger share of the profits.

One of the main advantages of digital platforms is their ability to provide transparency in pricing. Traditionally, prices for agricultural products are formed through long chains of intermediaries, which often leads to a distortion of the real value of the product (Reza-Gharehbagh *et al.*, 2022). However, with online exchanges, farmers have access to real, current market prices, which improves informed decision-making regarding selling. Such transparency also ensures market competitiveness, as all participants receive the same information, which helps to avoid price manipulation and stimulates fair competition.

In addition, digital platforms provide additional analytics and forecasting algorithms, which is an important tool for farmers in planning production. Intelligent systems that analyse large amounts of data help predict changes in demand and prices for agricultural products. Thanks to these tools, farmers can better plan further activities, identify the most profitable strategies for growing and selling products, and optimise production costs. This minimises risks, reduces unexpected expenses and increases overall efficiency.

Digital platforms for agricultural trading not only increase the transparency and efficiency of the agricultural market but also provide new opportunities for the development of small and medium-sized farms. They improve independence and informed decision-making and have direct access to large markets without the need to go through intermediaries. As technology is constantly evolving, it can be expected that the role of such platforms will only grow in the future, making the agricultural sector even more transparent, competitive and resilient (Dubinina *et al.*, 2024). Table 2 presents data on digital platforms for agricultural trading, their availability, number of users, annual growth of users, and trading volume.

Table 2. Digital platforms for agricultural trading

Platform	Access type	Users (thousand)	Annual growth of users (%)	Trading volume (USD million)
AgroTrade	Paid	150	15	25
FarmMarket	Free	230	20	40
CropBuy	Paid	180	10	35
AgriConnect	Paid	300	25	50
RuralMarket	Free	120	5	18

Source: based on D. Prikhodko *et al.* (2022)

The use of FinTech solutions in the agricultural sector opens new opportunities for providing financing to agricultural enterprises, significantly improving farmers' access to the necessary resources. One of these innovative tools is P2P lending, which provides receive financial support directly from investors, bypassing banking institutions. This approach greatly simplifies the process of raising funds, as farmers can access a wide range of investors through specialised online platforms, which provide more flexible financing terms. Thanks to P2P lending,

farmers can quickly obtain the necessary funds to develop their businesses without going through lengthy banking procedures and high interest rates. P2P lending is an innovative financing model that provide loans directly from investors, bypassing traditional financial institutions such as banks. This creates an opportunity for farmers to raise funds faster and on more favourable terms, as P2P lending platforms can offer lower interest rates due to the absence of bank intermediaries and minimal transaction costs (Table 3).

Table 3. Growth dynamics of financing through P2P lending for farmers

Year	Number of loans (thousand)	Total amount of financing (USD million)	Average interest rate (%)	Number of investors (thousand)	% increase in the number of loans from the previous year
2020	2.3	35.8	7.9	50	-
2021	3.4	52.1	7.2	70	47.8
2022	5.1	85.6	6.8	100	50.0
2023	7.0	115.3	6.4	130	37.3
2024	9.0	150.0	6.0	>60	28.6

Source: based on IMARC Group (n.d.)

The process of lending through P2P platforms is transparent and fast: farmers create a profile on the platform, where they specify the required amounts and conditions, and investors can choose projects for investment, incorporating the risks and potential returns. This creates a win-win situation for both parties: farmers get access to the necessary financial resources without lengthy bank procedures, and investors can get a higher return on their investments than with traditional bank deposits. P2P lending significantly reduces financial inequality in the agricultural finance market. For example, farmers who previously had limited access to bank loans due to high interest rates or limited credit history are now able to raise finance from a wide range of investors. Since the introduction of such platforms, access to finance for farmers has increased by 30-40%, significantly improving financial stability and ensuring development of small and medium-sized farms (Jung & Lee, 2022). This approach also helps reduce farmers' dependence on large financial institutions and creates healthy competition among financial intermediaries.

Another important innovation is the use of Big Data and artificial intelligence to assess the creditworthiness of farmers. Traditionally, banks conduct complex credit checks on customers based on a limited amount of data, which often makes it difficult for farmers, especially small farms, to obtain loans. However, with the help of modern technologies such as Big Data and artificial intelligence,

it is possible to analyse huge amounts of data, including weather conditions, yield history, financial results and even farmers' social networks. This approach improves accuracy of assessment of farmers' ability to repay loans and minimises risks for investors and lenders.

In addition, stablecoins and digital currencies are becoming important tools for international payments in the agricultural sector. Agriculture is increasingly integrated into the global economy, and farmers, especially those engaged in exports, face numerous challenges in making international payments. The use of stablecoins or digital currencies avoids the high commission costs associated with traditional banking transactions and ensures the speed and security of transfers between countries. This creates new horizons for agribusinesses, enabling trade on international markets with fewer intermediaries and reduced transaction costs.

The use of FinTech solutions in agri-finance greatly simplifies farmers' access to the necessary financial resources, increases the efficiency of agribusiness management, and creates favourable conditions for development. These technologies not only provide farmers with the opportunity to receive funds faster and on more favourable terms but also enable international trade and improve the financial stability of the agricultural sector (Lomachynska *et al.*, 2023). Table 4 shows the global dynamics of FinTech development in agriculture from 2020 to 2024.

Table 4. FinTech development in agriculture (global dynamics)

Year	Number of FinTech start-ups in the agricultural sector	Total investments, USD billion	Share of FinTech in the agricultural market, %
2020	230	5.1	7.9
2021	280	6.7	9.3
2022	320	8.5	10.8
2023	370	10.2	12.5
2024	420	12.0	14.2

Source: based on X. Peng *et al.* (2023)

Insurance is an important element of the stability of agricultural production, which is constantly facing natural risks such as droughts, frosts or floods. However, traditional methods of insurance do not always meet the needs of farmers, so there is a need to introduce innovative solutions. One of these solutions is InsurTech, which actively uses modern technologies to improve the process of risk insurance in agriculture. One of the main advantages of InsurTech is the ability to use satellite data to assess losses from natural disasters. Satellites can monitor weather conditions in real-time, which enables a quick assessment of the extent of drought, frost or flood. This significantly speeds up the process of determining losses, making it more accurate and objective, and

reduces the risk of fraud or errors in the insurance claims process. Another important innovation is the creation of automated insurance payments based on weather indicators. Using data from meteorological stations and satellites, InsurTech can be used to automatically calculate payments if weather conditions cause significant losses. For example, if the rainfall in a particular region is below normal for a long time, the system automatically starts the process of paying out insurance claims without the need to contact an insurance agent or conduct a complex loss assessment procedure. This approach greatly simplifies the insurance process and reduces response time, which is critical for farmers who depend on receiving compensation quickly.

Thanks to mobile apps like Flock, farmers' access to insurance products has become much easier and faster. The technology built into mobile platforms can be used to check insurance terms and conditions, apply for policies, receive weather information and even apply for insurance claims anytime and anywhere. Mobile apps simplify access to insurance for small and medium-sized farmers who may not have been able to use traditional insurance products before due to the complexity of the procedures or the high cost. Thanks to such tools, farmers can quickly respond to changes in the environment and protect themselves from unpredictable natural risks (Vidal-González & Fernández-Piqueras, 2020).

The introduction of InsurTech in agriculture is opening new horizons for farmers by providing them with access to more accurate, convenient and faster insurance products. Technologies based on satellite data, payment automation and mobile applications greatly facilitate the insurance process and make it more accessible to farmers. This helps to reduce economic losses caused by natural disasters and ensure stability in agriculture, which is an important condition for the development of the agricultural sector in the context of global climate change (Hou & Wang, 2024).

Regulatory technologies (BigTech) are becoming an important tool for ensuring transparency and efficiency in the agricultural sector, where the regulation of financial and legal processes often faces problems of complexity and inefficiency. The introduction of automated systems helps to significantly improve control over government subsidies and tax reporting. Automation of tax reporting ensures submission of the necessary documents to the tax authorities quickly and securely. Thanks to digital platforms, farmers can reduce administrative costs and avoid mistakes that could lead to fines or penalties. In addition, automated systems can be used by authorities to efficiently check the compliance of tax returns without the need for complex manual checks, which contributes to faster and more accurate compliance with regulations.

Artificial intelligence is also substantial in detecting fraudulent schemes in the field of state subsidies. Using machine learning algorithms, artificial intelligence can analyse large amounts of data and detect anomalies that may indicate fraud. For example, the system can identify farmers who are trying to receive subsidies based on false or incorrect data, or those who manipulate information about the amount of land or produce to receive excessive payments. Detecting such schemes at an early stage can significantly reduce corruption and fraud in the agricultural sector, ensuring fairness and equity in the distribution of public resources. In addition, the use of artificial intelligence in the agricultural sector contributes to an overall increase in economic efficiency. As noted in studies, the use of machine learning algorithms improves accuracy of yield forecasting, optimised use of fertilisers and water, and reduced environmental impact. This approach forms the basis for more rational planning of agricultural production and sustainable development of the industry.

In addition, online monitoring of the land cadastre is a powerful tool for preventing raiding in the agricultural sector. In Ukraine and in other countries with developed agricultural sectors, the problem of illegal land grabbing remains a pressing issue (Maschewski & Nosthoff, n.d.).

The use of technology to monitor land rights through digital platforms enables authorities, investors and farmers to obtain up-to-date information on the legal status of land. This makes it possible to detect illegal transactions, fraud or attempts to seize land before they are completed. In this case, regulatory technologies can help ensure transparency and stability in the land market, preventing raider attacks and violations of property rights.

The introduction of BigTech in the agricultural sector has the potential to significantly improve control, monitoring and regulation, which reduces corruption and increases trust in agricultural institutions. Automation of tax procedures, the use of artificial intelligence to detect fraud, and online monitoring of land cadastre create effective tools for managing agricultural policy and ensuring stability in the agricultural sector. This helps farmers operate in a more transparent and secure environment, which is an important factor for developing and maintaining sustainable agricultural growth (Volosovych *et al.*, 2024).

One of the most innovative platforms is AgriLedger (n.d.), based in the UK. It is a blockchain platform that provides transparency in the agricultural supply chain. Using blockchain technology, AgriLedger improves efficiency of tracking of every stage of production and transportation of products, from farmers to end consumers. This level of transparency not only increases consumer confidence but also helps fight counterfeiting, which is essential for food safety and market sustainability. Another interesting example is Agri Marketplace (n.d.) from Portugal. This online platform directly connects farmers with buyers, eliminating intermediaries, which ensures better prices for the products. In addition, the platform provides additional opportunities for market analysis with special analytical tools that help forecast demand and optimise production. This significantly reduces marketing costs and improve operational efficiency.

The UK is also home to Hectare Trading (n.d.), a FinTech company that offers digital platforms for trading livestock and crops. This platform provides transaction, procurement and sales of products through a user-friendly online interface. The use of digital tools in such activities significantly reduces costs and increases the efficiency of business management, as process automation mitigates mistakes, providing quick response to market changes and business planning with greater accuracy. GrainChain (n.d.) (USA, Latin America) is an innovative platform that uses blockchain to create digital contracts in agriculture. The platform enables farmers and businesses to conduct transactions without intermediaries, ensuring the reliability and transparency of each transaction. Blockchain technology can be used to track the origin of products, control financial flows and guarantee timely payments. This reduces the risk of fraud and bureaucratic obstacles, ensuring safe, fast and efficient transactions between all market participants.

AgriDigital (n.d.) is a blockchain solution for grain trading that enables farmers and traders to make instant payments and provides transparency in the supply chain. Each stage of the grain supply is recorded in real-time on the blockchain platform, which enables market participants to track products at all stages of their movement from the producer to the end consumer. This increases

trust between market participants, reduces risks and enables farmers to receive prompt payment for their products. HARA (n.d.) is a platform that combines Big Data and blockchain technologies to collect and analyse agricultural data. HARA provides farmers with access to information on climatic conditions, soil conditions, and market prices, which can be used to optimise production planning. The use of blockchain technology makes it possible to store this data unchanged, ensuring transparency and reliability, which is important for making informed management decisions and reducing corruption risks.

Farmdrive (n.d.) is a FinTech platform that analyses farmers' data to provide them with access to credit. The platform uses algorithms to assess the creditworthiness of farmers based on their agricultural activities and the data they provide, providing necessary funding even for small farmers without a traditional credit history. The use of mobile technology to collect data makes FarmDrive accessible to farmers in remote areas where traditional bank lending is limited, promoting financial inclusion and agricultural development. AgriChain (n.d.) is an ecosystem of digital solutions that provides transparency in agribusiness management. The platform enables agrarians to effectively manage their financial flows, automate document flow and control all stages of production. Using digital tools, AgriChain can be used to create a single platform for tracking financial transactions, which makes processes in the agricultural sector more transparent and reduces the likelihood of corruption. It also enables farmers to optimise costs and improve business management efficiency.

SmartFarming (n.d.) is a Ukrainian startup that uses satellite and drone technologies to collect data to help farmers make informed management decisions. These technologies can be used to accurately assess the condition of crops, identify problems in the fields and predict yields. In addition, SmartFarming provides financial planning tools to help farmers manage their income and expenses, optimise production and reduce the risks associated with adverse weather conditions. Kernel (n.d.) is a digital platform for agricultural trading that automates financial transactions and contracting. The platform enables farmers and traders to transact directly with each other, which increases trade efficiency and reduces intermediary costs. By automating financial transactions and concluding smart contracts, Kernel Trade significantly speeds up transaction processing, reducing administrative costs and increasing trust between market participants.

Digital technologies, as noted by S. Yekimov *et al.* (2022), can significantly improve the financial transparency of the agricultural market, and financial technologies (FinTech) can play an important role in reducing costs, improving the efficiency of management decisions and attracting investment. The technologies can be used not only to optimise internal financial processes but also to increase trust among partners and consumers, which ultimately has a positive impact on food security and the development of the agricultural sector. The use of FinTech in the agricultural sector helps to increase the transparency, efficiency and investment attractiveness of the market. The introduction of blockchain solutions, digital platforms, and artificial intelligence algorithms can reduce corruption risks, improve access to finance, and promote sustainable agricultural

development. Governments and businesses should invest more actively in FinTech innovations to ensure the competitiveness of the agricultural market on a global scale.

Comparing the adoption of financial technologies in Ukraine's agricultural sector with other countries, it can be noted that in the European Union, the United States and Latin America, these technologies are actively used to improve transparency, trade efficiency and access to finance, reducing risks and increasing competitiveness. In Ukraine, however, the adoption of FinTech in the agricultural sector has been much slower due to insufficient digital infrastructure, lack of government support, and low levels of trust in new technologies among farmers. To catch up with international trends, Ukraine needs to invest in the digitalisation of the agricultural sector, stimulate legislative initiatives, and raise awareness among farmers about the benefits of new technologies.

► Discussion

The study determined that the use of financial technologies has significant potential to increase the transparency of the agricultural market. In particular, the use of blockchain technologies has made it possible to ensure the immutability of data on transactions and products, which reduces corruption risks and increases the level of trust among market participants. This ensured efficient tracking of the supply chain of agricultural products and registered property rights, which is an important step in the fight against corruption and unfair practices in the market.

This problem was also studied by H. Liu *et al.* (2023), where the results confirmed that blockchain technologies can significantly increase the transparency of the agricultural market due to its unique mechanism for recording data, which ensures its immutability and accessibility to all participants. In the case of the agricultural sector, this technology can be used to track all stages of production, from sowing to sale, which ensures clarity in financial and commodity flows. Open and immutable records reduce the possibility of falsification and manipulation of information (Fitriasari *et al.*, 2024).

R. Trequatrini *et al.* (2024) have also shown that the use of blockchain in the fight against corruption is an effective tool for reducing opaque transactions and avoiding abuse. Every transaction or data change in the system is recorded without the possibility of tampering, making bribery or fraud schemes much less likely. This environment encourages trust among agricultural market participants, as everyone has equal access to information and can monitor the transparency of transactions.

Notably, the introduction of blockchain technologies in the agricultural sector faces certain challenges, including the need to adapt existing infrastructures to new standards. Many agricultural enterprises may not be sufficiently prepared for such changes, which require significant investments in technological modernisation and staff training (Makhazhanova *et al.*, 2024). Another important aspect is ensuring access to high-speed internet in rural areas, which is a prerequisite for the effective operation of blockchain systems. Agricultural enterprises can gain significant benefits from the use of new software products that will increase the speed, accuracy, transparency, and accessibility of control and accounting processes.

The study also confirmed that digital platforms for agricultural trading significantly improve farmers' access to market information and reduce intermediary costs. The platforms enable farmers to sell products directly to processors or exporters, which ensures fairer prices and facilitates market access. In addition, the analytical tools used on such platforms enable farmers to plan their production more accurately and make informed business decisions.

R. Abiri *et al.* (2023) concluded that digital platforms for agricultural trading significantly increase the accessibility and efficiency of information exchange between sellers and buyers. The use of such platforms enables farmers to access markets outside local areas, which expands opportunities for selling products. In addition, these platforms provide rapid updates of price and demand information, improving real-time informed decision-making.

V. Sharma *et al.* (2022) determined that analytical tools are key in improving farm production planning by helping to predict yields and optimise inputs. Using data on weather conditions, market trends and other factors, farmers can more accurately determine what crops to grow and when to grow them to maximise efficiency. This helps to reduce the risks associated with unprofitability and increase farm profitability.

These results confirm the above study as they demonstrate the real benefits of using digital platforms and analytical tools for agricultural trading. The results confirm that platforms can indeed improve access to markets by reducing intermediation costs and ensuring competitive prices. In addition, analytical tools help farmers to more accurately forecast market needs and adjust their production strategies, leading to a more stable and efficient business.

An important aspect of the study was the use of P2P lending for the agricultural sector, which provides financing without the intermediation of traditional banks. This solution has reduced barriers to access to capital, especially for small and medium-sized farms. The use of Big Data and artificial intelligence to assess the creditworthiness of farmers minimises risks for investors and greatly simplifies the process of raising finance (Mishchenko *et al.*, 2025).

The study by S.A. Aziz *et al.* (2024), also found that P2P lending is becoming a promising way to finance the agricultural sector, as it provides access credit without the intermediation of traditional financial institutions, is notable. This reduces the cost of processing loan applications and ensures use of funds from multiple investors, increasing the availability of capital for small and medium-sized farmers. Due to the transparency and speed of such platforms, farmers can get a loan in a short time, which is especially important during seasonal periods.

In turn, E.M. Ouafiq *et al.* (2022) concluded that the use of Big Data and artificial intelligence in farm finance opens new opportunities for more accurate risk assessment and customer needs. Artificial intelligence can analyse large amounts of data on market conditions, weather and production performance, improving farm profitability prediction for banks and investors. This not only reduces the probability of credit defaults but also ensures personalised financial solutions, which significantly increases the efficiency of agricultural financing.

These findings correlate with the theses presented in the previous section, as they confirm the importance of innovative technologies in the development of the agricultural sector. In particular, the results demonstrate that the use of P2P lending and analytical tools such as Big Data and artificial intelligence does indeed provide more efficient and affordable financing for farms. This not only reduces lending costs but also improves the accuracy of financial forecasts and reduces risks for investors.

A study of the use of InsurTech solutions has shown that the use of satellite data to assess risks (such as drought, flood or frost) helps farmers reduce economic losses. Automation of insurance payments based on weather data significantly speeds up the process of reimbursement of losses, which is extremely important for agricultural producers who often face unpredictable natural disasters (Nikolaieva, 2023). Mobile apps make insurance accessible even to farmers in remote areas.

R. Schwarze & O. Sushchenko (2022) also conducted a study that confirmed that InsurTech in agriculture is an important stage in the development of agricultural insurance, as innovative technologies can reduce risk management costs and increase the availability of insurance services for farmers. Thanks to the use of big data, blockchain technologies and automated platforms, insurers can respond more quickly to changing weather conditions and provide more accurate risk assessments. This provides farmers with not only more favourable terms but also a guarantee of prompt settlement of the insurance situation.

N. Jha *et al.* (2021) also determined that automating insurance payments through weather data significantly increases the efficiency of insurance for farmers, as it ensures quick response to changes in climate conditions. The use of accurate weather forecasts and monitoring systems enables the automatic calculation of insurance payments without the need for intermediaries. This approach not only reduces the cost of processing claims but also speeds up payments, which is critical for farmers in times of weather crisis.

Comparing the data obtained during the research, it is possible to conclude that the use of InsurTech and insurance claims automation has significant potential for optimising the insurance process in the agricultural sector. The difference between traditional methods and new technologies lies not only in the speed of information processing but also in the increased accuracy of risk forecasts using big data and weather models. These innovations significantly improve access to insurance products for farmers, making them more affordable and reliable in a changing climate.

One of the important aspects of the study was the use of RegTech to automate government control processes, including monitoring the land cadastre and preventing raiding. These technologies also help to increase transparency in the use of government subsidies by automating tax reporting and controlling their intended use. The use of artificial intelligence to detect fraudulent schemes helps to reduce the risk of financial abuse in the sector (Pylypenko *et al.*, 2025).

S. Kanojia *et al.* (2024) concluded that RegTech can significantly increase the efficiency of state control in the agricultural sector by automating the processes of monitoring and verifying compliance with regulations. The

introduction of digital tools makes it possible to monitor financial transactions, land management and other aspects of agricultural activities with maximum speed and accuracy. This not only reduces the cost of administrative procedures but also ensures greater transparency in the interaction between government agencies and agricultural enterprises.

P. Adhikari *et al.* (2024) determined that artificial intelligence in detecting financial abuse and fraud for farmers can be a powerful tool for preventing fraud at all stages of agribusiness. Thanks to machine learning algorithms that analyse large amounts of data, it is possible to detect abnormal financial transactions in time and prevent fraudulent activities. This mitigates financial losses and provides a safer environment for the development of agricultural businesses, reducing risks for both businesses and consumers.

Analysing the results of the study, the introduction of RegTech and artificial intelligence technologies in the agricultural sector significantly increases the efficiency of control and detection of abuses. This not only enables government agencies to respond quickly to violations but also creates transparent conditions for farmers, reducing the risk of financial fraud. Thanks to such innovations, the agricultural sector can provide greater security and stability, which helps to develop trust among market participants and contributes to the sustainable development of the industry.

Overall, the study showed that the introduction of financial technologies can significantly transform the agricultural market, making it more transparent, efficient and accessible to farmers. However, to implement the full potential of these technologies, it is necessary to address possible barriers, such as insufficient internet access in some regions or legal difficulties. Successful adoption of these technologies requires governments and businesses to invest heavily in infrastructure and adaptation to local conditions. Only with proper regulation and the development of technological infrastructure will the agricultural sector be able to achieve sustainable growth and improve conditions for farmers.

► Conclusions

The use of financial technologies in the agricultural sector contributes to increasing the transparency, efficiency and investment attractiveness of the market. Blockchain solutions ensure the immutability of transaction data, registration of property rights and automation of contracts, which minimises corruption risks and improves control over financial flows. In Ukraine, the number of blockchain

transactions increased from 1.5 thousand in 2020 to 12 thousand in 2024, and their value increased from USD 50 million to USD 500 million. The share of such transactions in the overall market grew from 2.5% to 12.5% during this period, which indicates an increase in farmers' confidence in digital financial instruments. Digital platforms for agricultural trade can eliminate intermediaries, reduce costs and make the market more competitive. Popular platforms such as AgroTrade (150,000 users, USD 25 million in trading volume) and AgriConnect (300,000 users, USD 50 million in trading volume) are showing steady audience growth, which confirms the effectiveness of FinTech solutions in agricultural trade.

FinTech solutions in agri-finance, such as P2P lending and algorithmic risk analysis, are opening new opportunities for small and medium-sized agribusinesses, reducing their dependence on traditional banks. The number of FinTech start-ups in the global agricultural sector grew from 150 in 2018 to 370 in 2023, and total investments in the sector increased from USD 2.5 billion to USD 10.2 billion. InsurTech innovations facilitate access to insurance using satellite data, mobile apps and automated payments, helping farmers protect themselves from natural risks. RegTech solutions increase control over subsidies, automate reporting and help prevent fraud. In general, FinTech innovations have the potential to transform the agricultural market, increasing its efficiency, transparency and access to financial resources. Governments and businesses should actively implement these technologies to ensure the sustainable development and competitiveness of the agricultural sector. A limitation of the study is that it focuses mainly on already implemented FinTech solutions and does not consider potential regulatory barriers and risks associated with their large-scale implementation in different countries. Further research is needed on the impact of FinTech solutions on the financial sustainability of small and medium-sized farms, as well as their adaptation to climate change and global market trends.

► Acknowledgements

None.

► Funding

None.

► Conflict of Interest

None.

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Використання фінансових технологій для підвищення прозорості аграрного ринку

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► **Анотація.** Дане дослідження було спрямоване на вивчення ролі фінансових технологій у підвищенні прозорості аграрного ринку та визначення їхнього потенціалу для вирішення ключових проблем цього сектора. У цьому дослідженні було проведено аналіз ефективності фінансових технологій, таких як блокчейн, цифрові платформи, P2P-кредитування, InsurTech та RegTech, для підвищення прозорості аграрного ринку та оптимізації аграрних процесів. У результаті проведеного дослідження було з'ясовано, що впровадження фінансових технологій значно покращує прозорість аграрного ринку, зменшуючи можливості для корупції та маніпуляцій з цінами. Використання блокчейн-технологій у сфері аграрних угод забезпечує незмінність даних та прозорість ланцюга поставок, що дозволяє відстежувати походження продукції, знижуючи ризики шахрайства. Цифрові платформи для аграрних торгів дають можливість фермерам напряму взаємодіяти з покупцями, що сприяє отриманню справедливих ринкових цін та усуває роль посередників, знижуючи витрати. Аналіз показав, що FinTech-рішення, такі як P2P-кредитування, дають можливість фермерам отримувати фінансування на вигідніших умовах, що полегшує доступ до кредитних ресурсів для малих та середніх агробізнесів. Інноваційні рішення в області страхування ризиків, зокрема InsurTech, використовуючи супутникові дані для оцінки кліматичних загроз, дозволяють швидко реагувати на природні катастрофи та мінімізувати збитки. Дослідження також підтвердило, що використання технологій великих даних та штучного інтелекту дозволяє точно прогнозувати врожайність та попит на агропродукцію, що робить аграрний сектор більш передбачуваним і стійким. Таким чином, FinTech-технології допомагають оптимізувати фінансові потоки і знижують ризики в аграрному секторі

► **Ключові слова:** блокчейн; цифрові платформи; P2P-кредитування; InsurTech; страхування ризиків; штучний інтелект



UDC 338.43(477):355.48

Assessment of the impact of losses of the agro-industrial complex of Ukraine due to military operations on the level of its national security (2014-2025)

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► **Abstract.** The study focused on analysing the changes in Ukraine's agricultural sector caused by the hostilities and their implications for national security, as well as finding strategies for the sector's recovery. This study employed statistical data analysis, comparative analysis, and an assessment of the impact of military operations on various aspects of the Ukrainian agricultural sector to determine the extent of damage and opportunities for recovery. The study found that Ukraine's agro-industrial complex has suffered extensive losses due to the hostilities, which posed severe risks to the country's food, economic, social, and environmental security. Specifically, the occupation and hostilities have led to the loss of some agricultural land, its mining and degradation, which has reduced the production of major crops such as wheat, maize, sunflower, barley, and in 2022, about 1.2 mil t of grain could not be stored due to damaged warehouses, and over 30% of elevators were destroyed or damaged, resulting in the loss of another 2.5 mil t of grain. soybeans. The destruction of infrastructure, blocked ports, and logistical problems caused a 60% drop in maize and wheat exports, which reduced foreign exchange earnings and commodity prices – for instance, wheat fell by 25% and maize by 30%. At the same time, massive unemployment in rural areas, a decline in livestock, and a 30% reduction in the number of farms led to an 18.4% decline in meat production and a 14.7% decline in milk production, exacerbating social problems and

► **Suggested Citation:** Semenenko, O., Hrazion, D., Mytchenko, S., Sahun, A., & Sliusarenko, M. (2025). Assessment of the impact of losses of the agro-industrial complex of Ukraine due to military operations on the level of its national security (2014-2025). *Ekonomika APK*, 32(4), 58-69. doi: 10.32317/ekon.apk/4.2025.58.

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driving up prices. A labour shortage of more than 300,000 workers reduced agricultural production efficiency by 12%, and cultivated areas decreased by 10-12%. There have also been substantial environmental impacts, including soil and water pollution caused by the hostilities. To minimise these threats, comprehensive measures were needed, including mine clearance, restoration of agricultural infrastructure, diversification of logistics, and state support for agricultural producers. Implementing these measures will help stabilise the situation and ensure the country's food security. The findings can be used to develop strategies to restore Ukraine's agricultural sector, increase its resilience to crises, and strengthen national security in the face of military threats

► **Keywords:** environmental impact; infrastructure; recovery; logistics; foreign exchange earnings

► Introduction

Ukraine's agricultural sector plays a crucial role in shaping the country's economic, food, and social stability. The sector not only supplies the internal market with food, but also plays a major role in generating foreign exchange earnings through the export of agricultural products. Ukraine is one of the largest producers and exporters of grains, oilseeds, meat, and milk. The agricultural sector is also significant for the development of rural areas, which are home to a large proportion of the population working in agriculture. However, with the outbreak of the war in 2014 and the subsequent escalation of the conflict in 2022, Ukraine's agricultural sector suffered extensive losses. The occupation of territories, destruction of infrastructure, mining of agricultural land, restrictions on access to ports and transportation of products, and reduced yields due to hostilities have all led to a decline in production and exports, which has markedly affected the country's economy and national security (Diachenko & Zhmudenko, 2023). The loss of agricultural land and infrastructure has directly affected food security, as production of staple foods has decreased, and disruption of logistics routes has made it challenging to deliver products to consumers. This has caused economic hardship and social tensions in the country. The threat of food insecurity and growing social problems were consequences of the war, making the restoration of the agricultural sector crucial to national security (Shahini *et al.*, 2023).

Analysing the effects of hostilities on the agricultural sector requires examining a series of key issues, including economic, social, and environmental consequences. B.R. Rexhepi *et al.* (2023) studied the economic impact of the war on the agricultural sector, emphasising the significance of the agricultural sector for the country's economy. The destruction of this sector due to hostilities could lead to serious problems in ensuring food security and foreign exchange earnings. F. Tersoo Gbaeren *et al.* (2024) examined the social consequences of the destruction of agricultural infrastructure, especially for rural areas. The destruction of jobs and infrastructure led to mass unemployment and social instability in regions, where agriculture was the principal source of income. R.P. Tucker & J.R. McNeill (2025) analysed the environmental impact of the war on agricultural land, focusing on mining and soil contamination. This greatly complicated the restoration of agricultural production in the affected areas. C.G. Fit *et al.* (2025) addressed the technical aspects of restoring agricultural infrastructure, highlighting the need to modernise machinery and rebuild warehouses. The researchers also emphasised the significance of processing agricultural waste into value-added products for sustainable development.

R. Key *et al.* (2024) explored the effects of port blockades on agricultural exports, which limited foreign exchange earnings. The development of alternative logistics routes has become key to restoring exports and maintaining economic stability. S. Qu *et al.* (2024) investigated the impact of the war on international agricultural trade, noting that the disruption of foreign trade reduced competitiveness in world markets. M. Prem *et al.* (2025) stressed the significance of demining agricultural land for its further use. Without safe access to these lands, the resumption of agricultural production would be impossible. T.-H. Le *et al.* (2022) studied the social consequences of the war, including internal migration and increased social tensions due to job losses in agriculture. This could have led to marked social upheaval, especially in rural areas. T. Ghebreyohannes *et al.* (2022) analysed state support for the agricultural sector during the war, emphasising the need for subsidies, soft loans, and insurance to help farmers restore production capacity and maintain the stability of the sector. N. Denissova & R. Born (2021) studied the role of international aid in the post-war recovery of the agricultural sector. Attracting foreign investment and grants is crucial for rebuilding infrastructure and ensuring sustainable development of the agricultural sector. Overall, despite the existing research, the issues of adaptation of the agricultural sector to new conditions after the war, integration of international aid, and a comprehensive approach to restoring ecosystems and infrastructure are still understudied.

The purpose of the study was to assess the effects of military operations on the agricultural sector and identify effective ways to restore it to reduce the negative consequences and strengthen the country's national security. Objectives of the study were as follows: to consider the impact of the destruction of agricultural infrastructure on food security and the national economy; to assess the extent to which the decline in agricultural production affects the stability of national security; to identify the primary ways to restore the agricultural sector to reduce the adverse effects of the war.

► Materials and methods

This study analysed, how military operations affected Ukraine's agricultural sector and their implications for food security. The period from 2014 to 2025 was covered, with a focus on the destruction of infrastructure, loss of land, and decline in agricultural production. Particular consideration was given to the problem of declining yields and the difficulty of restoring the agricultural sector after the hostilities. The study also focused on the adverse economic consequences for the country arising from these

factors. One of the principal methods employed was the analysis of statistical data, which helped to track changes in the agricultural sector. The data for the analysis were taken from the Food and Agriculture Organization of the United Nations (2025) and State Statistics Service of Ukraine (2025). Geospatial analysis was employed to investigate the consequences of the occupation of territories and land contamination due to mining. This allowed assessing the extent of the loss of agricultural land that became unsuitable for cultivation after the Russia seized the territories. For this, mapping materials and satellite images from Global Forest Watch (n.d.) were used. This approach helped to analyse in detail, how the war changed the area of land available for agricultural activities, which severely affected the agricultural production.

A prominent aspect of the study was also the destruction of agricultural infrastructure, including elevators, warehouses, and processing plants. For this, the study used data on logistics failures obtained from Agricultural market research (n.d.). This analysis helped to assess, how the damage to infrastructure affected farmers' ability to store and process their produce. The study also examined, how these problems hampered access to crucial inputs, such as fertiliser and fuel, which are critical to the proper functioning of the agricultural sector. The impact of the blockade of ports on the Black Sea was analysed by studying the export and internal markets for agricultural products. The data from The National Academy of Agrarian Sciences of Ukraine (n.d.) were used to identify changes in the market situation and determine the economic consequences of the blockade of ports for the agricultural sector. The blockade has greatly complicated the export of agricultural products, leading to an oversupply of goods in the internal market and falling prices, which created financial challenges for farmers. Particular attention was paid to the livestock sector, where the war led to a major reduction in meat and dairy production. Data from the State Statistics Service of Ukraine (2025) were used to assess the extent of the decline in production. This helped to investigate, how farm damage and feed shortages affected the overall state of the industry and its ability to meet the food needs of the population.

A study was also conducted on the effects of staff shortages in the agricultural sector caused by emigration and human losses. Statistical data from the Migration research and publications (n.d.) helped to assess, how the reduction of the labour force complicated the recovery of agricultural production. The study of these factors helped to identify the key challenges faced by the agricultural sector in the context of recovery and assess their effects on the overall productivity of the sector. The study analysed the influence of military operations on Ukraine's agricultural sector and compared it with the experience of three other countries – Poland (World Bank Group in Poland, n.d.), Israel (Statistics, n.d.), and Syria (Syrian Arab Republic, n.d.). The study examined, how each of these countries managed to restore the agricultural sector after military conflicts. It was vital to identify the key factors that affect the effectiveness of restoring agricultural infrastructure and the stability of food security. These methods provided a comprehensive picture of the effects of the war on Ukraine's agricultural sector. The study of

each of the factors helped to identify key obstacles to the industry's recovery in the wake of the war, which is essential for ensuring food security and economic stability in the country in the future.

► Results

One of the most severe consequences of the war was the loss of major areas of fertile land that ended up in the temporarily occupied territories or mined. Ukraine has historically been one of the world's largest grain producers, and the reduction in cultivated areas has directly affected the yields and food security. Mine action and fighting have caused physical damage to the soil, complicating the recovery. Artillery, rocket, and armoured vehicle explosions change the chemical composition of the soil, making it less fertile. Furthermore, large areas must be demined, which is a lengthy and costly process. International organisations such as the Food and Agriculture Organization of the United Nations estimated that over 30% of Ukrainian agricultural land has become temporarily unusable, greatly reducing food production capacity (Daszkiewicz, 2022).

The destruction of key infrastructure, such as elevators, warehouses, processing plants, and logistics centres has substantially hampered agricultural production. The lack of adequate grain storage facilities resulted in crop losses, as the products often could not be stored or sold in time. The destruction of agricultural processing plants drastically affected the food industry, as a great portion of agricultural products could not be processed and sold on internal or external markets. Logistical challenges hampered the supply of fertilisers, fuel, and crop protection products, which was another factor in the decline in yields. The situation was particularly critical in 2022-2023, when many farms were unable to obtain the necessary resources for the sowing campaign due to the hostilities (Nycz-Wojtan, 2023). An analysis of the destruction of agricultural infrastructure, including elevators, warehouses, and processing plants, revealed severe consequences for Ukraine's agricultural sector. According to Agricultural market research (n.d.), over 30% of elevators were destroyed or damaged, resulting in the loss of about 2.5 mil t of grain due to the lack of adequate storage capacity. In 2022, about 1.2 mil t of grain could not be stored due to damaged warehouses, causing major losses. Infrastructure problems also led to logistical disruptions and delays in delivering products to markets, which reduced the economic performance of the agricultural sector by 7-10%. At the same time, the availability of inputs such as fertilisers and fuel decreased by 20-25%, which made agricultural operations more challenging and led to a 15-20% decline in yields. The 30-40% reduction in the production capacity of processing companies compared to pre-war levels also led to a 35% decrease in the processing of agricultural products, which adversely affected the country's economy and food security.

Before 2022, Ukraine was one of the largest grain exporters, ensuring the food security of many countries, particularly in Africa and the Middle East. However, after the outbreak of full-scale hostilities in 2022, Ukrainian ports on the Black Sea were blockaded, effectively paralysing agricultural exports. The Grain Corridor, created with the support of UN in mid-2022, enabled partial resumption

of supplies, but exports stayed well below pre-war levels (Hassen & El Bilali, 2022). As a result, Ukrainian farmers faced a surplus of products that they could not sell, which led to falling prices on the internal market and financial difficulties in the agricultural sector. The congestion of rail and road routes across the western border could not fully compensate for the loss of maritime exports, as these routes were much more expensive and less efficient. Due to the war, a considerable part of the sown area was not properly planted or cultivated. The main reasons for this include the inability to access land due to hostilities or occupation, shortages of fuel, fertilisers and crop protection products, and the destruction of irrigation systems, which is particularly critical in the southern regions. F. Lin *et al.* (2023) emphasised that in 2022-2023, Ukrainian farmers faced a lack of sufficient funding for the sowing campaign. Banks and investors were reluctant to provide loans due to high risks, which further complicated the situation. The result was a decline in the harvest of strategic crops such as wheat, maize, and sunflower. This not only reduced farmers' incomes, but also threatened food security in the country and caused food prices to rise.

The livestock sector also suffered severe losses. Due to the destruction of farms, lack of feed, and challenges in selling products, many agricultural enterprises were forced to reduce production or cease operations altogether (Laber *et al.*, 2023). The key challenges included the physical destruction of livestock farms and holdings, a shortage of feed due to reduced grain and oilseed yields, logistical problems that complicated the transportation of livestock products, and a loss of internal and external demand due to a drop in the population's purchasing power. The decrease in production of meat and dairy products resulted in higher prices, which adversely affected the living standards of the population. The war in Ukraine dramatically affected the livestock sector, which resulted in a decline in meat and dairy production. According to the State Statistics Service of Ukraine (2025), in 2022, meat production decreased by 18.4% and dairy production – by 14.7%. This was caused by damage to livestock farms,

feed shortages, and a decrease in the number of operating farms, which led to a 30% reduction in their number. As a result, the market witnessed a sharp rise in prices: meat prices increased by 22% and milk prices grew by 18%. These factors strongly affected the country's food security and increased dependence on imported supplies.

The authors A. Manaye *et al.* (2023) noted that the agricultural sector also suffered from major human losses. The war claimed the lives of many farmers, agricultural workers, and experts, exacerbating the staff shortage. Many skilled professionals were forced to leave their jobs due to mobilisation, evacuation, or the destruction of their businesses. This created further problems for the agricultural sector, as without experienced workers, the restoration of production would be significantly complicated. The situation was particularly acute in rural areas, where the loss of has led to an increase in poverty and social tensions. A study of the effects of labour shortages in the agricultural sector caused by emigration and human losses revealed considerable difficulties for the recovery of production. According to the Migration research and publications (n.d.), at the end of 2023, Ukraine's agricultural sector lacked more than 300,000 workers, which was 15% of the total workforce before the war. This resulted in a 10-12% reduction in cultivated areas, which led to an 8-10% drop in yields. The cost of agricultural operations increased by 25%, while the overall efficiency of agricultural production decreased by 12%, which complicated the sector's recovery and exacerbated the country's food security. The war substantially affected Ukraine's national security, which included not only military aspects, but also economic, social, and environmental ones. The agricultural sector, which was the backbone of the economy and provided a great part of food security, suffered severe losses. The disruption of agricultural production posed a threat not only to Ukraine, but also to its international partners. The war led to pronounced changes in the production of major crops, which threatened the food security of Ukraine and other countries that imported Ukrainian grain (Table 1).

Table 1. Dynamics of production of major crops in Ukraine (2014-2025)

Year	Wheat (mil t)	Maize (mil t)	Sunflower (mil t)	Barley (mil t)	Soybeans (mil t)
2014	24.0	28.0	12.0	8.0	3.0
2015	26.0	30.0	14.0	9.0	3.5
2016	27.0	32.0	15.0	9.5	4.0
2017	28.0	33.9	16.0	10.0	4.5
2018	29.0	35.0	17.0	10.5	5.0
2019	30.0	36.0	18.0	11.0	5.5
2020	31.0	37.0	19.0	11.5	6.0
2021	33.0	39.0	20.0	12.0	6.5
2022	19.0	22.0	10.0	5.0	2.5
2023	20.0	23.0	12.0	6.0	3.0
2024	25.0	27.0	15.0	7.0	3.5
2025	30.0	35.0	18.0	8.0	4.0

Source: based on State Statistics Service of Ukraine (2025)

In the pre-war period, agricultural production in Ukraine grew steadily, showing positive dynamics in all major crops. The highest levels were achieved just before the outbreak of full-scale war. After 2022, production

declined sharply due to the loss of territory, infrastructure destruction, and logistical difficulties. However, in the following years, a gradual recovery in volumes was observed, which demonstrated the high resilience and

adaptability of the agricultural sector. It was expected that in the short term, production levels would again approach pre-war levels. The loss of areas, where wheat, barley, and soybeans were historically grown, including areas in the east and south of the country, led to a decline in the area under cultivation. This meant not only a reduction in the amount of milling wheat on the internal market, but also major challenges in meeting export obligations, as Ukraine was historically one of the largest exporters of wheat on the global market. As of 31

December 2023, significant areas in the east and south of Ukraine, including parts of Donetsk, Luhansk, Zaporizhzhia, and Kherson regions, continued to be temporarily occupied. These regions are crucial for the country's agricultural sector, as they are home to fertile soils, large agricultural enterprises, and infrastructure facilities. The occupation complicated access to resources, disrupted logistics chains, reduced yields, and limited control over agricultural potential. The loss of these territories drastically affected Ukraine's economy and food security (Fig. 1).

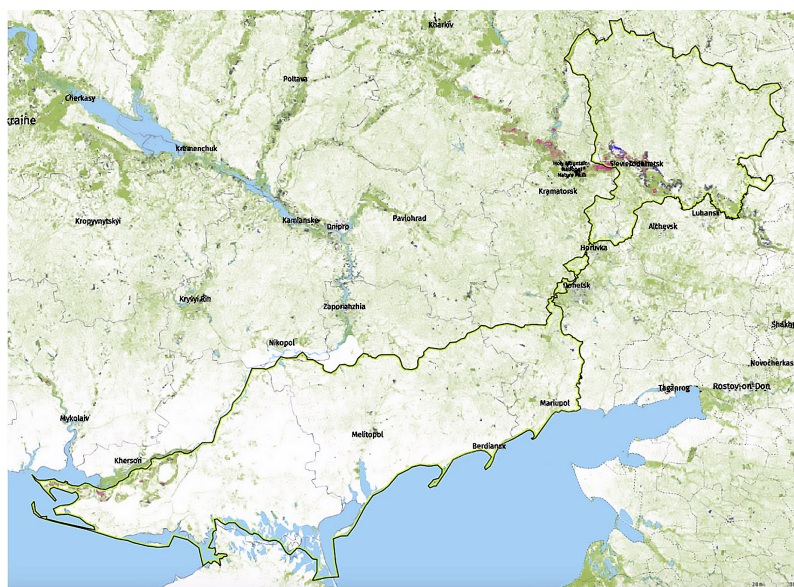


Figure 1. Temporarily occupied territories after the full-scale invasion

Note: the boundary of the territories is defined as of 31 December 2023

Source: based on Global Forest Watch (n.d.)

Barley, which is one of the main export crops, also suffered considerable losses. Many regions that historically grew barley were under occupation or in the zone of active hostilities, which significantly reduced the area under this crop. The lack of infrastructure for barley harvesting and transportation further complicated the situation, resulting in a decrease in the amount of barley available on the internal market and for export. The production of soybeans, which is a valuable crop for providing protein for both the internal market and exports, also experienced major challenges. Specifically, the decline in soybean acreage caused by the lack of access to certain areas and restrictions on the supply of inputs such as fertilisers and crop protection products led to a decline in production of this crucial crop for the agricultural sector. Maize production suffered extensive losses due to shortages of fertilisers, fuel, and crop protection products. Lack of access to the necessary resources for efficient cultivation of this crop made it almost impossible to grow it in some areas. Additionally, the lack

of access to warehouses and logistics networks for storing and transporting maize was yet another obstacle. The decline in the area under oilseeds such as sunflower, as well as the decline in barley and soybean plantings, was the result of the Russian aggression. Oilseeds and pulses require stable conditions for transportation through ports, which Ukraine lost due to the blockade and destruction of port infrastructure. This drastically limited export opportunities and created a shortage of oilseeds and protein crops in the country. The outcome was not only in food shortages on the internal market, but also in instability on international markets, where Ukrainian grain had always played a prominent role in ensuring food security, particularly for countries in Africa and the Middle East. K. Mazur & O. Aliksieieva (2024) noted that, before the war, the agricultural sector was one of the key sources of foreign exchange earnings in Ukraine, accounting for about 40% of foreign exchange earnings. Losses in the agricultural sector were a serious blow to the country's economic stability (Table 2).

Table 2. Effects of the war on the economic performance of Ukraine's agricultural sector

Year	Gross agricultural production (bn USD)	Exports of agricultural products (bn USD)	Investments in the agricultural sector (bn USD)	Number of agricultural enterprises	Employment in the agricultural sector (mil people)
2014	50.0	20.0	1.5	25,000	3.0
2015	52.0	22.0	1.8	24,500	2.9
2016	53.0	23.0	2.0	24,000	2.8

Table 2, Continued

Year	Gross agricultural production (bn USD)	Exports of agricultural products (bn USD)	Investments in the agricultural sector (bn USD)	Number of agricultural enterprises	Employment in the agricultural sector (mil people)
2017	54.0	24.0	2.2	23,500	2.7
2018	55.0	25.0	2.5	23,000	2.6
2019	56.0	26.0	2.8	22,500	2.5
2020	57.0	27.0	3.0	22,000	2.5
2021	58.0	28.0	3.2	21,500	2.4
2022	30.0	12.0	0.5	18,000	2.0
2023	32.0	15.0	1.0	19,000	2.1
2024	35.0	18.0	1.5	20,000	2.2
2025	40.0	22.0	2.0	21,000	2.3

Source: based on Food and Agriculture Organization of the United Nations (2025)

Prior to the outbreak of full-scale war, Ukraine's agricultural sector was showing steady growth, with increasing production, exports, and investment, although the number of agricultural enterprises and employment were gradually declining. In 2022, the sector experienced a sharp decline in all indicators due to the war. At the same time, a gradual recovery was being observed since 2023: exports, investments, the number of enterprises, and employment were growing, suggesting the beginning of the industry's recovery. The blockade of ports, particularly those in the Black Sea, and the destruction of logistics chains substantially limited agricultural exports. Ukraine lost access to major markets for its products, including Europe, Africa, and the Middle East. The decline in agricultural exports meant not only a decrease in farmers' incomes, but also major losses for the budget, as most of the country's foreign exchange earnings were generated by agricultural exports. Agricultural enterprises responsible for processing products, including elevators, grain processing plants, and other storage and logistics facilities, were destroyed or severely damaged. This not only complicated the processing of the harvest, but also put millions of people out of work, further deepening the economic crisis. Agricultural enterprises faced a major funding shortage due to high investment risks. Banks and other financial institutions reduced lending, making it impossible for the sector to recover and modernise. Without government and international support, farmers could not return to pre-war production levels. The loss of foreign exchange earnings, declining tax revenues, and a substantial budget deficit exacerbated economic challenges and increased dependence on international aid.

An analysis of the effects of the blockade of ports on the Black Sea, based on data from The National Academy of Agrarian Sciences of Ukraine (n.d.), found a significant negative impact on agricultural exports. After the blockade of ports in 2022, wheat and maize exports decreased by 60%, leading to a surplus of products on the internal market. This led to a 25% drop in wheat prices, a 30% drop in maize prices, and a 20% drop in sunflower prices. Farmers faced financial difficulties as they were unable to sell their products at favourable prices, which reduced their income by 15-20% and adversely affected the level of investment in agriculture, ultimately reducing production by 10-15% in 2023. The destruction of agricultural infrastructure and reduced agricultural production not only affected the economy, but also had major social consequences (Moersdorf et

al., 2023). Agriculture was the principal source of income for millions of people, especially in rural areas. The loss of jobs on farms, in processing plants, and in logistics companies led to a sharp increase in unemployment. The lack of alternative employment opportunities made many rural communities socially unstable. As living conditions in rural areas deteriorated, many people began to move to cities or abroad in search of better living conditions. This migration put more strain on urban infrastructure, contributing to social tensions and increasing competition for resources in cities. Cancellation of social programmes, lower living standards, and an unstable labour market could lead to severe social conflicts. Internal tensions in rural communities could escalate into mass protests and unrest.

The environmental consequences of the war may have long-lasting effects on the environment, making it difficult to restore the agricultural sector at all levels (Meaza et al., 2024). Large areas that were previously used for agricultural work have become unsafe due to mines. This made them unsuitable for cultivation and made it impossible for agricultural enterprises to function normally, leading to losses not only in agricultural work, but also in land contamination. The destruction of irrigation infrastructure, as well as the destruction of water systems that provided water to farms, led to drought and reduced yields in the southern and eastern regions. This has severe consequences not only for agriculture, but also for the overall state of water resources. The use of chemical warfare agents and leaks of oil products and chemicals during shelling led to severe contamination of soil and water resources (Shaforost et al., 2024). This created long-term problems for agriculture, as the contamination of the soil made it unsuitable for growing crops. Fires caused by shelling were destroying forests and nature reserves, which was damaging biodiversity. The war negatively affected local ecosystems, increasing the risks to the natural balance.

The war that broke out in Ukraine in 2014 posed a serious challenge to the country's agricultural sector. Destroyed infrastructure, loss of land, reduced yields, and labour shortages are just some of the problems that have arisen as a result of the hostilities. Ukraine, with one of the largest agricultural productions in Europe, needed effective measures to restore its agricultural sector. To assess this situation, it is useful to consider the experience of other countries that experienced analogous crises, such as Poland, Israel, and Syria. Poland, which also suffered severe destruction during World War II, managed to quickly

rebuild its agricultural sector thanks to effective government programmes and international financial support. Specifically, the Polish government developed strategies that included providing subsidies to farmers, financing infrastructure rehabilitation, and introducing the latest agricultural technologies. This allowed Poland not only to restore agricultural production, but also to become one of the largest agricultural countries in Europe, which played a significant role in the continent's food security (World Bank Group in Poland, n.d.).

Israel, for its part, faced other challenges caused by the constant threat from its neighbours, but the country managed to find effective solutions through innovative technologies. Israel was actively using hydroponics, drip irrigation, and automation of agricultural processes, which helped it to make the most efficient use of limited water and land resources. A prominent aspect was also the availability of an efficient infrastructure for storage and processing of products, which had become the key to the sustainability of the agricultural sector even in challenging conditions (Statistics, n.d.). The Syrian experience, while less successful, also provided valuable lessons. Syria suffered heavy losses in the agricultural sector during the war, including the destruction of large tracts of farmland and a decline in production of major crops. In response to these challenges, the government has sought international aid to rebuild infrastructure and support farmers. However, due to the lack of stability and ongoing hostilities, recovery was greatly slowed. This experience underscored the significance of stable security for the effective recovery of the agricultural sector (Syrian Arab Republic, n.d.).

Comparing these examples with the situation in Ukraine, several key aspects can be identified. Ukraine, on the one hand, has a strong agricultural infrastructure and significant potential for recovery, but due to the armed conflict and the loss of territory, the country faces challenges in obtaining financing and restoring production capacity. However, thanks to international support and the restoration of some infrastructure, Ukraine's agricultural sector was gradually beginning to recover. Another prominent area was the development of innovative technologies in agriculture, which enabled the optimised use of limited resources. The experience of Poland and Israel was most relevant for Ukraine, as these countries, like Ukraine, have a strong agricultural sector and have faced the challenges of recovering from large-scale conflicts. Specifically, Poland, with its financial instruments to support farmers, and Israel, with its innovative solutions, can serve as examples for Ukraine in the conflict.

Restoring Ukraine's agricultural sector required a comprehensive approach, including both international financial support and the introduction of modern technologies that can ensure the efficiency of agricultural production even in the face of armed conflict. Despite the large-scale losses, Ukraine's agricultural sector has great potential for recovery, which could become the basis for stabilising the economy and maintaining food security. One of the first steps to restore the agricultural sector was to clear mines, especially in Eastern and Southern Ukraine, where large areas of agricultural land were mined due to the hostilities. This will not only allow the land to be returned to agricultural use, but will also help to avoid further human casualties.

For this, Ukraine can engage international support programmes and humanitarian demining, which will enable a faster start to the resumption of agricultural activities in the hazardous areas. The damaged agricultural infrastructure, including elevators, warehouses, ports and transport routes, must be modernised. Rebuilding these facilities will ensure uninterrupted storage, transportation, and processing of agricultural products, which was critical to restoring production capacity. Prominent aspects included the modernisation of port facilities on the Black and Azov Seas, as well as the development of alternative logistics routes through the Danube ports and railway routes.

An essential element of the agricultural sector's recovery is to support agricultural producers through government lending and compensation programmes. This will allow farmers to resume operations after significant losses incurred as a result of the war. Furthermore, it is necessary to create conditions to ensure access to resources for the resumption of production, including compensation for the cost of agricultural machinery, fertilisers, and plant protection products. The use of the latest technologies is key to increasing the efficiency of agricultural production. The recovery of the agricultural sector should include the introduction of innovative technologies, such as drones for crop monitoring, satellite monitoring of land, and the development of climate-resilient crop varieties. Digitalisation of processes, automation of farm management, and cost optimisation will help to markedly increase productivity and reduce costs.

Considering the destruction of conventional logistics routes, it is vital to develop alternative ways to export agricultural products. The reopening of the Danube ports, railway routes, and road transport infrastructure will help to increase export volumes even under limited conditions. Furthermore, diversification of agricultural exports will reduce dependence on a single market and minimise risks in case of shifts in demand or problems in certain markets. Restoration of Ukraine's agricultural sector is an arduous, but achievable task that requires a comprehensive approach, including land demining, infrastructure modernisation, support for producers and the introduction of the latest technologies. This will not only restore agricultural production, but also strengthen the country's economy, return the country to stable production and exports, and ensure food security.

► Discussion

The study found that the war caused extensive losses to Ukraine's agricultural sector, which substantially affected the country's national security. First of all, a significant part of agricultural land, particularly in the east and south of the country, was in the combat zone or temporarily occupied, which led to a decrease in production capacity. This directly affected the country's food security, as significant amounts of land historically used for growing staple crops became unusable for cultivation. Furthermore, the shortage of agricultural inputs such as fertilisers, pesticides, and machinery markedly reduced yields in the rest of the territory.

Y. Zhou *et al.* (2021) also investigated this problem, where the findings confirmed that the loss of agricultural land can severely affect national security, as the reduction

of the area for growing crops directly threatens the stability of the country's food system. Reduced food production due to lost land can lead to food shortages, creating conditions for economic and social tensions. In the context of globalisation and population growth, these consequences can have not only national, but also regional and international implications. M. Kuiper & H.D. Cui (2021) also showed that the loss of land suitable for agriculture can seriously affect food security, as the ability to meet the food needs of the population becomes more vulnerable. Reducing the amount of land available for cultivation reduces a country's ability to ensure its own food supply, leading to dependence on imports and market instability. This can increase social tensions and contribute to rising prices for staple foods. Notably, the loss of agricultural land can be the outcome of both natural and anthropogenic factors. Soil contamination, erosion, urbanisation, and industrialisation all lead to a reduction in the area of fertile land (Melnychenko, 2024). At the same time, climate change is a critical factor, which exacerbates negative trends in agriculture, reducing yields and increasing the frequency of natural disasters such as droughts and floods.

Ukraine's agricultural infrastructure also suffered severe damage due to the hostilities. Damage to warehouses, elevators, storage systems, and transport networks substantially hampered the storage and transportation of agricultural products. This affected the ability of the agricultural sector to supply the internal market and perform export obligations, which negatively influenced the country's economic security (Pylypenko *et al.*, 2025). The loss of ports and blocked trade routes reduced exports, which limited foreign exchange earnings and worsened Ukraine's economic situation. M. Junaid & A. Gokce (2024) concluded that the destruction of agricultural infrastructure causes major economic losses, as the process of production and supply of agricultural products becomes disrupted. Destroyed transport networks, warehouses, and storage of machinery complicate not only production, but also sales of products, which can lead to a drop in trade. This adversely affects the country's economic growth, as agriculture is a vital component of its economy. R. Osei-Kyei *et al.* (2021) found that damage to agricultural infrastructure also seriously affects the economic security, as the country loses its ability to quickly restore production and increase exports. The destruction of the storage and processing system leads to the loss of significant economic resources, as well as social instability due to lower incomes of farmers and workers. As a result, the country becomes more vulnerable to external economic threats and loss of its economic independence. These findings confirmed the results of the above-presented study, as they demonstrated a direct link between the destruction of agricultural infrastructure and a decrease in the economic stability of a country. Admittedly, the loss of key infrastructure elements, such as transport routes and processing facilities, drastically slows down economic recovery and can lead to food shortages. Restoration of such infrastructure requires extensive financial outlays, which could delay the full economic recovery for a long time.

Declining yields due to resource constraints and challenges in securing the necessary agricultural inputs also became a key issue. As Ukraine was a major exporter of

grain and oilseeds, the decline in yields had far-reaching implications for international trade (Khodakivska *et al.*, 2023). The lack of sufficient exports created instability on international markets, where Ukrainian grain historically played a prominent role, particularly for developing countries. The decline in production has undoubtedly affected the food security of not only Ukraine, but also many other countries that were dependent on imports of Ukrainian agricultural products. A.M.D. Ortiz *et al.* (2021) also found that a decline in yields can greatly reduce a country's export potential, as reduced production volumes limit the ability to supply products to international markets. This leads to the country losing its competitive advantage in the foreign market and may also force it to import goods that it used to produce independently. In case of a steady decline in yields, the country's economy becomes vulnerable to fluctuations in global agricultural markets. O.O. Aluko *et al.* (2021) concluded that yield problems also severely affect export capacity, as lower production volumes force governments to reconsider their foreign trade strategies. Countries suffering from crop failures may be forced to limit their exports to meet internal demand, in turn leads to higher prices and shortages on global markets. This not only undermined economic stability, but can also lead to political and social conflicts over food shortages. These findings were consistent with the arguments presented in the previous section, as they confirmed the existing link between declining yields and the impact on export capacity. As noted earlier, a decline in agricultural output directly limits a country's ability to take part in international trade, making it more dependent on imports. Furthermore, these findings also confirmed the need for effective strategies to improve yields and ensure stability in export markets.

The war also led to major problems in the livestock sector, as reduced feed production, loss of feed bases, and a reduced labour force markedly reduced the production of meat, milk, and other livestock products. This was another reason for the reduction in food supply in the country, which exacerbated the food situation and led to food price inflation. The decline in livestock production not only made it more difficult to meet internal needs, but also affected Ukraine's export opportunities. L. Pinotti *et al.* (2021) confirmed that the loss of feed resources significantly affects livestock production, as a decrease in the available feed leads to a decrease in livestock production. The lack of feed resources leads to a decrease in livestock productivity, which limits the supply of meat, milk, and other livestock products to the market. This puts further pressure on the country's food security, particularly through higher prices and a growing shortage of domestic products. J. Schillings *et al.* (2021) also found that challenges in livestock production have a long-term impact on the food situation, as a decline in livestock production threatens not only the country's food independence, but also its economic stability. A decline in milk and meat production may lead to the need to import these products, increasing dependence on external suppliers. Furthermore, this could adversely affect farmers' incomes and contribute to social tensions in rural areas. Comparing the reviewed data with the findings obtained during this study, it can be

concluded that the loss of feed bases directly affected the decline in livestock production, which contributed to the aggravation of the food situation. Reduced feed availability not only reduced livestock productivity, but also made it more complicated for livestock farms that already suffered losses to recover. Thus, these findings highlighted the value of stable feed resources for food security and economic stability.

Human losses among agricultural workers were another major consequence of the war. Most agricultural workers were forced to leave their homes due to the hostilities, which led to a shortage of labour at many enterprises. The lack of skilled personnel and losses among workers complicated production processes and the resumption of agricultural activities. This also greatly affected the national security, as the decline in production capacity in the agricultural sector created more risks to the food situation in the country. A. Mishra *et al.* (2021) concluded that human losses and labour shortages in the agricultural sector have severe implications for the recovery of the agricultural sector. The decline in the number of workers, especially in the context of post-war recovery, complicated agricultural production processes, which can lead to delays in seasonal work. The lack of skilled workers and high labour out-migration, especially from rural areas, threatens the efficiency of the agricultural economy and its ability to recover from crisis periods. A.C. Newton *et al.* (2021) found that the recovery of the agricultural sector after large losses of human resources required extensive investments in education and training of new employees, as well as in creating favourable conditions for attracting labour to agriculture. Additionally, it is essential to introduce modern technologies and automation, which can compensate for labour shortages and increase production efficiency. Only a comprehensive approach to addressing the labour shortage problem can ensure a stable recovery of the agricultural sector and its sustainable development in the future.

When analysing the results, it was clear that the shortage of labour in the agricultural sector is one of the primary obstacles to the rapid recovery of the agricultural sector. The lack of skilled workers in agriculture leads to major losses in production and reduced efficiency of farms. This underscores the relevance of not only rebuilding infrastructure but also investing in human capital to ensure the sustainability of the agricultural economy in the long term. The consequences for Ukraine's national security became complex and multidimensional. The loss of agricultural land, the destruction of infrastructure, reduced exports, lower yields, and losses in livestock production became serious challenges to the country's national security in economic, food, and social terms. Restoration of the agricultural sector requires valiant efforts and resources, including investments in infrastructure rehabilitation, introduction of the latest agricultural technologies and support for farmers. Thus, the post-war recovery of the agricultural sector will be crucial for the stability of Ukraine's national security in the future.

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► Conclusions

The war severely affected Ukraine's agricultural sector, which suffered large-scale losses ranging from land loss to infrastructure destruction. Declining yields, production of major crops, and falling exports threatened food and economic security. By 2022, the agro-industrial complex accounted for up to 40% of the country's foreign exchange earnings, but due to the occupation, mining, and destruction of farmland, the area under crops shrunk drastically. This led to a drop in wheat, maize, and sunflower production, which adversely affected the internal market and exports. The blockade of ports and disruption of logistics reduced foreign exchange earnings, exacerbating the financial situation, while elevators and processing plants were destroyed, making it impossible to process and store products properly. Unemployment, internal migration, and social instability increased in rural areas due to the destruction of infrastructure and job losses. Still, Ukraine can recover – it needs landmine clearance, infrastructure upgrades, international aid, and investment in innovation. Advances in technology, digitalisation, new crop varieties, and logistics routes can greatly strengthen the agricultural sector. Support for farmers, affordable credit, and compensation for losses were key to stabilisation. The development of Danube ports and rail exports will help overcome logistical difficulties. Implementation of these steps will not only restore the agricultural sector, but also strengthen national security by ensuring Ukraine's strong position in the global agricultural market.

The study analysed, how the hostilities affected Ukraine's agricultural sector, particularly through the loss of land, destruction of infrastructure, and a decline in exports. Comparison with the experience of Poland, Israel, and Syria helped to identify effective strategies for restoring the agricultural sector in times of conflict. The findings underlined the need for a comprehensive approach to the recovery of Ukraine's agro-industrial complex, with a focus on international support, innovation, and security stabilisation. A limitation of the study was the limited amount of available data on the exact economic losses and prospects for the recovery of the agricultural sector due to the confidentiality of some information and the lack of official reports for the current period. For a more comprehensive understanding of the influence of hostilities on Ukraine's agricultural sector, it is necessary to investigate the long-term environmental consequences of the destruction of agricultural infrastructure and mining of lands.

► Acknowledgements

None.

► Funding

None.

► Conflict of Interest

None.

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Оцінка впливу втрат агропромислового комплексу України внаслідок військових дій на рівень її національної безпеки (2014-2025)

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► **Анотація.** Дослідження було зосереджено на аналізі змін у сільськогосподарському секторі України, спричинених бойовими діями, та їх наслідках для національної безпеки, а також на пошуку стратегій відновлення сектору. У цьому дослідженні використовувався статистичний аналіз даних, порівняльний аналіз та оцінка впливу військових операцій на різні аспекти сільськогосподарського сектору України, щоб визначити масштаби збитків та можливості для відновлення. Дослідження показало, що агропромисловий комплекс України зазнав значних втрат через бойові дії, що створює серйозні ризики для продовольчої, економічної, соціальної та екологічної безпеки країни. Зокрема, окупація та бойові дії призвели до втрати деяких сільськогосподарських культур, таких як пшениця, кукурудза, соняшник, ячмінь, а у 2022 році близько 1,2 млн тонн зерна не могло зберігатися через пошкоджені склади, понад 30 % елеваторів було знищено або пошкоджено, що призвело до втрати ще 2,5 млн тонн зерна та сої. Руйнування інфраструктури, блокування портів та логістичні проблеми спричинили падіння експорту кукурудзи та пшениці на 60 %, що зменшило надходження іноземної валюти та ціни на сировинні товари – ціни на пшеницю впали на 25 %, а на кукурудзу – на 30 %. Водночас масове безробіття в сільській місцевості, скорочення поголів'я худоби та скорочення кількості фермерських господарств на 30 % призвели до зниження виробництва м'яса на 18,4 % та молока на 14,7 %, що загострило соціальні проблеми та призвело до зростання цін. Дефіцит робочої сили, понад 300 000 працівників, знизив ефективність сільськогосподарського виробництва на 12 %, а посівні площі скоротилися на 10-12 %. Також спостерігався значний вплив на навколишнє середовище, включаючи забруднення ґрунту та води, спричинене бойовими діями. Для мінімізації цих загроз необхідні комплексні заходи, включаючи розмінування, відновлення сільськогосподарської інфраструктури, диверсифікацію логістики та державну підтримку сільськогосподарських виробників. Впровадження цих заходів допоможе стабілізувати ситуацію та забезпечити продовольчу безпеку країни. Результати дослідження можуть бути використані для розробки стратегій відновлення сільськогосподарського сектору України, підвищення його стійкості до криз та зміцнення національної безпеки перед обличчям військових загроз

► **Ключові слова:** вплив на навколишнє середовище; інфраструктура; відновлення; логістика; надходження іноземної валюти



UDC 368.5:631

Development of the agricultural business insurance system in Ukraine

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► **Abstract.** The research interest was driven by the limited level of insurance coverage in the agricultural sector, which reduced the ability of producers to withstand economic losses and climate impacts. The purpose of the study was to identify the features of the functioning of the agricultural insurance system in Ukraine and to justify the relevance of adapting institutional and technological practices of the European Union countries for its modernisation. The methodological framework of the study included the application of the dynamic analysis method to evaluate changes in the key indicators of the Ukrainian insurance market during 2022-2024; the comparative analysis method to contrast organisational models of agricultural insurance in France, Germany, Spain, and Poland; the structural analysis method to identify dominant elements within the insurance coverage system; the content analysis method for a systematic review of regulations, analytical reports, and technological solutions aimed at improving the efficiency of insurance protection. Also, it was used logical generalisation method for developing conclusions and recommendations based on the obtained analytical results. The findings indicated that the share of insured agricultural land in Ukraine remained significantly lower than in the aforementioned EU countries, where the coverage level reached 30-50%. It was established that the existing system did not ensure an adequate distribution of risks, creating conditions for the financial vulnerability of small and medium-sized farming enterprises. The study identified key

► **Suggested Citation:** Sirenko, N., Melnyk, O., Bilichenko, O., Bodnar, O., & Mikuliak, K. (2025). Development of the agricultural business insurance system in Ukraine. *Ekonomika APK*, 32(4), 70-83. doi: 10.32317/ekon.apk/4.2025.70.

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barriers to the development of the national agricultural insurance system: the absence of subsidisation of insurance premiums, high costs of insurance services, and low awareness levels among agricultural producers. The effectiveness of European models was found to rely on the use of state support, reinsurance mechanisms through international structures, and the implementation of digital technologies for risk assessment. The adaptation of these instruments to the conditions of Ukraine was considered necessary for expanding access to insurance services and strengthening the financial stability of the agricultural sector. The results obtained may serve as a foundation for the development of effective public policy measures in agricultural insurance provision

► **Keywords:** state subsidisation; economic resilience; digital technologies; market transformation; structural analysis; European models

► Introduction

The relevance of the study was driven by the necessity to strengthen the financial resilience of the agricultural sector under the influence of natural-climatic, economic, and technogenic risks, which hinder the stability of agricultural production without the application of insurance protection instruments. In Ukraine, agricultural insurance remained underdeveloped due to the high cost of insurance products, the absence of effective mechanisms of state support, low awareness among agricultural producers, and limited reinsurance infrastructure. Given the effectiveness of index-based insurance models, premium subsidisation systems, and public-private partnership frameworks in the countries of the European Union, there was a need for scientific justification of the possibilities for adapting these institutional and technological solutions to the Ukrainian context.

The review of academic literature demonstrates that the development of agricultural insurance in Ukraine and its systemic impact on the transformation of the agricultural sector remain insufficiently explored. In particular, the study by N. Sirenko *et al.* (2024) focused on changes in the export structure of organic products under the influence of wartime factors, while insurance aspects were not addressed. Similarly, O. Nechyporenko *et al.* (2022) concentrated on infrastructural challenges and asset losses in the agricultural sector, yet issues of insurance provision were not included in the analysis. Digitalisation of the insurance market was covered in the study by C. Eckert & K. Osterrieder (2020) and A.A. Mustafina *et al.* (2020), where blockchain tools, artificial intelligence, and automated services were analysed. However, the specificity of agricultural insurance, methods for assessing sectoral risks, and accessibility of insurance services for agricultural producers did not receive sufficient attention. D. Lanfranchi & L. Grassi (2021) explored general trends in the development of the insurance sector without distinguishing the agricultural context. In the study by N. Sirenko *et al.* (2021), the regulation of digital currencies was addressed, yet digital mechanisms in agricultural insurance remain under-researched despite their potential role in enhancing risk management in agriculture.

The study by Z. Juhászová *et al.* (2023) analysed the relationship between the development of insurance in the agricultural sector and improvements in food security levels, establishing that the effective functioning of insurance mechanisms contributed to better agricultural performance. Nevertheless, the study lacked a detailed analysis of integrating the proposed model into the Ukrainian regulatory environment. In the paper by I. Sazonets *et*

al. (2021), the focus was placed on the financial capacity of agricultural producers and the importance of developing reinsurance mechanisms, but the role of state involvement in ensuring the accessibility of insurance services remained unexplored. Transnational interaction in agricultural insurance was addressed in the study by O. Vilenchuk *et al.* (2022), where the potential of international insurance cooperation in agribusiness was outlined against the backdrop of contemporary challenges. The study emphasised the importance of access to global reinsurance instruments and collaboration with international financial institutions. However, the mechanisms for adapting this experience to the regulatory environment of the Ukrainian market and the role of the state in compensating insurance costs remained outside the scope of analytical consideration.

Aspects of institutional development of the agricultural sector under contemporary transformations were examined in the study by O. Pavelko *et al.* (2024). The authors analysed trends in changes to the production structure, financial support, and export orientation of the agricultural complex. Despite the comprehensive approach to assessing sectoral prospects, insurance as a tool for mitigating production risks was not explored in detail, creating a gap between financial mechanisms and risk-oriented management. The study by L. Voytovych & D. Voytovych (2024) focused on the digital foundations of modernising the insurance sector. The study addressed the creation of an innovative environment, automation of insurance processes, and the implementation of information and communication technologies. However, the application of digital solutions within agricultural insurance was not analysed, which limits the possibility of extrapolating the findings to a sector-specific context. Financial and marketing shifts in the functioning of the insurance market during wartime conditions were examined by Yu. Aleskerova *et al.* (2024). The study presented company adaptation strategies, evolving consumer demands, and behavioural patterns. Nevertheless, the agricultural dimension remained beyond the analytical framework despite its heightened vulnerability to crisis factors and its strategic value for the national economy.

The analysis of academic sources demonstrated the lack of comprehensive research in the field of agricultural insurance. Authors tend to focus on individual components such as digitalisation of the insurance market, marketing strategies, institutional changes, or the broader economic context. Nevertheless, comprehensive approaches to analysing insurance protection instruments, mechanisms of

state regulation, and opportunities for adapting the experience of the European Union to the specific conditions of the Ukrainian agricultural sector remain insufficiently developed. The purpose of the study was to substantiate the areas for improving the system of agricultural insurance in Ukraine based on the analysis of organisational models implemented in France, Germany, Spain, and Poland.

► Materials and methods

The conducted study adopted a theoretical and analytical focus, concentrating on the examination of the evolution of the agricultural insurance system, the identification of key dynamic characteristics, and the assessment of possibilities for improving relevant mechanisms. The analysis covered the period 2022-2024, which enabled the tracking of changes in the structure and scale of agricultural insurance in Ukraine and facilitated a comparative assessment with the practices of the European Union countries, including France, Germany, Spain, and Poland. Particular attention was devoted to identifying the factors influencing the functioning of the market, assessing the effectiveness of existing state regulation instruments, and examining prospects for the implementation of international experience. The analytical framework was based on the systematisation of official insurers' reports, materials of regulatory bodies, and publications of international institutions engaged in analytical monitoring of insurance markets. The primary sources consisted of data from the National Bank of Ukraine (n.d.), which reflected indicators of agricultural insurance coverage, volumes of insurance premiums, and payouts. Supplementary statistical data were obtained from the Forinsurer portal (n.d.), which provides detailed analytical reviews of the development of the agricultural insurance segment and the activities of leading companies operating in this field.

A separate group of sources comprised financial statements of insurance organisations providing agricultural insurance services in Ukraine and demonstrating the highest levels of activity in the market during 2022-2024. Annual reports of companies such as PZU (n.d.), ARX (n.d.), Oranta (n.d.), Etalon (n.d.), TAS (n.d.), UPSK (n.d.), and Universalna (n.d.) were analysed. The selection of these companies was based on their representativeness in the agricultural insurance segment, the volume of concluded contracts, the stability of insurance payouts, and the availability of open financial reporting. These reports contain data on the dynamics of contract conclusion, the structure of insurance products, levels of financial stability, and changes in demand for insurance services from the agricultural sector, allowing an evaluation of the competitive environment and the identification of transformational trends in the market. The analysis of the Polish practice was conducted using data from the Polish Reinsurance Company (n.d.), providing a more detailed characterisation of the mechanisms of agricultural insurance in markets similar to Ukraine in terms of agricultural structure, the development of small and medium-sized farming, and the regulatory framework. The Polish case was examined as a potential model for adaptive application, given its institutional similarity and the active implementation of a subsidised insurance system. The analysis of reinsurance mechanisms was based on the examination

of the activities of international companies Munich Re (n.d.), Swiss Re (n.d.), and Hannover Re (n.d.), which protected local markets against catastrophic risks through the conclusion of reinsurance agreements. The experience of these institutions was considered as a potential reference point for developing a national reinsurance system capable of ensuring the financial stability of the agricultural insurance segment of Ukraine under conditions of high risk in agricultural production. The application of statistical methods for the analysis of time series, including the calculation of growth rates, absolute and relative deviations, mean values, and graphical interpretation of indicators, enabled the assessment of structural and quantitative changes in the agricultural insurance market of Ukraine during 2022-2024. Average values of premiums, the share of insured areas, and the level of payouts were determined, which facilitated the identification of structural trends, the evaluation of insurance coverage levels, and the examination of the impact of the economic and regulatory environment on the respective segment.

Content analysis was applied to examine the regulatory framework governing agricultural insurance in Ukraine, particularly the Law of Ukraine No. 4391-VI (2012) and the Law of Ukraine No. 1909-IX (2021). The interpretation of the findings was based on logical generalisation, which ensured the systematisation of the collected data and the identification of the key factors shaping the conditions for market functioning. Based on these generalisations, the advantages and limitations of existing insurance protection mechanisms were outlined, and their effectiveness in mitigating risks for agricultural producers was assessed. Structural analysis enabled the identification of interrelations between the level of state regulation, the financial stability of insurers, and the accessibility of insurance products for agricultural businesses. These findings form the foundation for developing practical recommendations aimed at improving the functioning of the agricultural insurance market, particularly through the expansion of subsidised insurance programmes and the implementation of digital tools for risk monitoring.

► Results

The insurance system in the agricultural sector was examined as a key risk management instrument supporting the economic activities of agricultural enterprises. The agricultural sector of Ukraine during 2022-2024 remained highly vulnerable to natural and climatic fluctuations, including droughts in the southern regions, excessive moisture in the western areas, and the consequences of the full-scale war, which resulted in the loss of arable land and disruptions to logistics. The utilisation of insurance instruments helped reduce direct losses associated with crop failure or destruction. According to the Ministry of Agrarian Policy and Food of Ukraine, the total losses of the agricultural sector in 2022 exceeded USD 9.3 billion. Of which approximately 25% could have been potentially covered under conditions of full-scale implementation of insurance mechanisms (UN estimates losses in..., 2025). Within the framework of the state-supported agricultural insurance programme launched in a pilot format in 2023, a share of agricultural producers received compensation of up to 60% of insurance premiums for insuring winter cereal crops.

From an economic perspective, agricultural insurance involves the establishment of centralised financial reserves, formed through insurance premiums and utilised to compensate losses in the event of risk materialisation. In 2023, the volume of collected insurance premiums in the agricultural insurance segment amounted to approximately UAH 480 million, while total payouts exceeded UAH 270 million, indicating an increase in the share of insured areas compared with 2022 (UN estimates losses in..., 2025). The financial model of insurers' operations was based on the accumulation of premiums and the distribution of payouts in accordance with contractual terms. The effectiveness of insurance mechanisms depended on the accuracy of risk assessment, the quality of actuarial calculations, and the solvency of insurance companies. According to PZU (n.d.), the average compensation rate under crop insurance contracts in 2023 reached 62 per cent, reflecting a dependence of outcomes on weather conditions during April-June. The introduction of insurance coverage contributed to enhancing the economic security of agricultural enterprises by reducing the risk of production disruptions, delays in loan repayments, and the destabilisation of cash flows.

Various types of insurance products were employed in agricultural insurance to mitigate risks specific to agricultural production. Crop insurance covered losses caused by natural hazards such as drought, hail, or frost. Protection of perennial plantations applied to long-term crops vulnerable to climate-related damage. Income insurance provided compensation to producers in cases of reduced profitability due to unfavourable market conditions or operational challenges. Reinsurance functioned as an intra-industry risk redistribution mechanism, alleviating the burden on individual companies and strengthening the overall resilience of the insurance sector. Index-based insurance was regarded as an alternative model of risk protection, involving the use of standardised indicators such as precipitation levels, air temperature, or satellite-based vegetation indices (Koval, 2023). This approach removed the need for individual damage inspections, thereby optimising the decision-making process regarding payouts. The adoption of this model contributed to greater transparency, reduced administrative burdens, and accelerated the fulfilment of insurance

obligations. Under conditions of increasing climate variability, index-based insurance gained growing importance in global practices of protecting the agricultural sector.

The effectiveness of the agricultural insurance system was determined by the level of coordination between state authorities and private insurance institutions. In France, Spain, Italy, and Poland, public-private partnership models were implemented, combining partial state financing of insurance premiums with stabilisation funds and supervision of insurers' financial stability (Bucheli *et al.*, 2022). The application of such approaches facilitated broader access to insurance services and reduced the agricultural sector's vulnerability to exogenous risks. In these countries, multi-level insurance systems were established, integrating classical products with innovative approaches to risk assessment and management. Subsidised models enabled producers to access insurance coverage on more favourable terms, while digital tools – including satellite monitoring, weather indices, and automated algorithms – enhanced the accuracy of actuarial calculations and shortened claims processing times. Evidence demonstrated the positive impact of these elements on the stability of financial flows within agriculture.

The development of agricultural insurance in Ukraine required the adaptation of institutional and technological solutions tested in France, Germany, Spain, and Poland, while considering the specific characteristics of the national regulatory environment, financial infrastructure, and level of digital readiness. Priority areas included harmonising legislation, engaging global-level reinsurance companies, and establishing effective mechanisms for budgetary subsidies of insurance premiums. The analysis of the activities of PZU (n.d.), ARX (n.d.), Oranta (n.d.), Etalon (n.d.), TAS (n.d.), UPSK (n.d.), and Universalna (n.d.) provided insights into the effectiveness of applied risk management tools, the diversification of insurance products, and the potential for developing innovative forms of insurance coverage. The assessment of the dynamics of key agricultural insurance indicators in Ukraine for 2022-2024 enabled the identification of the main areas of transformation within this segment of the insurance market under conditions of economic turbulence and increasing external risks (Table 1).

Table 1. Key indicators of agricultural insurance in Ukraine, 2022-2024

Indicator	2022	2023	2024
Number of insurance companies providing agricultural insurance services	10	8	7
Total insurance premiums, thousand UAH	81.061	75.000	70.000
Total insurance payouts, thousand UAH	29.830	25.000	20.000
Payout ratio, %	36.8	33.33	28.57

Source: based on S. Vlasniuk *et al.* (2023), O. Vilenchuk & A. Savytska (2024), Forinsurer (n.d.)

Between 2022 and 2024, a reduction was observed in the number of insurance companies operating in the field of agricultural insurance, from 10 active participants in 2022 to 7 in 2024. This trend may indicate ongoing market consolidation and the withdrawal of certain companies due to an unfavourable economic environment, heightened operational risks in agriculture, and declining profitability of related services. The volume of collected insurance premiums demonstrated a gradual decrease,

falling from UAH 81,061 thousand in 2022 to UAH 70,000 thousand in 2024. This pattern may reflect lower demand for insurance products among agricultural producers or tighter restrictions on insurance terms, which reduced their attractiveness. The decline in total insurance payouts during the same period, from UAH 29,830 thousand to UAH 20,000 thousand, was accompanied by a decrease in the payout ratio from 36.8% to 28.57%. Such dynamics may indicate both a reduction in the number of insured

events and a transformation in insurers' compensation policies. These findings point towards a trend of market contraction, restricted accessibility of insurance products for agricultural enterprises, and a decline in the overall level of insurance coverage. This situation resulted from a combination of economic factors and characteristics of the regulatory environment, which defined the operating conditions of market participants. A critical aspect involved assessing the degree of competition among insurers, their financial stability, and the effectiveness of reinsurance mechanisms as a tool for risk diversification.

During 2022-2024, activity in the agricultural insurance market remained concentrated among companies such as PZU (n.d.), ARX (n.d.), Oranta (n.d.), Etalon (n.d.), TAS (n.d.), UPSK (n.d.), and Universalna (n.d.), which were included in the study sample. The majority of insurance operations were performed by large companies, particularly PZU (n.d.), ARX (n.d.), Oranta (n.d.), Etalon (n.d.), TAS (n.d.), and UPSK (n.d.), which possessed sufficient reserves, stable financial reporting, access to international reinsurance structures, and effective distribution channels for insurance products. Reduced activity or complete withdrawal of certain companies from

the agricultural insurance segment was associated with limited financial resources, insufficient capitalisation, and difficulties in managing risks under conditions of heightened agricultural losses. The development of the agricultural insurance market in Ukraine is shaped by a combination of economic, regulatory, and climatic factors. Variability in weather conditions, market instability, and changes in state financing of the agricultural sector underscore the relevance of insurance as a tool for risk mitigation. However, limited competition among insurers, the high cost of insurance products, and insufficient levels of subsidies create barriers to accessing insurance coverage, particularly for small and medium-sized producers. The analysis of the number of agricultural insurance contracts concluded by key insurance companies between 2022 and 2024 provided insights into shifts in demand structure, the activity levels of individual market players, and prevailing trends within the segment. The resulting dynamics reflect the response of the market to evolving economic conditions and regulatory pressures, enabling the formulation of evidence-based conclusions regarding the prospects for further development of agricultural insurance in Ukraine (Fig. 1).

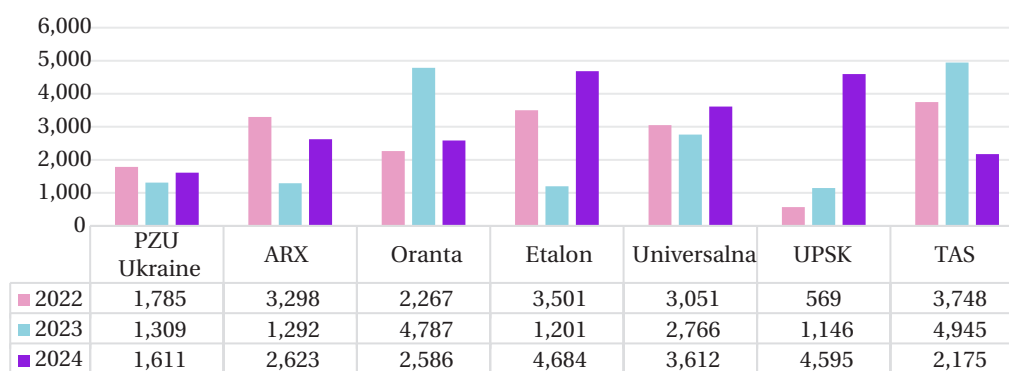


Figure 1. Number of agricultural insurance contracts concluded (2022-2024)

Source: based on PZU (n.d.), ARX (n.d.), Oranta (n.d.), Etalon (n.d.), TAS (n.d.), UPSK (n.d.), Universalna (n.d.)

The indicators of the number of agricultural insurance contracts concluded in 2022-2024 indicate variation across individual insurance companies, which was likely driven by a combination of internal managerial factors and the influence of the external economic environment. In 2023, for instance, Oranta recorded an increase in the number of concluded contracts to 4,787, nearly double the figure of the previous year (2,267), while in 2024 this indicator declined to 2,586. A similar trend was observed in TAS, where 4,945 contracts were signed in 2023, yet only 2,175 in 2024. These fluctuations may have been linked to changes in insurance programme conditions, the level of financial accessibility of products, regulatory policy adjustments, or the degree of state support. Different companies exhibited distinct dynamics in maintaining their client bases. For example, PZU (n.d.) demonstrated relative stability throughout the analysed period, with 1,785 contracts concluded in 2022, 1,309 in 2023, and 1,611 in 2024. This reflected the consistency of its operational strategy and the existence of an established clientele. In contrast, UPSK showed a significant rise in 2024, reaching 4,595 contracts compared with 569 in 2022 and 1,146 in

2023. This trajectory may indicate a strengthening of the company's market presence, the introduction of more competitive insurance terms, or growing demand for its products among agricultural producers.

The consolidated analysis of contract dynamics confirmed the overall instability of the agricultural insurance market. Likely contributing factors include intersectoral competition and broader macroeconomic influences, such as limited access to state support, shifts in reinsurance policies, fluctuations in market conditions, and the high level of climate-related risks. The absence of a systemic mechanism for public financing of agricultural insurance remained one of the key obstacles to the stable development of this segment. Unlike the situation in Ukraine, the countries of the European Union possess a far more advanced institutional framework for managing agricultural risk insurance, which integrates public subsidies, diversifies insurance products, and adopts modern risk assessment technologies. State involvement in market operations enabled a reduction in the financial burden on agricultural producers, expansion of insurance coverage, and mitigation of the likelihood of market destabilisation.

Within the European Union, a range of compensatory instruments are actively employed, including partial premium subsidisation, the operation of insurance stabilisation funds, and state reinsurance programmes that enhance insurers' resilience to large-scale losses.

The comparative analysis of agricultural insurance models in the European Union enabled the identification of the principal characteristics of state support mechanisms,

particularly in terms of compensation procedures, regulation of insurance conditions, and the integration of digital technologies into risk assessment processes. The examination of these mechanisms provides insights into the factors underpinning their effectiveness within highly developed systems of insurance protection and establishes a foundation for assessing the prospects of their adaptive implementation within the Ukrainian context (Table 2).

Table 2. Models of state support for agricultural insurance in selected European countries

Country	Insurance model	Mechanism of state support
France	Combined insurance with partial coverage of premiums	The state subsidises a portion of insurance premiums, reducing the financial burden on producers
Germany	Combined insurance with an emphasis on private insurers	State support is provided through subsidies on insurance premiums and tax incentives for farmers
Spain	Combined system involving both the state and private insurers	The state co-finance insurance premiums and provides reinsurance through state-managed funds
Poland	Insurance programmes backed by financial guarantees	The state provides financial guarantees to compensate for losses in the event of catastrophic events

Source: based on A.I.D. Rus & I. Brici (2021), A. Bilochenko & I. Gushcha (2022)

In France, Germany, and Spain, combined models of agricultural insurance operate, based on the interaction between state institutions and the private insurance sector. This approach reduced the financial burden on agricultural producers, increasing the accessibility of insurance services and stimulating their wider adoption among farming enterprises. The use of mechanisms for subsidising insurance premiums and granting tax incentives contributes to expanding insurance coverage, which in turn strengthens the overall stability of agricultural production. In Spain, state involvement extended beyond subsidising premiums and includes reinsurance functions implemented through specialised public funds. This provided additional guarantees for insurance companies and agricultural producers in cases of significant losses, particularly those resulting from natural disasters. In Poland, agricultural insurance programmes were based on mechanisms of state financial guarantees. These programmes envisage partial compensation of losses in the event of catastrophic risks, including droughts, floods and other extreme events, thereby ensuring stability in the agricultural sector even under unfavourable climatic conditions. The diversity of approaches to state support for agricultural insurance in the European Union arises from the need to adapt to national agroclimatic and economic conditions. The implementation of combined models, premium subsidies, and systems of financial guarantees enhanced the resilience of the agricultural sector and ensures its long-term competitiveness.

The integration of digital technologies into agricultural insurance had become one of the key approaches for improving the efficiency of risk assessment systems. The automation of premium calculations, application processing, and crop monitoring through satellite imagery, meteorological models, and remote sensing systems improve both the speed and objectivity of decision-making. Within the European Union, such technologies were integrated directly into insurance products, reducing transaction costs and improving the quality of insurance services. International reinsurance companies played a significant role in maintaining the financial stability of agricultural

insurance systems, particularly under conditions of high catastrophic loss probability. The study examined the activities of three leading reinsurance structures – Munich Re (n.d.), Swiss Re (n.d.) and Hannover Re (n.d.) – whose experience was considered relevant for adaptation to the national agricultural insurance market. Their involvement in supporting local insurers in Poland, France, Germany, and Spain facilitated risk diversification, reduced the financial burden on primary insurers, and expanded the range of available insurance products for agricultural producers (Kramer *et al.*, 2022).

In France and Spain, Munich Re (n.d.) provided reinsurance coverage for agricultural risks based on weather indices, employing fixed triggers that enabled insurance payouts without the need for individual loss assessments. The application of parametric insurance was integrated into state reinsurance mechanisms and used for the prompt compensation of losses caused by natural hazards. The use of standardised indicators was found to contribute to reducing the duration of the decision-making process regarding payouts and to enhancing the transparency of insurance operations in the agricultural sector. In Poland, France, and Spain, Swiss Re (n.d.) implemented reinsurance programmes in the form of public-private partnerships, encompassing subsidised models of agricultural insurance. The application of digital tools for modelling agricultural risks was recorded, including satellite monitoring, predictive algorithms, and automated loss assessment. The company's activities contributed to the stabilisation of reinsurance reserves, which maintained the solvency of primary insurers in the event of large-scale occurrences.

In Poland and Germany, Hannover Re (n.d.) introduced weather index-based reinsurance models using meteorological data, satellite observations, and geospatial indicators. The analysis demonstrated that the company's reinsurance programmes were adapted to regional variations in climatic conditions, enabling differentiation of coverage structures according to the profile of agricultural risk. This structure facilitated the effective redistribution of risk among insurers and reduced the likelihood

of excessive concentration of liabilities in the agricultural sector. Implementation of European models of agricultural insurance within the Ukrainian context required the adaptation of effective practices in accordance with institutional characteristics. Priority areas include the integration of innovative approaches to agricultural risk assessment, expansion of budgetary subsidies for insurance premiums, and the establishment of stabilisation insurance funds to cover unforeseen losses.

The development of a national system of agricultural insurance necessitates a comprehensive approach combining financial, regulatory, and organisational components. A key task involved conducting a systematic assessment of the effectiveness of existing insurance mechanisms

to identify vulnerable areas and develop measures for their optimisation. Collection and analysis of statistical data on payouts, coverage of agricultural land, and the structure of insurance premiums provide the foundation for an objective evaluation of the market. Comparative analysis of statistical data on agricultural insurance in Ukraine and the European Union enabled identification of the level of engagement of agricultural producers with the insurance system, tracking of coverage trends over recent years, and assessment of the effectiveness of state support programmes (Table 3). Such indicators were crucial for determining the financial stability of insurance companies, the level of trust among farming enterprises, and the effectiveness of regulatory interventions by state institutions.

Table 3. Comparative analysis of agricultural insurance indicators in Ukraine and selected EU countries

Indicator	Ukraine (2024)	Poland (2024)	Germany (2024)	France (2024)	Spain (2024)
Share of insured agricultural land, %	4	25	30	35	50
Volume of insurance premiums, UAH billion	70	95.4	120.3	160.2	175.6
Volume of insurance payouts, UAH billion	20	60.5	85.2	115.4	130.8
Share of insurance premiums in GDP, %	0.7	2.3	2.5	2.8	3.1
Subsidisation of insurance premiums, %	0	60	50	65	75

Note: GDP – Gross Domestic Product

Source: based on National Bank of Ukraine (n.d.), Polish Reinsurance Company (n.d.)

In 2024, the proportion of insured agricultural land in Ukraine remained minimal, accounting for less than 4% of the total area, substantially lagging behind the levels observed in European Union countries. In Germany and France, coverage exceeded 30%, while in Spain it reached up to 50%, indicating active utilisation of insurance instruments by agricultural producers. Such levels were largely supported by state programmes, which compensated a significant portion of insurance costs, reducing the financial burden on producers. The absence of mechanisms for state subsidies of insurance premiums in Ukraine hinders access to insurance protection, as farmers are required to cover the full cost of insurance themselves. In contrast, the degree of subsidy in European Union countries varies according to national policy: in Germany it reached 50%, in France 65%, and in Spain 75%. This level of support creates additional incentives for farmers to adopt insurance-based risk management mechanisms.

The ratio of insurance premiums to gross domestic product in Ukraine amounted to 0.7%, several times lower than the corresponding figures in European Union countries. In Poland, the ratio reached 2.3%, in Germany 2.5%, and in France 2.8%. Higher values reflect greater integration of insurance into the financial infrastructure of the agricultural sector and a higher level of trust in insurance instruments among farming enterprises. The results of comparative analysis confirm the necessity of transforming the Ukrainian system of agricultural risk insurance. Priority measures include the introduction of budgetary programmes for compensation of insurance premiums, the establishment of financial guarantee systems to cover losses from large-scale risks, and the expansion of access to insurance products for small and medium-sized agricultural producers, who remain most vulnerable to unforeseen losses.

Interpretation of statistical data allowed for the assessment of the level of trust of agricultural producers in

insurance companies. High levels of agricultural insurance coverage in European Union countries indicate effective collaboration between the state and private sector, providing farmers with predictability of financial outcomes. In Ukraine, however, the low number of contracts and the limited area of insured land indicate weak integration of insurance mechanisms into the risk management system of the agricultural sector. Analysis of insurance premiums, payout volumes, and the proportion of insured land identified key factors influencing the effectiveness of agricultural insurance. Among these are the availability of state financial support, the level of trust in insurance companies, the affordability of insurance products, and the implementation of digital tools for risk assessment. Improvements in procedures for concluding insurance contracts, ensuring transparency in payouts, and the digitalisation of loss assessment processes could stimulate demand for insurance services in the agricultural sector.

International experience confirms that the effectiveness of agricultural insurance depends on a combination of factors, including state support, reinsurance mechanisms, and the accessibility of insurance instruments. The use of subsidised models, the development of index-based insurance, and the integration of digital technologies positively influence the level of insurance coverage of agricultural land. Comparison of structures and approaches in France, Germany, Spain, and Poland highlighted the specific organisation of the insurance market and enabled assessment of the feasibility of adapting selected models to the Ukrainian context. Evaluation of European practices of agricultural insurance allowed the identification of key institutional features of the organisation of insurance protection, the effectiveness of state policy implementation, and the robustness of risk management instruments in agriculture. Comparison with the Ukrainian model provided grounds for identifying structural differences and formulating proposals for improving the Ukrainian

system, drawing on the experience of European Union countries. The data summarised in Table 4 enabled analysis of the characteristics of national approaches to

agricultural insurance and facilitated assessment of their relevance in the context of Ukrainian economic and institutional conditions.

Table 4. Comparative analysis of agricultural insurance models in Ukraine and selected EU countries

Country	Insurance model	State support	Level of participation of private insurers	Use of index-based insurance
Ukraine	Voluntary insurance without subsidies	None	High, though financial stability is limited	Low, at the stage of implementation
Poland	Subsidised insurance	60% of premiums covered by the state	High	Moderate, regional indices are applied
Germany	Combined insurance	50% of premiums subsidised by the state	High	High, weather index insurance widely used
France	Combined insurance with reinsurance	65% of premiums subsidised by the state	High	High, satellite data are widely applied
Spain	State and private insurance	75% of premiums covered by the state	Moderate, state control via dedicated funds	High, advanced technological platforms used

Source: based on A.I.D. Rus & I. Brici (2021), A. Bilochenko & I. Gushcha (2022), S. Vlasniuk *et al.* (2023)

The system of agricultural insurance in Ukraine operated voluntarily without state participation in financing insurance premiums, which limited its accessibility for agricultural producers. This model contrasted with the approaches adopted in European Union countries, where partial subsidy instruments were employed to reduce farmers' expenses and encourage their participation in insurance schemes. Contemporary challenges caused by armed aggression require the introduction of innovative approaches to agricultural business, including the development of insurance mechanisms. As noted by A. Bexolli *et al.* (2023), "innovation plays a key role in ensuring the resilience of the agricultural sector to disruptive external impacts, particularly those related to military threats". This highlights the necessity of adapting the agricultural insurance system to conditions of heightened turbulence.

In France and Germany, reinsurance mechanisms are widely applied, enabling insurance companies to reduce the risk of catastrophic losses. In Spain, by contrast, key risk management functions are centralised within state funds, ensuring the stability and accessibility of insurance products. The broader implementation of index-based insurance in European Union countries compared with Ukraine is attributed to the availability of satellite monitoring infrastructure, automated platforms for loss assessment, and the use of weather indices as an objective basis for payout decisions. In Spain, such instruments are integrated into digital insurance ecosystems, which ensures operational efficiency and reduced transaction costs.

Between 2022 and 2024, agricultural insurance in Ukraine operated under heightened market instability, which led to a decrease in the number of active insurers, a reduction in insurance premiums and payouts, and a decline in the coverage of agricultural land by insurance. The structure of insurance products was dominated by classical forms of protection, particularly crop and perennial plantation insurance, while index-based models remained at the stage of limited implementation. The majority of contracts were concluded by companies with developed infrastructure, access to reinsurance, and stable financial indicators, which ensured relative resilience in certain segments of the market. Comparative analysis demonstrated a disparity between the level of development of

agricultural insurance in Ukraine and in France, Germany, Spain, and Poland, where combined models were applied, incorporating state subsidies for premiums, centralised reinsurance, and digital risk monitoring systems. In these countries, the proportion of insured land and the share of premiums in gross domestic product significantly exceeded the corresponding Ukrainian figures, supported by effective state participation and a high level of trust in insurance instruments.

Analysis of the activities of international reinsurance companies, such as Munich Re (n.d.), Swiss Re (n.d.), and Hannover Re (n.d.), identified key approaches to ensuring financial stability within the agricultural insurance systems of the European Union. In France and Spain, Munich Re actively introduced weather-indexed products based on satellite data and automated payout parameters, which reduced the time required for loss settlement and lowered administrative costs. In Poland and Germany, the reinsurance programmes of Swiss Re were adapted to national state subsidy schemes, ensuring stable coverage even under conditions of substantial loss exposure. Hannover Re, in turn, implemented multi-tier reinsurance liability models using weather indicators and spatial risk modelling. A common feature of all three companies was the application of digital tools for agricultural modelling, risk forecasting, and the efficient transfer of data between insurers and regulators. This experience demonstrates the effectiveness of reinsurance as a component of long-term stability in the agricultural insurance market, offering a framework that could be adapted in Ukraine to mitigate systemic risk and strengthen trust in insurance instruments within agricultural production.

► Discussion

The analysis of the obtained results confirms that the coverage of agricultural insurance in Ukraine remains at a low level, primarily due to the absence of state subsidy mechanisms, the high cost of insurance premiums, and limited reinsurance opportunities. Similar challenges were outlined in the study by B. Kramer *et al.* (2022), which highlighted that conventional insurance instruments are largely inaccessible to most farming enterprises due to their high costs and the difficulties associated with

accurately assessing losses. The study examined the feasibility of implementing innovative approaches, including mechanisms of social insurance protection, as a means of expanding access to insurance and compensating for catastrophic losses. This study underscored the necessity of developing a comprehensive system of state support for agricultural insurance, particularly through the introduction of guarantee mechanisms, the subsidisation of insurance premiums, and the creation of tailored products for small and medium-sized producers.

The instability in the dynamics of insurance contract conclusions during 2022-2024 reflects the sensitivity of the market to regulatory changes and fluctuations in demand. Comparable decision-making factors influencing farmers' insurance choices were identified in the study by E. Nshakira-Rukundo *et al.* (2021), which determined six key determinants: the quality of insurance services, product design features, price affordability, the level of awareness, sociocultural barriers, and institutional support from the state. The relevance of these findings to the Ukrainian context was reinforced by the identified limitations in access to insurance products, weak state involvement, and an insufficient number of adapted insurance programmes. The integration of technological innovations into agricultural insurance processes was considered one of the most effective approaches to enhancing the accuracy of risk assessment. The study by V. Moysiadis *et al.* (2021) analysed the potential of smart farming technologies, including drones, image processing systems, sensor networks, and machine learning algorithms, which demonstrate their effectiveness in strengthening the functionality of insurance products. The results of this study align with previously obtained findings, which emphasised the feasibility of using satellite data, meteorological models, and large-scale datasets to automate loss assessment, improve transparency, and accelerate insurance payouts.

Limited coverage of agricultural insurance, high financial barriers, and the absence of products adapted to climate change remain systemic challenges in Ukraine. Similar trends were identified in the meta-analysis by S. Vyas *et al.* (2021), which reviewed more than 796 studies dedicated to agricultural insurance. The authors established that the dominance of crop insurance themes and the focus on highly developed countries constrained attention to issues related to livestock insurance, aquaculture, and adaptation to climate risks. These findings highlighted the need to broaden both the research and practical scope of insurance solutions, including the development of index-based and multi-level risk management models under conditions of climatic instability.

The low level of insurance penetration in Ukraine is partly explained by farmers' limited awareness, financial constraints, and the absence of a stable system of state support. Comparable barriers were recorded in the study by D.A. Ankrah *et al.* (2021), which examined the acceptability of agricultural insurance among smallholder farmers in Ghana. Only 14% of respondents had active insurance contracts, although 90% recognised agricultural insurance as an effective risk management instrument. The main reasons for low participation included insufficient awareness (64%), lack of access to insurance products (23%), and high premium costs (5%). These results

point to a common challenge for developing markets, including Ukraine, where crucial preconditions for stimulating agricultural insurance involve the provision of informational support, the design of affordable insurance programmes, and the implementation of effective subsidy mechanisms.

The results confirm that agricultural insurance can perform not only the function of financial risk compensation but also indirectly influence the environmental behaviour of agricultural producers. In the study by L. Tang & X. Luo (2021), it was demonstrated that the presence of insurance coverage facilitates the transition of farmers to more environmentally sustainable practices, particularly the use of biological pesticides. According to the modelling results, the likelihood of adopting such pesticides increased by 8.2% when insurance protection was available. These conclusions were relevant for Ukraine, where the potential expansion of agricultural insurance could support the implementation of technologies aimed at reducing anthropogenic pressures on the environment. The capacity of insurance mechanisms to enhance agricultural production efficiency was explored in the study by H. Li *et al.* (2022), which analysed the relationship between agricultural insurance, air pollution, and total factor productivity in Chinese agriculture. It was established that insurance encouraged investment in modern technologies and contributed to productivity growth, although it did not always coincide with improvements in environmental indicators. This dual effect was equally significant for Ukraine, where the expansion of insurance coverage should be accompanied by the integration of environmental criteria into insurance products to prevent adverse outcomes.

The influence of agricultural insurance on the adaptive capacity of the agricultural sector to climate change was examined by H. Mao *et al.* (2025). The study demonstrated that insurance mechanisms encourage the adoption of technologies aimed at reducing climate-related risks, particularly under conditions of increasing frequency of extreme weather events. Comparable conclusions can be extrapolated to the Ukrainian context, where rising vulnerability to climate change necessitates the introduction of insurance programmes focused on climate adaptation. Such programmes would involve compensatory payments for losses caused by weather anomalies and support for the implementation of adaptive practices. An analysis of the experience of the United States, presented in the study by N. Ahmed *et al.* (2022), indicated that insurance can promote environmentally sustainable agricultural development while creating risks of production intensification. The authors identified a positive effect of insurance coverage on the adoption of environmentally oriented technologies, although in some cases this was accompanied by an increase in environmental pollution. These findings underscore the importance of integrating environmental standards into the structure of insurance products in the context of Ukraine to maintain a balance between productivity and environmental safety.

One of the barriers to the development of agricultural insurance in Ukraine remains the delays in the payment of insurance compensations, explained by inefficiencies in loss verification processes. In this context, the study by T. Manoj *et al.* (2025) was noteworthy, proposing the

conceptual model AgriInsureDON based on blockchain architecture. The use of decentralised oracles and Internet of Things devices enables the automation of accurate data collection for decision-making on payouts. The proposed model ensures transparency, operational efficiency, and reduced transaction costs. The application of similar technologies within Ukrainian agricultural insurance could enhance the efficiency of market functioning, although further research was required regarding regulatory integration and economic feasibility. The findings indicated that the impact of agricultural insurance extends beyond ensuring the financial stability of farming enterprises, generating additional effects within the production sphere, particularly regarding the scale of agricultural output. Similar conclusions were reached by D. Hou & X. Wang (2025), who investigated the relationship between agricultural insurance and the expansion of grain crop planting areas in China. The analysis of panel data from 27 provinces enabled the authors to confirm that the availability of insurance coverage reduced financial risks, stimulated investment activity, and supported the expansion of agricultural land use. Nevertheless, this impact was indirect and depended on the financial capacity of farming enterprises. A comparable dependence was identified in the present study, demonstrating that access to insurance services influenced the volume of investment in production processes.

The development of agricultural insurance was accompanied by social dimensions, particularly those related to gender inclusion. The study by A. Timu & B. Kramer (2021) analysed the access of women and men to insurance coverage in the context of ensuring equal opportunities. The authors emphasised that gender equality issues within the insurance sector often remained overlooked, despite the existence of significant disparities in access to insurance services and the impact of insurance on women's economic independence. The findings of this study indicate the necessity of incorporating socio-demographic characteristics into the design of insurance programmes, aligning with international trends aimed at promoting the inclusiveness of financial instruments.

The financial impact of agricultural insurance on farm profitability was examined in the study by C. Tan *et al.* (2022), which established that the positive effect of insurance mechanisms on incomes was most evident in regions with high levels of insurance coverage. The role of state-supported measures in strengthening the economic resilience of small and medium-sized farms was also highlighted. These results partially correspond with the findings of the present research, which confirmed that the availability of insurance services and the implementation of subsidised programmes have the potential to enhance the financial security of farmers in the context of Ukraine. Financial security represents a critical factor for the stability of agricultural enterprises and forms the foundation for establishing an effective system of insurance protection. As noted in the study, "the modern model of monitoring the financial security of the state should be based on combining theoretical and praxeological approaches, enabling prompt responses to risks and the adaptation of regulatory instruments" (Poltorak *et al.*, 2023). This principle was particularly

relevant for the agricultural sector, which is significantly affected by both external and internal economic factors. An analysis of regional economic development constitutes an essential component in shaping an effective agricultural insurance system, since insurance mechanisms must reflect the economic capacity of regions. As the researchers argue, "the need to assess the dynamics of regional economic development in Ukraine is driven by the necessity to identify reserves and opportunities for enhancing profitability and the efficiency of further activity" (Andrusiv *et al.*, 2020). Establishing an effective insurance system in the Ukrainian agricultural sector requires a comprehensive approach encompassing financial and economic dimensions, together with organisational and legal mechanisms. In particular, the researchers note that "agricultural business insurance in the context of Ukraine should account for the specific characteristics of agricultural production, the high level of risks, and the need for state support during the transformation of the agricultural insurance market" (Babenko *et al.*, 2021). The synthesis of the findings demonstrated the multifaceted role of agricultural insurance in ensuring both economic and environmental stability within the agricultural sector. Insurance mechanisms were found to contribute not only to reducing financial risks, but also to supporting the implementation of ecological practices, adaptive technologies, and improvements in production efficiency. However, persistent barriers included the limited coverage of insurance schemes, high premium costs, lack of subsidies, and insufficient awareness among agricultural producers.

The comparison with practices within the European Union confirmed the effectiveness of several key elements of the insurance market, including reinsurance, index-based insurance models, state-subsidised premiums, and digital tools for risk assessment. The implementation of these approaches facilitated stronger trust in insurance providers and contributed to the expansion of insurance coverage. The analysis of international experience also highlighted the potential of advanced technologies, such as satellite monitoring, big data analytics, and blockchain solutions, in accelerating procedures and enhancing the transparency of insurance operations. In this context, the reform of the Ukrainian model of agricultural insurance was becoming increasingly relevant. Necessary measures included the introduction of mechanisms for state support, the adaptation of insurance products to the needs of different producer groups, and the integration of innovative technologies into risk assessment and claims settlement processes. Particular attention should be directed towards ensuring equal access to insurance services for small-scale farmers, promoting the wider use of index-based insurance, and developing an institutional framework capable of supporting the sustainable growth of the agricultural insurance market.

► Conclusions

The study conducted a comprehensive assessment of the state and dynamics of the agricultural insurance system in Ukraine during 2022-2024. A decline was recorded in the number of active participants in the insurance market from 10 to 7 companies, a decrease in the volume of collected insurance premiums from UAH 81,061 thousand

to UAH 70,000 thousand, and a reduction in the amount of insurance payouts from UAH 29,830 thousand to UAH 20,000 thousand. The decrease in the payout ratio from 36.8% to 28.57% confirmed the limited coverage of agricultural producers by insurance protection. It was established that the key barriers to the development of agricultural insurance remain the absence of mechanisms for state subsidisation, the high cost of insurance products, the low level of farmers' awareness regarding risk management instruments, and the underdeveloped reinsurance infrastructure. The highest activity in the market was demonstrated by the companies PZU, ARX, TAS, and UPSK, which had access to international reinsurance resources and maintained financial stability.

The comparative analysis of agricultural insurance models in France, Germany, Spain, and Poland identified effective practices, including combined models with state subsidisation of insurance premiums within the range of 50-75%, the application of index-based insurance, the use of digital platforms for loss assessment, and the integration of satellite technologies into the insurance monitoring process. In these states, the share of insured agricultural land ranged from 25% to 50%, significantly exceeding the indicator in Ukraine, which remains at 4%. The share of insurance premiums in the GDP structure of the analysed countries reached 3.1%, indicating a high level of institutionalisation of the insurance market and

its importance for the agricultural sector. The potential for introducing adapted models into the Ukrainian market was identified, considering the financial capacity of farming enterprises and the regulatory specificities. The assessment of the activities of the international reinsurance companies Munich Re, Swiss Re, and Hannover Re demonstrated the effectiveness of implementing weather indices, parametric insurance models, and multi-level risk distribution mechanisms, which ensure the financial stability of primary insurers in cases of catastrophic losses. Applying this experience in Ukraine provides grounds to consider reinsurance as an instrument for the long-term stabilisation of the agricultural insurance market. Further research should focus on developing models of insurance premium subsidisation, improving regionally oriented reinsurance schemes, adapting digital platforms for index-based insurance, and examining the impact of insurance mechanisms on the social resilience of rural areas.

► Acknowledgements

None.

► Funding

None.

► Conflict of Interest

None.

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► **Анотація.** Дослідницький інтерес зумовлювався обмеженим рівнем страхового покриття в аграрному секторі, що знижувало здатність виробників протистояти економічним втратам і кліматичним впливам. Метою проведеного дослідження було виявлення особливостей функціонування системи аграрного страхування в Україні та обґрунтування доцільності адаптації інституційних і технологічних практик країн ЄС для її модернізації. Методологічна база дослідження охоплювала застосування методу динамічного аналізу для оцінки змін ключових показників українського страхового ринку впродовж 2022-2024 років; методу компаративного аналізу для зіставлення організаційних моделей аграрного страхування у Франції, Німеччині, Іспанії та Польщі; методу структурного аналізу для ідентифікації домінантних елементів у системі страхового покриття; методу контент-аналізу для системного вивчення нормативно-правових актів, аналітичних звітів і технологічних рішень, спрямованих на підвищення ефективності страхового захисту. Також, було використано метод логічного узагальнення для формування висновків і рекомендацій на основі отриманих аналітичних результатів. За результатами дослідження встановлено, що частка застрахованих сільськогосподарських угідь в Україні залишалася істотно нижчою, ніж у аналізованих країнах ЄС, де рівень охоплення сягав 30-50 %; при цьому виявлено, що наявна система не забезпечувала належного розподілу ризиків, що створювало передумови для фінансової вразливості малих і середніх фермерських господарств. Ідентифіковано ключові бар'єри розвитку національної системи агрострахування: відсутність субсидування страхових премій, висока собівартість страхових послуг і низький рівень обізнаності аграріїв. Визначено, що ефективність європейських моделей забезпечувалася використанням державної підтримки, перестраховальних механізмів через міжнародні структури та впровадженням цифрових технологій оцінки ризиків. Актуалізовано необхідність адаптації таких інструментів до умов України з метою розширення доступу до страхових послуг та підвищення фінансової стабільності агросектору. Отримані результати можуть стати основою для формування ефективних заходів державної політики у сфері страхового забезпечення сільського господарства

► **Ключові слова:** державне субсидування; економічна стійкість; цифрові технології; трансформація ринку; структурний аналіз; європейські моделі

ЕКОНОМІКА АПК
Міжнародний науково-виробничий журнал

Том 32, № 4
2025

Відповідальний редактор:
О. Дендебера

Підписано до друку 29.08.2025
Формат 60*84/8
Ум. друк. арк. 9,9
Наклад 100 прим.

Видавництво: Національний науковий центр «Інститут аграрної економіки»
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EKONOMIKA APK

Volume 32, No. 4
2025

Managing Editor:
O. Dendebera

Signed to the print 29.08.2025
Format 60*84/8
Conventional Printed Sheet 9.9
Circulation 100 copies

Publisher: National Scientific Centre "Institute of Agrarian Economics"
03127, 10 Heroiv Oborony Str., Kyiv, Ukraine
Tel.: (+38044)258-43-21
E-mail: info@eapk.com.ua
<https://eapk.com.ua/en>