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# Practical study of the implementation of circular economy at agricultural enterprises of Ukraine

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**Abstract.** Given the role of the agricultural sector in the development of the Ukrainian economy, it is important to find methods to improve the efficiency of its operation. Since one of them is the introduction of a circular economy, the study of cases of its application in the country is relevant. The purpose of the study was to show an example of the implementation of this concept in Ukraine, depicting the advantages and disadvantages of its application. The main research methods were analysis, comparison, and forecasting. The most significant example of implementing the principles of circular economics at the enterprise, namely the company Myronivsky Hliboproduct, was evaluated. It was shown that the company's approach is based on processing waste into biogas and using it as energy. This process not only helps to avoid increasing $CO_2$ emissions into the atmosphere, but also makes much more efficient use of the available resources. In addition, the features water recycling and existing trends in this area were described. Special attention was paid to the difficulties that the company faced during the start of the full-scale Russian invasion in 2022, and what actions were taken to improve the situation. Conclusions were also drawn about the likely opportunities for the company to achieve its goals in the context of the circular economy, considering current trends in the development of Ukraine. The practical value of the study lies in its usefulness for developing recommendations for enterprises to implement the concept of a circular economy. In addition, data from the study can be used by state representatives to improve the effectiveness of policy implementation in the agricultural sector

**Keywords:** biogas; water resources; finance; public administration; sustainable development

## INTRODUCTION

Circular economics is a management concept that is developed to reduce waste and maximise resource efficiency (Barros *et al.*, 2020; Morseletto, 2020). In a traditional (linear) economy, production, use and emissions are sequential stages, while in a circular economy, a closed loop is formed in which resources are used more efficiently and waste is reduced or completely recycled for use in a new production cycle. This allows achieving

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some of the main advantages, namely, the possibility of long-term use of resources (saving them), increasing the environmental friendliness of production. However, the use of this method has its drawbacks: despite the possibility of saving money in the long term, at the initial stage, the company is forced to invest in technology, equipment purchase and training of qualified employees. This leads to the fact that not all companies are able and willing to apply such principles (Mehmood *et al.*, 2021; Corvellec *et al.*, 2022). Thus, the study of cases of implementation of this concept by companies remains relevant, especially in the practice of Ukrainian companies in the agricultural sector, because this area is the most promising for using this concept.

A significant number of researchers have investigated the environmental component of development in Ukraine as a whole. Thus, H. Zelinska *et al.* (2022) examined innovative features of the country's development, including in the context of sustainable development. Researchers paid considerable attention to the fact that innovative technologies should help achieve the principles of this concept, but almost did not provide clear examples of their use. The use of digital technologies in accounting at livestock enterprises was investigated by M. Misiuk & M. Zakhodym (2023). They described the importance of introducing digitalisation in accounting to increase the efficiency of enterprises and, in particular, improve their condition in the context of achieving the sustainable development goals. A. Berxolli *et al.* (2023) investigated innovations in Ukrainian agriculture to mitigate the impact of war. Although the proposals can improve the efficiency of agricultural enterprises, even ensuring their more sustainable development, it is only the beginning of this extensive process. Implementation of the concept of circular economy in the context of regions on the example of the Kharkiv region was studied by S. Strapchuk & O. Mykolenko (2021). Researchers have identified new approaches to production and consumption within the framework of this concept to maximise the efficiency of production at each stage of the life cycle. In addition, special attention was paid to the interregional development of the circular economy, but trends at the level of individual enterprises were not assessed. M. Zlotnik (2022) assessed the problems in implementing the digital economy model in Ukraine. The researcher noted the main barriers to implementing the concept, including: financial difficulties, undeveloped infrastructure, low level of ecological culture. However, the findings do not provide clear recommendations for the development of the national policy in this area.

The purpose of the study was to consider the practical case of using the concept of circular economy in Ukraine on the example of the Myronivsky Hliboproduct company, which will allow drawing conclusions about what advantages and disadvantages exist in this concept, and what are the features of its use in Ukraine.

## MATERIALS AND METHODS

The study used some sources that provide access to statistical information, one of which is the website of the Ministry of Finance (n.d.). This is not the official website of the Ministry of Finance of Ukraine, but it provides separate useful statistical information about the current functioning of the country.

Myronivsky Hliboproduct (MHP) was chosen as a case study for the analysis of the circular economy. The reason for the choice was that this company provides the most information in the context of actions aimed at sustainable development, and also achieved a noticeable improvement in its own activities in this area. The data was taken from the company's financial statements related to the achievement of the sustainable development goals (MHP, 2022). The study evaluated a significant number of indicators that characterise the methods used by MHP aimed at achieving the sustainable development goals, in particular, more active use of renewable energy sources and reuse of water resources. However, it is worth paying attention to the fact that data on the company is available only until 2021. It can be assumed that this is conditioned by the beginning of a full-scale Russian invasion of Ukraine in 2022. This has led to a complication of the company's functioning capabilities, and therefore, the achievement of sustainable development goals and even the development of such reports. Given the situation in the country, it can be assumed that in the conditions of war, the company's ability to comply with the principles of the circular economy has worsened, but full-fledged conclusions can be formed only after the end of the war. The company provided information separately about Ukrainian and foreign enterprises in its reports, so it is necessary to clarify that this study uses data only on the facilities located on the territory of Ukraine. All constructions and calculations were generated using Microsoft Excel.

One of the main research methods used in the study was analysis. It was used to assess a significant amount of data sources aimed at investigating features of development of the circular economy in Ukraine. This method also allowed drawing conclusions about how past trends in Ukraine's development in the field of agriculture enabled it to achieve results that are relevant for 2024. Using the comparison, various principles of achieving a circular economy were evaluated, with special attention to forming an understanding of the advantages and disadvantages of each of them. The method of forecasting, in turn, allowed making estimates of how the MHP can develop in the context of achieving its own strategic goals of sustainable development in the long term, taking into account the war, the possibility of its end, and the state's actions in the new conditions. The tabular method was used to display information and make it easier to understand.

## RESULTS

The case of MHP is one of the most famous examples of the circular economy concept in Ukraine. It actively uses innovative technologies for converting organic waste (in this case, chicken manure) into biogas. This process not only reduces $CO_2$ emissions, but also generates clean energy, heat and steam, contributing to energy security. By-products include organic fertilisers that support soil fertility and position Ukraine as a global player in the agricultural market. This is also particularly relevant, given the country's development during the war: according to estimates of the Bioenergy Association of Ukraine, internal resources can replace about 20 billion cubic metres of gas, or UAH 160 billion (provided the average gas price is UAH 8) (Circular economy is..., 2020; Ministry of Finance, 2023). Representatives of the company themselves suggest that the existence of urgent problems with significant amounts of waste can be beneficial for the country in the future, when technologies for their processing become more common and affordable.

Representatives of the company often attend various conferences where they talk about their own approaches to achieving the sustainable development goals. For example, Oleksandr Dombrovsky, Chairman of the Board of Global 100% RE Ukraine, President of MHP Eco Energy, during the third International Conference "National Challenge: Soil Degradation or Restoration of Soil Fertility", stressed the potential of implementing circular economy principles to solve the problem of soil fertility in Ukraine (An environmental revolution..., 2021). He stressed that the circular economy model is crucial for the "green" transformation, which is in line with the practices of the European Union. MHP adheres to the basic principles of this model, and its division MHP Eco Energy, in fact, is engaged in processing industrial waste into clean energy and fertilisers, contributing to reducing carbon emissions, increasing clean energy production, and improving environmental, food, and energy security. In addition, he called on other companies and organisations to adhere to this approach, in order to switch Ukraine to more environmentally friendly production methods.

In order to assess some of the components of implementing the principles of circular economics at MHP, it is worth examining the data that characterise their transition to sustainable development. Until 2022, the company annually prepared a "Sustainable Development Report", which contained sufficient data that characterised the company's approach and results to achieving the sustainable development goals. However, the publication of such data stopped in 2022 due to the beginning of a full-scale Russian invasion of Ukraine. Within the framework of Table 1, it is possible to evaluate the data that characterise the company's use of certain types of conventional fuel in dynamics (n terms of $CO_2$ emitted during their combustion).

***Table 1.*** *Data characterising the use of certain types of conventional energy sources by MHPs in terms of $CO_2$ emissions from their combustion in the period from 2016 to 2021, metric tonnes of $CO_2$*

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| Combustion of natural gas | 226,964 | 161,930 | 186,414 | 160,107 | 165,289 | 212,491 | -6.4% | -1.1% |
| Diesel fuel use | 181,771 | 167,307 | 151,620 | 155,296 | 142,464 | 148,446 | -18.3% | -3.3% |
| Gasoline fuel use | 16,415 | 14,529 | 12,356 | 8,335 | 8,464 | 1,065 | -93.5% | -36.6% |
| Use of compressed/liquefied gas propane butane methane and their mixtures | 0 | 0 | 0 | 2,526 | 5,211 | 4,401 | 74.2% | 20.3% |
| Total | 425,150 | 343,766 | 350,390 | 328,579 | 321,428 | 373,673 | -12.1% | -2.1% |

***Source:*** *compiled by the authors based on reporting data of MHP (2022)*

As can be seen from Table 1, the company is rapidly reducing emissions from propane-butane-methane fuel sources, such as natural gas, diesel, and gasoline (a decrease of 6.4, 18.3 and 93.5%, respectively, since 2016). However, compressed/liquefied gas, which is considered to be more environmentally friendly than other traditional sources, has become more widely used. Table 2 also shows $CO_2$ emissions from various sources of renewable energy in dynamics.

***Table 2.*** *Data on the use of certain types of renewable energy sources by MHP in terms of $CO_2$ emissions from their combustion in the period from 2016 to 2021, metric tonnes of $CO_2$*

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| Combustion of biomass | 33,530 | 36,067 | 42,260 | 35,308 | 103,342 | 80,097 | 138.9% | 15.6% |
| Combustion of sunflower husks and pellets | 44,251 | 55,778 | 54,453 | 52,812 | 47,309 | 54,199 | 22.5% | 3.4% |
| Total | 77,251 | 91,845 | 96,713 | 88,120 | 150,651 | 134,296 | 73.8% | 9.7% |

***Source:*** *compiled by the authors based on reporting data of MHP (2022)*

Table 2 shows that $CO_2$ emissions from renewable energy sources are gradually increasing. However, due to the fact that this is associated with the transition to renewable sources, this trend can be considered positive. Data on the total amount of $CO_2$ emitted into the atmosphere (separately from renewable and non-renewable sources and in total) is shown in Table 3. The company's $CO_2$ emissions remained virtually unchanged over the period under study. Nevertheless, the fact that the company is switching to the production of energy from renewable sources, that is, the existing structural changes in energy production, can already be considered a positive factor in the country's development in this area. It is the increase in emissions in the reports that is attributed to increased poultry production and changes in the use of natural gas for production purposes. Trends in the types of resources used to manufacture the company's products (e.g. packaging) are shown in Table 4.

***Table 3.*** *$CO_2$ emissions from renewable and non-renewable energy sources between 2016 and 2021, metric tonnes of $CO_2$*

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ from traditional sources | 425,150 | 343,766 | 350,390 | 328,579 | 321,428 | 373,673 | -12.1% | -2.1% |
| $CO_2$ from renewable sources | 77,251 | 91,845 | 96,713 | 88,120 | 150,651 | 134,296 | 73.8% | 9.7% |
| Total | 502,401 | 435,611 | 447,103 | 416,699 | 472,079 | 507,969 | 1.1% | 0.2% |

***Source:*** *compiled by the authors based on reporting data of MHP (2022)*

***Table 4.*** *Use of different types of materials in the production of MHP products in the period from 2017 to 2021, tonnes*

| Year | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|
| Non-renewable, tonnes | 390,264 | 404,632 | 364,858 | 317,801 | 419,194 | 7,41% | 1.4% |
| Renewable, tonnes | 3,399,295 | 3,721,033 | 4,120,266 | 4,027,223 | 4,180,192 | 22.97% | 4.2% |
| Total, tonnes | 3,789,559 | 4,125,665 | 4,485,124 | 4,345,024 | 4,599,386 | 21.37% | 3.9% |
| Non-renewable, % | 10.3% | 9.8% | 8.1% | 7.3% | 9.1% | x | x |
| Renewable, % | 89.7% | 90.2% | 91.9% | 92.7% | 90.9% | x | x |

***Source:*** *compiled by the authors based on reporting data of MHP (2022)*

Renewable energy sources occupy mainly a large share in the production of MHP products, and, in addition, this share is gradually increasing, which indicates the existing positive trends in this area. Table 5 contains data describing the use of energy from renewable and non-renewable sources.

***Table 5.*** *Energy consumption from different sources by MHP in the period from 2016 to 2021, TJ*

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| Natural gas | 3,852 | 2,895 | 3,333 | 2,864 | 2,957 | 3,802 | -1.3% | -0.2% |
| Diesel | 2,173 | 2,274 | 2,061 | 2,111 | 1,936 | 2,018 | -7.1% | -1.2% |
| Petroleum | 240 | 207 | 176 | 152 | 121 | 119 | -50.4% | -11% |
| Compressed/liquefied gas | x | 24 | 29 | 42 | 88 | 75 | 212.5% | 25.6% |
| Electricity | 112 | 1,471 | 1,647 | 1,892 | 1,858 | 1,902 | 1,598.2% | 60.3% |
| Total from non-renewable sources | 7,385 | 6,871 | 7,246 | 7,061 | 696 | 7,916 | 7.2% | 1.2% |

Table 5, Continued

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| Biogas | 34 | 479 | 562 | 469 | 137 | 1,065 | 3,032.4% | 77.5% |
| Sunflower husk combustion | 489 | 661 | 670 | 672 | 580 | 626 | 28% | 4.2% |
| Total from renewable sources | 523 | 114 | 1,232 | 1,141 | 195 | 1,691 | 223.3% | 21.6% |
| Total energy consumption | 7,908 | 8,011 | 8,478 | 8,202 | 891 | 9,607 | 21.5% | 3.3% |
| From renewable sources, % | 7 | 14 | 15 | 14 | 22 | 18 | 157.1% | 17.0% |

***Source:*** *compiled by the authors based on reporting data of MHP (2022)*

As can be seen from Table 5, production from non-renewable sources increased by only 7%, while from renewable sources – by more than 200%. The share of renewable energy production in general has also increased significantly. Notably, the company is engaged in the sale of generated energy: and although these values are not significant (131 TJ in 2017 and 429 TJ in 2021), however, the fact that the company has the ability to sell energy indicates positive trends in its development.

In its sustainability reports, the company constantly emphasises that it is committed to environmental responsibility, for which is the responsibility of the company's board of directors. Each MHP facility in Ukraine has a full-time environmental protection specialist, while the European operating segments have different environmental management structures. Key aspects of MHP's environmental policy include a plan to achieve carbon neutrality by 2030, integrating environmental considerations into core business decisions, complying with environmental legislation, continuously improving environmental management efficiency, reducing emissions, reducing waste, preserving fresh water, preserving biodiversity, and using renewable energy. In the future, the company plans to increase the use of renewable energy, focusing on the development of biogas production facilities. Separately, it is worth considering how MHP uses water resources. This can be estimated by analysing the data from Table 6.

***Table 6.*** *Data on the use of water resources by MHP in the period from 2016 to 2021, thousands of cubic meters*

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| Surface water | 3,872 | 3,739 | 4,810 | 6,093 | 6,982 | 6,742 | 74.1% | 9.7% |
| Ground water | 5,929 | 6,040 | 6,417 | 6,997 | 6,878 | 7,111 | 19.9% | 3.1% |
| Wastewater from third-party organisations | 0 | 34 | 438 | 438 | 439 | 438 | 1,194.98% | 66.9% |
| Municipal and other water supply systems | 109 | 111 | 286 | 288 | 250 | 251 | 130.5% | 14.9% |
| Total | 9,909 | 9,924 | 11,952 | 13,816 | 14,549 | 14,542 | 46.7% | 6.6% |

***Source:*** *compiled by the authors based on reporting data of MHP (2022)*

MHP is gradually increasing the use of water resources, despite the fact that it considers reducing the negative impact on water to be one of its goals. However, in their report, they note that the activities of MHP enterprises do not affect the water balance in the regions, since they strictly adhere to the relevant regulations, including restrictions on the use of land adjacent to coastal strips. Although the general trend was to increase the use of income, in 2021 its volumes decreased. MHP performs actions to ensure the reuse of water resources. Some data on this issue are shown in Table 7.

***Table 7.*** *Data on water waste disposal by MHP in the period from 2016 to 2021, tonnes*

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| Reuse | 4,441 | 60,408 | 9,117 | 70,732 | 81,143 | 63,017 | 1,319% | 55.6% |
| Composting | 7,642 | 3,479 | 3,443 | 16,829 | 7,269 | 3,283 | -57% | -13.1% |
| Isolation of valuable components | 51,799 | 1,279 | 1,111 | 112 | 102 | 59 | -99.9% | -67.7% |
| Combustion | 7,642 | 3,479 | 3,443 | 2,610 | 987 | 16,308 | 113.4% | 13.5% |
| Disposal to landfill | 5,968 | 17,087 | 17,574 | 13,143 | 11,754 | 11,412 | 91.2% | 11.4% |
| Storage at MHP enterprises | 483 | 1,343 | 123 | 529 | 4,432 | 2,484 | 414.3% | 31.4% |

Table 7, Continued

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Total change | Year-per-year change |
|---|---|---|---|---|---|---|---|---|
| Transferred to contracted third parties | 61,086 | 28,586 | 25,843 | 25,219 | 24,096 | 28,867 | -52.7% | -11.7% |
| Total | 131,534 | 112,281 | 139,280 | 129,174 | 129,783 | 125,430 | -4.6% | -0.8% |

***Source:** compiled by the authors based on reporting data of MHP (2022)*

As can be seen from Table 7, the total utilisation of water resources by the company has also decreased, which is not a good indicator of the achievement of the sustainable development goals. Thus, the main area in which MHP works to achieve the sustainable development goals and achieve a circular economy is the synthesis of biogas from broiler chicken waste and its use as alternative energy sources (Kumar *et al.*, 2023; Kristia & Rabbi, 2023). In the future, there are plans to switch to the production of biomethane (a renewable analogue of natural gas) and biodiesel (respectively, an analogue of diesel). In general, this approach to waste recycling in the industry is quite effective, and the company should continue working in this line, solving problems that may arise along the way (Ebrahimian *et al.*, 2022; Kalita *et al.*, 2023). As of 2024, the biggest problem for MHP is the war in Ukraine. At the beginning of the invasion, the company quickly began to take active actions in supporting Ukrainians, ensuring cooperation with other companies and international partners.

It is important that the state, as one of the important actors influencing the development of enterprises, also helps companies achieve sustainable development goals. Although active conduct of such activities is unlikely in a war, however, after it ends, government officials should begin to pay more attention to such companies and their environmental initiatives. Comprehensive state support should include financial assistance, namely access to subsidies and financing for agricultural enterprises that implement circular practices. Other important components are the provision of information support and advice for farmers and the creation of favourable legislation, the creation of appropriate infrastructure for the development of renewable energy, the possibility of waste disposal, processing of raw materials from agricultural enterprises, etc. Such a set of measures will contribute to the sustainable and environmentally responsible development of agriculture in the context of a circular economy.

## DISCUSSION

The concept that MHP uses is just one of the options for how the company can achieve circular development. For example, instead of using waste as sources for fertiliser production (Neeraj *et al.*, 2022; Pajura *et al.*, 2023), it is possible to use waste collection to produce products for other industries: one option is the production of packaging from recycled materials (Ibrahim *et al.,* 2022). There are more such examples, but each company should choose the option that it considers the most effective, which will be influenced by both the financial capabilities of the company and the long-term development strategy: it is likely that it will be formed by using several options for waste processing at once (for example, simultaneous production of energy and fertilisers).

In general, cyclical economics in agriculture was studied by T. Selvan *et al.* (2023). Researchers emphasised the negative impact of traditional food production methods on the environment and their contribution to the development of non-communicable diseases. The paper describes the degradation effects that occur due to the use of a conventional production model, and speaks about the need to switch to a circular one. Researchers also noted the importance of investigating various practices of organic agriculture and agroforestry (biodynamic agriculture, regenerative practices of agroforestry) for the possibility of their use in the future. Given that these practices mimic natural ecological processes, they can simultaneously provide a high level of efficiency in the context of manufactured products and have a positive impact on the environment. Ultimately, researchers note the importance of providing companies with financial support in order to enable them to implement such methods. In the framework of the study on the circular economy in Ukraine, such methods of influencing the environment in the agricultural sector were not evaluated. This is due to the fact that they are not common within the country; however, it is expected that with their more active use in other countries, these methods will be used in Ukraine as well.

The circular economy in the agricultural sector was studied by J.F. Velasco-Munoz *et al.* (2022). The results indicate a growing interest in this area of research with a focus on environmental aspects. Researchers emphasised the existence of problems with feeding a growing population, the negative impact of agriculture on the environment, and the potential of a circular economy to solve these problems. Circular economy is evaluated as a solution for reducing resource consumption, waste generation, and negative impact on the environment in the agri-food system. The economic and social benefits of implementing the principles of a circular economy, and the potential to increase gross domestic product (GDP), create jobs and increase the profitability of farmers, were evaluated. The study highlights the importance of moving from a linear to a cyclical economic model in food production. As part of the assessment of the situation with the circular economy in Ukraine, the importance of developing this concept in the long term was also described. However, it is necessary to pay attention to the fact that such initiatives are likely not to have significant support from the state, since as of 2024, the primary problem in the country is war.

The introduction of a cyclical economy in the agricultural supply chain based on data from Indonesia was studied by R. Nattassha *et al.* (2020). The study highlights the importance of a circular economy in the agricultural supply chain, and emphasises its role in reducing food waste, improving production efficiency, and promoting sustainability. As part of the study, the researchers proposed a conceptual model aimed at improving the efficiency of agriculture in the circular economy: it functions based on understanding the circular economy as a whole system of seven areas that companies should pay attention to when implementing the model. The importance of using state support to support "green" producers was also described. As noted above, state support is indeed an important component of the qualitative development of such companies. Enterprises with a circular economy can effectively resist the negative impact on the environment. However, only if these two components interact can qualitative results be achieved in the context of achieving the sustainable development goals.

The path of sustainable development of agriculture based on the concept of circular economy was investigated by L. Zhenjian *et al.* (2021). Researchers have shown that significant efforts have been made in China to modernise agricultural production. The development of the agricultural circular economy has become an important strategy for stimulating this modernisation process and is an integral part of achieving sustainable development in the agricultural sector. Thus, researchers note that the concept of circular development is an important component of the future development of the economy of any country. However, certain features of its implementation should be personalised depending on the cultural, social, and economic characteristics of the state. The importance of the circular economy concept was also assessed in this paper on its implementation in Ukraine. Given the need to pay much more attention to environmental issues, applying the concept of a circular economy can be one of the most effective ways to improve the situation.

A system for assessing the state of transition to sustainable development at cyclical agricultural enterprises was developed by S. Rodino *et al.* (2023). Researchers emphasised the heterogeneity of the circular economy in agriculture, drawing attention to the diverse consequences of its implementation and the need for a diverse set of indicators to effectively measure the state of implementation of this concept. These indicators should cover the following aspects: resource use, waste management, assessment of environmental sustainability, and overall efficiency of the agricultural system. Their research drew considerable attention to the fact that international cooperation with other countries plays a significant role in this area. It was also noted that there is a need to develop more accurate measurement methods adapted to the specifics of agriculture in different regions, in order to form more objective assessments of the ecological state of enterprises. Although this study did not focus on the development of such assessment methods, the authors agree that this may help the state in the future to assess compliance with the concept of a circular economy by individual enterprises and thus regulate the amount of their support.

## CONCLUSIONS

Myronivsky Hliboproduct is an example of successful integration of the principles of circular economy into a large agricultural enterprise. The company's innovative approach to converting organic waste, in particular chicken manure, into biogas demonstrates its commitment to achieving the sustainable development goals, which goes beyond simple responsibility for the environment. This process not only reduces $CO_2$ emissions, but also generates clean energy, heat and steam, which significantly contributes to Ukraine's energy security. Despite a break in the publication of sustainability reports due to the beginning of a full-scale Russian invasion, the data available and analysed in the study until 2022 show significant progress of MHP in the context of the development of the circular economy. The trends in biogas production and the unchanged level of $CO_2$ emissions despite the company's overall expansion demonstrate the effectiveness of the policy. MHP's commitment to becoming carbon neutral by 2030 and integrating environmental considerations into business decisions reflect the company's long-term plans to achieve its sustainable development goals. The company's approach goes beyond energy production and covers water management. Although some steps have already been taken in this area, the efficiency of solving these problems is relatively lower than in the field of energy production from biomaterials.

The main problem of the company's development as of 2024 is the consequences of a full-scale Russian invasion of Ukraine. As part of the study, it is difficult to assess exactly how it affected the company in terms of achieving a circular economy, but considering other areas of its activities, the company helped Ukrainians from the very beginning of the war, especially in the field of food security support, demonstrating compliance with the principles of corporate and social responsibility. It is to be expected that the situation in terms of the development of the circular economy is deteriorating. However, after the end of the war, together with state support, which plays an important role in achieving sustainable circular production, and with the improvement of the situation in the country in all its areas in general, the restoration of the company's strategic goals in this area will continue. That is why a promising area for future research is to analyse the achievement of circular economy principles by other Ukrainian and global companies to compare their approaches.

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## CONFLICT OF INTEREST

None.

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# Практичне дослідження впровадження циркулярної економіки на аграрних підприємствах України

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**Анотація.** Зважаючи на роль аграрного сектору для розвитку економіки України, важливо знаходити методи підвищення ефективності його функціонування. Оскільки одним із них є впровадження циркулярної економіки, то дослідження кейсів її застосування в країні є актуальним. Ціллю дослідження стало показати приклад впровадження даної концепції в Україні, зобразивши вигоди та недоліки від її застосування. Основними методами дослідження стали аналіз, порівняння та прогнозування. В рамках роботи було проведено оцінку найбільш вагомого прикладу впровадження принципів циркулярної економіки на підприємстві, а саме компанії «Миронівський Хлібпродукт». Було показано, що основою підходу компанії є переробка відходів на біогаз та використання його в якості енергії. Цей процес не лише дозволяє не збільшувати викиди $CO_2$ в атмосферу, але й значно ефективніше використовувати наявні в неї ресурси. Крім того, описувалися особливості вторинної переробки водних ресурсів та існуючі тенденції в цьому напрямку. Особлива увага зверталася на те, з якими складнощами стикнулася компанія під час початку повномасштабного вторгнення Росії 2022 року, та які дії були вжиті для покращення ситуації. Також було зроблено висновки стосовно того, якими є вірогідні можливості досягнення компанією цілей в розрізі циркулярної економіки, зважаючи на сучасні тенденції розвитку України. Практична цінність роботи полягає у користі для формування рекомендацій підприємствам щодо впровадження концепції циркулярної економіки. Крім того, дані з роботи можуть бути використані представниками держави для підвищення ефективності впровадження політики в аграрній сфері

**Ключові слова:** біогаз; водні ресурси; фінанси; державне управління; сталий розвиток

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# Modern cultivation technologies in improvement of corn quality

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**Abstract.** Research on the development of sustainable and productive methods of corn cultivation is becoming relevant due to the growing demand for food resources and the need to optimise agrotechnical processes. The study aims to conduct a comparative analysis of maize cultivation under different tillage methods. A field experiment was conducted to achieve this goal, phenological observations of corn plant development was made, and grain quality was studied. The results of the maize yield analysis show that ploughing to a depth of 30 cm produces the highest maize yield of 91.6 c/ha while disking to a depth of 15 cm results in the lowest yield of 80.6 c/ha. The study proved that the method of tillage affects grain quality indicators, in particular, the content of crude fibre, starch, protein and crude fat. Thus, when ploughing to a depth of 30 cm, the starch content in the grain was 70.9%, crude fibre – 2.12%, protein – 10.2%, and crude fat – 4.225%. The correlation and regression analysis showed that the coefficient of determination ($R^2$) for tillage is about 0.9, which means that the model accurately describes the available data, and for grain quality indicators, $R^2$ is in the range of 0.66-0.99, which also indicates a strong relationship between the factors under study. The practical significance of the research results is that they can serve as a basis for optimising the agronomic processes of maize cultivation to increase yields and improve grain quality

**Keywords:** productivity; chemical composition of grain; ploughing; morphological and biometric parameters; agrotechnical solutions; agriculture

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## INTRODUCTION

Modern agriculture is constantly evolving, relying on advanced technologies to achieve high productivity and crop quality. One of the key crops that is important for food and feed production is corn. The growing demand for this crop puts great pressure on agricultural systems, requiring improved tillage practices to maximise the quality and quantity of maize produced (Korchak *et al*., 2023).

V. Dumych *et al*. (2023) note that one of the key challenges for farmers is the need to ensure a high-quality crop to meet the needs of the population. Modern tillage technologies can optimise sowing, irrigation and crop care, reducing resource consumption and increasing production efficiency. The competitiveness of Ukrainian agricultural production is closely linked to the introduction of innovative approaches and the use of advanced technologies. According to Yu.V. Mashchenko & I.M. Sokolovska (2023), precision agriculture provides an opportunity to individualise approaches to soil cultivation, considering its properties and the needs of a particular site. Modern monitoring and automation systems allow farmers to obtain accurate data on soil and plant conditions, assisting in informed decision-making to improve crop yields and quality.

V.M. Kabanets *et al*. (2023) and T. Marchenko *et al*. (2023) also emphasise that alternative tillage systems, such as no-till or minimum tillage, can sometimes contribute to higher yields than conventional methods, such as mouldboard tillage, depending on the soil type. The authors' research also indicates the impact of different tillage systems on maize grain quality, including size and nutrient content. At the same time, environmental aspects are becoming increasingly important in the agricultural sector. Modern technologies can reduce the environmental impact of agricultural processes, preserving natural resources and reducing the risk of soil and water pollution. In this context, P.V. Lykhovyd and V.O. Sharii (2023) emphasise the complexity and contextuality of issues related to maize cultivation. Therefore, it is essential to address the specifics of the terrain and specific agronomic factors when choosing the optimal tillage system to achieve the best results.

I.M. Masik *et al*. (2021) note that improving tillage technologies in the agricultural sector is an important area for achieving not only economic stability but also sustainable development, ensuring food security and addressing environmental sustainability. In this context, the use of modern tillage technologies to improve the quality of corn appears to be a necessary element of the strategy for sustainable development of the agricultural sector and meeting the needs of modern society. Despite the numerous scientific research available, the study of modern tillage technologies for maize cultivation is an important area of research, as there are aspects that remain unexplored and require further clarification. These include the specific properties of different soil types, the effectiveness of technologies in extreme weather conditions, the environmental impact of technologies and their impact on food quality and safety. A detailed study of these aspects is key to developing more comprehensive and sustainable approaches to maize production. Such a comprehensive approach will contribute to the sustainable development of the agricultural sector and ensure food security in the face of current challenges.

Thus, insufficient consideration of tillage and maize cultivation technologies can cause significant problems in agriculture. This includes negative impacts on the ecosystem, possible crop losses and product contamination, inefficient use of resources, environmental pollution by chemicals and lack of innovation. Solving these problems requires in-depth scientific and technological research, as well as the implementation of effective approaches to agricultural production. Therefore, in the modern agricultural sector, research aimed at improving soil cultivation technologies that contribute to the efficiency of growing high-quality corn grain is becoming increasingly important.

The study aimed to conduct a comparative analysis of corn cultivation under different tillage methods in the western forest-steppe of Ukraine. The following objectives were set: to determine how the selected tillage methods affect corn yields and to assess the impact of different tillage methods on grain quality indicators: crude fibre, starch, protein and crude fat content.

## MATERIALS AND METHODS

To determine the productivity and quality of maize grain during 2021-2023, a field experiment was conducted with phenological, laboratory and field observations of the growth and development of plants grown under different soil cultivation conditions in the western Forest-Steppe of Ukraine. The study was conducted on sod-podzolic light loamy soil. The amount of humus in this type of soil varies from 1% to 1.4%, the humus is of fulvate type. The reaction of the soil solution is acidic: the pH of KCl ranges from 4.6 to 6.1, and the hydrolytic acidity is 1.7-2.9 mg-eq/100 g of soil. Nutrient reserves are very low: nitrogen content ranges from 0.06% to 0.09%, phosphorus from 0.05% to 0.09%, and potassium from 1% to 1.5%. There are also low levels of trace elements.

Plots of different tillage systems were laid out for the experiment: variant 1 – ploughing to a depth of 30 cm, variant 2 – chisel tillage to a depth of 45 cm, and variant 3 – disking to a depth of 15 cm. The experiment was replicated three times, with a total plot size of 350 $m^2$ and an area of 100 $m^2$ per plot. The maize predecessor in the experiment was soybeans. Corn was sown when the top (0-10 cm) soil layer was warmed up to a temperature of 10-12 degrees Celsius. The optimum seeding depth was 6-8 cm, plant density was 60 thousand/ha, seeding rate was 20-25 kg/ha, and row spacing was 70 cm. In the experiments, the seed material of the mid-early maize hybrid Phenomenon (FAO 220) by Syngenta was sown. It is important to note that mineral fertiliser, diammonium phosphate $(NH_4)_2$ $HPO_4$, was also applied at a rate of 140 kg/ha for the main tillage.

Maize growth parameters, such as plant height, cob height and number of leaves, were determined directly in the field during periodic phenological observations. The length of the cob and the weight of 1000 kernels were obtained directly at harvest by measuring and weighing. Grain quality indicators, including crude fibre, starch, protein and crude fat content, were determined by refractometric method using an Atago PAL-3 refractometer (Japan). Corn yields were calculated manually, from each plot separately. Accurate measurements and records were made following all necessary protocols and methodologies to ensure data reliability (Order of the Ministry of Agrarian Policy of Ukraine No. 250, 2003; Determining the quality..., 2023).

Furthermore, during the data analysis, a correlation and regression analysis of the impact of tillage on the yield and quality of maize grain was conducted. The results obtained were processed to determine their reliability using the multivariate analysis of variance MANOVA method. For this purpose, Microsoft Excel software and Statistica 10 software packages were used. Differences between the results obtained were determined at the significance level of $P \leqslant 0.05$ using the Student's t-test. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

## RESULTS

The morphological and biometric parameters of maize plants, such as plant height, cob height, number of leaves, number of cobs per 100 plants and cob length, play an important role in determining the physiological structure and size of plants. These parameters are key to assessing the growth and productivity of the maize crop. The use of modern tillage technologies can have a significant impact on these parameters. For example, the optimal tillage method can provide better accessibility of nutrients, water and air to plants, which contributes to their more active growth and development. According to the results obtained, the assessment of morphological and biometric parameters indicates that ploughing to a depth of 30 cm leads to the highest values of most parameters. In particular, the height of plants under this treatment was 281 cm, which is 8 cm and 18 cm, respectively, more than in the variants of chisel tillage and disking.

An important indicator of maize development is the number of leaves, as it determines the plant's ability to photosynthesise and the efficiency of using light energy potential. The more leaves a plant has, the more surface area it has for photosynthesis, which increases the synthesis of organic matter and energy storage. Modern tillage practices can influence the number of leaves by improving soil structure, ensuring plant access to nutrients and optimising growth conditions. Ensuring optimal leaf growth in terms of quantity and quality is important to maximise photosynthesis and thus ensure high quality and yield of maize. In addition, the number of leaves can serve as an indicator of the overall health of the plant and its adaptation to the environment. Appropriate use of modern tillage practices ensures favourable conditions for maize growth and can influence its physiological state, including leaf quantity and quality.

In the study, the largest number of leaves (15.4) was formed by ploughing to a depth of 30 cm, while the number of leaves was also at the optimum level and amounted to 14.7 when chisel tillage was performed to a depth of 45 cm. It is worth noting that in areas with lower rainfall, deeper cultivation can help to preserve moisture and reduce the risk of plant desiccation. In wet areas, where water resistance may be a problem, shallower tillage may be advisable.

The number of cobs and their quality are key factors for maize yield and quality. Typically, a higher number of cobs per plant results in a higher total grain yield. However, it is important to keep in mind that to achieve maximum yields, sufficient nutrition and optimal conditions for each cob should be provided. Increasing the number of ears per plant can be considered one of the strategies to reduce the impact of stressful conditions such as drought or other abnormal weather conditions. The optimal number of cobs per plant can contribute to a more even distribution of nutrients. This can lead to an increase in cob size, weight and grain. The number of cobs can also affect grain quality, shape, colour, structure and chemical composition. However, it is important to maintain a balance between quantity and quality, as excessive cob density can also result in smaller cob size and grain. Taking these aspects into account, optimal management of the number of ears can help to achieve the desired balance between yield and grain quality of maize. Careful monitoring and maintenance of optimal growth conditions are key to achieving maximum effect.

According to the data obtained, the largest number of heads of cabbage per 100 plants was formed by ploughing to a depth of 30 cm and chisel tillage to a depth of 45 cm and was 106 and 104 pcs, respectively. The length of the head of cabbage was also the largest for ploughing and was 24 cm (Table 1).

***Table 1.*** *Morphological and biometric parameters of maize plants (average for 2021-2023)*

| Soil cultivation method | Plant height, cm | Header mounting height, cm | Number of leaves, pcs. | Number of heads of cabbage per 100 plants, pcs. | Head length, cm |
|---|---|---|---|---|---|
| Ploughing to a depth of 30 cm | 281 | 96.4 | 15.4 | 106 | 24 |
| Chisel tillage to a depth of 45 cm | 273 | 95.9 | 14.7 | 104 | 23.6 |
| Disking the soil to a depth of 15 cm | 262 | 93.7 | 13.6 | 103 | 23.2 |

***Source:*** *compiled by the authors*

Thus, the results obtained indicate that the choice of tillage method has an important impact on the development and characteristics of maize. Ploughing to a depth of 30 cm was the most effective among the methods considered. Grain productivity indicators, such as grain yield, grain weight and weight per 1000 grains, determine the efficiency of maize cultivation and grain quality. Grain yield indicates the proportion of useful product in the total weight of the ear, while grain weight per ear and weight per 1000 kernels are determined by genetic and agronomic factors. Evaluation of grain productivity indicators indicates that ploughing to a depth of 30 cm shows the highest grain yield (83.7%) and the highest grain weight per ear (82 g). This method of cultivation is also marked by the highest weight of 1000 grains – 290 g. Compared to ploughing to a depth of 30 cm, disking the soil to a depth of 15 cm showed lower grain productivity. The grain yield was 82.8%, the weight of grain per ear was 78 g, and the weight of 1000 grains was 94 g (Table 2).

***Table 2.*** *Corn grain productivity indicators (average for 2021-2023)*

| Soil cultivation method | Grain yield, %. | Grain weight, g | | Weight of 1000 grains, g |
|---|---|---|---|---|
| | | From one cob | From one plant | |
| Ploughing to a depth of 30 cm | 83.7 | 82 | 113 | 290 |
| Chisel tillage to a depth of 45 cm | 83 | 79 | 100 | 285 |
| Disking the soil to a depth of 15 cm | 82.8 | 78 | 94 | 273 |

***Source:*** *compiled by the authors*

Given the results of the analysis of corn yields over three years, it can be determined that ploughing to a depth of 30 cm is the most productive technology, which provides 91.6 c/ha of yield. This method was used to achieve stable and high crop yields. The least efficient in this case was disking the soil to a depth of 15 cm, with this method of cultivating the soil yielding 80.6 c/ha and some instability of results compared to other tillage methods. Thus, the choice of the optimal tillage method is important for successful maize cultivation (Table 3).

***Table 3.*** *Corn yield, tonnes per hectare*

| Soil cultivation method | Year | | | Average for 2021-2023 |
|---|---|---|---|---|
| | 2021 | 2022 | 2023 | |
| Ploughing to a depth of 30 cm | 91.9 | 91.3 | 91.5 | 91.6 |
| Chisel tillage to a depth of 45 cm | 89.1 | 89.2 | 89.3 | 89.2 |
| Disking the soil to a depth of 15 cm | 80.5 | 80.4 | 80.9 | 80.6 |
| $HIP_{0.05}$ | 2.25 | 1.98 | 2.19 | 2.06 |

***Source:*** *compiled by the authors*

Modern soil cultivation technologies can significantly improve corn production and grain quality. An important indicator of corn grain quality is starch content, especially in the context of its use in fuel processing. Over the years, research has shown that the starch content in grain averaged 64.3-70.9%. The maximum starch content in the grain (70.9%) was recorded when ploughing to a depth of 30 cm. In the context of the main tillage methods, chiselling to a depth of 45 cm and especially disking to a depth of 15 cm indicate a decrease in protein and crude fat content compared to ploughing. At the same time, the impact of these methods on the fibre content of grain was not detected (Table 4). Thus, modern tillage methods, in particular ploughing, can affect the quality of maize grain by ensuring the optimal content of starch and other chemical components. According to the results of the study, ploughing to a depth of 30 cm demonstrates the highest values among the tillage methods considered for all parameters under consideration - crude fibre, starch, protein and crude fat content. Such indicators characterise the high quality and nutritional value of the crop, which can be an important factor for feed producers, the food industry and other industries that use corn in their operations.

***Table 4.*** *Chemical composition of corn grain depending on the method of soil cultivation, % (average for 2022-2023)*

| Soil cultivation method | Content in grain, %. | | | |
|---|---|---|---|---|
| | Raw fibre | Starch | Protein | Raw fat |
| Ploughing to a depth of 30 cm | 2.12 | 70.9 | 10.2 | 4.22 |
| Chisel tillage to a depth of 45 cm | 2.1 | 69 | 9.8 | 4.18 |
| Disking the soil to a depth of 15 cm | 2.09 | 64.3 | 9.3 | 3.53 |

***Source:*** *compiled by the authors*

Thus, the method of soil cultivation affects the morphological and biometric parameters, grain productivity and yield of maize. This emphasises the importance of choosing the optimal method to achieve the desired results in the cultivation of this crop. However, to verify the reliability of the results obtained, a correlation and regression analysis was conducted. This highly effective statistical method is used to identify relationships between different variables. In this study, correlation and regression analysis were used to determine the relationship between the tillage method and yield, as well as between the tillage method and grain quality of corn. This analytical approach allows us to find out how significantly the selected tillage methods affect the yield and quality of the crop. According to the correlation and regression analysis, the reliability value for 2021 was R=0.9206, for 2022 – R=0.8881, and 2023 – R=0.8976, which means that the model accurately describes the available data. For the grain quality indicators, the coefficient of determination ($R^2$) is in the range of 0.66-0.99, which also indicates a strong relationship between the factors (Fig. 1).

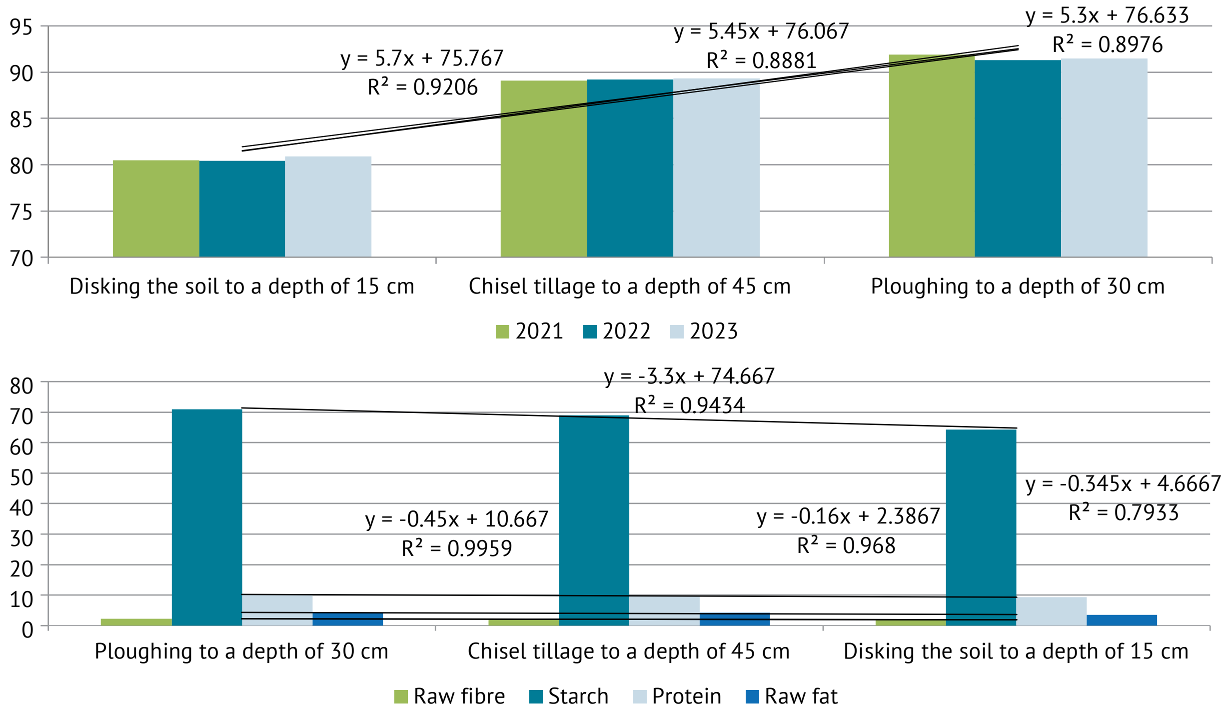


***Figure 1.*** *Correlation and regression analysis of the influence of the tillage method on corn yield and quality (average for 2021-2023)*

***Source:*** *compiled by the authors*

The results of the study of maize cultivation and the impact of tillage methods point to important aspects of agricultural practice. Ploughing to a depth of 30 cm stands out as the optimal method for ensuring high yields and grain quality. Not only does this approach contribute to higher grain yields, but it also improves the chemical composition of the grain, particularly the high starch content, which is key in the context of fuel production. On the other hand, chiselling and disking were less effective, resulting in less grain and lower quality in terms of chemical composition. Such a thorough analysis of tillage practices in terms of grain productivity and quality provides agronomists and farmers with a basis for making informed choices about the best maize cultivation practices depending on specific conditions and production goals.

Summarising the data presented, it is important to note that maize cultivation is a complex process that requires attention to various aspects, including soil tillage. Based on the data presented, 30 cm ploughing can be recommended as the optimal tillage method for achieving maximum yield and grain quality of maize in the western forest-steppe of Ukraine.

## DISCUSSION

Ukrainian agriculture plays a key role in the production of plant-based food products. Thanks to favourable climatic conditions, vast land area and long-standing agricultural traditions, Ukraine is actively developing the cultivation of various crops, including corn, which is growing steadily. However, agricultural production faces serious challenges, including climate change, efficiency and environmental friendliness, which must be addressed to ensure the sustainable development of plant-based food production in Ukraine. Current trends in the cultivation of plant-based food products in Ukraine demonstrate the need to integrate the latest technologies, comply with environmental standards and adapt to global challenges. Important aspects include ensuring product quality, efficient use of resources and creating a sustainable agricultural sector that meets the requirements of modern consumers and considers environmental aspects.

Due to the rapid development of modern tillage technologies, especially in the agricultural sector, the choice of the optimal method can significantly affect the yield and quality of any crop, including corn. Research conducted by scientists and our results also reveal important aspects of the impact of different tillage methods on corn production and quality. Y. Wang *et al.* (2021) indicate that tillage depth can affect the development of the corn root system. Deeper tillage methods can stimulate the development of plant roots, which helps them to penetrate deeper soil layers and better supply the plant with water and nutrients. M. Korchak (2022) and O. Tsyliuryk *et al.* (2023) emphasise that the choice of tillage method plays a key role in maize cultivation and achieving optimal yield and product quality results. The integration of innovative methods that consider modern requirements and standards in agriculture can help achieve more efficient and sustainable results in growing the crop. This study identifies the importance of selecting optimal agronomic practices to achieve successful results in agriculture.

According to G.P. Kovács *et al.* (2023), proper tillage improves soil structure and ensures the availability of nutrients for plants. This can have a positive impact on the development of maize, as it provides important conditions for its growth and the formation of a quality crop. In addition, according to A. Kundu *et al.* (2024), efficient tillage creates optimal conditions for the growth of vegetative mass and plant roots. This is a key aspect in maintaining plant resistance to stressful conditions, and a healthy and well-developed root system helps plants to better adapt to environmental changes and ensures their optimal physiology, which is also demonstrated in the study.

J. Li & Q. Lin (2023) add that the use of modern tillage technologies can help increase soil permeability and regulate soil moisture, which is important for maize growth in different climates. This research confirms that the right choice of tillage practices is key to optimising crop conditions and maximising its potential. Given the variety of agronomic methods and technologies, it is important to choose those that meet specific business conditions and contribute to higher yields and product quality. This approach considers the individual characteristics of soils, climatic conditions and other factors that may affect the cultivation of specific crops. M. Vandyk's (2023) research focuses on the biological activity of the soil, which can vary depending on the method of cultivation. The general approach is to use agricultural practices in a balanced way that promotes the development of beneficial biota and preserves soil structure to maintain yields and environmental sustainability.

T. Sullivan *et al.* (2023) point out that some tillage practices can have an impact on limiting weed spread and pest development. For example, deep ploughing can be an effective method of weed control compared to other methods. The deep rotation of the soil can help to plough weeds to a greater depth, reducing their ability to germinate and compete with crops. Another confirmation of the study can be found in the statements of other scientists who have investigated the impact of different tillage methods on corn production. R.K. Adhikari *et al.* (2023) and J.D. Clark *et al.* (2021)

pointed out the significant effect of ploughing on the depth of the topsoil on grain yield and quality of maize. Similar to our results, they confirm that this method of cultivation contributes to high grain yield, high grain weight per ear, and high weight per 1000 kernels.

The study also agrees with H.S. El-Beltagi *et al*. (2022) and M.N. Harish *et al*. (2022), who suggest the importance of modern tillage practices for improving maize quality and yield. The results indicate that traditional methods, in particular, shelf ploughing to a depth of 30 cm, are optimal for achieving the highest grain productivity. These findings emphasise the importance of proper tillage for achieving optimal results in agriculture, particularly in the context of maize production. Optimised tillage can improve not only soil structure, but also provide favourable conditions for plant growth and development, increasing their resistance to stress and contributing to yield growth (Taranenko *et al*., 2019; Auzins *et al*., 2023). Furthermore, considering the research of scientists such as I.M. Kovalenko & I.M. Masik (2018), it is possible to argue that innovative approaches to soil cultivation and the use of modern technologies can also have a significant impact on maize cultivation. Their views on the importance of developing stress-tolerant varieties and hybrids and the use of precision farming systems highlight the need to expand the arsenal of methods to achieve optimal results.

In support of this, according to W. Hassan *et al*. (2022), it is necessary to integrate different tillage approaches in the context of maize cultivation. The authors emphasise the importance of considering individual soil characteristics and soil structure when choosing a tillage method. They also emphasise that the use of modern technologies, such as precision farming and monitoring systems, can help to optimise the process of growing corn and increase its productivity. Thus, considering the opinion of scientists and researchers, it can be noted that improving tillage methods and introducing modern technologies in agriculture can contribute not only to increasing yields but also to creating a sustainable and efficient environment for corn cultivation (Wang & Hu, 2021; Halko *et al*., 2023).

When discussing the findings of the study, it is important to consider an integrated approach to maize cultivation and tillage, ensuring a balanced impact on the plant, soil and environment. Many of these findings are compatible with general trends in agriculture and highlight the importance of choosing the right technologies to optimise corn yield and grain quality. Such results from different scientists confirm the conclusions of the study. Thus, in summary, it is possible to state that the choice of the optimal tillage method is becoming a key aspect for achieving the best results in maize cultivation, which is of practical importance for agronomists and farmers in improving the productivity and quality of this important crop.

## CONCLUSIONS

Implementation of optimal soil tillage is a key element in modern agriculture, in maize cultivation. The study results show that tillage has a decisive impact on the development and yield of maize. Optimising the conditions for photosynthesis, water supply and nutrient supply to plants are key aspects that can be achieved by choosing the right tillage method. Ploughing to a depth of 30 cm proved to be the most favourable for the formation of the optimal number of leaves – 15.4 pcs. and the number of cobs per 100 plants – 106 pcs., which determines the overall success of corn cultivation.

The results of the maize cultivation analysis indicate that the yield increases when ploughing to a depth of 30 cm, reaching a maximum value of 91.6 cwt/ha, compared to the less efficient method of disking the soil to a depth of 15 cm, where the yield is only 80.6 cwt/ha. The study also confirms the impact of tillage on grain quality. For example, the grain obtained by ploughing to a depth of 30 cm had a starch content of 70.9%, crude fibre content of 2.12%, protein content of 10.2% and crude fat of 4.22%. These results emphasise the importance of choosing the optimal tillage method to achieve not only high yields but also improved grain quality. Correlation and regression analysis confirm a significant relationship between tillage practices, yield and quality of corn. The model used for the analysis accurately reflects the available data, which underlines the reliability of the results. Thus, to achieve maximum yield and grain quality of maize in the western Forest-Steppe of Ukraine on sod-podzolic light loamy soil, it is recommended to use ploughing to a depth of 30 cm as the optimal tillage method. This study can serve as a basis for an informed choice of maize cultivation technology, providing practical value for farmers and agronomists in choosing optimal agronomic solutions. Future research should examine the effectiveness of tillage under stressful conditions, such as drought or extreme temperatures, to help determine how different methods may affect crop resilience. Limitations of the study include the area of the study and the type of soil, which may limit the generalisability of the results to other regions with different climates and soils.

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## CONFLICT OF INTEREST

None.

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# Використання сучасних технологій обробітку ґрунту для підвищення якості кукурудзи

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**Анотація.** Дослідження розвитку стійких та продуктивних методів вирощування кукурудзи стає актуальним завданням у зв'язку із зростаючим попитом на продовольчі ресурси та необхідністю оптимізації агротехнічних процесів. Мета дослідження – провести порівняльний аналіз вирощування кукурудзи за різних способів обробітку ґрунту. Для досягнення цієї мети було закладено польовий дослід, здійснено фенологічні спостереження за розвитком рослин кукурудзи та вивчено якісні показники зерна. Отримані результати аналізу врожайності кукурудзи свідчать, що за проведення оранки на глибину 30 см формується найбільша врожайність кукурудзи – 91,6 ц/га, а за дискування ґрунту на глибину 15 см встановлено найменшу урожайність – 80,6 ц/га. За результатами дослідження доведено, що спосіб обробітку ґрунту впливає на показники якості зерна, зокрема: вміст сирої клітковини, крохмалю, протеїну та сирого жиру. Так, за оранки на глибину 30 см вміст крохмалю в зерні становив 70,9 %, сирої клітковини – 2,12 %, протеїну – 10,2 %, а сирого жиру – 4,225 %. Виконаний кореляційно-регресійний аналіз довів, що коефіцієнт детермінації ($R^2$) для обробітку ґрунту становить близько 0,9, це означає, що модель точно описує наявні дані, а для показників якості зерна $R^2$ перебуває в діапазоні 0,66-0,99, що також характеризує наявний сильний зв'язок між досліджуваними факторами. Практичне значення отриманих результатів дослідження полягає в тому, що вони можуть слугувати основою для оптимізації агротехнічних процесів вирощування кукурудзи з метою збільшення врожайності та покращення якості зерна

**Ключові слова:** врожайність; хімічний склад зерна; оранка; морфолого-біометричні показники; агротехнічні рішення; сільське господарство

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# Study of mechanical and technological properties of seed fruits of vegetable and melon crops

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**Abstract.** The analysis of literature sources shows that the production of seed material for vegetable and melon crops is one of the most important problems that exists in the field of agricultural processing. The production of cucumber and melon seeds is an urgent issue in view of the volume of their cultivation in Ukraine. To study the processes of fruit grinding and seed production in agriculture, the key parameters are the dynamic friction coefficient, the volume deformation coefficient and the static load coefficient, but existing methods and equipment are limited to determining the limit values of the indicators, not allowing a full study of the dynamics of changes in properties at different stages of the technological process. To solve this, it is proposed to develop new methods, in particular, the use of computer modelling, which will allow a more detailed study and optimisation of physical and mechanical properties and their changes. The aim of the article was to study the physical and mechanical

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properties of vegetable fruits, which have the greatest impact on the quality of the technological process of fruit seed grinding and preliminary seed extraction. The study was conducted in the problematic research laboratory of the Faculty of Engineering and Energy of Mykolaiv National Agrarian University. Experimental setups were used to determine the dynamic coefficient of friction of melon and cucumber seeds, a device for determining the initial density of seed fruits, and a device for determining the dependence of seed deformation on compressive load. Experimental data show that the most optimal values of the static coefficient of friction, depending on the type of surface, for cucumber and melon seeds are perforated sieves, the values of which are 0.75 and 0.85, respectively. Optimal values of dynamic friction coefficients for cucumber have a surface made of perforated sieve – 0.69 and for melon made of aluminium – 0.88. The dependence of the linear deformation of seed fruits on the specific pressure increases from 0.9 to 3.6. The values of fruit deformation from compressive load vary from 4.1 to 24.6. The research presented in the article is of practical importance and can be used in the field of agricultural production and in the development of new engineering solutions

**Keywords:** seed; experimental studies; surface; dependence

## INTRODUCTION

The global agricultural technology market is constantly evolving. Countries with developed agriculture are actively using mechanised and automated processes for seed preparation, which leads to increased productivity and reduced costs. In Ukraine, given its agricultural potential and role in the global agricultural sector, it is important to improve the technology for selecting and preparing vegetable and melon seeds. This will improve the quality and efficiency of production, ensuring stability in the agricultural sector and contributing to the competitiveness of Ukrainian products on the global market.

The production of seed material for vegetable and melon crops is one of the most important problems in the field of agricultural processing. The issue of obtaining cucumber and melon seeds is quite acute, given the volume of their cultivation in Ukraine (Havrysh *et al.,* 2022). An integral part of the development of technology and technological equipment for seed production is the study of the physical, mechanical and dimensional and mass characteristics of seed fruits and seeds of vegetable and melon crops (Fang *et al.,* 2020). The combination of qualities of seed fruits and seeds of vegetable and melon crops is an important basis for the design of working bodies and the machine as a whole. Technological equipment that provides a mechanised process of producing melon and cucumber seeds involves not only its theoretical substantiation in order to choose the right forms, machine designs and working bodies, but also experimental studies to confirm the theoretical premises (Pathania *et al.,* 2022).

V. Shebanin *et al.* (2019) note that to study the processes of fruit crushing and seed production, it is important to know such indicators as the dynamic friction coefficient, the coefficient of volumetric deformation of the seed fruit and the coefficient of static load (crushing force). Y. Yang *et al.* (2021), when studying the physical and mechanical properties of materials for the research and optimisation of technological processes, found that most existing methods and laboratory equipment are aimed at determining the critical values of the relevant parameters. However, these research tools do not always provide opportunities for in-depth analysis of patterns and establishing links between the deformation force and the deformation itself, especially in the context of different stages of the technological process, such as the grinding of seed fruits of vegetables and melons.

In light of the need to increase the efficiency of vegetable and melon seed production, modernisation and improvement of the seed fruit chopper and other processing equipment is becoming an important task. Modern requirements for seed quality and technological standards require that the production process be in line with them. In order to reduce seed losses and improve seed quality, Z. Stropek & K. Gołacki (2020) focused on the research and implementation of the latest solutions in the technological field, which will optimise production processes and ensure market competitiveness. In addition, J. Hou *et al.* (2021) emphasise that current trends in agriculture determine the increased demand for high-quality seeds to achieve optimal yields.

Therefore, improving the technical characteristics and functionality of seed treatment equipment is of strategic importance for producers. Furthermore, in the context of sustainability, reducing losses in the process can also contribute to reducing resource consumption and increasing the environmental efficiency of production. Such improvements can contribute not only to increased production efficiency, but also to sustainability and competitiveness in the vegetable and melon industry. Irrational operating modes of vegetable and melon seed crushing machines lead to a decrease in the quality of seed and irreversible seed losses, requiring the identification and resolution of design flaws and improvement of the technological process. The purpose of the study was to investigate the physical and mechanical characteristics of vegetable fruits, focusing on the parameters that most affect the quality of the technological process of seed grinding and preliminary seed extraction. To achieve this goal, the following tasks were performed: analysis of the influence of physical and mechanical parameters of seeds; development of an experimental approach; determination of optimal parameters for the technological process.

## MATERIALS AND METHODS

The study complies with ethical standards and adheres to the Convention on Biological Diversity (Secretariat of the..., 2011). The determination of the size and weight characteristics of the seeds and seeds was carried out during the final period of harvesting cucumber and melon fruits, when the seeds reached their maturity. It is during this period – their biological ripeness – that it is advisable to conduct research. Fruit length and fruit diameter were determined using a caliper SHC-1 with a division price of 0.05 mm. Fruit weight was determined on a balance with an accuracy of 1 g (Fig. 1, 2) (DSTU 8439:2015, 2017). Seeds of such crops as cucumber and melon are similar in size and weight characteristics (Ternavskyi *et al.*, 2022). This is evidenced by the results of his study, the main generalised statistical indicators of which are given in Tables 1 and 2. All experimental data were statistically processed, with the accuracy of the experiment being 5% and the confidence interval being 0.95 (Devi & Mani, 2017).


***Figure 1.*** *Determination of the size and weight characteristics of seedpods and seeds of melon fruit*
***Source:*** *authors' photo*

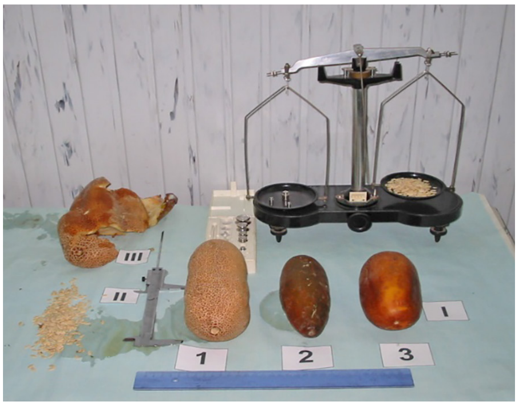


***Figure 2.*** *Determination of the size and weight characteristics of seedpods and cucumber seeds*
***Source:*** *authors' photo*

***Table 1.*** *Summary size and weight characteristics of melon and cucumber seeds*

| Culture, variety | Length, cm | | | Width, cm | | | Thickness, cm | | | Weight, g | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | min | max | aver. | max | min | aver | max | min | aver. | max | min | aver. |
| Cucumber | | | | | | | | | | | | |
| Nizhynskyi 12 | 10.75 | 8.85 | 9.78 | 4.3 | 2.5 | 3.4 | 1.8 | 1.3 | 1.55 | 4.9 | 3.3 | 4.17 |
| Koncurent | 10.85 | 8.65 | 9.75 | 4.15 | 2.65 | 3.4 | 1.85 | 1.2 | 1.52 | 5 | 3.5 | 4.25 |
| Melon | | | | | | | | | | | | |
| Kolgospnytsa | 12.4 | 10.4 | 11.35 | 6.46 | 4.56 | 5.51 | 2.05 | 1.10 | 1.56 | 6.8 | 4.2 | 5.47 |
| Ukrainka | 12.7 | 10.2 | 11.45 | 6.25 | 4.25 | 5.25 | 1.95 | 1.15 | 1.55 | 6.6 | 4.1 | 5.35 |

***Source:*** *developed by the authors*

***Table 2.*** *Size and weight characteristics of melon and cucumber seeds*

| Culture, variety | Length, mm | | | Diameter, mm | | | Weight, kg | | |
|---|---|---|---|---|---|---|---|---|---|
| | min | max | aver. | min | max | aver. | min | max | aver. |
| Cucumber | | | | | | | | | |
| Koncurent | 116 | 141 | 128.5 | 48.0 | 73.0 | 58.4 | 0.210 | 0.255 | 0.232 |
| Nizhynskyi 12 | 114 | 144 | 129 | 45.0 | 75.0 | 60.0 | 0.215 | 0.265 | 0.240 |
| Melon | | | | | | | | | |
| Kolgospnytsa | 150 | 260 | 205 | 180 | 215 | 197.5 | 0.45 | 1.45 | 0.95 |
| Ukrainka | 165 | 255 | 210 | 186 | 226 | 206 | 0.52 | 1.72 | 1.12 |

***Source:*** *developed by the authors*

Absolute weight refers to the weight of 1,000 seeds in grams at standard moisture content. In the process of seed production, it is very important to have data on the absolute weight of the newly separated seeds at the stage of separation. This indicator is used to make a control assessment of the grown seeds before mechanical extraction. It is known that the sowing qualities of seeds and their productive properties are directly dependent on the absolute weight of seeds (Neamtallah *et al.,* 2017). To study such physical and mechanical properties of fruits as the dynamic friction coefficient, volume deformation coefficient and static load coefficient, appropriate installations were made in the problematic research laboratory of the Faculty of Engineering and Energy of Mykolaiv National Agrarian University.

The technological process of the installation for determining the dynamic coefficient of friction (Fig. 3) is as follows: the product under study is placed in front of the cut-off plate 2 in the initial position; the approximate time (to the hundredth of a second) of the product passing from the cut-off plate to the laser beam 7 is set using the timer; when the "Start" button of the timer 6 is pressed, the cut-off plate 2 is raised by an electromagnet and, at the same time, the timer 6 starts counting down; when the product passes through the laser beam 7, the electrical circuit is opened and the time countdown stops; using further mathematical transformations, the friction-slip coefficient is calculated.

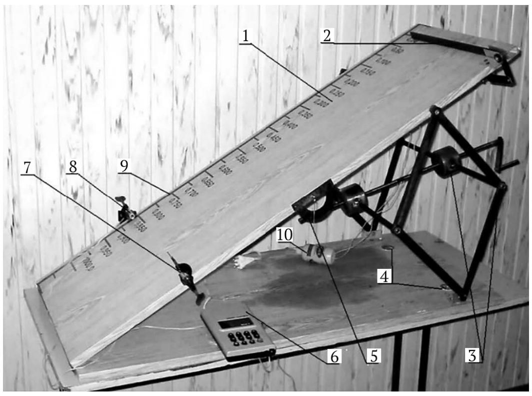


***Figure 3.*** *Dynamic friction coefficient determination unit*
***Notes:*** *1 – inclined surface, 2 – cut-off plate, 3 – device for changing the angle of inclination of the surface, 4 – balance sensor, 5 – angle meter, 6 – timer, 7 – laser, 8 – phototransistor, 9 – path measurement scale, 10 – electronics*
***Source:*** *authors' photo*

To increase the versatility of the installation, the following adjustment is provided for the purpose of realising the possibility of studying various types of products. By means of the lifting device 3, the angle of inclination of the surface 1 is changed and, by changing the position of the laser 7 and phototransistor 8, the path of the product from the cut-off plate 2 to the laser beam is changed, which in turn leads to a change in time, and, accordingly, leads to a change in the friction-sliding coefficient. On the inclined surface, it is possible to install any type of material whose friction coefficient is to be investigated.

The following formula is used to obtain the dynamic friction coefficient:

$$f = \frac{1}{cos\alpha}\left(sin\alpha - \frac{2s}{gt^2}\right) = tg\alpha - \frac{2s}{gt^2 \cdot cos\alpha}, \quad (1)$$

where $f$ – the dynamic coefficient of friction; $s$ – the distance travelled by the product under study, m; $t$ – the time for the product to travel the distance s, sec; $\alpha$ – the angle of inclination of the surface to the horizon, deg.

The coefficient of volumetric compression (deformation) of seed fruits is defined as:

$$K_v = \frac{P_{cm}}{\Delta V}, \quad (2)$$

where $P_{cm}$ – the compressive load, H; $\Delta V$ – the reduction of the volume of the seed fruit under study when a load is applied $P_{cm}$, m$^3$.

The determination of the coefficient of volumetric deformation of the fetus was carried out on a specially manufactured device (Fig. 4), which is similar in principle to the Znamensky device. It consists of a compression chamber and a piston with a plate on the rod for placing weights. The Znamensky apparatus is a measuring device used to determine the coefficient of volumetric deformation of materials, in particular, in this case, fruits. This device uses the principle of compressing a material with a piston and measuring the change in its volume. The description of the Znamensky device includes a compression chamber and a piston that performs the compression. Usually, a plate is placed on the piston to add weights, which are used to create standard compression conditions. This device measures the degree of compression of a material and records the change in its volume under the force. The Znamensky apparatus is an important tool for studying the mechanical properties of materials, and its use in experimental studies provides data on the volumetric deformation of fruits and their resistance to compression. The amount of linear deformation $\Delta_l$ is controlled by an indicator mounted on a plate arm, the stem of which interacts with a stop on the compression chamber. Before the start of each experiment, the fruits were weighed, and after placing them in the chamber and pre-compressing them with a piston, the volume $V_0$ at zero load was determined. The obtained values were used to determine the initial density of seed fruits.

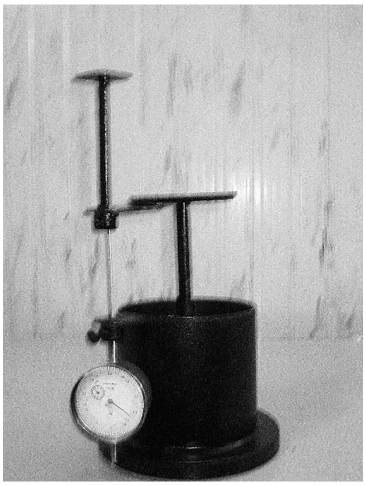

***Figure 4.*** *Device for determining the volume strain coefficient*
***Source:*** *authors' photo*

The dependence of linear strain on specific pressure was determined by the expression:

$$\Delta_l = \delta q = 4.5 \cdot 10^{-7} \cdot q, \qquad (3)$$

where δ – the inverse of the volume strain coefficient (obtained using the least squares method); *q* – the specific pressure.

To determine the dependence of the deformation of the seed on the compressive load, a special device was developed and manufactured (Fig. 5), which consists of posts fixed to the base, on which a rocker arm suspended on pins is installed. The rocker arm has a compression plate and a load plate. The test object is mounted on a height-adjustable platform. The amount of deformation is determined by the indicator.

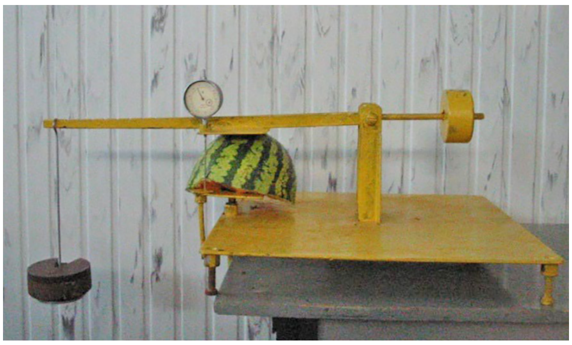

***Figure 5.*** *Setup for determining the effect of a compressive static load on the seed*
***Source:*** *authors' photo*

Changing the load acting on the seeders is done by increasing the number of weights mounted on the plate or moving it along the length of the rocker arm. Balancers are used to balance the rocker arm when the compressive force is set to zero at the beginning of the load (Zhang, 2022).

In fact, the load acting on the seed fruit is calculated by the expression:

$$P_{cm} = \frac{g m_6 l_1}{l_2}, \qquad (4)$$

where $m_в$ – the weight of the loads mounted on the plate; $l_1$ – the distance from the load plate to the rocker arm rolling axis; $l_2$ – the distance from the seeder mounted on the platform to the rolling axis of the rocker arm.

In the process of loading the seeder, the indicat or measures the amount of its deformation Δст, which corresponds to the applied force. Accordingly, the static load factor will be determined by the following equation:

$$\Delta_{cm} = XP_{cm} = 0.41P_{cm}, \qquad (5)$$

where *X* – the coefficient of fruit yield obtained by the least squares method, mm/H.

The experimentally obtained data are approximated by a first-order equation using the least squares method, followed by checking the mathematical description of the experimentally obtained data for adequacy using the Fisher criterion.

## RESULTS

In the context of a growing population and climate change, the importance of improving agricultural techniques and varieties of vegetables and melons is becoming increasingly important. The study of the mechanical and technological properties of seed fruits is an important component for the development and implementation of new methods of cultivation and processing aimed at improving agricultural efficiency and product quality. Vegetables and melons are of great importance as a source of food rich in vitamins, minerals and other nutrients. Ensuring high quality and quantity of seeds is becoming a key aspect for ensuring food security and responding to global market challenges (Gorzelany *et al.*, 2022).

The study of mechanical and technological properties includes a comprehensive approach focused on the study of physical, chemical and biological aspects of seed fruits. This allows not only to determine the optimal conditions for their cultivation, but also to develop technologies for harvesting, storage and processing aimed at maintaining high quality and commercial value. Mechanical and technological properties include physical, chemical and biological characteristics of seed fruits. Physical parameters, such as size, weight and hardness of the seed coat, affect the efficiency of harvesting, processing and transportation. The chemical composition of the seed determines its nutritional and economic value, as well as its resistance to disease. Biological characteristics, such as the seed fruit's tightness and germination ability, are important to ensure normal plant development. Technological aspects, such as storage, transport and handling methods, also have a significant impact on seed quality and value (Xia *et al.,* 2021).

One of the main challenges is to address disease resistance, optimise growth and yield, and develop varieties suitable for different agroclimatic conditions. High-precision studies of the mechanical and technological properties of seed fruits are a key tool for achieving these goals and creating sustainable and productive crops (Serhiienko *et al.,* 2023). The results of the studies of the static friction coefficients of melon and cucumber seeds made on different surfaces (perforated sieve, galvanised iron, aluminium plate) are presented in Table 3. Taking into account the choice of friction surfaces and the use of spokes to avoid seed rolling, the study allowed to determine the optimal conditions for the interaction of seeds of both crops.

***Table 3.*** *Static friction coefficients of melon and cucumber seeds*

| Culture, variety | Types of surfaces | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Perforated sieve | | | Galvanised iron | | | Aluminium | | |
| | min | max | aver. | min | max | aver. | min | max | aver. |
| Cucumbers: | | | | | | | | | |
| Nizhynskyi 12 | 0.6 | 0.9 | 0.75 | 0.52 | 0.72 | 0,62 | 0.5 | 0.84 | 0.67 |
| Koncurent | 0.58 | 0.88 | 0.73 | 0.48 | 0.68 | 0.58 | 0.48 | 0.82 | 0.65 |
| Melons: | | | | | | | | | |
| Kolgospnytsa | 0.79 | 0.95 | 0.87 | 0.71 | 0.81 | 0.76 | 0.73 | 0.85 | 0.79 |
| Ukrainka | 0.77 | 0.93 | 0.85 | 0.55 | 0.65 | 0.60 | 0.73 | 0.83 | 0.78 |

***Source:*** *developed by the authors*

Experimental data show that the most optimal indicators of the static coefficient of friction depending on the type of surface for cucumber and melon seeders are perforated sieves, the values of which are 0.75 and 0.85, respectively. Analysis of this table can reveal certain trends and differences between crops and types of surfaces. In particular, both cucumber varieties (Nizhynskyi 12 and Koncurent) have similar average values of static friction coefficients on different surfaces. The lowest values are observed for galvanised iron, which may indicate less friction in contact with this surface. The melon varieties (Kolgospnytsa and Ukrainka) also show similar average static friction coefficients. The highest values are observed on the aluminium surface, which may be important for the production process where friction can affect the movement and handling of the seedpods.

Thus, according to the results of static studies, it was found that perforated sieves are the most optimal surfaces for cucumber and melon seeders, having static friction coefficients of 0.75 and 0.85, respectively. Analysis of the table shows certain trends and differences between crops and types of surfaces. Cucumber varieties show similar values of static friction coefficients on different surfaces, with the lowest values for galvanised iron. Melon varieties also show similar values of static friction coefficients, with higher values on the aluminium surface. In general, the analysis of static friction coefficients allows to draw conclusions about the interaction of seed drills with different surfaces, which is important for optimising the technological processes of seed grinding and processing. Table 4 shows the results of dynamic indicators of the friction coefficients of melon and cucumber seeds.

***Table 4.*** *Dynamic friction coefficients of melon and cucumber seeds*

| Culture, variety | Types of surfaces | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Perforated sieve | | | Galvanised iron | | | Aluminium | | |
| | min | max | aver. | min | max | aver. | min | max | aver. |
| Cucumbers: | | | | | | | | | |
| Nizhynskyi 12 | 0.62 | 0.76 | 0.69 | 0.41 | 0.57 | 0.49 | 0.35 | 0.69 | 0.52 |
| Koncurent | 0.58 | 0.72 | 0.65 | 0.34 | 0.50 | 0.42 | 0.29 | 0.63 | 0.46 |
| Melons: | | | | | | | | | |
| Kolgospnytsa | 0.75 | 0.91 | 0.83 | 0.63 | 0.75 | 0.69 | 0.63 | 0.81 | 0.72 |
| Ukrainka | 0.69 | 0.85 | 0.77 | 0.47 | 0.59 | 0.63 | 0.79 | 0.97 | 0.88 |

***Source:*** *developed by the authors*

The analysis of the data in the table can indicate the nature of the interaction between seeds and different materials and help to optimise technological processes. Cucumber varieties have average dynamic friction coefficients that range from 0.35 to 0.76. The lowest friction coefficient is observed on aluminium surfaces and the highest on galvanised iron. Melon varieties also have average dynamic friction coefficients that range from 0.47 to 0.97. The minimum coefficient of friction is recorded on an aluminium surface, and the maximum – on galvanised iron. The optimum values of dynamic friction coefficients for cucumber are 0.69 on a perforated sieve surface and 0.88 on an aluminium melon surface. These data make an important contribution to understanding the dynamic friction properties of cucumber and melon seeds on different surfaces. Equation (3) describes the dependence of the linear strain on the specific pressure, which is shown in Figure 6. The dependence of linear deformation of seed fruits on specific pressure increases from 0.9 to 3.6. The values of fruit deformation from compressive load vary from 4.1 to 24.6. Figure 7 shows a graphical interpretation of the dependence $\Delta_{cm} = f(P_{cm})$.

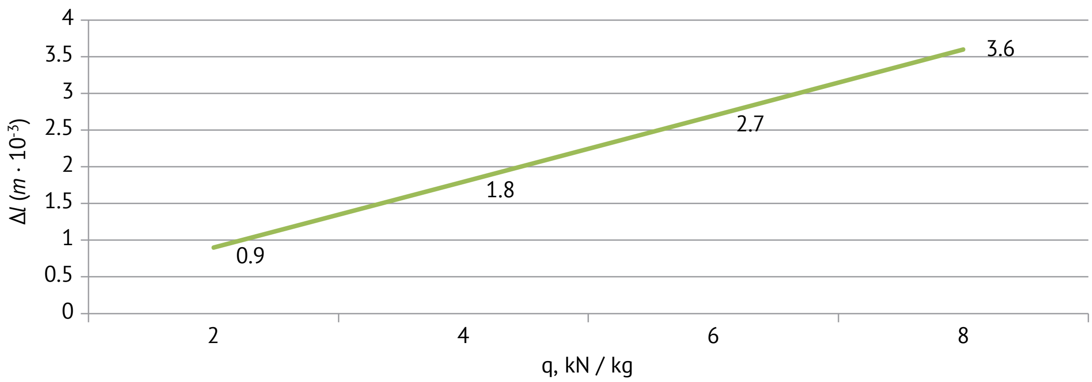


***Figure 6.*** *Dependence of linear deformation of seed fruits on specific pressure*

***Notes:*** $\Delta_l = 4.5 \cdot 10^{-7} \cdot q$

***Source:*** *developed by the authors*

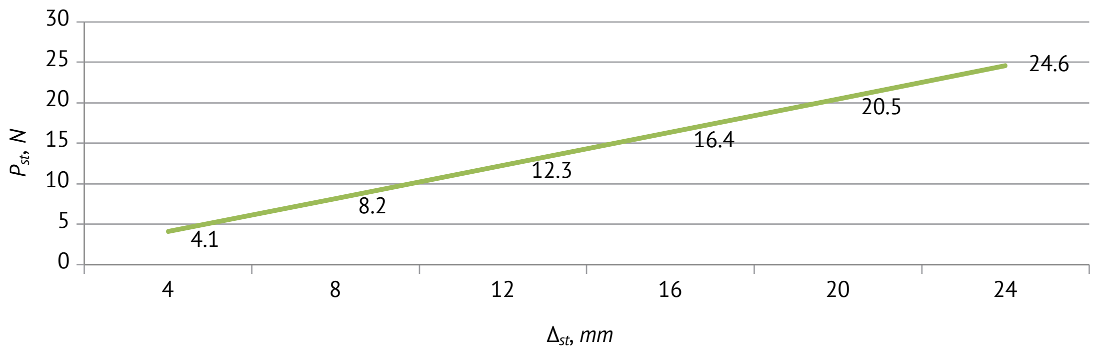


***Figure 7.*** *Dependence of fetal deformation on compressive load*

***Source:*** *developed by the authors*

The values of fruit deformation under compressive load vary from 4.1 to 24.6. These ranges of fruit deformation under compressive load indicate a large variability in the physical and mechanical properties of plant material. Low strain values, such as 4.1, may indicate high resistance of certain fruits to compressive stress, while high values, such as 24.6, may indicate less resistance and a pronounced ability of the material to change shape under load.

## DISCUSSION

In Ukraine, as in many other countries, the development of the agricultural sector is one of the key sectors for food security and economic growth. Vegetable and melon farming is an important part of the agricultural sector, providing a significant share of vegetable production for domestic consumption and export.

This study can be compared with the research of Y. Fang *et al.* (2020), who emphasise that in the context of growing vegetables and melons, the use of high-quality and viable seeds is of great importance. Optimal seed selection and preparation is a key step in growing high-quality products. The mechanical and technological aspects of seed handling, such as sorting, separation and preparation, can affect the yield and quality of the crops grown.

Comparing the study with the results of the authors, in particular Yu. Kononov & A. Lymar (2020), it is important to note that there are problems in obtaining high-quality seeds of vegetable and melon crops. The authors identify the need to expand the dialogue and take comprehensive measures to modernise seed production in Ukraine, which is also reflected in the study. The development of technological solutions and the introduction of the latest equipment should solve a number of problems that relate not only to the quality of the final product, but also to ensuring the efficiency of production in general. One of the main obstacles is the backwardness of the equipment used in the process of growing and processing seeds. With this in mind, the works of many authors, including G. Hu *et al.* (2021) and Y. Yi *et al.* (2021), confirm that it is important to improve seed selection and preparation technologies, as well as mechanised separation and sorting processes, to ensure maximum seed quality and purity. One of the key aspects is the study of the physical and mechanical properties of seed fruits. This includes analysing the strength of the shell, size, shape and weight of the seeds. The study of these parameters allows for the development of optimal mechanical processing methods, such as sorting and separation, to ensure efficient selection and preparation of seeds for high quality cultivation, which is also reflected in the study.

Z. Zheng *et al.* (2022) also note that mechanised seed separation and sorting processes are important for selecting the most viable and plantable specimens. Technologies that use optical sensors and other advanced methods can quickly and efficiently determine seed quality, as well as detect possible defects or diseases. The study of mechanical and technological properties also contributes to the development of new varieties and hybrids that meet the requirements of mechanised production. This may include the creation of hybrids with improved resistance to mechanical stress and increased yields, as revealed by the study.

A similar opinion is expressed by N. Kim *et al.* (2013), who note that in order to obtain high-quality seed material, the technological process should involve equipment that minimises its injury and loss and meets the requirements for the quality of the final product. The absence of such equipment requires a mandatory solution to this problem by developing new technological equipment. In addition, according to the data obtained, it is necessary to consider the possibility of using modern methods of seed processing and storage to increase its shelf life. An important aspect is to ensure a high level of energy saving and rational use of labour in seed production.

This study correlates with the work of V. Havrysh *et al.* (2022), according to which, for the successful implementation of improved technologies for the selection and preparation of vegetable and melon seeds, it is important to establish an effective mechanism for cooperation between all stakeholders. Authorities should ensure favourable regulation and create incentives for the introduction of new technologies in agriculture. Producers should be actively involved in the process of introducing new methods and techniques, and provide feedback on their effectiveness and practicality in the field. Scientists, in turn, play a key role in conducting experimental studies that allow for a deeper understanding of the mechanical and technological properties of seeds and establish optimal parameters for mechanised processes. It is important to take into account the best practices and experience of countries where a high level of mechanisation in seed production has been achieved, in particular in the European Union and the United States (Li *et al.,* 2022).

Stakeholders may also include representatives of agricultural businesses, farmers' associations, and other groups with an interest in improving seed production processes. This broad collaboration will facilitate the exchange of experience, resources and innovations, which in turn will contribute to the rapid adoption of advanced technologies. In summary, an integrated approach is key to the successful implementation and improvement of vegetable and melon seed production technologies in Ukraine.

## CONCLUSIONS

Experimental studies of the working processes of obtaining cucumber and melon seed material are peculiar, since the mechanised technological process of seed separation largely depends on the parameters and operating modes of the pressure-separating machine. Scientific substantiation of this process becomes impossible without a detailed study of the mechanical and technological properties of the seed mass and the peculiarities of operations related to the destruction of the seedpods and separation of seed-plant material.

The study included separate stages aimed at a detailed study of the mechanical and technological properties of the seed mass, which is important for a proper understanding of the seed separation process. At the same time, the focus was on the study of operations related to the destruction of the seed pods and the separation of seed-plant material using a pressure-separating machine. Experimental studies of the working processes of obtaining cucumber and melon seed material revealed significant features of the interaction of seeds with different surfaces, which determines the efficiency of technological processes of seed processing and grinding. The static friction coefficients showed that the perforated sieve is the most optimal surface for cucumber (0.75) and melon (0.85) seeds. Dynamic friction coefficients confirmed these results, indicating average values in the range of 0.35-0.76 for cucumber and 0.47-0.97 for melon on different surfaces. The study of fruit deformation due to specific pressure and compressive load revealed a large variability in the physical and mechanical properties of plant material. Strain values from 4.1 to 24.6 indicate different levels of fruit resistance to mechanical stress.

The dependencies and data on the size and weight and physical and mechanical characteristics of seed fruits and seeds of vegetable and melon crops obtained in this article are important for further design of the grinding device and study of the quality of the technological process of seed separation. Prospects for future research may include a more detailed study of the interaction of different varieties and types of vegetables with pressure-separating machines and further improvement of technological parameters to optimise the process.

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## CONFLICT OF INTEREST

None.

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# Дослідження механіко-технологічних властивостей насіннєвих плодів овоче-баштанних культур

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**Анотація.** Аналіз літературних джерел свідчить, що виробництво насіннєвого матеріалу овоче-баштанних культур є однією з важливих проблем, яке існує в галузі переробки сільськогосподарської продукції. Актуальним питанням є отримання насіння огірка та дині з погляду на обсяги їх вирощування в Україні. Для дослідження процесів подрібнення плодів та отримання насіння у сільському господарстві ключовими параметрами є динамічний коефіцієнт тертя, коефіцієнт об'ємної деформації та коефіцієнт статичного навантаження, але існуючі методи та обладнання обмежуються визначенням граничних значень показників, не дозволяючи повноцінне вивчення динаміки змін властивостей на різних етапах технологічного процесу. Для вирішення цього, пропонується розробка нових методик, зокрема використання комп'ютерного моделювання, що дозволить детальніше вивчити та оптимізувати фізико-механічні властивості та їх зміни. Метою статті було провести дослідження фізико-механічних властивостей плодів овочевих культур, які мають найбільший вплив на якість технологічного процесу подрібнення насіння плодів та попереднього отримання насіння. Дослідження проводилося в проблемній науково-дослідній лабораторії інженерно-енергетичного факультету Миколаївського національного аграрного університету. Використовувалися експериментальні установки для визначення динамічного коефіцієнта тертя насіння дині та огірка, прилад для визначення початкової щільності насіннєвих плодів та прилад для визначення залежності деформації насіння від стискаючого навантаження. Експериментальні дані свідчать, що найоптимальніші показники статичного коефіцієнта тертя в залежності від виду поверхні для насінників огірка та дині є перфоровані решета, значення яких відповідно складають – 0,75 та 0,85. Оптимальні значення показників динамічних коефіцієнтів тертя для огірка має поверхня з перфорованого решета – 0,69 та для дині з алюмінію – 0,88. Залежність лінійної деформації насіннєвих плодів від питомого тиску збільшується з 0,9 до 3,6. Значення деформації плоду від стискаючого навантаження змінюються в межах від 4,1 до 24,6. Дослідження, що наведенні в статті мають практичне значення і можуть бути використані в галузі сільськогосподарського виробництва та при розробці нових інженерних рішень

**Ключові слова:** насінник; експериментальні дослідження; поверхня; залежність

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# Agrarian integration: Theoretical foundations

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**Abstract.** The benefits of international economic integration have led to an increase in the number of integration groups. The sensitivity of the agri-food sector to liberalisation and its importance have led to the allocation of a separate chapter in regional trade agreements. The importance of foreign trade and food security, as well as their special significance for Ukraine, which has signed dozens of regional trade agreements and is one of the largest exporters of certain types of agri-food products, confirm the relevance of the study. The aim of the article is to analyse the theoretical foundations of international economic integration with a focus on the agricultural sector, identify its specific features and develop relevant proposals. To achieve this goal, the author used the methods of theoretical generalisation, abstract and logical, specification, analysis, and synthesis, which allowed to study the features of international economic integration in the agricultural sector, to formulate conclusions and proposals. The information base was based on scientific research, regional trade agreements, etc. As a result of the work carried out, the development of international economic integration was analysed with due regard to the agricultural sector. The article suggests allocation of the main goals of integration, their classification, definition and substantiation of risks. Among the main objectives of integration in the agricultural sector, it is proposed to allocate the following: ensuring the domestic demand for food of the required quality at an affordable price, taking into account the comparative advantages of the member states, increasing exports to third countries, based on the potential of the member states, and solving social problems. Taking into account the goals of sustainable development and global problems of mankind, it is proposed that the main goals should also include environmental issues and rational use of resources. The goals of integration are defined as one of the main prerequisites for its successful development, which is confirmed by the content of the relevant treaties and agreements. In practice, international economic integration can contribute to solving the problem of food security and development of the agricultural sector, production, in particular through the inflow of new technologies, foreign investment, etc. The development of intra- and extra-regional trade is envisaged as a result of harmonisation of product quality standards, increase of its competitiveness, etc. This should be facilitated, first of all, by a clear definition of goals, their implementation through an appropriate set of measures defined by country, and monitoring of implementation

**Keywords:** international economic integration; agricultural sector; goals; risk

## INTRODUCTION

International economic integration (IEI) is essential for the economic development of countries. Its influence is growing, as it covers a wide range of issues directly related to foreign trade, including competitiveness, environment, etc. That is why it is advisable to study the consequences of integration for certain sectors

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of the economy, in particular the agricultural sector, given its importance for food security in Ukraine and the world, and the specifics of production and trade in agri-food products. This is evidenced by the functioning of the Common Agricultural Policy (CAP) of the European Union (EU), and since the beginning of the grouping's activity. The relevance of the study is also confirmed by the importance of Ukraine's agricultural sector for the country's economy (since a significant share of exports of goods is accounted for by agri-food products) and for the international community (since Ukraine is one of the main exporters of certain types of agri-food products). The desire to benefit from the IEI is driving the growth of integration groups in the world, and the issues in this area have been studied by scholars for decades.

N. Voloshko & I. Kurinna (2019) note that objective factors encourage IEIs, and among the main ones are: the conjunctural attachment of participating countries to the world and regional markets, market maturity and sustainability of countries in terms of their economic development, the existing commonality of problems of socio-economic and scientific and technological development, etc. O. Zayats (2020) believes that the development of integration leads to the formation of huge economic and competitive spaces, which lead to an increase in the scale of production among member countries and, as a result, strengthening the power of the integration grouping as a whole. Moreover, each expansion of the grouping increases its economic power in the global economy, and it redistributes global integrated competitive power.

Some studies are also focused on the integration processes of individual integration groups, regions and countries, depending on their level of economic development and economic sectors. The results allow to develop the necessary proposals and recommendations for further integration and the use of methods. However, it is necessary to take into account the difference in positions and conclusions of different scientists. Thus, T. Burlai (2018) notes that the study of the modern experience of Central and Eastern European countries shows that despite a number of advantages of such a multisystemic development institution as European integration, its effectiveness has clear limits. This was particularly evident in the context of the eurozone crisis, when the processes of economic convergence between the "old" and "new" EU members slowed down significantly and the latter's "margin of safety and competitiveness" became apparent.

Due to the accession of new members, the EU is also facing certain difficulties. A. Kobylianska (2018) highlights such a specific part of its policy as the Eastern Partnership, which is an initiative of the grouping towards six Eastern European countries – Moldova, Georgia, Belarus, Armenia, Azerbaijan and Ukraine. Thus, promoting the establishment and strengthening of multilateral cooperation between the EU and the participating countries is one of the main objectives of the programme. By the way, the Eastern Partnership is similar to the EU's Southern Partnership (which includes EU and North African countries). This leads to a broader study of this issue.

Given the importance of the IEI and globalisation, it is worth noting that O. Pavlov (2022) confirms the hypothesis of their kinship and opposition, pointing to the difference in functions and overlap, which is most evident in the object dimension, which is expressed through various components of the internationalisation of economic activity. At the same time, world trade is attributed a key role, and its dynamics is constantly changing under the influence of the international division of labour, increased competition, specialisation, fragmentation of global value chains, and accelerating foreign direct investment. N. Patyka (2019) notes that the agricultural sector is increasingly involved in the IEI processes and highlights the historically significant role of agriculture in the development of Ukraine's economy.

There are the many benefits of international economic integration of countries in general, and in particular for certain sectors of the economy, which contributes to its development. T. Ilchenko (2020) believes that European integration for Ukraine is a key direction of modernisation and formation of an innovative model of socio-economic development, attraction of innovative technologies and investment resources, expansion of sales markets, increase of competitiveness of producers, and creation of new jobs.

Ye. Redziuk (2021) argues that integration economic unions, which guarantee appropriate mechanisms and instruments of institutional, financial and economic support for national economies, increase their resilience to external negative influences, improve intra-integration interstate flows of resources, including human, technological, and investment. These groupings contribute to a more systematic and powerful socio-economic growth of countries through synergy, as well as reduction of unproductive costs, prohibitions, and restrictions. It is emphasised that with the growth of the EU's gross domestic product (GDP) by USD 1 per capita, the foreign trade turnover of all goods will increase by 0.887 USD. The bilateral turnover of agricultural goods will increase by 1.693 USD. However, the increase in Ukraine's GDP has a much smaller impact, which is explained by the difference in the size of the economies of Ukraine and the grouping.

The purpose of the study was to analyse the development of international economic integration with due regard to the agricultural sector, the specifics of individual integration groups, and to develop proposals for classifying the goals of integration and identifying its risks. The methodological basis of the work was the dialectical method, which allowed for a comprehensive study of agrarian integration, taking into account its impact on activities within the economic process. The methods of historical and economic analysis were also used to study the development of agrarian integration, in particular, to identify the causes and features of its evolution in Western Europe. To achieve this goal, the abstract and logical method was also used to study the theoretical foundations of agrarian integration, and the historical method was used to analyse the development of IEI and to formulate relevant scientific views. The methods of theoretical generalisation, specification, analysis and synthesis allowed to identify the features of international economic integration in the agricultural sector, summarise the results of the work, draw conclusions and develop proposals for further research and development. The material basis of the work was formed by scientific works of Ukrainian and world scientists, regional trade agreements in general and with the participation of Ukraine, statistics of international organisations (TradeMap..., n.d.), materials of the World trade organisation (n.d.). The study paid special attention to the issues of agrarian integration, determining its importance for the development of the economies of the member countries of integration groups, in particular in terms of production, addressing the issue of domestic food security, deepening foreign trade, employment, etc.

## DEVELOPMENT OF THEORETICAL APPROACHES TO THE STUDY OF INTERNATIONAL ECONOMIC INTEGRATION

The development of international economic integration has led to a deepening of its study by scholars from different countries. B. Balassa (1962) made a significant contribution to the development of the IEI theory by identifying individual forms of integration and also studied the European common market. J. Viner (1950) analysed in depth the peculiarities of the customs union (CU), highlighted the effects of trade creation and rejection. G. Myrdal (1969), in addition to economic issues, paid special attention to social issues. The scientist argues that an economy is not integrated if all paths are not open to everyone, and if the remuneration for productive services is not equal for everyone, regardless of racial, social and cultural differences. R.G. Lipsey (1957), analysing the CU, takes into account trade distortions and notes the welfare gains and consequences for the consumer. P. Sabluk *et al.* (2010), studying regional integration, analyse the common goals of the groupings, trade in agricultural products, etc.

Since international economic integration has reached its greatest development in the EU, much of the research focuses on this grouping. For example, O. Bilorus (2008), studying the impact of globalisation on European integration processes and the comparative competitiveness of European integration structures, notes that the growing role of international unions and groups in the world economy is one of the most important consequences of globalisation. The scientist considers EU integration strategies as a factor of increasing the competitiveness of the economy, and also assesses the consequences of EU enlargement for the members of the grouping and Ukraine. O. Shnyrkov (2005) draws attention to the contradictory impact of free trade agreements on the development of trade liberalisation, analysing the EU trade policy. K. Mann (2015) describes how the process of European integration of Central and Eastern European countries since the 1990s has affected their GDP growth and concludes that it has been beneficial.

Other scholars have focused more on Ukraine's integration. Thus, M. Puhachov & A. Melnyk (2014) note that in case of creation of a free trade area with the EU, Ukraine will receive a number of benefits, including an increase in the level of technological support of agro-industrial complex (AIC) enterprises, acceleration of the development of institutional and market support of AIC enterprises, etc. O. Yatsenko *et al.* (2017) predicted the impact of the free trade area with the EU on the agricultural sector of Ukraine, in particular, they used a gravity model and identified new opportunities. Among the advantages are new opportunities for cooperation, integration of agricultural policy into the European one, etc.

Integration affects the development of individual industries, so sectoral integration is also being studied due to the benefits of international economic integration, including foreign trade liberalisation, prospects for new technologies, increased competitiveness, etc. However, the possible losses for individual industries should also be taken into account, so it is advisable to emphasise the importance of sectoral integration and its impact on the overall integration. Particular attention should be paid to agricultural integration, given the importance of the sector, its impact on related industries, and its importance, first and foremost, for Ukraine, which is one of the world's largest exporters of certain types of agri-food products. A. Filipenko & V. Filipenko (2013), studying the theories of the IEI, note that the concept of selective integration allows grouping members and third countries to participate in certain integration activities, depending on economic and political circumstances.

The concept of partial membership, according to which a country may participate in certain areas, does not require full participation in comprehensive integration, and is correlated with Schuman's theory of sectoral integration, which was popular in the first half of the 1950s (he initiated the creation of the European Coal and Steel Community and Euroatom, which later joined the European Economic Union) (Fedoryshyn, 2007). The concept of partial membership, which provides for the possibility of countries' participation in certain areas (e.g., joint foreign trade), is close to this theory (Filipenko & Filipenko, 2013). In the work of V. Ruban (2016) discusses the views of various scholars on this issue. For example, D. Mitrani believes that sectoral integration is gradually transforming into a new system with an autonomous institutional structure (his theory is confirmed by the evolution of European integration relations from the sphere of coal, steel and nuclear energy (European Coal and Steel Community, Euroatom) to the broad competence of European communities in the field of foreign economic relations of the European Economic Community and later the EU. E. Khaas, who first introduced the theory of neofunctionalism, which linked integration to the revival of social processes and the activities of political groups, noted that integration processes change not only the form but also the content of activities, and the phenomenon of sectoral integration is gradually evolving into a new system with an autonomous institutional structure (Ruban, 2016).

L. Sadula (2012) considered the views of the scientist Zh. Mone, the initiator of the European Atomic Energy Community (Euroatom). He believed that European unification should start with the economy, and defended "sectoral integration" rather than general integration, since integration in one sector would stimulate neighbouring sectors, which would eventually lead to general integration. The latter, under the right conditions, would replace sectoral integration as the engine of European unification (Sadula, 2012). A. Mokii, the author of the sectoral-regional model of integration, notes that this model corresponds to the tendency to formalise the inter-corporate division of labour, in which the most effective forms of territorial and production cooperation, industrial and commercial associations, special economic zones and economic activity regimes spread over a certain territory, industry, field of activity, etc. are the most effective (Fedoryshyn, 2007). A study by the Razumkov Centre (2020) considered sectoral integration as a large-scale, multi-speed and multi-vector process. Thus, sectoral integration is important for the economic development of countries and international economic integration in general.

## AGRICULTURAL INTEGRATION: DIFFERENCES IN THE PROCESS IN DIFFERENT REGIONS OF THE WORLD AND THE EU

Agrarian integration has a special place, given the importance of the sector and the specifics of agri-food trade. V. Sidenko (2008) notes that sectoral integration develops largely under the influence of the development of direct, not necessarily market-based, linkages, and is usually closely linked to the respective sectoral, namely industrial or agricultural policy, with their inherent measures to regulate markets and competition. And this alternative type of integration, up to a certain limit, is fully compatible with market integration of the economy as a whole, as evidenced by the EU's experience in implementing the Common Agricultural Policy and the Common Industrial Policy in a number of problematic sectors, including coal and metallurgy. Yu. Khan (2016) believes that the goal of integration is to increase mutually beneficial activities and gain competitive advantages in the agricultural market for the free movement of goods, technologies, labour, capital, etc. To a large extent, the level and dynamics of the agricultural sector's development determine the growth opportunities for related industries, resources for the agricultural sector, the processing industry and the agri-food market. An important integration component in this system is the grain market.

J. Goto (1997) studied the impact of integration on agricultural trade and suggested that the higher the degree of pre-integration protection and the lower the degree of product differentiation, the greater the impact of integration. This was tested in two EU enlargements – the accession of Greece in 1981 and Spain and Portugal in 1986 – and the evidence generally supported the theory. O.A. Shobande (2019) analysed the impact of economic integration on agricultural exports in selected West African countries and found that increased openness has a positive impact on the countries of the region. According to the study, population growth, the level of openness to international trade, etc. were among the most reliable factors determining agricultural exports in West Africa, but a negative impact was also identified.

O. Radchenko (2019), studying the IEI of the agro-industrial complex of Ukraine, notes that the process of integration into the European economic space will allow to implement market economic reforms and overcome the crisis that is typical for almost all sectors of the economy; to join forces to solve ecological and environmental problems, etc. D. Krysanov (2018) believes that of all the problems that need to be solved to intensify the integration of Ukraine's agricultural sector into the EU internal market, it is advisable to divide them into two: those that are already being completed and those that require deeper analysis and detail. It is worth noting that there have been positive developments, in particular, in the formation of a single regulatory space and gradual progress towards the integration of Ukrainian agricultural entities into the EU internal market. T. Zhytnyk (2018) analyses innovations in the agricultural sector in the context of European integration, noting that European countries such as the Netherlands and Germany are among the leaders of global innovations in Agritech.

Integration affects not only the development of trade, but also individual industries. This is also confirmed by the regional agreements concluded between the countries, which have separate sections, in particular on the agricultural sector. For example, in the fifth section of the Association Agreement between… (2014): economic and sectoral cooperation, in particular in the field of energy, including nuclear energy (Chapter 1), environment (Chapter 6), science and technology (Chapter 9), agriculture and rural development (Chapter 17); in the Agreement "On Free Trade…" (2018), which refers to special protection measures and export subsidies for agricultural products, the establishment of a Subcommittee on Agriculture (Chapter 2), and the environment (Chapter 12); the Free trade agreement between… (2010) states that "the parties shall establish a free trade area by concluding this Agreement and additional Agreements on Agriculture". Ukraine has also concluded these trade agreements, which confirms that the study of the agricultural sector and the development of international economic integration is quite relevant, as it is one of the largest exporters of certain types of agri-food products: cereals (5.2% of world exports, 8th position), sunflower seeds (26.2%, 1st position), honey (5.2%, 5th position), etc. (Trade Map…, n.d.). In addition, the agreements separately highlight issues of the agricultural sector, trade policy, etc.

The EU's agrarian integration has allowed it to achieve its goals and remain among the world's largest exporters for decades. Therefore, it is advisable to analyse it, paying attention to the EU's Common Agricultural Policy. Thus, I. Klymenko *et al.* (2011) argue that the EU CAP in a broad sense is a direction of the grouping's common policy, which is focused on the adoption of economically feasible and effective regulations that contribute to the competitiveness of agriculture and rural development, improvement of legal regulation of relations in the agricultural sector, etc. P. Nesenenko & K. Tonia (2021) note that the implementation of the EU's Common Agricultural Policy was based on the preconditions formed by the consequences of the Great Depression of 1929-1933 and the state of the economy in the postwar period.

N. Stezhko (2014) emphasises that the historical preconditions for the development of Western Europe became the basis for the introduction of international cooperation experience in the agricultural sector. The countries had narrow domestic markets and a high level of economic development. Seeking to remove the obstacles to the unification of internal markets and common economic policies, the countries sought to overcome the contradictions caused by existing national barriers that prevented effective engagement in the international division of labour (IDL) and transnationalisation of production and capital. They had roughly the same level of income, a high level of interregional trade, a high degree of industrialisation, and favourable conditions for intra-industry specialisation and cooperation, which allowed them to resolve the existing contradictions. Thus, the ruling circles of Western European countries were concerned about the trends in the development of the agro-industrial complex, which led to a way out of the situation with the help of international economic unions and agreements. N. Stezhko (2014) also believes that the IEI creates favourable conditions for the development of the world food system and solving food problems of countries at different levels of economic development, as well as new export opportunities, and enhances the flow of technology and foreign capital. Value chains are also connecting markets on a global scale, and a new agriculture of high-value goods has emerged. Regional markets are also opening up for traditional crops, in particular in the Common Market of South America (Mercosur) and Africa.

S. Piasetska-Ustych (2016) points out that the stages of formation and development of the CAP are inextricably linked to the processes of integration from simple to complex forms, i.e. from the preferential food trade area to the common economic mechanism for regulating the agricultural sector. Thus, at the inception of the CAP, national governments had autonomy to influence their agricultural sector, but later supranational institutions for regulating agricultural production were formed. The highest form of integration is already the delegation of CAP powers to special governing bodies and other institutions of the grouping. Moreover, the CAP is constantly being modernised. Since the 2000s, the leading idea of the CAP has been to ensure the sustainable functioning of the grouping's agricultural sector by financing rural development and strengthening environmental protection and agricultural product safety requirements. By the way, the CAP has changed at different stages. For example, V. Lypchuk & N. Lypchuk (2012) identify the main priorities of the CAP, which were defined by the European Commission in a communication of November 2010: payback of food production, balanced use of natural resources, and balanced territorial development. That is, the CAP covers not only trade and production issues. S. Kvasha & K. Kvasha (2013), analysing the development of agriculture in the EU, summarise the consequences of changes in the CAP: despite the small size of farms, producers in the grouping have achieved extremely high productivity, and the trend towards increasing production scale remains.

At the same time, S. Kvasha *et al.* (2014), considering the general factors of EU agricultural development, noted that during the implementation of the Common Agricultural Policy, special attention was paid to the issues of agricultural support. T. Zinchuk (2008), studying the issues of European integration and adaptation of the agricultural sector, noted the division of agricultural policy into agricultural and food policy. V. Lypchuk & N. Lypchuk (2012) point out proposals for changes in the main instruments of the CAP (regarding the use of direct payments, market-based instruments, and rural development). The proposal is to introduce a so-called "green" payment component for producers who fulfil three tasks: diversification of agriculture, i.e. farms with an area of more than 3 hectares should produce at least three crops, and each of them should not exceed 70%; preservation of natural fodder lands; and designation of at least 7% of the land used for nature conservation activities.

## PREREQUISITES FOR EFFECTIVE DEVELOPMENT OF AGRARIAN INTEGRATION AND ENVIRONMENTAL PROTECTION IN EU POLICY

A country's economy is a complex structural organism that unites various industries, internal regions, and institutional sectors, the potential and structure of which differ. Each of them is characterised by its own processes of generation and distribution of effects, which the macroeconomic effect usually masks. A significant discrepancy between the global (macroeconomic effect) and some local optima (for certain industries and regions) may undermine the stability of the economy in free trade zones even if the total macroeconomic effect is positive (Shnyrkov *et al.*, 2013).

For the effective development of integration, the correct setting of goals is of particular importance. Thus, P. Nesenenko & K. Tonia (2021) note that almost 40% (€59 billion per year) of the EU budget is spent annually to achieve the CAP goals, with the total budget expenditure proportional to the agricultural production of the grouping countries and the size of the cultivated area. France (29 million hectares), Spain (24 million hectares) and Germany (about 17 million hectares) have the largest cultivated agricultural area. Therefore, considerable attention should be paid to the development of IEI in the agricultural sector, its impact on trade, production, as well as product quality and social issues. Agrarian integration involves achieving a number of goals, and it is proposed to highlight the priority ones, which are presented in Figure 1.

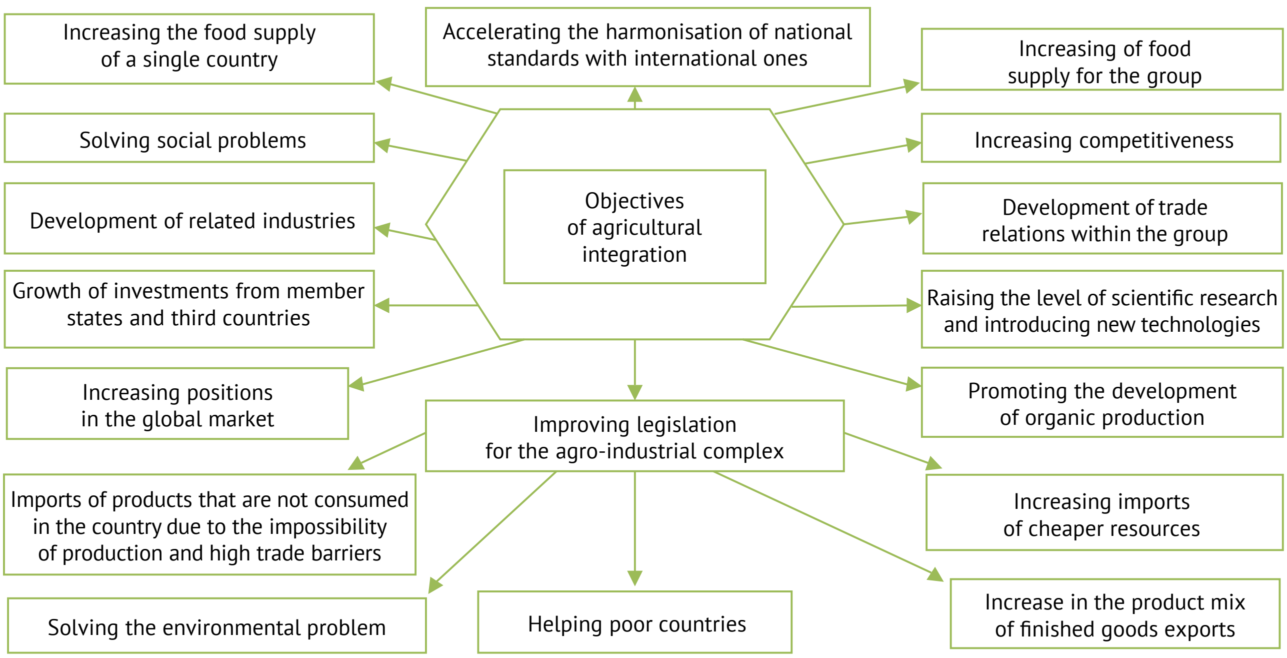


***Figure 1.*** *Goals of international agricultural integration*

***Source:*** *author's development*

At the same time, the goals of integration are one of the determining prerequisites for its effective development, which can be confirmed by the content of regional trade agreements (RTAs). P.A. Samuelson (1993) noted that the argument in favour of free trade is based on the fact that international specialisation makes it possible to increase labour productivity in accordance with the law of comparative advantage. This makes it possible to increase the volume of world production, and all countries can raise their living standards. This confirms the expediency of trade liberalisation in integration groups. The classification of agricultural integration goals is shown in Figure 2.

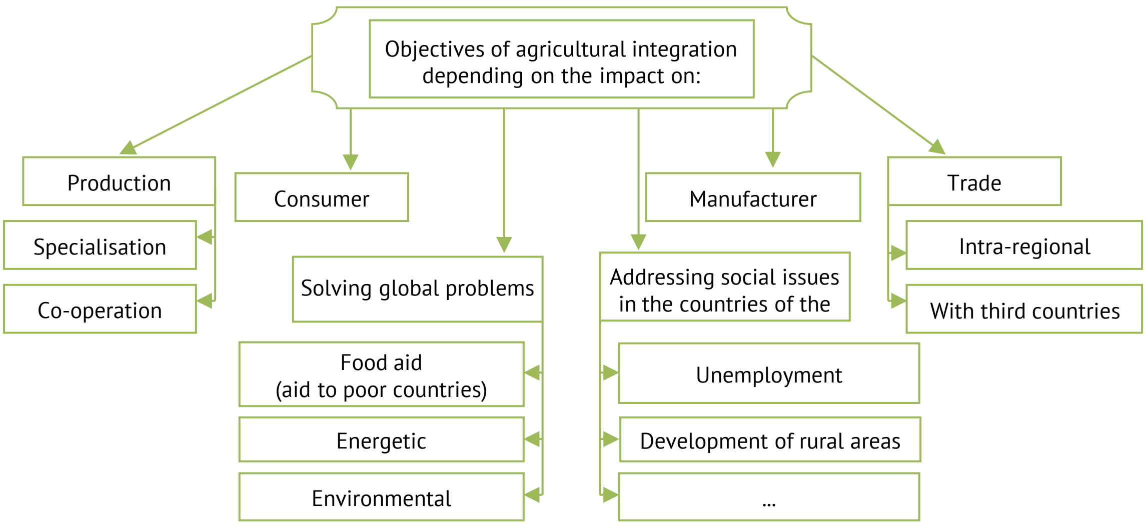


***Figure 2.*** *Classification of goals of international agricultural integration*
***Source:*** *author's development*

Agrarian integration is proposed to be defined as the unification of agricultural markets to increase their competitiveness, harmonise quality standards, and jointly solve the food problem of the grouping and partly the world, taking into account the comparative advantages of the member states, their production and export potential. In addition, integration can contribute to the development of the agricultural sector and production in general, in particular through increased foreign investment, new technologies, etc. At the same time, it is worth considering the possibility of a decrease in production, which may be caused by the liberalisation of foreign trade and decisions taken in integration groups.

Along with the introduction of new technologies and increased labour productivity as a result of integration, there is a possibility of a reduction in employment in agriculture. Thus, IEI can have a significant impact on the economic development of the country as a whole and its individual sectors, and it can also lead to certain threats. Risks from IEI are an important factor in determining the feasibility of integration. V. Sidenko (2008) concludes that the optimal use of potential benefits from integration, as well as the neutralisation of new risks, depend on the extent to which national policies of the participating countries focus on ensuring innovation and national competitiveness in an open economic environment. S.V. Piasetska-Ustych (2016) notes that an additional risk for the CAP is that no reliable mechanism has been developed to prevent the transformation of agriculture in less developed countries into a raw material zone of the "old core" of EU leaders.

A. Nin-Pratt & X. Diao (2014) assessed the impact of the Southern African Development Community free trade agreement on agriculture. They found negative welfare effects for regional importers due to increased imports from inefficient regional producers, and to increase the benefits, it is necessary to implement regional policies that go beyond regional agreements, in particular those aimed at increasing investment, product diversification and agricultural productivity.

O. Popko (2019) notes that Ukraine's involvement in integration and global processes has new opportunities, but also risks and threats, and it is impossible to formulate a national strategy for integration into the world economic space if they are not taken into account. In addition, an assessment of the real state of the country's economic complex, its individual sectors and its own capabilities is a prerequisite for a timely and appropriate response to such challenges, reorientation of producers to new international markets with an increase in exports of value-added goods. I. Klymenko *et al*. (2011) point out that the Common Agricultural Policy combines elements of foreign trade, regulatory, market, price and structural policies and argue that the CAP is both a "best practice" and a risk factor for Ukraine. This is true for virtually all countries that integrate or join an already functioning grouping.

In view of the above, integration risk in the context of agricultural integration, and international economic integration in general, should be viewed as the probability of losses at the macro, meso, or micro levels. Risks can be: 1. rejection of trade; 2. reduction of exports to third countries (prevention – do not increase trade barriers for them); 3. risk of lost opportunities due to the inability to integrate with another grouping; 4. risk of losses when leaving the grouping; 5. risk of reform costs, and even the possibility of their ineffectiveness. Risks may arise from a harsh protectionist policy towards third countries, rapid liberalisation within the grouping, etc. Risks of agricultural integration are growing as the sector depends on natural and climatic conditions, price fluctuations, etc. Therefore, it is advisable to investigate the possibility of specific risks and try to avoid them at the stage of concluding the RTA, as well as by developing appropriate mechanisms to be applied in case of their occurrence.

The Treaty establishing the European Community (1957) states that the common market covers agriculture and trade in agricultural products (Article 32), and defines the objective of the common agricultural policy (Article 33). This means that the importance of the agricultural sector and trade in agri-food products in the EU is not decreasing, which is confirmed by the grouping's policy both at the initial and subsequent stages of integration. However, the higher the level of integration, the deeper and wider its impact on the agricultural sector, related industries and the development of the economy as a whole, and not only the economy, but also, for example, the environment. By the way, V. Kachuriner (2022) emphasises that achieving a balance between compliance with environmental regulations and competitive agricultural products is a key focus of EU policy. In addition, the link between agriculture and the environment is based on the concept of "sustainable agriculture".

N. Bobytskyi (2020) mentions the EU's European Green Deal (EGD) programme, which primarily concerns the agricultural sector and industry, and aims to make the European continent environmentally neutral by 2050. The scientist assumes that EU companies will be protected by phytosanitary regulations and carbon tariffs, as well as receive significant financial support, which will increase competition for Ukrainian producers. It is worth noting that the EGD will stimulate organic farming in the agricultural sector, and Ukraine is a leader in exporting organic products to the grouping. Moreover, while the latter has limited opportunities for extensive expansion of its agribusiness, Ukraine has a significant growth margin. N. Fedorchuk (2021) concludes that most of the obligations under the EGD are financially unaffordable for agricultural producers, so the EU is allocating just over a trillion euros by 2050 to implement the agreement for producers in the grouping alone.

S. Shcherbyna (2021) states that in the field of agricultural production, the EU's top priorities are to reduce environmental impact and comply with European quality standards. Although the pace of EGD implementation has slowed due to the priority of responding to COVID-19, the European Commission has emphasised that the recovery should be focused on a more sustainable, green and digital Europe, with solutions that benefit the economy as well as the environment. This approach was supported by a number of EU countries, including France and Germany. This shows that agricultural integration has a significant impact on the economic development of member states, the agricultural and related sectors of the economy, as well as trad e, and the higher the level of integration, the wider and deeper the impact.

Taking into account the significant impact of agrarian integration in different periods, which is confirmed by the research of various scholars, it is of particular importance to define the goals of integration, the methods to achieve them, in particular the possibility of developing individual programmes for specific countries, taking into account their comparative advantages, as well as monitoring their implementation and results. This will allow adjusting the relevant measures and setting new goals.

## CONCLUSIONS

The analysis shows the existence and expediency of studying agrarian integration as a component of international economic integration. Thus, agrarian integration is a consequence or goal of the association of countries through liberalisation of foreign trade within the grouping, development of strategies and introduction of appropriate mechanisms, with the aim of improving food security of the grouping, increasing exports both within and outside the grouping, increasing labour productivity, applying new technologies and improving the living standards of the rural population and agricultural workers. The article reveals that one of the main prerequisites for the effective development of integration in the agricultural sector is the definition of its objectives, as evidenced by the articles of certain regional trade agreements. In addition to the importance of defining the goals of integration, its development largely depends on the development of methods for achieving them, with the definition of programmes, taking into account the characteristics of member countries and mandatory control over their implementation and results. The development of the agricultural sector is particularly influenced by international economic integration, which is driven by changes in trade policy, increased access to new technologies, increased foreign direct investment, increased competition, etc. The impact of integration may also affect the volume of agricultural production, with growth or decline depending on the decisions made within the associations. Agrarian integration is proposed to be viewed as the unification of agricultural markets to increase their competitiveness, harmonise quality standards, and jointly solve the food problem of the grouping and partly the world, taking into account the comparative advantages of the member states, their production and export potential. This should contribute to the economic development of the member states and, in particular, their agricultural sector. The impact of agrarian integration can have a significant impact on foreign trade in agri-food products within and outside the grouping, so it requires harmonisation of quality standards, increasing its competitiveness, identifying products that need the most protection at the beginning of integration, etc. Particular attention should be paid to identifying the risks of agricultural integration, the likelihood of their occurrence, and the justification of methods and measures to reduce or eliminate them. In the future, it is advisable to deepen the theoretical foundations of agrarian integration, its impact on international economic integration in general, methodological approaches to assessing the integration of agricultural markets, the specifics of regional trade agreements on trade in agri-food products between partner countries and their importance for the development of the IEI.

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## CONFLICT OF INTEREST

None.

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## Аграрна інтеграція: теоретичні засади

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**Анотація.** Вигоди від міжнародної економічної інтеграції зумовили збільшення кількості інтеграційних угрупувань. Чутливість агропродовольчого сектору до лібералізації тайого важливість зумовили виділення окремого розділу в регіональних торговельних угодах. Важливість зовнішньої торгівлі, продовольчої безпеки, а також їх особливе значення для України, яка підписала десятки регіональних торговельних угод та є одним з найбільших експортерів окремих видів агропродовольчої продукції, підтверджують актуальність дослідження. Метою статті є аналіз теоретичних засад міжнародної економічної інтеграції з виділенням аграрного сектору, виявлення особливостей та розробка відповідних пропозицій. Для досягнення мети використовувались методи теоретичного узагальнення, абстрактно-логічний, конкретизації, аналізу, синтезу, які дозволили дослідити особливості міжнародної економічної інтеграції в аграрному секторі, сформувати висновки та пропозиції. Інформаційною базою слугували наукові дослідження, регіональні торговельні угоди та ін. В результаті проведеної роботи проаналізовано розвиток міжнародної економічної інтеграції з врахуванням аграрного сектору. Запропоновано виділення основних цілей інтеграції, їх класифікацію, її визначення та обґрунтовано ризики. Серед основних цілей інтеграції в аграрному секторі пропонується виділяти забезпечення внутрішньої потреби у продовольстві необхідної якості за доступною ціною з врахуванням порівняльних переваг країн-членів об'єднання, збільшення експорту до третіх країн, виходячи з потенціалу країн-учасниць, та вирішення соціальних проблем. Враховуючи цілі сталого розвитку та глобальні проблеми людства, пропонується до основних цілей відносити також питання екології та раціонального використання ресурсів. Цілі інтеграції визначено як одну з основних передумов її успішного розвитку, що підтверджується і змістом відповідних договорів, угод. На практиці, міжнародна економічна інтеграція може сприяти вирішенню проблеми продовольчої безпеки та розвитку аграрного сектору, виробництву, зокрема через надходження нових технологій, іноземних інвестицій та ін. Передбачається розвиток внутрішньо- та позарегіональної торгівлі внаслідок гармонізації стандартів якості продукції, підвищення її конкурентоспроможності та ін. Цьому, передусім, мають сприяти чітке окреслення цілей, їх реалізація через відповідний комплекс заходів, визначених по країнах, та контроль за реалізацією

**Ключові слова:** міжнародна економічна інтеграція; аграрний сектор; цілі; ризик

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# Intersectoral adaptation of Ukrainian farms in the context of war

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**Abstract.** In the current economic environment, farms must respond to the challenges of the external environment and look for mechanisms to adapt and overcome the crisis, as well as diversify their business as additional sources of income. Therefore, the study of possible cross-sectoral adaptations of farms is a relevant research topic. Therefore, the purpose of this article is to provide a scientific basis for the predicates of diversification of farms' activities in overcoming the challenges of war. The study is based on classical approaches to management and marketing, as well as foresight predicates of agricultural development. The content of adaptation directions of farms' development was interpreted using empirical methods. The article analyses the sources of risks and threats, identifies targets and key aspects of the formation of intersectoral adaptation of farms: metrics, goals and foresight competences. As a result of the study of macro trends in the security of the agricultural sector, hypothetical analytical generalisations were formed, due to the uncertainty of the timeframe of the war and the impossibility of calculating the expected losses. Thus, the study made it possible to formulate theoretical and practical insights

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into the formation of adaptation mechanisms in the strategic perspective. The author substantiates the need for systematic and continuous monitoring of threats and invasions by systematising traditional and forecasting new risks. The key determinants of foresight adaptation under the influence of global trends are formulated. The mechanism of its implementation is presented through the identification of areas of intersectoral adaptation. The study is of practical value, generating information for farms, rural communities, stakeholders and potential investors who can benefit from the foresight of prospects and expectations formed in the context of cross-sectoral adaptation of farms in the post-war period

**Keywords:** innovations; diversification; foresight adaptation; economic security; inter-sectoral partnership; agrotourism; land management

## INTRODUCTION

In today's world, climate change, market and technological transformations pose new challenges for rural producers. Understanding and improving the cross-sectoral adaptations of Ukrainian farms is key to ensuring the productivity, efficiency and sustainability of the agricultural sector, especially in the context of growing military threats and losses from military aggression. Therefore, the study of intersectoral adaptations of farms is relevant.

The key role of farms in the development of the economy of territorial communities and the country as a whole is confirmed both in the academic field and by the government's stimulating policies. For example, G. Kukel *et al*. (2020) emphasised the significant social role of farming, which contributes to the creation of a significant number of jobs in rural areas. Farming as a source of investment in infrastructure, development of the rural economy, as well as contributing to the sustainability of local communities through taxes paid is reflected in the works of N. Bakhur (2020) and N. Bulavinova *et al*. (2021). The multiplier effect of developed farming (in particular, the positive impact on food processing, logistics, trade, transport, tourism, etc.) is analysed by P. Bhattacharyya (2022).

The intersectoral adaptation of farms in the context of war is a complex and relevant topic, especially in the context of the current situation in Ukraine. The topic presented is cross-disciplinary, as it is at the intersection of scientific approaches of the agro-industrial complex and a set of industries that diversify farm activities: technology and innovation; transport and logistics; agritourism; food processing and consumption; marketing and outsourcing; land management; financial institutions; healthcare, etc. Therefore, research papers that consider areas of cooperation and partnership with other sectors of the economy that contribute to the formation of additional sources of income for farms and the development of rural (local) communities are valuable for the study. Thus, there are many developments in the agricultural sector in the academic field. Current research covers digitalisation (Bacco *et al.*, 2019) and the use of artificial intelligence (Holzinger *et al.*, 2023).

The escalation of a full-scale war on the territory of Ukraine poses challenges for farms and agriculture in general. Thus, online analytics shows the adaptability and ability to overcome war risks: Ukraine increased the share of agricultural imports to the European Union by 11% in January-September 2023 compared to last year (Tomczyk, 2023) and became the third largest supplier of agricultural products after Brazil and the United Kingdom (Prysiazhna, 2023). It is an indisputable fact that the war has had a significant negative impact on the agricultural sector and agriculture in the country: destruction of agricultural production and processing infrastructure; agricultural machinery, crops and animals; loss of labour potential due to displacement and mobilisation; destruction of grain storage facilities and storage infrastructure; logistical difficulties; contamination and unusable land; embargoes on European markets – all these factors make it important to develop strategies to ensure the sustainability of the agricultural sector.

The need to develop mechanisms for adapting to the challenges of war and restoring agriculture in the post-war period is generating relevant interests among scientists, professionals and local communities. From a scientific point of view, these mechanisms need to be developed with the understanding that the "non-standard" reality of the Ukrainian economy, new problems and challenges cannot be solved by traditional approaches, and therefore require innovative thinking. First and foremost, this concerns Ukraine's positioning in the global world as an agrarian and digital state, which is characterised by the integrated development of industries and intellectual potential. Therefore, an empirical study of cross-sectoral adaptations is an important task for the recovery of agriculture, a significant share of which is represented by farms in Ukraine. Accordingly, the aim of the study was to examine the strategies and mechanisms used by farms in Ukraine to successfully adapt to the challenges posed by the military conflict. The article is aimed at identifying the best ways to support and develop the agricultural sector in the face of unpredictable economic and social circumstances, contributing to the sustainable functioning of the industry in the context of military instability.

## MATERIALS AND METHODS

The study is based on the interpretation of the theory and practice of intersectoral adaptations of farms in Ukraine. In this context, the research methodology is aimed at interpreting operational definitions and modelling key approaches to the formation of intersectoral adaptations of Ukrainian farms in the context of war.

The semantic analysis and contamination of the definitions of "adaptation" and "foresight" allowed to establish a link between the concepts and formulate an understanding of the context of "foresight adaptation". The application of an integrated approach to the research methodology, consistent with the concept of "foresight adaptation", allowed not only to analyse the aspects of farm survival during martial law, covering economic, social, environmental and other factors, but also to identify hypothetical areas of their adaptation through the use of cross-sectoral activities. Accordingly, the key approaches to intersectoral adaptation of Ukrainian farms were formed, which determined the focus of the study and priorities in the formation of foresight adaptations. A partnership model was also constructed, which focused on the key actors in the process of intersectoral adaptation of farms.

The analysis of the functioning of farming in Ukraine, which is seeking ways to survive and adapt during the war, is a multidimensional task complicated by a large number of factors affecting agriculture. The applied method of statistical data analysis allowed to get an idea of the dynamics of the number of farms, their activities, and to highlight the problems, needs and strategies for survival during the war. It is important to keep in mind that the data obtained is not fully representative, and only field research and on-site observations can provide more detailed information about the conditions faced by farmers during the war. This is due to the lack of complete official statistical reports. In determining the prospects for farm development, the dynamics of the number of farms during the military timeframe was analysed: from the beginning of the war in Ukraine to the date of the study (2014-2024), which operated under the threat of escalating hostilities and formed strategies for adaptation and development. The article assesses the stimulating interactions between the agro-industrial complex and the state based on the analysis of expenditure items from the Ukrainian budget for the agro-industrial complex in 2024.

The application of the horizon scanning method confirmed the positive prospects for the development of farming in the post-war period. Based on the analysis of global trends in agriculture, digital innovations, etc., the directions of revitalisation of the agricultural sector were identified. The reference modelling helped to identify areas for inspiring cross-sectoral adaptations of Ukrainian farms and diversification of their activities. The main risks and areas of their management, in particular through intersectoral partnerships, were characterised. A robust procedure for exploratory and confirmatory analysis of the study of cross-sectoral adaptations was applied to a dataset collected through the processing of official statistics (Ministry of Agrarian Policy and Food of Ukraine, 2022; Ukrstat, 2024), as well as online data sources.

It should be noted that this study has a number of limitations that reveal issues that require additional research. Firstly, as of the beginning of 2024, many areas of priority agricultural development are under occupation and suffer from destruction. Therefore, it is difficult to assess and predict the extent of the damage. Secondly, due to the uncertain timeframe of the war escalation and the impossibility of quantifying losses and damage to land resources, material and technical resources, and the infrastructure of the agricultural sector, statements of foresight adaptations remain a priori probabilistic. Thirdly, analytics on agriculture during martial law is incompletely reflected, so analytics can only be generated from online sources.

## RESULTS

The expediency of cross-sectoral adaptation, which is based on the entrepreneurial idea of using achievements, skills, technologies or strategies that have already been successfully used in other industries or areas of activity, is to achieve the goal of improving productivity, competitiveness or overcoming environmental challenges by business entities, including farms. The formation of cross-sectoral adaptations of farms is an important strategic task, as it allows to ensure the sustainability and development of the agricultural sector under martial law in Ukraine. The theoretical aspects of this process should be substantiated by the following approaches (Fig. 1). The systemic approach involves considering a farm as a complex system that interacts with other sectors of the economy in creating and organising the consumption of agricultural products. The synergistic approach, in turn, aims to create synergies, i.e. interactions that lead to a positive effect for all participants, including diversification of business income sources. The emphasis on innovation and technological progress is key to shaping cross-sectoral adaptations, as the introduction of the latest technologies, such as the Internet of Things, artificial intelligence, drones, and others, can improve production efficiency and ensure innovative development of farms in the production, service and logistics of agricultural products and services.

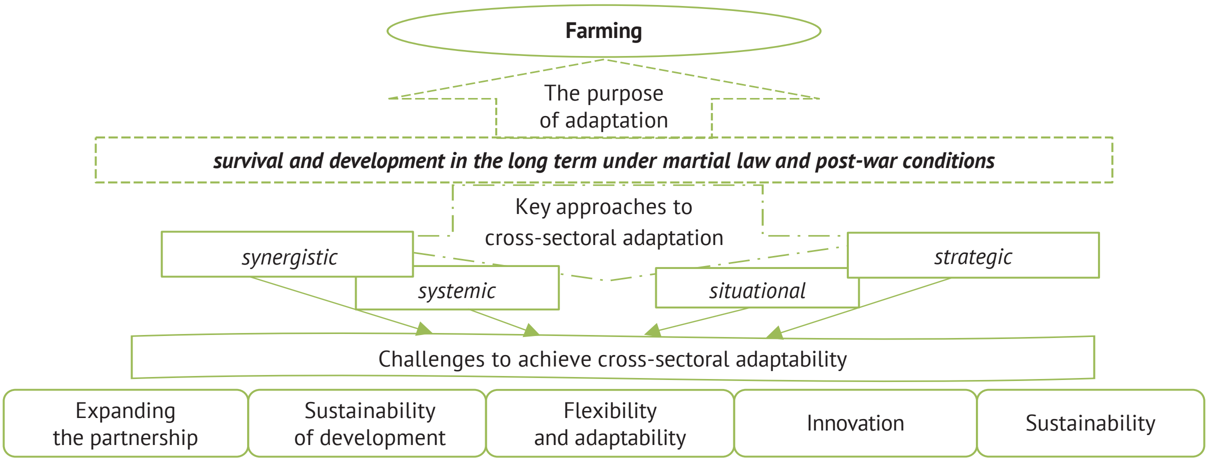


***Figure 1.*** *Key approaches to cross-sectoral adaptation of farms*
***Source:*** *authors' development*

The development of partnerships between farms and other sectors, such as industry, finance, tourism, education, etc., is important for the effective exchange of resources, ideas and experience. Strategizing for cross-sectoral adaptation involves developing long-term visions and plans that take into account not only internal but also external factors that may affect farms. Consideration of sustainability and resilience, flexibility and adaptability approaches build the necessary competencies of farmers to operate in a dynamic crisis environment and respond effectively to threats and risks. They determine the success of farms in the current economic climate of Ukraine, where change has become the norm. Understanding and applying these concepts allows farmers not only to survive, but also to successfully adapt to the new conditions of military threats and innovate for sustainable development. Based on this, it can be stated that cross-sectoral adaptation of farms can include cooperation and interaction with different industries and sectors of the economy to achieve greater resilience and efficiency. Such cross-sectoral partnerships would be based on communication and comparative links (Fig. 2).

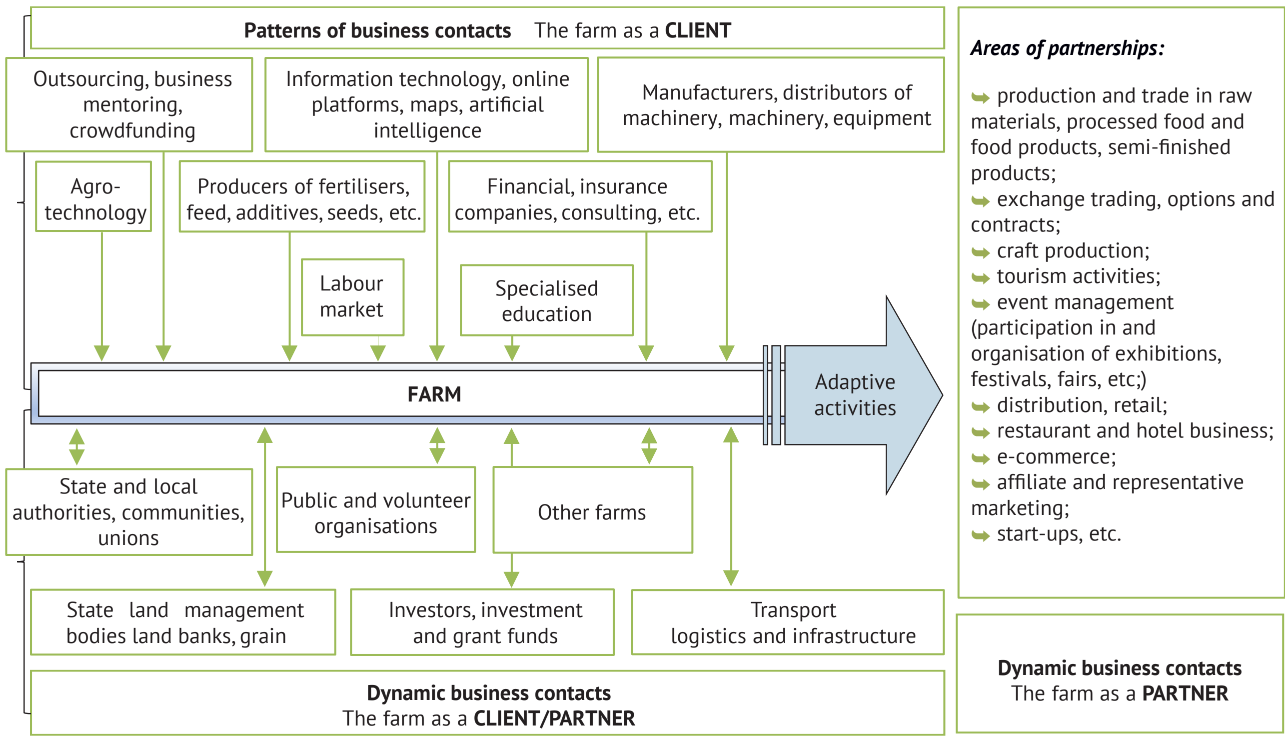


***Figure 2.*** *Model of partnership in cross-sectoral adaptation of farms*
***Source:*** *authors' development*

In the context of farming, the industries with which partnerships are formed are also comparators – those with which certain aspects of agriculture can be compared to gain important information, learning or best practices. Such benchmarking can help farmers improve their methods, optimise processes and achieve greater productivity.

In view of the above, it is reasonable to operationalise the term "foresight adaptation" as a tool for forecasting and strategizing anti-crisis and stress-resistant patterns of intersectoral adaptation of farms. The semantic analysis of the term "adaptation" in the works of M. Turko (2016), A. Voronina & A. Zenina-Bilichenko (2016) and Ya. Sikora (2022) revealed its consistent interpretation as a behavioural response to changes (challenges) in the environment. As for the term "foresight", the Cambridge Dictionary (n.d.) defines it as the ability to judge the expected future correctly and plan your actions based on this knowledge. Foresight as a comprehensive competence-based approach to forecasting, which operates with a system of methods and tools for processing the information field to determine possible scenarios of events, assessing the future state of a particular object (micro/macro system) and formulating strategies for the development of certain economic units, is described in the studies by L. Bovsh *et al.* (2023) and M. Bosovska *et al.* (2023). As a result, the contamination of terms allows to formulate foresight adaptation as a comprehensive competence-based approach to the formation of strategic behavioural responses of a business entity (farm) to changes (challenges) in the environment to determine possible scenarios for the unfolding of events in a certain frame.

The developed theoretical approaches allow to form the basis for considering practical insights into the intersectoral adaptation of farms in Ukraine and to determine further prospects for their development in the sector in intersectoral partnership. Before Russia's full-scale invasion of Ukraine, farm entrepreneurship and private households were actively developing. When considering the statistics on the development of farming in Ukraine, there is a tendency to increase the number of farms since 2016, when this figure has sharply decreased due to foreign policy factors (Fig. 3).

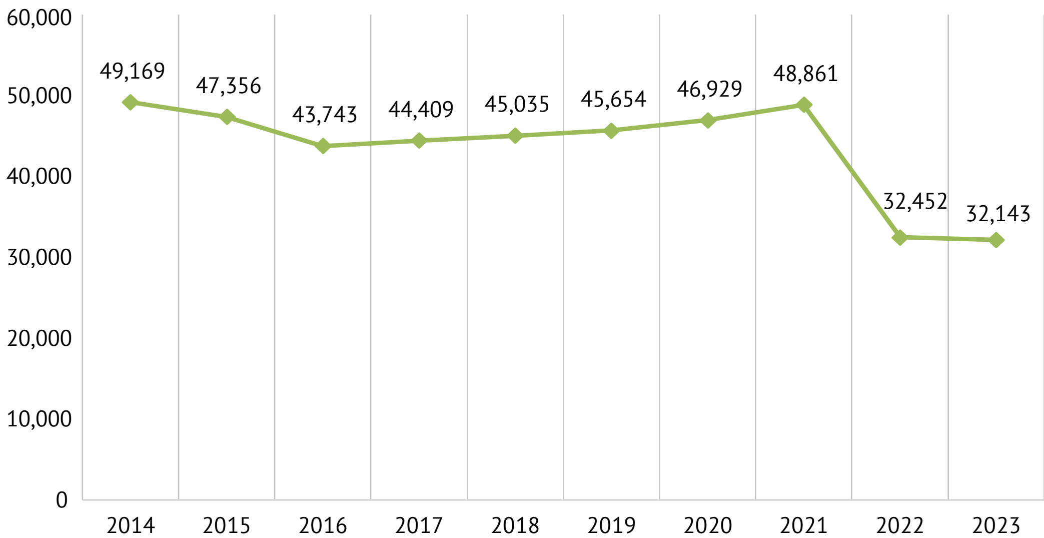


***Figure 3.*** *Dynamics of farming development in Ukraine, 2014-2023, units*
***Source:*** *compiled by the authors based on I. Slobodianyk (2023); Ukrstat (2024)*

During the pandemic crisis, the number of farms has been steadily increasing. Thus, in 2019, 45,654 units were recorded, in 2020 – 47,803 units; in 2021, respectively, 48,868 farms (Ukrstat, 2024), which indicates the prospects for the development of farming and its investment attractiveness. With the outbreak of a full-scale war, a share of farms ceased operations due to being in the combat zone, in the temporarily occupied territories, or in the territories that have been de-occupied but are mined, destroyed, and in need of fundamental restoration. Thus, the risks and threats are deepening and are determined by the uncertainty of both the timing of the end of the war and the forecasting of losses and damage to the ecosystem and agricultural land of Ukrainian territories. Therefore, it is important to study global trends and their impact on Ukrainian farms. It is proposed to summarise the main trends based on complementing the views presented in the scientific literature and online sources. For this purpose, the horizon scanning method was applied, the results of which are shown in Table 1.

**Table 1.** *Markers for scanning the horizons of global trends in Ukrainian farms*

| Key areas of focus | Horizon scanning, 2019-2021 | Horizon scanning, 2022-2023 | Prospects (post-war) |
|---|---|---|---|
| Internet of Things (IoT) systems in agriculture | monitoring the condition of plants and soil; decision-making based on Data Science; remote control of facilities (irrigation systems); automation of growing and harvesting processes (autonomous tractors and drones for spraying fertilisers or processing the field); use of sensors and biometric systems to monitor animal health and behaviour; accurate plant inventory and variety recognition using cameras and sensors; weather monitoring; integration with smart markets and digital communication and sales platforms | development of artificial intelligence and data analytics, overcoming the logistical challenges of war on digital communication platforms and marketplaces; further introduction of automated technologies (robots to perform tasks in the field), which improves efficiency and reduces labour costs in the face of «staff shortages» and physical harm to workers; the need to demilitarise agricultural land; cybersecurity threats | increasing the number of sensors to monitor various parameters, such as soil quality, plant health, weather and animal health; increasing the number of digital markets and platforms that bring together farmers, buyers and other participants to exchange information and agricultural products; expanding the use of drones, robots and cobots |
| Digital platforms and markets | total digitalisation started in 2019 during the lockdown and continued during the full-scale invasion: e-commerce and online trading platforms; mobile applications and web services; online sales of craft farming products; platforms for hiring freelancers and organising crowdsourced tasks; expansion of financial platforms and electronic payment systems for convenient online payments and transfers; the vigorous development of social media, blockchain technologies, agro- and IT technologies; business monitoring platforms for start-ups; government financial support for farms | | |
| Precision Agriculture | optimisation of field management, plant monitoring, efficient use of resources and sustainable production: use of global positioning systems (GPS) and global navigation satellite systems (GNSS) to accurately determine the location of tractors, equipment and plants; automatic driving technology; electronic mapping systems to create detailed field maps that help to effectively manage land resources | impossibility of use due to significant amounts of mined land, losses from the explosion of the Kakhovka hydroelectric power station, damage from shelling and risks of physical destruction; prevalence of partially automated farming | continuation of pre-war trends and the use of GPS and GNSS systems for field demining and land cultivation; technologies for precession tillage; improvement of cobots and drones for production processes |
| Genetic technologies and modification of organisms | improvement of genome editing technologies, in particular the CRISPR/Cas9 system, to increase plant yields and resilience; to create crop and livestock products with certain properties (increased nutrient content, quality); application of biotechnology to develop new plant varieties that can be grown in different climatic conditions and be resistant to extreme factors | creation of genetic jars and banks of varietal plants for biodiversity conservation | transition to eco-technologies for biodiversity conservation, improving plant resistance to stressful conditions, increasing productivity and reducing environmental impact, improving Gene Drive technologies to control pest populations and spread desirable genetic properties in natural populations |
| Organic farming and sustainability | the trend towards healthy eating (healthy properties of agricultural products, absence of chemical fertilisers and pesticides); growing attention to educating farmers about the benefits and techniques of organic farming, as well as training generations of farmers; increasing popularity of organic viticulture and winemaking | increasing the popularity of local and community initiatives that promote resource conservation and local development; development of new methods in the field of organic livestock farming that ensure sustainable animal husbandry and welfare | continuation of pre-war trends; increase in the area for organic farming; improvement of production methods and sustainable farming practices (crop rotation, use of green fertilisers and restoration of soil fertility, etc.); expansion of certification systems for organic production, obtaining organic status; increased participation of organic farmers in health markets |
| Global product market | spreading the concepts of vegetarianism, veganism, etc. (struggle for the market of meatless alternatives); introduction of new products of plant origin (vegetable proteins, dairy alternatives, etc.); increasing consumer interest in traceability of products, ethical production and sustainable development - the practice of using smart labels and QR codes on product packaging; research and development of new flavours, ingredients and combinations | promotion of products from local farmers, organic farming and products from the region, including due to the logistical problems of the military timeframe; search for channels for exporting products, embargoes of European markets, etc. | improving the use of smart technologies, artificial intelligence and blockchain to improve the technical aspects of supply and quality of agricultural products; increasing exports and expanding markets |

Table 1, Continued

| Key areas of focus | Horizon scanning, 2019-2021 | Horizon scanning, 2022-2023 | Prospects (post-war) |
|---|---|---|---|
| Direct sales and agritourism | increasing popularity of direct sales of products from farmers to consumers through consumer markets, rural fairs and direct sales from farms; intensification of agritourism (excursions, participation in agricultural work and rural recreation programmes, development of agritourism routes); expansion of agro-farmers' markets and specialized stores that sell the products of farmers and artisans | increasing interest in local food and local taste traditions, continuing trends in agritourism development | continuation and development of pre-war trends, creation of diversified farms, support of local communities in the development of agritourism and improvement of rural infrastructure |
| Risk management and insurance | main sources of risks: weather, price, production, financial, trade; objects of insurance: crops and livestock; insurance of trade and commercial risks; liability | insurance solutions for life, health and safety on the farm prevail, covering injuries and emergencies; property; cyber security | continuation of previous trends; development of insurance and incentive programmes for farmers aimed at reducing risks and promoting sustainable development |
| Education and support | cooperation with universities and training centres, separate video lessons in social media, webinars and mobile applications for training and development of farmers aimed at mastering the following competences: use of digital communication technologies; financial literacy; risk management and use of insurance instruments; use of innovative technologies (digital systems, robots (cobots), drones, artificial intelligence, modern agricultural technologies and «digital farming», etc.), support for women's farming | | |
| Developing strategies to adapt to climate change and reduce the environmental impact of production | development of methods aimed at preserving soil fertility, avoiding erosion and reducing the use of chemicals; introduction of «digital farming» for the point application of resources (water, fertilisers, pesticides) and optimisation of field cultivation; energy-efficient irrigation systems, solar panels, and energy-saving technologies to reduce emissions and dependence on unsustainable energy sources; increased attention to recycling and waste management to reduce negative environmental impact; development of strategies to optimise water use in agriculture, including technologies for rainwater conservation and use, as well as water management techniques; identifying and implementing risk management strategies that take into account possible risks associated with climate change and ensure the flexibility and resilience of agriculture in new conditions | overcoming the ecocide caused by the explosion of the Kakhovka hydroelectric power station and the flooding of agricultural land, identifying and implementing risk management strategies that take into account possible military risks, as well as derivative risks associated with climate change and soil fertility; developing strategies for adaptation to external threats, pandemics and man-made disasters | creation of agroecosystems to restore biodiversity and soil cover; agroecological practices (introduction of compatible crops, use of natural enemies of pests, avoidance of chemical pesticides); hydroponics and aeroponics systems (growing plants without using traditional soil); intensification of rural ecotourism as a way to generate income for farms and promote the conservation of natural resources; development and implementation of economic incentives for agro-ecological farms, («green loans»); involvement in global initiatives and work on sustainable agriculture standards to jointly address climate change and ensure sustainable production |

***Source:*** *authors' development based on V. Burkynskyi et al. (2022); R. Abbasi et al. (2022); O. Tabenska (2023)*

Thus, the trends in farming, activated by the lockdowns of the coronavirus pandemic, indicate the use of digital technologies in communications and agricultural production, which provides consumers and farmers with new opportunities for interaction and development. Such technologies allow farmers to optimise their operations, reduce costs and increase yields, making precision agriculture a key component of modern agriculture. In addition, these aspects indicate a growing interest in organic farming and socially responsible sustainable production in 2019-2023. These trends reflect the need for constant adaptation and implementation of the latest approaches to ensure the effective development of farming in the face of climate change, military and environmental challenges. The state and government agencies, through the legislative framework, budgeting and quota systems, create the basis for the development or hindering of agribusiness. In the second year of the full-scale war, the Government has allocated at least UAH 4.2 billion in the 2024 budget to support the agricultural sector (Table 2).

***Table 2.*** *Expenditure items from the Ukrainian budget for the agricultural sector in 2024*

| Directions of budgeting | Volume, UAH million | Share, % |
|---|---|---|
| Humanitarian demining | 2,000 | 47.5 |
| The program of partial compensation of the cost of agricultural machinery | 1,000 | 23.8 |
| Subsidies per hectare of agricultural land for activities in the de-occupied territories | 796 | 18.9 |
| Support of organizations of water users and farmers who use reclaimed land | 205 | 4.9 |
| Fish breeding complexes and raising of fry for stocking reservoirs, compliance with financial obligations to international organizations | 125.3 | 3.0 |
| Loans for farms on MTB | 80 | 1.9 |
| **In total** | **4,206.3** | **100.0** |

***Source:*** *developed by the authors based on the Ministry of Agrarian Policy and Food of Ukraine (2022); Agroreview (2023)*

The priority of state support is the reintegration of the territories affected by the hostilities into the national agricultural sector. In particular, almost half of the budget is allocated to compensate for the costs of humanitarian demining of agricultural land, and 19% to restore operations in the de-occupied territories.

The government plans to allocate an additional UAH 1.37 billion in non-refundable grants for the creation or development of processing enterprises, including in the areas of horticulture, berry growing, viticulture and greenhouse construction. However, large agricultural enterprises and farmers are in no hurry to apply for the grant programmes because of the current format of subsidies:

- ➥ remains a situational measure of assistance, not a systemic regulatory and controlling activity for the responsible operation of the agro-industrial complex (AIC);
- ➥ does not play a key role in shaping the business model of large agricultural holdings and medium-sized agricultural companies due to the lack of such a need or the fact that their business does not meet the parameters of assistance programmes;
- ➥ creates bureaucratic obstacles to the preparation and submission of a package of documents;
- ➥ it is not always conducive to their involvement due to the current state requirements for granting, according to which the decision to issue a grant is made by the Employment Centre, not a banking institution or a specialised committee. The farmer is forced to spend the funds won on creating additional jobs and increasing wage/taxation costs rather than investing in processing, developing material and technical resources, agricultural technologies and promising areas of activity to create added value.

Thus, in the perspective of the post-war recovery of Ukraine's agricultural sector, the state of land and agricultural resources, the consequences of infrastructure destruction within the affected territorial communities, the spread of artificial intelligence and the reduction in human resource needs should be taken into account, so it is necessary to review approaches to state support for agricultural producers and the procedure for obtaining grants.

Based on the rationale for the term "foresight adaptation" and global trends in agriculture, the directions for inspiring the development of farming in Ukraine, which is the basis for inter-sectoral partnership, are systematised (Fig. 4).

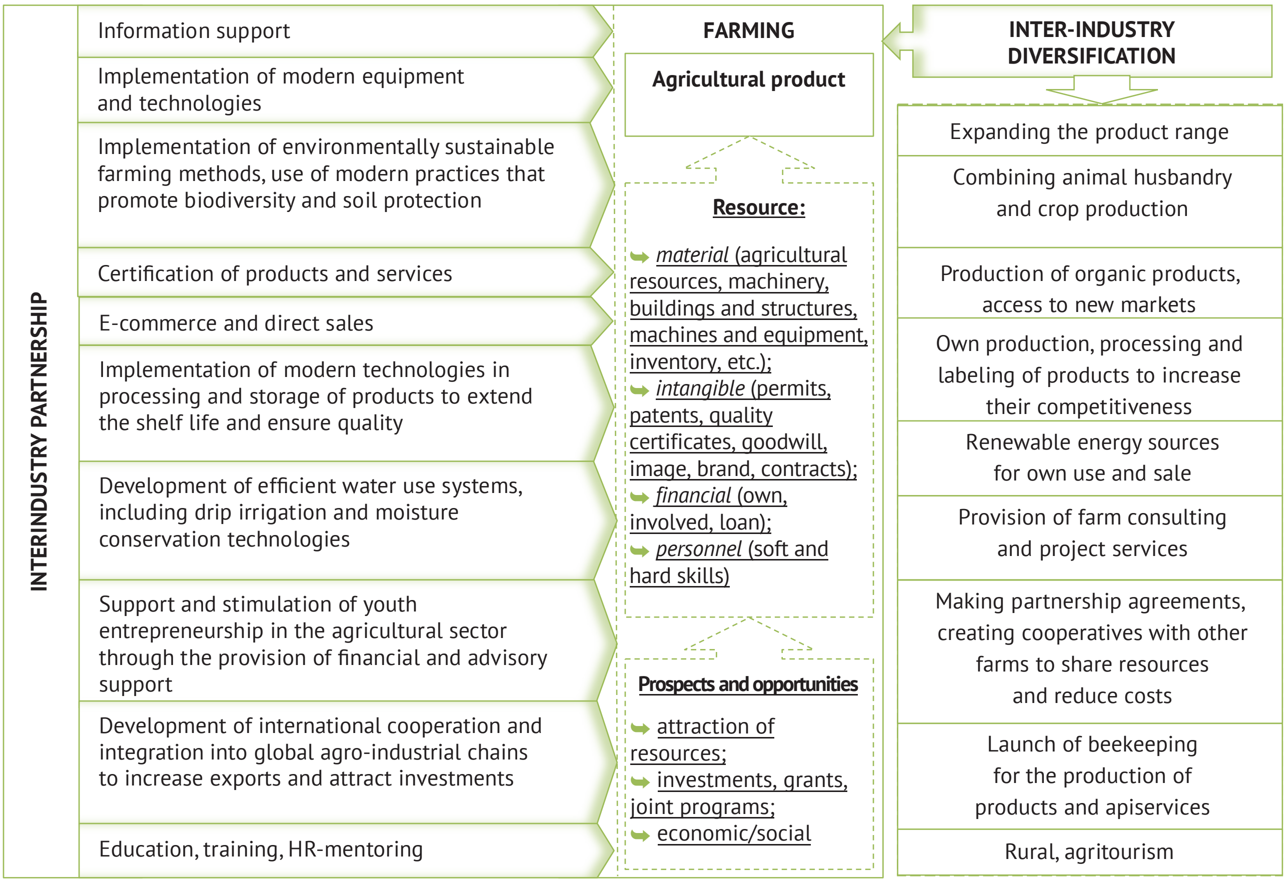


***Figure 3.*** *Reference model of inspiration for the development of farming in Ukraine*
***Source:*** *authors' development based on Y. Chomei & T. Nanseki (2018); S. Neogi & B.K. Ghosh (2022); A. Bernzen et al. (2023)*

Figure 4 shows that the prospects for diversification of farming development are described in many ways. Of particular note is the multidirectional expansion of the production range, which includes exotic or niche crops, environmentally friendly and organic crop and livestock products, which is a current trend.

Rural tourism and agritourism, as promising areas of adaptive development, also have many areas for organising additional sources of income and cooperation. World practice shows that the integration of farming and tourism activities is an integral part of the comprehensive socio-economic development of rural areas, and will also serve as an additional income for farmers, especially in the difficult socio-economic conditions of the military timeframe in Ukraine. And given the current realities, farmers need to quickly study demand, prepare interesting offers, effectively advertise them, establish quality service at reasonable prices, and cooperate with tour operators. Organising gastronomic tours and trips to farms with accommodation in rural green estates attracts tourists because it is a unique opportunity for them to:

- to be in an environmentally friendly environment and consume environmentally friendly products;
- to communicate with flora and fauna;
- learn about local traditions, customs and culture;
- get involved in agricultural work, including apiary, mowing, grazing, grape harvesting, etc;
- witness and participate in craft production;
- take part in recreational activities (e.g., wagon or boat rides, bird watching, fishing, etc.)

For entrepreneurs, this is one of the opportunities to organise a multi-vector mutually supportive business, which in the context of the crisis caused by the war can be an effective way of survival, as they can not only produce agricultural products, provide gastronomic and hospitality services, but also sell new knowledge and emotions about rural development, nature, ecology, landscape, etc. Such activities involve organising recreation on the basis of a farm using all resources as a base for tourist attractions.

In general, the theoretical and practical aspects of cross-sectoral adaptation of farms in Ukraine have shown the possibilities of restoring agriculture and the Ukrainian economy in the post-war period. After all, the cross-sectoral nature of farming demonstrates the possibility of creating new businesses and start-ups involving both business and NGOs, as well as local communities and the government, which is a prerequisite for overcoming the war and post-war crisis, macroeconomic problems of unemployment and poverty.

## DISCUSSION

The study aimed to develop hypotheses about the importance of farming in Ukraine for the development of local communities and the country. Accordingly, the question of the prospects of farming as a component of economic recovery policy in the war and post-war period became a matter of debate. The scientific sources studied confirmed this hypothesis with practical insights from other researchers. In particular, O. Vitryak & V. Tkachuk (2021), assessing the effectiveness of small farms, stated their key role in rural development. I. Bezhenar & O. Hryshchenko (2023) defined farming as a form of management that has become one of the leading in the world practice of developed countries due to its uniqueness and ability to adapt to the current challenges of the global economy, which is open to innovation and multi-vector development. The global scale of agricultural production as the most important pillar for human survival is emphasised in the article by X. Liu (2023). The prospects of farming as a highly profitable and fast-growing sector are annotated in S. Felix (2020). In addition, some authors also note the importance of farming as a social aspect in rural development. K.R. Terzano (2021) proves the psychological benefits, in particular for the development of schoolchildren in the process of their socialisation and environmental education. A collinear view is traced in the work of E.L. Chaverest (2023), where farms are considered in terms of volunteer assistance to communities: they provide food and employment for local residents, teach the younger generation about relationships with nature, etc. This confirms the view that farming has a positive social and economic impact.

However, farming is a seasonal activity. Accordingly, it needs financial support to maintain employees and fixed assets during periods of inactivity. This can be seen in the article by A. Bonanno (2019), which notes the unstable nature of the availability of jobs and income of agricultural enterprises, as well as the work by N. Patyka *et al.* (2023), which states that the development of Ukrainian rural areas is possible through the support of farming by rural territorial communities. Therefore, it is advisable to agree and emphasise the importance of intersectoral adaptations of farms, which create significant opportunities for the development of farming and rural areas through diversification and partnership, as well as the use of the latest technologies. Since the main idea of cross-sectoral adaptation is to use the achievements, skills, technologies or strategies that are already successfully used in other industries or areas of activity and apply them in your own field in order to improve productivity, competitiveness or solve new problems, it is also worth agreeing with these arguments of researchers S.H. Chin (2022), J.K.L. Chan (2023) and K. Dashper (2023).

Consideration of the aspects of intersectoral adaptation of farms in Ukraine has brought up the aspect of diversification. The key studies are those of H.I. Ansoff (1957), who introduced the term "diversification" into the scientific vocabulary and developed a matrix used in decision-making on diversification, and L. Bovsh *et al.* (2020), who determined that the purpose of diversification of a business entity is to manage capital (investments) in order to distribute economic risk and create additional sources of financing. The prospects of the proposed measures as an effective way to diversify activities are confirmed by modern farms. Thus, in Ukraine, farms with integration into tourism are most common in Western Ukraine. One of the most popular is the "Western Snail" tourist route, which offers a full-fledged gastronomic tour with a farm tour (Horbohory, n.d.). They bring together producers who are ready to organise product tasting at the enterprise or in a tasting room. The cognitive and gastronomic purpose of the trip is promoted by Dooobraferma (Dooobraferma Official Website, n.d.), where the owner offers hard cheeses, honey, poultry, and Zinka (Zinka Official Website, n.d.), a brand focused on dairy goat farming, crop production, animal husbandry, gardening, and processing of animal products, etc.

However, studies have shown that farms do not always consider rural green tourism and the organisation of rural green homestays for tourists on their territory as one of the areas of business development, because the introduction of additional activities of farmers in the form of rural green tourism requires high-quality management, to see the real opportunities and risks from the introduction of this type of activity. Since the issue of farm development is closely related to the management of strategic resources (land, water, forests, etc.), which are subject to regulatory mechanisms and strict state control over their distribution and use, it is predicted that the directions of intersectoral adaptation of farms, including in terms of agritourism development opportunities, will correlate with changes in legislation in the field of land and natural resources (Water Code of Ukraine, 2023;

Land Code of Ukraine, 2024). Thus, analysing the results of research by S. Nikitchenko *et al*. (2022), it can be concluded that the intersectoral adaptation of Ukrainian farms in the context of war through the introduction of rural green tourism practices can be a significant support for the farm business as a whole.

Despite the fact that the implementation of intersectoral adaptive areas of farm development is expected to generate additional financial revenues, entrepreneurs face a number of problems: lack of experience; difficulty in finding the necessary information; uncertainty at the legislative level; remoteness of farm recreation centres from tourists (poor transport links); insufficient advertising; lack of support at the state level. Therefore, partnership support, based on the association of farm owners, is important – the All-Ukrainian public non-profit organisation "Union of Rural Green Tourism of Ukraine" (n.d.). Farm business owners have the opportunity to integrate into the tourism sector by diversifying their activities and business mentoring.

Thus, the analysis of studies on inter-sectoral adaptations of Ukrainian farms has shown that, while emphasising the main advantages of the sectoral activity itself, a sustainable search for new ideas, development opportunities through diversification and inter-sectoral partnerships is an integral part of scientific research. The main results of the study are similar and consistent with those presented in the works of other researchers.

## CONCLUSIONS

The post-war recovery of Ukraine's economy is expected to be based on the traditionally developed and export-oriented sector of activity, which is agriculture. As an integral chain in shaping the food security of Ukraine and the world, it includes various areas: agriculture, livestock, fisheries, forestry, etc. Farming business has unique opportunities for development. Given Ukraine's favourable climate, land, landscape, and labour resources, the activities of agricultural entities, including farming, should be aimed at preserving and developing its financial independence, profitability, and export potential, which requires a scientific approach to developing appropriate tools.

The article scientifically substantiates the key approaches to intersectoral adaptation of farms, which are based on the principles of systemicity, synergy, innovation, sustainability, resilience, flexibility and adaptability of a business entity (farm). As a result of the study of patterns of intersectoral adaptation of farms, it is stated that it may include cooperation and interaction with various industries and sectors of the economy to achieve greater sustainability and efficiency. At the same time, the main goals (survival and development of a farm) can be ensured by developing a foresight adaptation mechanism in the form of a comprehensive competence-based approach to the formation of strategic behavioural responses of a business entity (farm) to changes (challenges) in the environment to determine possible scenarios of events in a certain frame. This hypothesis was confirmed by analysing the dynamics of the number of farms in 2014-2023, which shows an upward trend despite the logistics crisis and military risks. A study of trend markers using the horizon scanning method showed that national farms should take into account global trends and agricultural development trends, as they will determine the preferences of agricultural consumers and the export goals of recipient countries in the future. In addition, the innovations presented here greatly simplify operations by optimising physical labour costs, minimising the risks of working on land with a potential mine risk, improving the quality of agricultural products, etc. However, like any innovation, they require financial support from state and local authorities, as well as private investment. This paper analyses the planned areas of expenditure to support the development of farming in Ukraine in 2024. In particular, to compensate for the costs of humanitarian demining of agricultural land and to receive non-refundable grants for the creation or development of processing enterprises, including in the areas of horticulture, berry growing, viticulture and greenhouse construction. For the effective use of state grants, attracted investments, etc., the reference model of development inspiration, which includes both business partnerships and diversification of activities, is proposed for practical use by farms. At the same time, diversification areas have been selected from practical insights – the activities of successful farms, which include the production of various types of agricultural products and position them both in direct sales and e-commerce.

Thus, overcoming the environmental and infrastructural damage, material and human losses, and sometimes critical destruction caused by the war, requires balanced state legislative and financial support, including changes to the regulation and organisation of land management, budgeting and the procedure for receiving grants by farms. The recommendations presented here are intended to facilitate the effective development of farms in the future. At the same time, it creates a basis for further research and discussion to address gaps in existing theories, improve understanding of new phenomena and trends in the macro environment, and explore fundamental issues that have not yet been addressed. Further research on adaptation mechanisms for agribusiness development could be aimed at identifying and substantiating theoretical and practical insights into the formation and implementation of state policy in the field of e-government development and Ukraine's integration into the global information space in order to quickly adapt farms to the European and international agricultural market.


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## CONFLICT OF INTEREST

None.


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# Міжгалузева адаптація фермерських господарств України в умовах війни

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**Анотація.** В сучасних умовах господарювання, фермерські господарства повинні реагувати на виклики зовнішнього середовища та шукати механізми адаптації й виходу з кризи, а також диверсифікації бізнесу як додаткових джерел доходу. Тому опрацювання можливих міжгалузевих адаптацій фермерських господарств є актуальною темою дослідження. Відтак, метою даної статті стало наукове обґрунтування предикатів диверсифікації діяльності фермерських господарств у подоланні викликів війни. Підґрунтям дослідження стали класичні підходи менеджменту і маркетингу, форсайт-предикати розвитку аграрної сфери. Інтерпретацію змісту адаптаційних напрямів розвитку фермерських господарств було здійснено за допомогою емпіричних методів. В статті здійснено аналіз джерел ризиків та загроз, визначено цільові орієнтири та ключові аспекти формування міжгалузевої адаптації фермерських господарств: метрики, цілі та форсайт-компетентності. В результаті опрацювання макротрендів безпеки аграрної галузі було сформовано гіпотетичні аналітичні узагальнення, що пов'язано з невизначеністю таймфрейму війни та неможливістю прорахунку очікуваних збитків. Таким чином, проведене дослідження дозволило сформулювати теоретичні та практичні інсайти щодо формування адаптаційних механізмів в стратегічній перспективі. Обґрунтовано необхідність системного й безперервного моніторингу осередків загроз та інвазії шляхом систематизації традиційних та прогнозування новітніх ризиків. Сформульовано ключові детермінанти форсайт-адаптації під впливом глобальних трендів. Механізм її реалізації представлено через ідентифікацію напрямів міжгалузевої адаптації. Дослідження має практичну цінність, формуючи інформацію для фермерських господарств, сільських громад, стейкхолдерів та потенційних інвесторів, які можуть отримати вигоду від передбачувань перспектив та очікувань, що формуються в розрізі міжгалузевої адаптації фермерських господарств у пост-воєнний період

**Ключові слова:** інновації; диверсифікація; форсайт-адаптація; економічна безпека; міжгалузеве партнерство; агротуризм; землевпорядкування

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# Research of the vacuum low-temperature frying process *Pleurotus eryngii*

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**Abstract.** Mushrooms are consumed because of their nutrients and therapeutic bioactive compounds, historically used in medicine, and representatives of the genus *Pleurotus* are edible species rich in dietary fibre, vitamins, micro- and macroelements, and carbohydrates. The aim is to theoretically substantiate the vacuum frying of oyster mushroom pieces and to obtain a crispy product with optimal consumer characteristics. In the course of the study, the methods of vacuum low-temperature frying, organoleptic study, orthogonal test, single-factor and statistical analysis were used. The factors affecting the quality of vacuum roasting of oyster mushrooms: pre-drying time, temperature and roasting time are analysed. The relationship between oil content and sensory evaluation is described and analysed. The optimal technological parameters of vacuum frying were determined. *Pleurotus eryngii* with a thickness of 2 mm were completely inactivated under boiling conditions for 90 s at 80°C, and for 10 s at 90 and 100°C. If prolonged cooking takes place, the oyster mushroom texture becomes soft and is not amenable to further processing under vacuum at low temperature. Therefore, in order to save production energy and reduce the loss of flavour and nutrients, cooking at 80°C for 90 s was chosen. It has been shown that the treatment of *Pleurotus eryngii* with maltodextrin before vacuum frying reduces the oil content after frying, provides a homogeneous structure, good taste and crispiness of the product. Optimal parameters were obtained: 2 mm slices, mass fraction of maltodextrin 15%, sonication duration 15 min. The influence on the sensory evaluation of the primary and secondary order is described: frying temperature > pre-drying time > frying time. The specific

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parameters for which the product will obtain the best sensory characteristics were indicated, namely: frying for 10 min, pre-drying for 20 min, frying temperature of 90°C. The factors influencing the oil content were analysed: pre-drying time > frying time > frying temperature. It was found that the product can obtain the lowest oil content when pre-drying for 30 minutes and frying at 80°C for 10 minutes. The practical value of the study lies in the optimal conditions of the process under investigation: pre-drying time with hot air 20 min, frying temperature 80-90°C, frying time 10 min, frying vacuum 0.08-0.09 MPa

**Keywords:** oyster mushroom; quality; one-factor test; orthogonal test; sensory evaluation; blanching; oil

## INTRODUCTION

Roasting fresh *Pleurotus eryngii* is a new way of eating that further meets the needs of different consumers. At the same time, roasting plays an important role in improving the quality of the food. After frying, the shape shrinks and becomes hard and brittle. A layer of golden yellow gradually forms on the surface, releasing the unique flavour of fried food, which is crispy and tasty.

A. Pérez-Montes *et al.* (2021) noted in their work that the use of edible mushrooms in the food industry is explained by their physicochemical composition and economic availability. *Pleurotus eryngii* is rich in bacteria, crispy and delicate in texture, white in colour, has a unique almond aroma and abalone flavour, which is why it is called the almond abalone mushroom. It is native to Southern Europe, North Africa and Central Asia.

The nutritional value of mushrooms depends on the conditions of their cultivation. According to F. Ayimbila & S. Keawsompong (2023), the protein content ranges from 18 to 37%. In the studies of J. Raman *et al.* (2021), the content of proteins, carbohydrates and dietary fibre was 15.4-28.6, 61.3-84.1, 33.3%, respectively. Scientists H. El-Ramady *et al.* (2022) concluded that every 100 g of dried *Pleurotus eryngii* contains 11.95-35.5% protein, 39.85-63.03% carbohydrates, 36.78 g of total sugar, 1.06-7.50% fat, 6.20-28.29% dietary fibre, 2.97-10.7% ash, which is suitable for diabetics and the elderly.

*Pleurotus eryngii* is rich in nutrients. It contains a lot of protein, carbohydrates, and many vitamins and minerals. It has a crispy and delicate taste, and has the effects of lowering blood sugar, lowering blood fat, preventing cancer, enhancing immunity, antioxidant, antibacterial and anti-aging effects, as well as anti-fatigue and anti-aging. According to the analysis of A. González *et al.* (2020), *Pleurotus eryngii* protein contains 18 types of amino acids, and the content of 8 types of essential amino acids of the human body is 42.0% of the total amino acids, which is in line with the reference protein model proposed by the Food and Agriculture Organization, World Health Organization. A study on mice conducted by Y. Zhao *et al.* (2020) showed a decrease in animal body weight when eating *Pleurotus eryngii*. A review article by S.K. Dubey *et al.* (2019) analysed the use of mushrooms in the treatment of diabetes and obesity. This opinion was also confirmed in research by J. Ślusarczyk *et al.* (2021). They drew attention to polysaccharides, which exhibit immunoregulatory and antitumour properties by activating the body's immune system. Currently, most mushrooms are fresh foods, and a small portion is processed into dried products (Fang *et al.*, 2021). At the same time, scientists J.-W. Bai *et al.* (2023) pay considerable attention to the study of drying methods and conditions: hot air drying, infrared drying, microwave drying.

Vacuum low-temperature frying technology, according to D. Yang *et al.* (2020), mainly refers to using the principle of lowering the boiling point of water in a negative pressure vacuum and using vegetable oil with strong antioxidant ability as the medium to achieve the process of frying and dehydration under low temperature conditions. Compared with conventional pressure frying, it can better retain the original colour, taste and nutrients of the material, and at the same time can reduce the degree of degradation of oil oxidation and carcinogen formation. In addition, it is easy to form a loose and porous structure and crispy taste.

Fresh *Pleurotus eryngii* has an extremely high water content and soft and delicate tissues. After the processes of colour protection, blanching and dipping, the moisture content of the tissues will increase further due to the destruction of some tissue cells. If vacuum frying is carried out directly, the high water content will result in a high oil content in the product; if vacuum frying is carried out after freezing treatment, although it is beneficial for the flatness of the product, it will result in an increase in oil content. A. Ren *et al.* (2018) believe that the ice crystals that form during freezing will make the structure of the vacuum fried product fluffier. During the vacuum frying process, the ice crystals are directly evaporated, so the product will have a certain expansion effect, but the space formed by the expansion will be replaced by the oil phase, causing the product to have a high oil content. A study by J.R. Barbosa *et al.* (2020) found that vacuum frying is carried out directly after freezing. At this time, the temperature difference between the material and the fat is large, and the structure of the material after freezing is more loose, which is conducive to the penetration of the oil phase, which also leads to high oil content in the product.

It is generally believed that there are two ways of fat adsorption in the vacuum frying process: one is the contact and adsorption of fat with the material surface; the other is the replacement of the water phase with the oil phase during the mass transfer process during vacuum frying. The greater the surface tension, the harder it is for the oil to be adsorbed by the product, as confirmed by J. Zhang & L. Fan (2021). For the first method of adsorption, the surface tension of the material can be changed to reduce oil adsorption, for example by adding a surfactant. For the second method, the goal of reducing oil adsorption can be achieved by reducing the aqueous phase space. Typically, the method used to reduce the oil content is to increase the soluble solids content and reduce the moisture content before frying.

The aim of the work was to create a theoretical basis for quality control of vacuum frying of crispy oyster mushroom slices in a vacuum.

## MATERIALS AND METHODS

The study used vacuum low-temperature frying technology to process the *Pleurotus eryngii* slices, and hot air impregnation and pre-drying to increase the dry matter content and decrease the moisture content to reduce the oil content of the product. A one-factor test was used to investigate the moisture and oil content of *Pleurotus eryngii* slices during vacuum frying and to determine the appropriate test range for the orthogonal test. The moisture content, oil content and sensory evaluation were used as indicators to determine the optimal frying parameters and degreasing parameters during the vacuum low-temperature frying process of *Pleurotus eryngii* slices.

The following instruments and equipment were used: TP-200D electronic scales (manufacturer: Xiangyi Balance Instrument Equipment Co., Ltd.); VF-40C vacuum fryer (manufacturer: Zhong Shan VK Vacuum Machinery Co, Ltd.); HH-S constant temperature oil bath (manufacturer: Jiangsu Jintan Huanyu Scientific Instrument Factory); SZT-06A fat meter (manufacturer: Suzhou Tianwei Instrument Co., Ltd.); drying cabinet type 101-2 (manufacturer: Shanghai Experimental Instrument Factory); KQ-50B ultrasonic cleaner (manufacturer: Kunshan Ultrasonic Instrument Co, Ltd.).

The sequence of the study was as follows: (1) Fresh *Pleurotus eryngii* without rot and mechanical damage washed in running water is selected. (2) After washing, *Pleurotus eryngii* is cut into pieces and sliced longitudinally, with a thickness of about 2 mm. (3) The sliced *Pleurotus eryngii* pieces are placed in hot water for blanching, and the time of placement is recorded. They are taken out immediately after blanching and quickly cooled with running water. (4) The cooled *Pleurotus eryngii* pieces are placed in a maltodextrin solution of a certain concentration for immersion by ultrasonication. After soaking, the *Pleurotus eryngii* pieces are taken out and the surface moisture is dried. (5) The processed *Pleurotus eryngii* pieces are placed in a drying oven for pre-drying at a certain temperature. (6) The pre-dried *Pleurotus eryngii* slices are placed in an airtight container and placed in a sealed place. (7) The vacuum frying device is switched on and the frying temperature, frying time and oil removal time are set. The palm oil is heated to the set temperature, the slices of *Pleurotus eryngii* are placed on the frying grid, the frying container is closed, which is placed in the frying chamber, the frying chamber door is closed, and then the vacuum pump is switched on for vacuuming. When the vacuum degree reaches approximately 0.08-0.09 MPa, the vacuum frying container is lowered. (8) After the frying process is complete, the oil level in the frying container rises. The frying container is degreased under vacuum. After degreasing, the motor and vacuum pump are turned off, the vacuum valve is opened to blow out the air, and the experimental product is taken out. (9) Crispy whole slices of *Pleurotus eryngii* with uniform texture are selected for packaging in a nitrogen environment.

In order to prevent the darkening reaction of *Pleurotus eryngii* slices, bleaching and enzymatic treatment were performed during the preliminary hot air drying and vacuum roasting process. The presence of peroxidase activity is used as an indicator of whether the enzyme is completely destroyed. In order to determine the relationship between temperature and blanching time and peroxidase activity, *Pleurotus eryngii* was cut into slices of about 2 mm thickness and blanched in water at 60, 70, 80, 90, 100°C. The mushroom slices were taken out after 2, 5, 10 and 15 s and tested with 2-methoxyphenol test solution. If the colour of the *Pleurotus eryngii* slices did not change, it meant that they were completely inactivated.

The dipping treatment of *Pleurotus eryngii* pieces was carried out before vacuum low-temperature frying. Ultrasonically assisted impregnation was used to promote the impregnation. Using ultrasonic impregnation with a slice thickness of 2 mm as a fixed parameter, the effect of maltodextrin concentration and material-liquid ratio on the solid content of *Pleurotus eryngii* slices was studied. In each group, pieces of *Pleurotus eryngii* were selected after blanching, and two factors, maltodextrin concentration and material-to-liquid ratio, were used to study the change in solid content of

2 mm pieces of *Pleurotus eryngii* after blanching. The impregnation concentration was 10, 15, 20, 25%; the material-to-liquid ratio was 5, 10, 15, 20 ml/g for a one-factor experiment. The difference in quality was used to determine the solid content of *Pleurotus eryngii* pieces after immersion and to determine the optimal parameters of the immersion process.

Before vacuum low-temperature frying, *Pleurotus eryngii* slices undergo a certain pre-drying process, which can appropriately reduce the moisture content of mushroom slices and reduce the replacement of water phase with oil phase during the vacuum frying process, which can effectively reduce the oil content of products after rapid vacuum frying. In order to study the effect of the pre-drying process on the quality of *Pleurotus eryngii* pieces, *Pleurotus eryngii* pieces with a thickness of about 2 mm after blanching and dipping were subjected to hot air drying at 60, 70 and 80°C, respectively. After evaluation, the moisture content, colour and deformation of the *Pleurotus eryngii* pieces were evaluated as indicators and measured every 10 minutes to determine the optimal parameters of the pre-drying process. In order to study the effect of frying temperature on product oil content and sensory quality, the pre-drying conditions were set to dry at 60°C for 20 minutes, vacuum frying time was 10 minutes, vacuum degree was 0.08-0.09 MPa, frying temperature was 70°C, frying was performed at 80, 90, 100 and 110°C, degreasing speed was 350 rpm, and degreasing time was 10 minutes. Each time 100 g of *Pleurotus eryngii* pieces were sampled for the one-factor test, the oil and water content of the final product was determined and the product was sensory evaluated.

Vacuum frying conditions have a great impact on the colour, crispness, fat content, flavour, appearance and other qualities of *Pleurotus eryngii* (Table 1). Taking the hot air pre-drying time, vacuum frying temperature and vacuum frying time as factors, the corresponding level of each factor determined according to the single-factor test is taken as the level of the orthogonal test, and the L9 orthogonal test is designed to determine the final vacuum oil frying process.

***Table 1.*** *Sensory assessment criteria and methods*

| Assessment | Colour | Crispness | Fat content | Taste characteristics | Shape | General perception |
|---|---|---|---|---|---|---|
| 0-2 | Yellowish brown, strong browning | Harder or softer | High oil content, oily taste | No *Pleurotus eryngii* scent or *Pleurotus eryngii* scent is very strong, difficult to to perceive | The whole is twisted, severely broken, and the burning phenomenon is serious | Very poor |
| 3-4 | Yellow with strong browning at the edges | General | High oil content, oily surface | The smell of *Pleurotus eryngii* is not obvious | Sections of *Pleurotus eryngii* are more degenerated and slightly burnt | Not enough |
| 5-6 | Yellow, with a slight browning | Crispy crust | Slightly higher oil content | General | Slices of *Pleurotus eryngii* rolled up all around | Common |
| 7-8 | Light yellow | Relatively crispy | Moderate oil content | *Pleurotus eryngii* has an obvious aroma | *Pleurotus eryngii* slices are slightly twisted | Good |
| 9-10 | Light yellow, uniform colour | Very crunchy | Low oil content, no greasy feeling | *Pleurotus eryngii* has a distinct and moderate flavour and is easy to digest | Slices of *Pleurotus eryngii* are whole, without curling | Excellent |

***Source:*** *authors' own development*

In order to study the effect of degreasing time after vacuum frying on the oil content of *Pleurotus eryngii* slices, a test was conducted to degrease *Pleurotus eryngii* slices fried under optimal vacuum frying conditions using the centrifugal rotation method. The speed of degreasing by centrifugal rotation of the vacuum frying equipment was set at 350 rpm. After vacuum frying, centrifugal rotational degreasing was carried out for 2, 4, 6, 8, 10 and 12 min, and the effect of degreasing time on the oil content of *Pleurotus eryngii* was determined and analysed. Excel 2010 was used to organise and analyse the test data, and a line graph was drawn using Origin 9.0.

## RESULTS AND DISCUSSION

Table 2 shows the effect of different blanching temperatures and times on peroxidase activity in *Pleurotus eryngii* slices. It can be seen that the peroxidase is inactivated by scalding at 60°C for 60 s and 70°C for 30 s after 30 s in the middle of the mushroom slices, but there is still activity on the marginal epidermis. This may be due to the fact that the peroxidase in the mushroom epidermis is active, which in turn may be due to the distribution of polyphenolic substrates in different parts of *Pleurotus eryngii* and different polyphenol oxidase activities. The peroxidase of *Pleurotus eryngii* was completely inactivated by scalding at 80°C for 90 s, 90 and 100°C for 10 s. However, if the blanching time is too long, the texture of *Pleurotus eryngii* becomes soft. Considering the need to save energy in production and reduce the loss of flavour nutrients, the blanching process parameter was set at 80°C and blanching for 90 s. The results of this experiment are consistent with those of A. Ren *et al.* (2022). The authors proposed blanching in boiling water at 100°C for 3 min. In P. Piyalungka *et al.* (2019), it was practically established that with an increase in temperature (90-110°C) and roasting time (10-30 min), the oil content, hardness, and darkening of the samples increased.

***Table 2.*** *Effect of different blanching temperature and time on peroxidase activity Pleurotus eryngii*

| Time (s)/ Temperature | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | ++ | ++ | ++ | ++ | ++ | + | + | + | + | + | + | + |
| 70 | ++ | ++ | + | + | + | + | + | + | + | + | + | + |
| 80 | + | + | + | + | + | + | + | + | - | - | - | - |
| 90 | - | - | - | - | - | - | | - | - | - | - | - |
| 100 | - | - | - | - | - | - | - | - | - | - | - | - |

***Notes:*** *"++" – general colour change; "+" – edge colour change; "-" – colour change*
***Source:*** *authors' own development*

Impregnating *Pleurotus eryngii* flakes before vacuum frying can not only increase the dry matter content of *Pleurotus eryngii*, but also reduce the moisture content before vacuum frying to reduce the oil content of the final product by reducing the water phase. At the same time, it is also conducive to maintaining the flatness of the product, and can increase the crispiness of *Pleurotus eryngii* slices and obtain better sensory quality. In addition, by improving the taste, it also improves the quality of *Pleurotus eryngii* slices, effectively reducing costs, which is consistent with the opinions of M. Kidoń & J. Grabowska (2021) and J. Zhu *et al.* (2022).

To determine the effect of maltodextrin concentration on the dry matter content of *Pleurotus eryngii*, slices (2 mm thick, blanched at 80°C for 90 s), weighing 30 g, were selected and immersed for 15 min at a material to liquid ratio of 1:5. The dry matter content of *Pleurotus eryngii* slices varies with malt. The same phenomena were observed by T.-V.-L. Nguyen *et al.* (2023), studying the effect of different maltodextrin contents (0, 6, 7, 5, 9 and 10,5 g/100 g of pulp) on the drying rate of avocado pulp, and J.W. Siccama *et al.* (2021), demonstrating the drying technology of asparagus concentrate. The dependence of the change in the mass fraction of dextrin is shown in Figure 1.

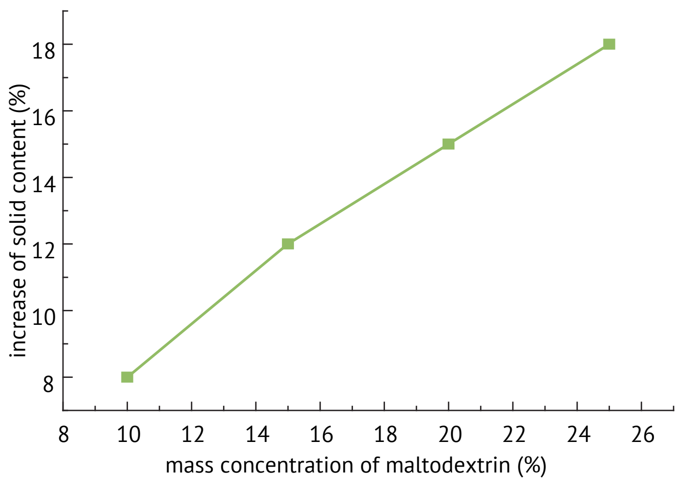


***Figure 1.*** *Effect of maltodextrin concentration on dry matter content*
***Source:*** *authors' own development*

The figure above shows that within a certain range, the concentration of maltodextrin can increase the solid content of *Pleurotus eryngii* slices. The higher the mass fraction of the impregnating solution, the more the dry matter content increases, but when the mass fraction of the impregnating solution exceeds 15%. At that time, the sweetness of maltodextrin is relatively high, which masks the original flavour of *Pleurotus eryngii,* so it is ideal to choose maltodextrin with a mass fraction of 15% as an impregnating solution. S. Lachowicz *et al.* (2020) confirmed the positive effect of adding maltodextrin at 15% in preparation for vacuum drying of Saskatoon fruit, juice and berry pomace.

To determine the effect of the material-liquid ratio on the solid phase content of *Pleurotus eryngii*, sliced and blanched slices (2 mm thick, blanched at 80°C for 90 s) weighing 30 g were selected, immersed in maltodextrin with a concentration of 15% for 15 minutes, after which the dry matter content of the *Pleurotus eryngii* slices would change. The dependence of the change in the liquid ratio is shown in Figure 2.

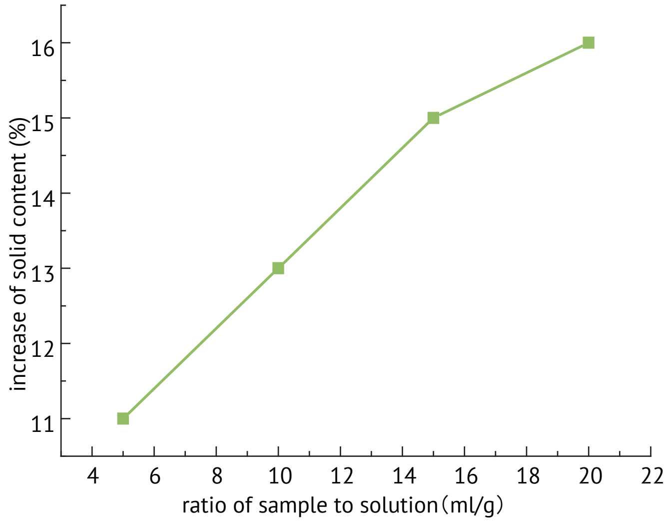


***Figure 2.*** *Effect of sample to solution ratio on solid phase content*
***Source:*** *authors' own development*

Figure 2 shows that the greater the mass ratio of *Pleurotus eryngii* flakes to the impregnating liquid, the higher the impregnation efficiency, and when the ratio of impregnating liquid exceeds 15 ml/g, the dry matter content increases slowly. Therefore, the mass ratio of *Pleurotus eryngii* pieces to malt dextrin impregnating solution was determined to be 15 ml/g. A. Ren *et al.* (2018) reported that shiikate mushroom chips cut into 6 mm thickness and soaked in a 50% maltodextrin solution resulted in a vacuum-fried product with the highest dehydration efficiency index, lowest oil content, and higher sensory performance.

Comprehensively taking into account the above test results, the optimal parameters of the process of dipping *Pleurotus eryngii* slices before vacuum low-temperature roasting were determined, which are as follows: thickness of *Pleurotus eryngii* slices – 2 mm, mass fraction of maltodextrin - 15%, ultrasonic impregnation for 15 minutes, at which the material-liquid ratio is 15 ml/g. The developed algorithm is consistent with the result reported by J. Zhang *et al.* (2021). The *Pleurotus eryngii* pieces after blanching and immersion are removed and dried to dry the surface moisture, and then subjected to the hot air pre-drying test (Table 3).

***Table 3.*** *Effect of different drying temperatures and times on moisture content and appearance Pleurotus eryngii*

| Drying time, min | Drying temperature 60°C | | Drying temperature 70°C | | Drying temperature 80°C | |
|---|---|---|---|---|---|---|
| | Moisture content, % | Exterior | Moisture content, % | Exterior | Moisture content, % | Exterior |
| 10 | 80.9 | No discolouration, no shrinkage | 79.2 | No discolouration, no shrinkage | 79.0 | No discolouration, no shrinkage |
| 20 | 77.9 | No discolouration, no shrinkage | 77.2 | Colour does not change, slightly shrinks | 75.4 | Does not change colour, does not shrink |
| 30 | 72.7 | Colour hardly changes, slightly shrinks | 68.0 | Slight discolouration and shrinkage | 64.5 | Some colours change, shrinkage is more severe |

Table 3, Continued

| Drying time, min | Drying temperature 60°C | | Drying temperature 70°C | | Drying temperature 80°C | |
|---|---|---|---|---|---|---|
| | Moisture content, % | Exterior | Moisture content, % | Exterior | Moisture content, % | Exterior |
| 40 | / | Colour hardly changes, shrinks | / | Some colours change and shrink | / | Colour changes strongly and serious shrinkage occurs |

***Notes:*** *since the colour and shape of the Pleurotus eryngii slices have undergone obvious changes after drying for 40 minutes, it is not suitable for frying and the moisture content was not measured*
***Source:*** *authors' own development*

Table 3 shows that as the drying time increases, the moisture content of *Pleurotus eryngii* slices gradually decreases. The *Pleurotus eryngii* slices pre-dried by hot air at 60°C can effectively delay the deformation and discolouration of *Pleurotus eryngii* slices during the pre-drying process, while ensuring the dehydration rate, which can minimise the vacuum roasting process. The *Pleurotus eryngii* slices are highly deformable, shrinkable and hardenable. The *Pleurotus eryngii* slices dried at 60°C cannot shrink, and there is no obvious discolouration. The effect of hot air pre-drying is the best.

To investigate the effect of frying temperature on the oil and water content and sensory quality of the product, 100 g of 2 mm thick slices of *Pleurotus eryngii* were blanched and dipped, and the pre-drying conditions were set to 60°C for 20 min and vacuumed. After vacuum frying, centrifugal degreasing was performed at 350 rpm, the oil and water content of the product was measured, and a sensory evaluation of the product was performed based on an overall score of 60 points. The standard sensory score, as well as the results of the moisture and oil content of the product, are given in Table 4 and shown in Figure 3.

***Table 4.*** *Results of sensory evaluation of Pleurotus eryngii pieces with different roasting temperatures*

| Temperature | Colour | Texture | Greasy feeling | Taste | Shape | Acceptance | Assessment |
|---|---|---|---|---|---|---|---|
| 70 | 8 | 4 | 7 | 5 | 8 | 5 | 37 |
| 80 | 9 | 8 | 8 | 7 | 8 | 8 | 48 |
| 90 | 7 | 8 | 7 | 7 | 7 | 8 | 44 |
| 100 | 7 | 8 | 7 | 7 | 7 | 8 | 44 |
| 110 | 6 | 8 | 6 | 6 | 7 | 7 | 40 |

***Source:*** *authors' own development*

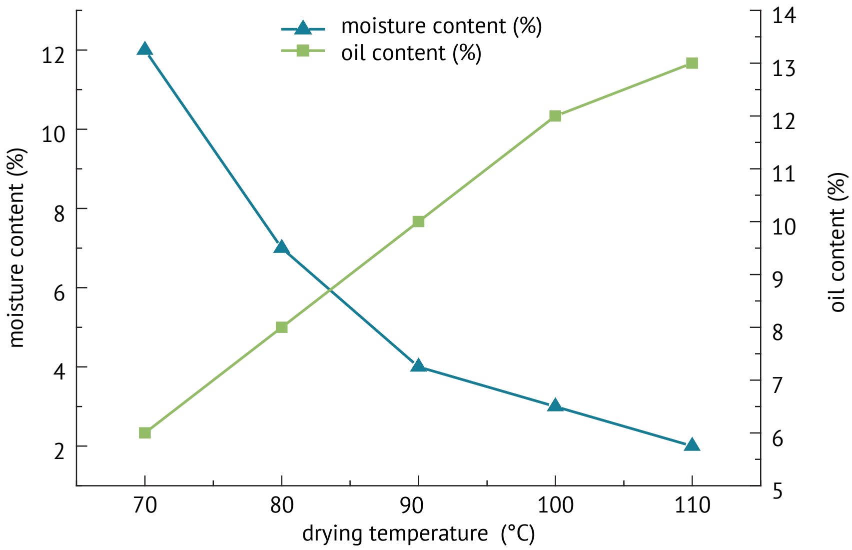


***Figure 3.*** *Effect of frying temperature on moisture and oil content in Pleurotus eryngii*
***Source:*** *authors' own development*

It can be seen that under the same conditions of hot air pre-drying time, degree of vacuum and vacuum roasting time, the roasting temperature affects the water and oil content of *Pleurotus eryngii*. The higher the roasting temperature, the lower the final moisture content of the product, and the higher the oil content, these two values are inversely proportional. At a frying temperature below 90°C, the moisture content of the product exceeds 7%; at a frying temperature of 100°C, the oil content of the product is 43.23%, and at a temperature of 110°C, the oil content is 44.86%. No significant changes in oil content are observed. In addition, Table 4 shows that at frying temperatures between 80 and 100°C, the sensory scores of the products exceed 44 points, and better sensory quality can be obtained at oil temperatures between 80 and 100°C. The importance of organoleptic characteristics was noted in their work by M.R. Hilapad *et al.* (2020) noted that fried oyster mushroom pieces for 20-35 minutes are characterised by higher scores (6.85-7.79). Similar findings were obtained by A. Shah *et al.* (2020), analysing the effect of vacuum frying on onion slices. The authors established the dependence of temperature and duration of vacuum frying: 30, 25 and 20 minutes at 80, 90 and 100°C, respectively. This study showed that the colour and texture of the chips were optimal at 90°C. And as a result of research by I. Izham *et al.* (2022) it is stated that the optimal process variables for processing mushrooms were 110 minutes of hot air drying at 75°C. The highest desirability index of 0.648 was achieved.

In order to investigate the effect of frying time on the oil and water content and sensory quality of the product, 100 g of 2 mm thick slices of *Pleurotus eryngii* were blanched and dipped, and the hot air pre-drying temperature was 60°C. The sensory evaluation is based on a total score of 60 points. The sensory evaluation criteria and the results of the moisture and oil content of the product are shown in Table 5 and Figure 4.

***Table 5.*** *Results of sensory evaluation of Pleurotus eryngii pieces with different roasting times*

| Frying time | Colour | Texture | Greasy feeling | Taste | Shape | Acceptance | Assessment |
|---|---|---|---|---|---|---|---|
| 5 | 8 | 2 | 8 | 3 | 8 | 3 | 32 |
| 10 | 7 | 8 | 7 | 7 | 7 | 8 | 44 |
| 15 | 7 | 8 | 7 | 7 | 7 | 8 | 44 |
| 20 | 6 | 9 | 6 | 8 | 6 | 7 | 42 |
| 25 | 4 | 9 | 4 | 6 | 4 | 5 | 32 |

***Source:*** *authors' own development*

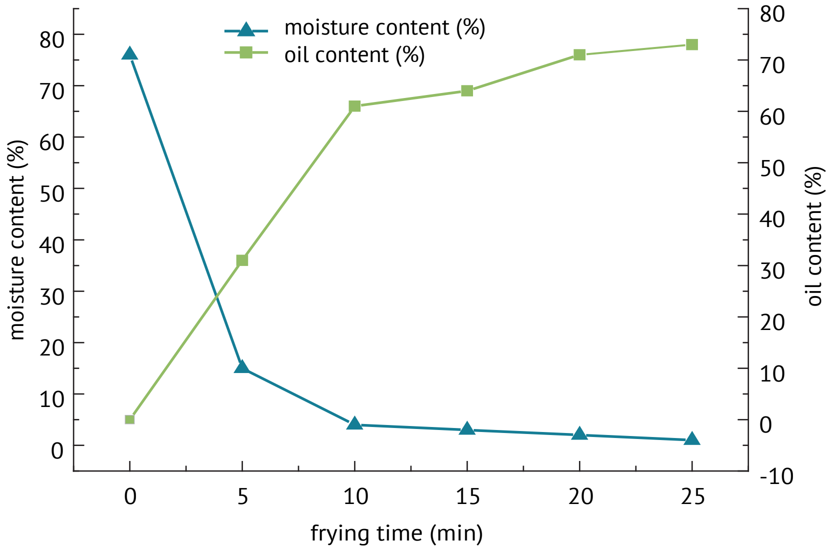


***Figure 4.*** *Effect of frying time on moisture and oil content in Pleurotus eryngii*

***Source:*** *authors' own development*

In order to maintain the crispness and shelf life of the product after frying, it is usually necessary to keep the moisture content below 8%. Figure 4 shows that the oil content increases more rapidly before frying for 10 minutes (from 1.88 to 35.8%), and after 10 minutes the oil content increases more slowly, and the oil content tends to stabilise after 20 minutes. At the same time, the water content decreased sharply before 5 minutes (from 77.9 to 13.6%), and the water content decreased to 3.93% within 5 minutes. After 10 minutes, the decrease became stable. It can be seen that the moisture content dropped below 7% when fried for 15 minutes. Therefore, in order to achieve a safe moisture content, the oil content is the lowest. Confirmation of this can be found in A. Ren *et al.* (2018), where the researchers statistically confirmed that pretreatment significantly affected the colour of shiitake mushroom chips ($p < 0.05$).

Furthermore, as can be seen from Figure 4, the dehydration process of *Pleurotus eryngii* slices fried in a vacuum at low temperature can be divided into three stages. The first stage lasts from 0 to 5 min. During this time, accelerated drying takes place. The water inside the *Pleurotus eryngii* pieces boils rapidly under the influence of negative pressure and high temperature, and flows out of the internal tissues of *Pleurotus eryngii* as steam. The moisture content in the pieces of *Pleurotus eryngii* decreases significantly, and the water that evaporates at this time is mainly free water in the outer layer. The second stage is the stage of uniform dehydration. This stage occurs in about 5-10 minutes. At this time, the overflowing water is mainly free water that diffuses from the inner layer to the outer layer. The rate of dehydration is affected by the rate of water diffusion, so the dehydration rate remains basically stable. The third stage occurs after 15 minutes, and the water content of the *Pleurotus eryngii* pieces remains almost unchanged at this stage. At this stage, only a small amount of bound water continues to evaporate, so the change in water content is very small. In the third stage, the moisture content changes very little. Continuing to fry will only result in a deterioration of the colour and taste of the product and wasted energy.

The change in oil content with frying time is basically divided into two stages. The first stage is the period from 0 to 10 minutes. During this time, the oil content increases from 1.88 to 35.8%. After 15 minutes, most of the free water has evaporated, the dehydration rate becomes slow, and all the oil phases replace the water phase. The rate also becomes slower, so the oil content basically stabilises and reaches equilibrium. The decrease in oil content was consistent with the studies of A. Ren *et al.* (2022). The authors confirmed that the mechanism to reduce oil absorption by ultrasonic osmosis was the pre-treatment with ultrasound before vacuum frying. This created a high vapour pressure in the sample structure reducing the oil absorption during frying.

In the process of vacuum low-temperature frying, the frying temperature, frying time and the degree of vacuum have a great influence on the product quality. In this test, the fixed vacuum degree is in the range of 0.08-0.09 MPa, and the orthogonal test is designed according to the three factors that affect the quality of vacuum-fried *Pleurotus eryngii* pieces, frying temperature and frying time. Vacuum low-temperature roasting is orthogonal. The level selected for the test is shown in Table 6.

The oil content and sensory quality of *Pleurotus eryngii* slices produced by vacuum low-temperature frying are related to consumer perception.According to the sensory evaluation criteria in Table 1, nine groups of orthogonal tests were evaluated to determine the oil content of each group, and the range of sensory evaluation and oil content was analysed. The results of the orthogonal test and the vacuum frying process are shown in Table 7.

***Table 6.*** *Factors in the vacuum frying process conditions*

| Level | Factor | | |
|---|---|---|---|
| | Drying time, min | Frying temperature, °C | Frying time, min |
| 1 | 10 | 80 | 10 |
| 2 | 20 | 90 | 15 |
| 3 | 30 | 100 | 20 |

***Source:*** *authors' own development*

***Table 7.*** *Orthogonal experimental design of vacuum frying process conditions*

| No. | Factor | | | | Overall sensory score | Oil content, % |
|---|---|---|---|---|---|---|
| | A Zero column | B Drying time | C Frying temperature | D Time frying | | |
| 1 | 1 | 1 | 1 | 1 | 43 | 45.2 |
| 2 | 1 | 2 | 2 | 2 | 47 | 43.8 |
| 3 | 1 | 3 | 3 | 3 | 37 | 40.1 |
| 4 | 2 | 1 | 2 | 3 | 42 | 46.6 |

Table 7, Continued

| No. | Factor | | | | Overall sensory score | Oil content, % |
|---|---|---|---|---|---|---|
| | A<br>Zero column | B<br>Drying time | C<br>Frying temperature | D<br>Time frying | | |
| 5 | 2 | 2 | 3 | 1 | 40 | 34.8 |
| 6 | 2 | 3 | 1 | 2 | 39 | 24.5 |
| 7 | 3 | 1 | 3 | 2 | 41 | 53.5 |
| 8 | 3 | 2 | 1 | 3 | 44 | 45.3 |
| 9 | 3 | 3 | 2 | 1 | 45 | 30.6 |
| K Sensor 1 | 42.3 | 42.0 | 42.0 | 42.7 | | |
| K Sensor 2 | 40.3 | 43.7 | 44.7 | 42.3 | | |
| K Sensor 3 | 43.3 | 40.3 | 39.3 | 41.0 | | |
| R Sensor | 3.0 | 3.3 | 5.3 | 1.7 | | |
| K Oil 1 | 43.0 | 48.4 | 38.3 | 36.9 | | |
| K Oil 2 | 35.3 | 41.3 | 40.3 | 40.6 | | |
| K Oil 3 | 43.1 | 31.7 | 42.8 | 44.0 | | |
| R Oil | 7.833 | 16.700 | 4.467 | 7.133 | | |

***Source:*** *authors' own development*

The range analysis shows that the primary and secondary order factors affecting the sensory evaluation are as follows: roasting temperature > pre-drying time > roasting time, roasting for 10 min under the conditions of pre-drying with hot air for 20 min and roasting temperature of 90°C. The best sensory quality was obtained. The analysis of the oil content range shows that the order of factors affecting the oil content is: pre-drying time > frying time > frying temperature. When the pre-drying time is 30 min and the frying temperature is 80°C, the product can be obtained after frying for 10 min. The lowest oil content is obtained. However, when the pre-drying time was 30 minutes, the *Pleurotus eryngii* slices deformed more severely than the *Pleurotus eryngii* slices dried for 20 minutes during the dehydration process, and the sensory evaluation was slightly worse. These findings were consistent with the opinion reported by C. Wang *et al.* (2019).

Comprehensively considering the two factors of reducing the oil content in the final product and improving the sensory quality of the product, the optimal process conditions were obtained: hot air pre-drying time 20 min, roasting temperature 80-90°C, roasting time 10 min, and vacuum degree 0.08-0.09 MPa. Figure 5 shows the appearance of *Pleurotus eryngii* slices after vacuum roasting. It can be seen that the slices of *Pleurotus eryngii* are light yellow, with small pores formed on the surface as a result of air drying.

***Figure 5.*** *Appearance of Pleurotus eryngii pieces after vacuum roasting*

***Source:*** *authors' own development*

Thus, using the combined vacuum frying process, mushrooms with a crispy texture were obtained, which can be considered an appropriate attribute for the manufacture of a snack-type product. It should be noted that oyster mushrooms have high nutritional and health benefits, good antioxidant properties due to biologically active compounds (phenol) and are a source of vegetable protein.

## CONCLUSIONS

In order to inactivate the peroxidase of *Pleurotus eryngii*, taking into account the need for energy saving in production and reducing the loss of flavour nutrients, the blanching process parameter was set at 80°C for 90 s. In order to reduce moisture in the product and increase dry matter, oyster mushroom impregnation with maltodextrin (15%) in a ratio of 1:5 for 15 min was used. Taking into account the test results, the ideal parameters for forming *Pleurotus eryngii* slices by dipping before vacuum frying at low temperature were determined, which included: thickness of 2 mm, mass fraction of maltodextrin of 15% and 15-minute ultrasonic impregnation. Subsequent studies have shown that during the pre-drying process, it is possible to delay the deformation and discolouration of *Pleurotus eryngii* by using hot air (60°C) for pre-drying while maintaining the same dehydration rate, which minimises the vacuum frying process. When the frying temperature remains below 90°C, the moisture content of the product exceeds 7%. However, when the temperature rises to 100°C, the oil content of the product reaches 43.23%, and at 110°C it increases even further to 44.86%. It should be noted that there are no significant fluctuations in the oil content. In addition, when the frying temperature falls between 80 and 100°C, the product's sensory scores exceed 44 points. It can therefore be concluded that maintaining the oil temperature between 80 and 100°C results in excellent sensory performance. Temperature, frying time and the degree of vacuum have a significant impact on the quality of the product during the low-temperature vacuum frying process. These are the three factors that determine the design of the orthogonal dough, which has a fixed vacuum degree in the range of 0.08-0.09 MPa. The ideal process conditions were achieved by taking full account of two factors to reduce the oil content of the final product and improve the sensory qualities of the product: pre-drying time with hot air 20 minutes, frying temperature 80-90°C, frying time 10 minutes, and vacuum degree 0.08-0.09 MPa. The appearance of the *Pleurotus eryngii* pieces after vacuum frying has light yellow surface sections with small pores. Therefore, future research may be aimed at producing safe snacks from different types of edible mushrooms.

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## CONFLICT OF INTEREST

None.

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## Дослідження процесу вакуумного низькотемпературного смаження *Pleurotus eryngii*

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**Анотація.** Гриби споживаються через їх поживні речовини та терапевтичні біологічно активні сполуки, історично використовувалися в медицині, а представники роду *Pleurotus* є їстівними видами які багаті харчовими волокнами, вітамінами, мікро- та макроелементами, вуглеводами. Мета – теоретично обґрунтувати вакуумне смаження шматочків гливи, отримати хрусткий продукт з оптимальними споживчими характеристиками. В процесі дослідження використано методи вакуумного низькотемпературного смаження, органолептичного дослідження, ортогонального тесту, однофакторного та статистичного аналізу. Проаналізовано чинники, що впливають на якість вакуумного смаження гливи: час попереднього сушіння, температуру та час смаження. Описано та проаналізовано зв'язок показників вмісту олії та сенсорної оцінки. Були визначені оптимальні технологічні параметри смаження у вакуумі. *Pleurotus eryngii* товщиною 2 мм були повністю інактивовані в умовах проварювання протягом 90 с при 80 °С, і протягом 10 с при 90 °С і 100 °С. Якщо відбувається тривале варіння, текстура гливи стає м'якою, погано піддається подальшій обробці під вакуумом при низькій температурі. Тому, з метою економії виробничої енергії та зменшення втрати смаку і поживних речовин, було обрано приготування при 80 °С протягом 90 с. Зазначено, що обробка *Pleurotus eryngii* мальтодекстрином перед смаженням у вакуумі, зменшує вміст олії після смаження, забезпечує однорідну структуру, гарний смак і хрусткість продукту. Було отримано оптимальні параметри: зрізи по 2 мм, масова частка мальтодекстрину 15 %, тривалість ультразвукової обробки 15 хв. Описано вплив на сенсорну оцінку основного і вторинного порядку: температура смаження > час попереднього сушіння > час смаження. Було зазначено конкретні параметри, за яких продукт отримає найкращі сенсорні показники, а саме: смаження 10 хв, попереднє сушіння 20 хв, температура смаження 90 °С. Було проаналізовано фактори впливу на вміст олії: час попереднього сушіння > час смаження > температура смаження. Було встановлено, що продукт може отримати найменший вміст олії за умови попереднього сушіння 30 хв, температури смаження 80 °С протягом 10 хв. Практична цінність дослідження полягає у визначених оптимальних умов досліджуваного процесу: час попереднього сушіння гарячим повітрям 20 хв, температура смаження 80-90 °С, час смаження 10 хв, ступінь вакууму смаження 0,08-0,09 МПа

**Ключові слова:** глива; якість; однофакторний тест; ортогональний тест; сенсорна оцінка; бланшування; олія

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# The current status and prospects of growing plant-based food products in the present conditions of the Ukrainian agricultural sector

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**Abstract.** The agricultural sector in Ukraine plays a key role in the national economy, providing high-quality and sustainable food supply for the population. However, even with favourable natural and climatic conditions and extensive land area, the industry faces numerous challenges, such as war, economic instability, and loss of control over land resources. The purpose of the study is to analyse the current state of growing plant-based food products in Ukraine to identify key challenges and opportunities. To achieve this goal, the gross harvest, yield, and acreage of the main agricultural crops, the share of agricultural value added in the gross domestic product in Ukraine, and the value of agricultural exports to the European Union for the period 2015-2022 were analysed. The results show that sales volumes in agriculture increased by 75.9%, indicating a positive development of the industry. However, this positive development is accompanied by an increase in product prices, which can lead to inflationary pressures. The instability of the agricultural sector is confirmed by a sharp increase in the share of value added in 2021 and a decline in 2022. However, an important positive aspect is a significant increase in the yield and value of exports, which indicates the successful influence of the Ukrainian agricultural sector on international markets. The study shows that despite the existing challenges, the agricultural sector has demonstrated flexibility and adaptability, especially in the context of changes in acreage and crop production volumes. Measures aimed at introducing modern technologies, stimulating innovation, improving the level of education and developing export opportunities can become a catalyst for the sustainable development of the agricultural sector. The results obtained are necessary for the development of specific measures and strategies aimed at improving the situation in the agricultural sector of Ukraine and ensuring its sustainable development

**Keywords:** gross harvest; value added; competitiveness; export; agricultural production

## INTRODUCTION

The agricultural sector of Ukraine, as a key sector of the economy, plays a crucial role in ensuring food security and growing plant-based food products. This industry is not only an important component of national production, but also a determining factor for the country's sustainable development. Against the backdrop of global challenges such as climate change, limited resources and the need to ensure food security, Ukraine's agricultural sector is becoming a key player in solving these problems. The importance of ensuring the profitability and sustainability of agricultural activities requires an integrated approach covering economic, environmental

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and social aspects. Therefore, the relevance of this study is determined by the need to address the challenges facing the agricultural sector of Ukraine in the context of global trends. In particular, maintaining ecological balance, ensuring access to resources, and maintaining food security are becoming important tasks for which the agricultural sector should pay due attention.

According to Y. Danko *et al*. (2020), current trends in the cultivation of plant-based food products in Ukraine indicate the need to integrate the latest technologies, comply with environmental standards, and adapt to global challenges. Important aspects include ensuring product quality, efficient use of resources and, creating a sustainable agricultural sector that meets the requirements of modern consumers and considers environmental aspects. Maintaining and increasing the competitiveness of the Ukrainian agricultural market is conditioned by the innovation and improvement of cultivation methods aimed at creating environmentally friendly and safe products for consumers. In this context, I. Kulyk (2019) argues that it is important to analyse existing cultivation technologies, implement modern management methods, and consider the sustainable use of natural resources and the preservation of soil fertility. Achieving success in the agricultural sector of the Ukrainian economy will be determined not only by the volume of production, but also by the introduction of innovations aimed at increasing productivity and ensuring sustainable development of agricultural production.

H. Kvita *et al*. (2020) note that the analysis of the state of the agricultural sector and its interaction with plant production will help identify key problems and opportunities facing modern farmers and agricultural enterprises. Consideration of these aspects will provide an understanding of the factors that affect the efficiency of growing plant-based food products, and indicate ways to optimise production based on modern requirements. O. Krupchan & V. Korol (2022) also highlight the need to investigate and implement modern agricultural technologies, such as agricultural work, irrigation systems, fertiliser use, and plant protection, to ensure maximum productivity with minimal environmental impact. They also note the importance of ensuring high quality standards for plant-based food products, which affects their perception on the world market.

V. Dankevych *et al*. (2022) point to the complexity of the challenges facing Ukraine's agricultural sector and the need to integrate modern technologies, scientific developments, and sustainable management to achieve economic success, ensure food security, and solve environmental problems. The application of innovative solutions such as modern tillage methods, efficient fertilisers, and hybrid technologies allows the agricultural sector to remain competitive and sustainable in the changing conditions of the modern world (Roberts, 2021). Growing plant-based food products today also requires innovative strategies and modern approaches to agricultural activities. According to E. Shahini *et al*. (2023), the introduction of agrointelligence and modern irrigation technologies has contributed to a 15% increase in crop yields and a 20% reduction in irrigation water consumption, and modern genetically modified varieties have shown high resistance to stressful conditions, which has contributed to improving the quality of grown products. Due to these innovations, the agricultural sector of Ukraine can ensure sustainable food production, meeting the requirements of economic sustainability, environmental safety, and improved product quality. The transition to modern technologies using engineering will contribute to the further development of the agricultural sector and the introduction of sustainable agricultural production (Atanasov, 2023).

The purpose of the study was an in-depth analysis of the current state of plant food cultivation in Ukraine, identifying key challenges and opportunities, and ways to optimise production to achieve a sustainable, cost-effective, and competitive agricultural sector. To achieve the stated goal, the following tasks were set: to analyse the current state of growing plant food products and present strategies aimed at increasing sustainability and stimulating development in the field of agricultural production in Ukraine.

## MATERIALS AND METHODS

The theoretical segment of the study includes the papers by researchers in the field of agricultural development and in the field of research on the problems of transformations in agricultural production and its sale. In addition, the sustainable development goals and statistical data of the State Statistics Service of Ukraine were used as an information component of the study. The research materials were analysed using the methods of comparison and grouping, and the abstract and logical method was aimed at investigating the current state, problems, and prospects of growing plant-based food products in Ukraine.

In the course of the research, a complex of special and general scientific methods was used: generalisation – when working with literary sources for systematisation and generalisation of information; dialectical method – to investigate the regularities of the state and prospects of growing plant-based food products; grouping – to explore the totality of data and their logical combination; analysis – to analyse the collected information, draw conclusions and provide recommendations; statistical analysis – for quantitative expression of data; synthesis – to combine the obtained data into a concise and scientific description; scientific abstraction – to determine the essence of the model of development of the agricultural sector; comparative analysis – to contrast the results obtained and identify differences or similarities.

The paper also included a SWOT analysis, which helped to identify the strengths and weaknesses of the agricultural sector, and analyse opportunities and threats for developing strategies aimed at improving the sustainability and development of Ukrainian agricultural production. To effectively conduct a study on the cultivation of plant-based food products in the current conditions of the Ukrainian agricultural sector, the statistical data on production volumes, yields, and harvested areas of crops by their types were considered. In addition, the following indicators were analysed to determine the state and prospects of growing plant food products: the dynamics of gross harvest and yield, and the sown areas of the following crops: cereals and legumes, sugar beet, sunflower, soybeans, rapeseed, potatoes, and open-ground vegetable crops. Ultimately, the production of the main agricultural crops, the share of value added of the agricultural sector to the GDP of Ukraine, the cost of agricultural exports from Ukraine to the European Union for the period 2015-2022, and the volume and average prices of agricultural products sold by agricultural enterprises in January 2022 were considered.

The results obtained were processed for reliability using the MANOVA multivariate analysis of variance using Microsoft Excel and Statistica 10 software suites. Differences in the results obtained are possible at a significance level of P⩽0.05 according to the Student's t-test.

## RESULTS

A detailed analysis of the production of the main agricultural crops in Ukraine showed some growth in 2018-2020, but in 2021-2022 there was a significant decline and the dynamics of instability (Leal Filho *et al.*, 2023). In particular, the acreage of crops such as sugar beet and potatoes decreased, while the acreage of sunflower, rapeseed, and soybeans increased. The decrease in acreage may be conditioned by economic factors, losses from natural disasters, and external factors such as war. Along with this, there is a clear increase in the yield of almost all types of crops, which may indicate the introduction of more efficient technologies and modern methods of cultivation (Table 1).

***Table 1.*** *Dynamics of gross harvest, yield, and acreage of major agricultural crops in Ukraine*

| Years | Grain and leguminous crops | Industrial sugar beet | Sunflower | Soybeans | Rapeseed | Potatoes | Open ground vegetable crops |
|---|---|---|---|---|---|---|---|
| Gross harvest of basic agricultural crops, thous. hwt | | | | | | | |
| 2015 | 601,250 | 103,300 | 111,810 | 39,310 | 17,380 | 208,390 | 92,140 |
| 2016 | 660,880 | 140,110 | 136,270 | 42,770 | 11,540 | 217,500 | 94,150 |
| 2017 | 619,160 | 148,810 | 122,350 | 38,904.4 | 21,945.7 | 222,080 | 92,860 |
| 2018 | 700,565 | 139,677 | 141,651.7 | 44,608 | 27,506 | 225,039.7 | 88,845 |
| 2019 | 751,432 | 102,045.3 | 152,541.2 | 36,987.1 | 32,803.2 | 202,691.9 | 91,901.7 |
| 2020 | 633,445.4 | 82,565.2 | 131,358 | 27,709.3 | 25,863.5 | 208,586.8 | 91,137.3 |
| 2021 | 566,967.6 | 83,989.5 | 122,108.6 | 23,623.4 | 26,300.5 | 208,688.2 | 81,254.9 |
| 2022 | 538,637.1 | 99,414.6 | 113,287.4 | 34,438 | 32,502.7 | 208,992.1 | 86,452.1 |
| Yield of the main agricultural crops, hwt/ha | | | | | | | |
| 2015 | 41.1 | 436 | 21.6 | 18.4 | 25.9 | 161 | 206 |
| 2016 | 46.1 | 482 | 22.4 | 23 | 25.7 | 166 | 211 |
| 2017 | 42.3 | 465.5 | 20.1 | 19.7 | 27.9 | 167.8 | 197.9 |
| 2018 | 47.4 | 508.5 | 23 | 25.8 | 26.5 | 170.5 | 204.7 |
| 2019 | 49.1 | 461.1 | 25.6 | 22.9 | 25.6 | 154.8 | 205.9 |
| 2020 | 42.9 | 409.5 | 20.6 | 20.9 | 23.4 | 157.4 | 199.9 |
| 2021 | 39.7 | 362.4 | 20 | 19.8 | 23.9 | 165.1 | 192.6 |
| 2022 | 45.8 | 541.2 | 21.6 | 22.6 | 28.7 | 173.5 | 195.2 |
| Acreage of the main agricultural crops, thous. ha. | | | | | | | |
| 2015 | 14,739 | 237 | 5,105 | 2,158 | 682 | 1,291 | 440 |
| 2016 | 14,401 | 292 | 6,073 | 1,869 | 455 | 1,312 | 442 |
| 2017 | 14,607 | 318 | 5,943 | 1,994 | 789 | 1,324 | 440 |
| 2018 | 14,848 | 279 | 6,058 | 1,709 | 1,042 | 1,319 | 433 |
| 2019 | 15,318 | 221 | 5,928 | 1,609 | 1,282 | 1,309 | 445.8 |
| 2020 | 14,759.1 | 201.6 | 6,381.3 | 1,323.2 | 1,104.9 | 1,325.4 | 455.8 |
| 2021 | 10,203.2 | 193.8 | 6,110.5 | 1,183.4 | 1,112.8 | 1,263.9 | 421.9 |
| 2022 | 12,171.1 | 184.1 | 5,292.8 | 1,558.9 | 1,161.1 | 1,207.7 | 439.2 |

***Source:*** *State Statistics Service of Ukraine (Areas, gross harvests..., 2023)*

Monitoring and analysis of data on the dynamics of the development of the agricultural sector and the development of strategies to improve the sustainability and efficiency of agricultural production showed that the production of fruits and berries in Ukraine remained at a stable level of about 9.8-10.0 million tonnes during the period from 2015 to 2022. Despite small fluctuations, this stability may indicate a certain conservatism in the cultivation of fruits and berries in Ukraine, or it may be due to difficulties in market access or other economic factors. The production of sunflower and potatoes also remains at a high level, which cannot be noted about the production of sugar beet, which remains at a fairly low level during all the years studied (Fig. 1).

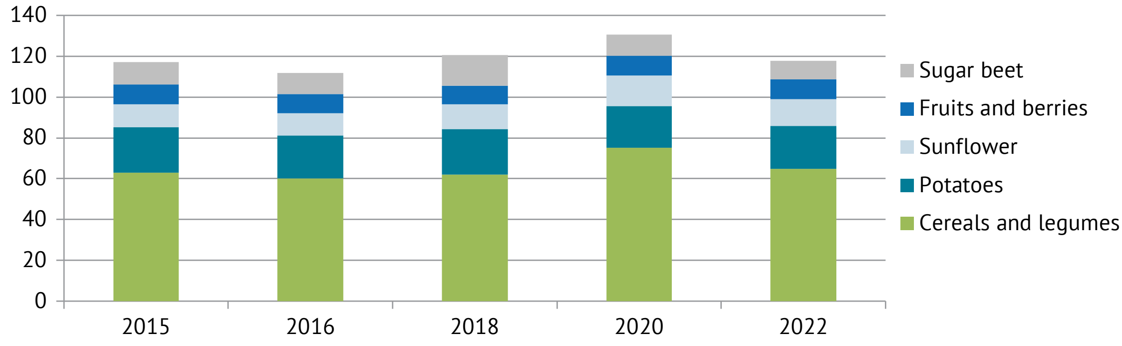


***Figure 1.*** *Production of the main agricultural crops in Ukraine, mln. t.*
***Source:*** *State Statistics Service of Ukraine (Volume of production..., 2023)*

The production of the main agricultural crops in Ukraine is influenced by various trends and factors that can be decisive for the agricultural sector. In particular, agroclimatic conditions can affect crop yields and production. Extreme weather events, such as droughts or floods, can lead to crop losses and reduced production. Economic instability can affect the financial capacity of agricultural enterprises. Changes in the amount of available financial resources can affect the choice of technologies, production volumes, and business efficiency. Changes in consumer demand for specific agricultural products can affect production and acreage. Adaptation to changes in consumer demand may require a reorientation of agricultural production. In addition, the loss of control over agricultural land due to war can significantly affect the volume of production and acreage. Economic turbulence and significant mass migration of the population can lead to significant changes in agriculture. In particular, the displacement of the population, including agricultural workers due to war, can affect the availability of labour and production efficiency. To overcome these challenges and ensure the sustainability of the agricultural sector, it is important to develop strategies to adapt to changes, improve cultivation methods, develop modern technologies, and promote sustainable agricultural development. Figure 2 shows that the share of value added of the agricultural sector to gross domestic product in Ukraine was marked by a sharp increase in 2021. This indicated positive trends in agriculture and its significant contribution to the economy. However, a sharp decrease in this share in 2022 is the result of the influence of various factors, in particular, the war.

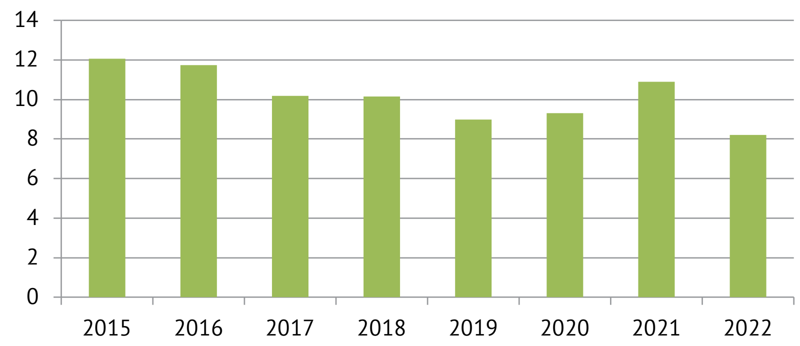


***Figure 2.*** *Share of value added of the agricultural sector to GDP in Ukraine, %*
***Source:*** *State Statistics Service of Ukraine (National accounts (GDP), 2023)*

However, despite the existing instability in gross production volumes, in general, the analysed data indicate a stable increase in the value of agricultural exports from Ukraine to the European Union during the study period, with intensive growth in 2022. Such dynamic growth may indicate a positive impact of the Ukrainian agricultural sector on the international market (Fig. 3). The dynamics of agricultural exports to the European Union indicates a steady demand for Ukrainian agricultural products in the region. The intensity of export value growth in 2022 can be the result of successful implementation of international marketing strategies, improving product quality and maintaining trade relations with partners in the European Union. This underscores the importance of Ukraine's agricultural sector as a key player in the international agricultural arena, capable of ensuring stability and growth in the face of global challenges.

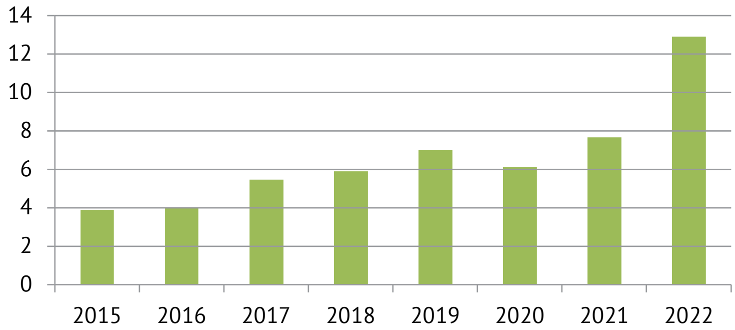


***Figure 3.*** *Value of agricultural exports from Ukraine to the European Union, billion USD*
***Source:*** *State Statistics Service of Ukraine (Commodity structure of..., 2022)*

In addition, a detailed analysis of sales volumes shows that the volume and average prices of agricultural products sold by agricultural enterprises in January 2022 increased by 75.9%, which may indicate a positive development of the agricultural sector. Total sales of oilseeds increased by 50.6%, while average prices remained high. Potato sales increased by 63.1%, but average prices declined. Sales of vegetables decreased by 6.4%, but average prices increased significantly. Sales of white crystalline sugar decreased by 13.8%, but average prices also increased. In general, sales volumes of most product categories have increased, which indicates a positive development of agriculture. However, it is important to note that product prices have also increased, which may affect inflation and consumer prices (Table 2).

***Table 2.*** *Volumes and average prices of agricultural products sold by agricultural enterprises in January 2022*

| Product name | Implemented | | Average sales prices | |
|---|---|---|---|---|
| | Thous. t. | In % compared to the corresponding period in 2020 | UAH per tonne | In % compared to the corresponding period in 2020 |
| Grain and leguminous crops | 3,662.2 | 175.9 | 6,675.6 | 108.5 |
| Of them | | | | |
| Wheat | 621.9 | 150.7 | 7,686.1 | 108.6 |
| Grain corn | 2,908.1 | 181.7 | 6,438.1 | 109.3 |
| Barley | 88.3 | 234.4 | 6,907.1 | 114.6 |
| Rye | 14.7 | 272.4 | 5,176 | 107.5 |
| Oilseed seeds | 826.8 | 150.6 | 17,691.4 | 105.9 |
| Of them | | | | |
| Soybeans | 104 | 122.9 | 16,045.6 | 111.9 |
| Rapeseed | 3.7 | 285.4 | 20,834.4 | 167.6 |
| Sunflower seeds | 7,174 | 155.3 | 17,904.8 | 104.4 |
| Potatoes | 22 | 163.1 | 5,248 | 84.2 |
| Vegetable crops | 16.4 | 93.6 | 15,486.1 | 154 |
| Fruit and berry crops | 13.8 | 145 | 7,584.1 | 78.3 |
| White crystalline beet sugar | 43.3 | 86.2 | 18,057.3 | 115.3 |

***Source:*** *State Statistics Service of Ukraine (Implementation of agricultural..., 2022)*

According to many researchers, modern technologies have recently been actively used in agriculture in Ukraine, including digital innovations, genetic engineering, and agroecological approaches. Digital innovation drives the use of monitoring and management systems such as sensors, GPS technologies, and data acquisition systems to improve production processes and optimise resource management. The Internet of Things (IoT) is also widely used to collect and process information about the state of crops, climatic conditions, humidity levels, etc. (Leschuk *et al*., 2022). In the field of genetic engineering, research and implementation of genetically modified organisms (GMOs) is carried out to create plants with improved properties, such as resistance to pests, diseases and creating favourable conditions for harvesting. Agroecological approaches include expanding the area of organic farms and using environmentally friendly methods of tillage. Sustainable use of soils is also important to reduce the impact of agricultural processes on the soil and its fertility (Glauben *et al*., 2022; Rawtani *et al*., 2022). A SWOT analysis of Ukraine's agricultural sector was carried out to provide a more detailed understanding of the sector, reflecting the internal and external factors that affect its state and prospects. It is important to note that among the strengths stand out a significant volume of production, favourable geographical location and potential for innovative development. However, weaknesses such as outdated equipment and technology, high costs, and insufficient infrastructure can limit the industry's ability to reach its maximum potential. New opportunities arise from increased global demand for organic and eco-friendly products, opportunities to become a key player in the global market, and increased investment in agriculture and infrastructure. However, threats such as poor management efficiency, innovation complexity, and workforce challenges require careful management and strategic planning to ensure the sustainability and development of the industry in a global market environment (Table 3).

***Table 3.*** *SWOT-analysis of the agricultural sector of Ukraine*

| | Internal factors | External factors |
|---|---|---|
| Strengths | 1. Significant production volume.<br>2. Geographical location.<br>3. Potential for innovative development. | 1. Increasing global demand for organic and eco-friendly products.<br>2. Reducing the cost of products on international markets. |
| Weaknesses | 1. Outdated equipment and technologies.<br>2. High costs for the production and operation of equipment.<br>3. Insufficient infrastructure for storing and transporting products.<br>4. Lack of innovative technologies. | 1. Lack of competitiveness in world markets.<br>2. Changes in trade agreements and tariffs.<br>3. Impact of geopolitical conflicts and wars on exports and market access. |
| Opportunities | 1. Significant production volume.<br>2. Potential for innovative development and improvement of product quality and increased competitiveness.<br>3. Development of new sales markets. | 1. Increasing global demand for organic and eco-friendly products.<br>2. Ukraine can become a key player in the agricultural market.<br>3. Increase investment in agriculture and infrastructure. |
| Threats | 1. Low efficiency of production and business process management.<br>2. Failure to implement innovation through a conservative approach.<br>3. Insufficient qualification of personnel and problems with the labour force. | 1. Negative impact of changes in trade agreements and tariffs.<br>2. Increased competition in global markets.<br>3. Impact of sanctions and trade restrictions. |

***Source:*** *developed by the author*

Based on the conducted research, a number of strategic areas for improving the sustainability and development of Ukrainian agricultural production have been identified. The first strategic area is the introduction of modern technologies, such as the latest agricultural technologies, to improve production efficiency and the use of automation and monitoring systems to optimise processes. The second area involves stimulating innovation in agriculture, including financial support and incentives for research and innovation. It is also important to create incubators and innovation centres to promote start-ups in the rural sector. The third area is the education and development of personnel, including improving the level of education of rural workers and farmers, and the introduction of training and training programmes for the effective use of modern technologies. The fourth strategic area is the sustainable use of natural resources. This includes the introduction of environmentally friendly methods of cultivation and production, and the rational use of water resources and reducing the impact on soils. The fifth area provides for the diversification of production, including the expansion of the range of agricultural products for different markets and the development of agrotourism and other alternative areas for additional income. The sixth area is sectoral cooperation, which provides for cooperation between agricultural enterprises and farmers' associations for joint development and resource conservation. The seventh area is the development of export opportunities, including expanding export markets and increasing the volume of agricultural exports, and active participation in international exhibitions and fairs to promote Ukrainian goods. These strategies are aimed at ensuring the sustainability and competitiveness of plant-based food products in the Ukrainian agricultural sector. Growing plant-based food products in Ukraine has growth prospects based on the use of the latest technologies, increasing the quality and competitiveness of products, and active participation in the global agricultural market. These strategies are aimed at ensuring the sustainability and competitiveness of plant-based food products in the Ukrainian agricultural sector.

Thus, the prospects for the growth of plant-based food products in Ukraine are based on the use of advanced technologies that help increase productivity and ensure high product quality. The introduction of the latest agricultural technologies, such as modern methods of tillage, efficient irrigation systems and the use of high-quality fertilisers, contributes to increasing yields and unifying products. Improving product quality includes not only the use of modern agrotechnical methods, but also compliance with high standards of product safety and quality. The introduction of quality control systems, including monitoring of production processes and implementation of certification standards, promotes the cultivation of products that meet the requirements of both domestic and international markets. Active participation in the global agricultural market opens up new opportunities for selling Ukrainian products. The expansion of export markets and participation in international exhibitions and fairs help promote and position Ukrainian agricultural products, ensuring their competitiveness at the global level. Thus, the development of the Ukrainian agricultural sector is based on a combination of modern technologies, high quality standards, and active participation in the global economic dimension. This creates favourable prospects for sustainable growth and competitiveness of Ukrainian products, and active participation of the country in the global agricultural market.

## DISCUSSION

Favourable natural and climatic conditions, a large land area and agricultural traditions create the potential for efficient cultivation of various crops in Ukraine. However, I. Irtyshcheva *et al*. (2023) argue that the conditions of 2024 set farmers not only the task of increasing production, but also high requirements for the sustainability and environmental safety of growing products. Ukrainian crop production plays a strategic role in ensuring food security, export potential, and sustainable development of the country, which is also correlated with the study. Y. Danko *et al*. (2020), N. Leschuk *et al*. (2022) and K. Deininger *et al*. (2023) emphasise that given the importance of plant production in the agricultural sector, it is important not only to increase the volume of cultivation, but also to ensure manoeuvrability and adaptability to modern consumer requirements and environmental standards, because the combination of productivity, quality, and sustainability is the key to the successful development of Ukrainian food production. Therefore, the benefits of increasing the number of farms switching to organic farming were noted. It is this approach that leads to an improvement in soil quality, a reduction in the negative impact on the environment, and an increase in consumer demand for organic products.

According to C. Van der Giesen *et al*. (2020), the expansion of areas for organic crops is becoming a key vector of development, as it not only meets global trends in ecological production, but also increases the competitiveness of Ukrainian agricultural products on the world market. An important step towards the sustainable development of the agricultural sector is also the use of renewable energy and green energy, which, coming from agricultural revenues, make a significant contribution to ensuring environmental sustainability. In addition, the state of Ukrainian agricultural production as of 2024 indicates a gradual increase in the production of plant products. In particular, farmers in Ukraine show a growing interest in the use of modern agricultural technologies, improving plant varieties and more efficient use of land resources. Genetic engineering opens up wide opportunities for growing plant-based food products that meet the challenges of our time. This contributes to improved yields, pest and disease resistance, and adaptation to climate change. The development of new varieties also allows for efficient use of resources, reduced environmental impact, and improved product quality (Pörtner *et al*., 2022).

The conducted research coincides with the opinion of L. Gutierrez *et al*. (2022), according to which the introduction of modern technologies, consideration of the principles of sustainable use of natural resources and diversification of production become crucial elements for achieving efficiency and sustainability. Innovation promotion, which is provided by financial support and the creation of innovation centres, defines a new stage in the development of the sector, where there is continuous improvement and introduction of advanced technologies. However, R. Ciaian *et al*. (2012) and M. Behnassi & M. El Haiba (2022) suggest that while the Ukrainian agricultural sector has significant potential for development, it also faces numerous challenges, such as outdated equipment and insufficient infrastructure. To overcome these obstacles, it is important to pay attention to the introduction of modern technologies, stimulating innovation, improving education and actively developing export opportunities. These measures can become a catalyst for the sustainable development of the Ukrainian agricultural sector, providing it with the necessary tools to overcome modern challenges and achieve full potential.

I. Salim *et al*. (2019) suggest that an important aspect of the development prospects is also consideration of socio-economic factors, such as the war, which significantly affected the agricultural sector due to loss of control over land resources, economic instability, and mass migration of the population. However, despite these difficulties, the increase in the value of agricultural exports to the European Union is a positive signal and indicates the successful adaptation of the Ukrainian agricultural sector to international market conditions, which is also confirmed in the study. Another confirmation of the conducted research can be found in the papers by D. Fiott (2022) and J. Eustachio *et al*. (2023), according to which performance management, strategic planning, and cooperation between business entities remain key factors for overcoming challenges and creating opportunities for the development of the agricultural sector. Sustainable use of natural resources, diversification of production, sectoral cooperation, and active development of export opportunities create a solid foundation for sustainable and competitive development of the Ukrainian agricultural sector in a global market environment.

Thus, summing up the above, it can be argued that in the conditions of active development and transformation of the Ukrainian agricultural sector, it is impossible to underestimate its significant role as a key component of the national economy. This sector not only ensures the stability of the economic situation in the country, but also has a huge potential to influence global economic and environmental challenges, and certain strategic areas have the potential to significantly improve the state and prospects of the Ukrainian agricultural sector. These strategies, focused on sustainability and coordinated growth, interact with each other and develop the basis for sustainable and competitive development of the Ukrainian agricultural sector in the global economic environment. Strategies aimed at sustainability and economic growth have great potential to improve not only the state of the agricultural sector, but also to influence the overall development prospects of Ukraine. In a global economic environment, stability and willingness to adapt are critical factors for successfully overcoming challenges and taking advantage of opportunities at the international level.

## CONCLUSIONS

Ukraine's agricultural sector is an important component of the national economy, determining the quality and stability of the food supply. Despite favourable natural and climatic conditions and a large land area, Ukraine's agricultural sector faces numerous challenges, such as war, economic instability, and loss of control over land resources. In the course of the study, it was found that sales volumes in agriculture increased by 75.9%, indicating a positive development of the industry, but this is accompanied by an increase in prices for products, which can cause inflationary pressure. The instability of the agricultural sector confirms a sharp increase in the share of value added in 2021 and a decline in 2022, but the positive aspect is a significant increase in yields and export values, indicating the successful impact of the Ukrainian agricultural sector on the international market. These changes pose challenges to domestic economic sustainability, but also point to potential opportunities for the development of the external agricultural sector. Measures aimed at introducing modern technologies, stimulating innovation, improving the level of education and developing export opportunities can contribute to the sustainable development of the agricultural sector. It is important to emphasise the need to address the problems of outdated equipment and insufficient infrastructure. Sustainability, adaptability, and reasonable use of resources are becoming key priorities for the Ukrainian agricultural sector in the face of global challenges and transformations. The integration of modern strategies aimed at sustainability and coordinated growth is an important step in achieving sustainable development and competitiveness of the Ukrainian agricultural sector. Thus, the agricultural sector of Ukraine has experienced significant challenges due to war and economic difficulties, but continues to show some potential for the development of agricultural products and impact on world markets, and understanding the positive and negative aspects allows developing more effective action plans for creating a competitive agricultural sector. Prospects for further study are to investigate the impact of war on agriculture and develop a clear strategy for adapting to economic instability.

## ACKNOWLEDGEMENTS

None.

## CONFLICT OF INTEREST

None.

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## Стан та перспективи вирощування рослинної харчової продукції в сучасних умовах українського аграрного сектору

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**Анотація.** Аграрний сектор в Україні відіграє ключову роль у національній економіці, надаючи якісне та стабільне харчове забезпечення для населення. Проте, навіть при сприятливих природно-кліматичних умовах та обширній земельній площі, галузь стикається з численними викликами, такими як війна, економічна нестабільність та втрата контролю над земельними ресурсами. Мета дослідження – провести аналіз поточного стану вирощування рослинної харчової продукції в Україні задля виявлення ключових викликів і можливостей. Для досягнення поставленої мети проаналізовано валовий збір, урожайність та посівні площі основних сільськогосподарських культур, частку доданої вартості аграрного сектору до валового внутрішнього продукту в Україні, вартість експорту сільськогосподарської продукції до Європейського Союзу за період 2015-2022 рр. Результати проведеного дослідження свідчать, що обсяги реалізації в сільському господарстві зросли на 75,9 %, вказуючи на позитивний розвиток галузі. Однак цей позитивний розвиток супроводжується зростанням цін на продукцію, що може призвести до інфляційного тиску. Нестабільність аграрного сектору підтверджується різким зростанням частки доданої вартості у 2021 році та спадом у 2022 році. Однак, важливим позитивним аспектом є значний приріст урожайності та вартості експорту, що свідчить про успішний вплив українського сільськогосподарського сектору на міжнародних ринках. У дослідження продемонстровано, що незважаючи на існуючі виклики, аграрний сектор продемонстрував гнучкість та адаптивність, особливо в контексті змін у посівних площах та обсягах виробництва сільськогосподарських культур. Заходи, спрямовані на впровадження сучасних технологій, стимулювання інновацій, підвищення рівня освіти та розвиток експортних можливостей, можуть стати каталізатором для сталого розвитку аграрного сектору. Отримані результати є необхідними для розроблення конкретних заходів та стратегій, спрямованих на покращення ситуації в аграрному секторі України та забезпечення його сталого розвитку

**Ключові слова:** валовий збір; додана вартість; конкурентоспроможність; експорт; сільськогосподарське виробництво

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# Efficiency of biological products and mineral fertilizers application on winter garlic crops in the conditions of the Right-Bank Forest-Steppe of Ukraine

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**Abstract.** The article presents the results of three years of research on the effectiveness of the influence of the biological product Phytohelp, mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME and bioadhesive Liposam on the structure of the winter garlic yield of the Lyubasha variety under drip irrigation. The relevance of the research is due to the search for new approaches to the development of technological methods for growing winter garlic, taking into account the specific conditions of unstable moisture in the Forest-Steppe. The purpose of the article is to establish the optimal doses and the ratio between them to achieve an increase in the quality and yield of winter garlic. The study was conducted on the experimental field of the Department of Vegetable Growing of the National Assessed Contribution of Ukraine of the Uman National University of Horticulture on podzolised heavy loamy black soil in 2017-2019. As a result, it was proved that in the conditions of the Right-Bank Forest-Steppe of Ukraine on podzolic chernozem under drip irrigation, a higher yield was obtained in plots with the combined use of the biological product Phytohelp at a rate of 1-2 l/ha, mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME and bioadhesive Liposam at a rate of 1 l/ha. This resulted in an increase of 9.0-10.6 t/ha compared to the control variant, respectively. Using the biopreparation Phytohelp and bioadhesive Liposam at a rate of 2/1 and 1/1 l/ha, a yield of 16.6-17.1 t/ha was obtained, where the increase to the control was 7.7-8.2 t/ha. The effect of foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME (4 g/2 l of water or 0.5 c/ha) on the yield of winter garlic was determined. The increase to the control was 1.6%. The results of this study may be useful for agricultural enterprises and farmers who grow garlic and other crops

**Keywords:** variety; growth; development; bulb; yield

## INTRODUCTION

The process of growing winter garlic under unstable moisture conditions in the Forest-Steppe faces numerous challenges, as unstable moisture conditions can negatively affect the yield and quality of this crop. The development of technological methods that take into account specific conditions of unstable moisture can ensure a more stable and higher yield of garlic, and research in this area can help garlic producers to implement optimal moisture management methods and increase the efficiency of cultivation. In addition, the development of new technological techniques can have a positive impact on the sustainability and productivity of the main crops in the Right-Bank Forest-Steppe of Ukraine. The development and introduction of modern

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competitive crop cultivation technologies that contribute to the maximum realisation of their productive potential is important for the efficient use of the bioclimatic potential of natural and climatic conditions, and optimal efficiency can be achieved by combining the use of biological products and mineral fertilisers, taking into account specific growing conditions and expert recommendations.

Scientists F. Yang *et al*. (2019) believe that fertilisation is a global management strategy to improve soil quality, and that the use of chemical fertilisers is an important factor in high agricultural production to increase yields. Y. Geng *et al*. (2019) noted that global yield growth is largely dependent on large investments in chemical fertilisers. Scientists J. Zhu *et al*. (2019) and G. Brunetti *et al*. (2019) noted that in order to maintain soil productivity, farmers applied large quantities of fertiliser, often exceeding the rate required by crops. According to F. Lv *et al*. (2020), excessive chemical fertilisers in the soil can lead to deterioration of soil quality, a decrease in organic matter content and a sharp decline in soil biodiversity, including acidification. This, in turn, can cause a wide range of environmental problems in freshwater, terrestrial and marine ecosystems. Y. Lin *et al*. (2019) noted that soil organic matter plays an important role in regulating atmospheric $CO_2$ concentrations and maintaining soil fertility and productivity. Scientists H. Cheng *et al*. (2020) argue that the use of organic fertilisers can also have a positive impact on soil characteristics. Organic fertilisers help to improve soil structure, increase soil fertility and the content of organic decomposed material. As a result, the mineralisation and nitrogen fixation processes in the soil can be regulated and improved. The use of organic fertilisers can affect the processes of nitrification and denitrification in the soil. The research of M. Qaswar *et al*. (2020) found that the use of a combination of organic and mineral fertilisers leads to a partial replacement of chemical fertilisers and stabilisation of corn and wheat yields, providing plants with all the necessary nutrients.

Under the influence of various factors, the nutritional value of garlic undergoes significant changes. One of the methods of levelling external stresses during the growing season is the system and technology of applying biological products and mineral fertilisers. As of 2024, the impact of combined fertilisation on crop yields and quality has not been sufficiently studied. That is why the purpose of the research was to study the impact of the biological product Phytohelp, the mineral fertiliser Drip Fert NPK and the bioadhesive Liposam on the growth and development, yield and quality of bulbs on podzolic black soil under drip irrigation.

## MATERIALS AND METHODS

The study complies with ethical standards and adheres to the Convention on Biological Diversity (Secretariat of the..., 2011). The research was conducted during 2017-2019 on the experimental field of the Department of Vegetable Growing of the National Assigned Contribution of Ukraine of the Uman National University of Horticulture on podzolised heavy loamy black soil. The area of the experimental plot is 12 $m^2$, the accounting plot is 10 $m^2$. Plots were systematically arranged. The experiment was repeated four times. Predecessor – early vegetables. The cloves of winter garlic variety Lyubasha were planted in the soil at the beginning of the second decade of October according to the scheme of 45x6 cm.

The experiments used the biological products Phytohelp for local fertilisation and the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME for foliar application (spraying on the leaf). The experiment includes the following options: without fertilisation (control); Phytohelp biological product – 1 l/ha; Phytohelp biological product – 2 l/ha; Phytohelp biological product – 1 l/ha + Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water; biological preparation Phytohelp – 2 l/ha + Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water; mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water (0.5 c/ha).

The biological product Phytohelp was applied simultaneously with watering for the first time – in the phase of three or four true leaves, the second – at the beginning of bulb formation with the appearance of inflorescences. Mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME was applied foliarly twice (during the period of intensive bulb growth in the first half of June with an interval of 10 days). According to the recommendations of the manufacturers of the studied preparations, the bioadhesive Liposam (1 l/ha) was added to their working solutions. In the control variant, garlic was watered only with water. In order to increase the yield of underground bulbs, the flower-bearing arrow was removed manually. Weeding during the growing season was carried out three times (manually), thus destroying weeds in winter garlic crops.

## RESULTS

According to the results of three years of research, the applied factors (fertilisation with the biological preparation Phytohelp, mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME and bioadhesive Liposam) significantly influenced the biometric parameters and formation of productivity elements of winter garlic variety Lyubasha. Thus, after biometric measurements, it was found that 30 days after germination, the height of plants exceeded the control by 4.1-4.8%. In the phase of intensive growth and development, the best results were recorded with the combined use of the biological product Phytohelp at a rate of 2 l/ha, mineral fertiliser $N_{15}P_5K_{30}$+ME – 4 g/2 l of water and bioadhesive Liposam at a rate of 1 l/ha. The height of the plants was 64.2 cm, which is 29.3% higher compared to the control variant. Reducing the rate of the biological product Phytohelp to 1 l/ha, the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water and the bioadhesive Liposam 1 l/ha, a lower height was observed, but the plants exceeded the control by 25.9%. In the variants where Phytohelp was applied at a rate of 1 l/ha and 2 l/ha, the height of plants was 53.6-54.7 cm, which is 24.5-25.0% more than the control. When applying foliar fertilisation with mineral fertiliser $N_{15}P_5K_{30}$+ME – 4 g/2 l of water and bioadhesive Liposam, this indicator was 23.8% higher than in the control. A month after germination, the use of the biological product Phytohelp at a rate of 1 and 2 l/ha in combination with foliar feeding with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser – 4 g/2 l of water and Liposam bioadhesive at a rate of 1 l/ha was more effective. The height of the plants was 58.6 and 65.0 cm. The use of only the biological product Phytohelp (1 l/ha – 2 l/ha) contributed to an increase of 11.1 and 11.3 cm, respectively. The mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water and the bioadhesive Liposam 1 l/ha provided a 26.8% increase in height (Fig. 1).

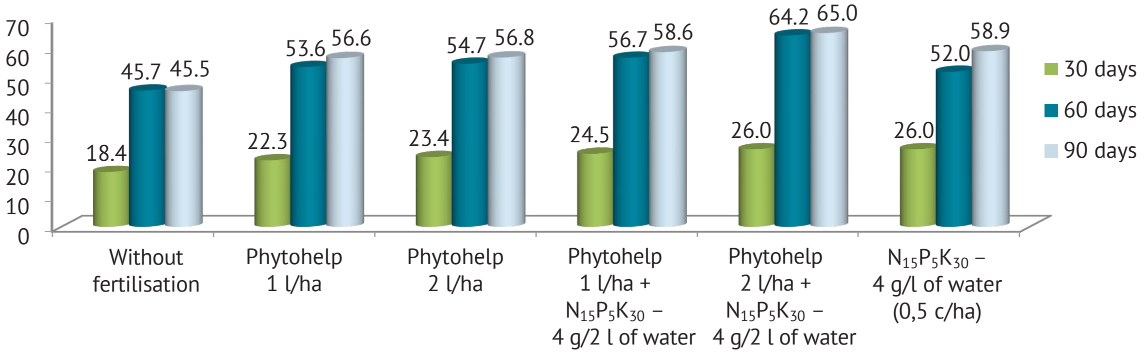


***Figure 1.*** *Plant height depending on the method of fertilisation with a biological product and complex mineral fertiliser 30, 60, 90 days after spring regrowth*

***Source:*** *author's development*

The use of biological products and foliar fertilisation with mineral fertiliser showed positive dynamics. Thus, the average number of leaves in 30 days after germination varied from 4.2 to 5.1 per plant. In the phase of intensive growth and development, in the control variant it was 2.2 pcs./plant lower than in the experimental variant, where the biological product Phytohelp was used at a rate of 2 l/ha and foliar fertilisation with mineral fertiliser $N_{15}P_5K_{30}$+ME – 4 g/2 l of water (bioadhesive Liposam at a rate of 1 l/ha). On the variants where the biological product Phytohelp was used at a rate of 1 and 2 l/ha, the number of leaves was 1.0-1.6 pcs./plant higher compared to the control. The use of foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water and Liposam bioadhesive 1 l/ha, the number of leaves per plant was 7.3, which is 1.5 more than in the control. Due to the partial drying of the tops of the leaves, the height of garlic plants before harvesting was in the range of 4.6-5.3 pcs./plant (Fig. 2).

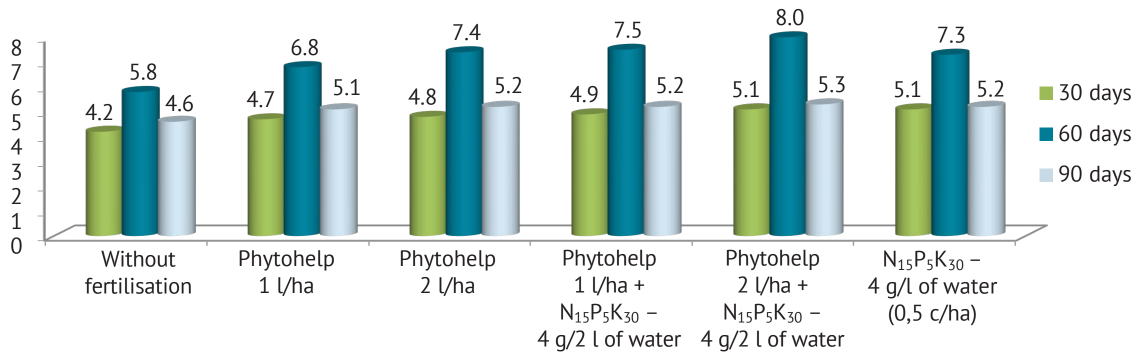


***Figure 2.*** *Number of leaves depending on the method of fertilisation with a biological product and complex mineral fertiliser 30, 60, 90 days after spring regrowth*

***Source:*** *author's development*

The studied plants of winter garlic differed in a complex of biometric parameters depending on fertilisation. The highest with the maximum surface area were mainly in the phase of intensive growth and development with the combined use of the biological product Phytohelp at a rate of 1 and 2 l/ha and the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water or 0.5 c/ha, the bioadhesive Liposam at a rate of 1 l/ha was 349.2 and 404.8 cm²/plant. A month after germination, this figure was lower, but exceeded the other experimental variant, where the biological product Phytohelp was used at a rate of 1 and 2 l/ha and the bioadhesive Liposam at a rate of 1 l/ha, respectively, by 41.7 and 63.5 cm²/plant. The use of foliar fertilization with mineral fertilizer Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water and bioadhesive Liposam at a rate of 1 l/ha (leaf area per plant) provided an assimilation surface of 361.7 cm²/plant, and in a month these data decreased to 180.0 cm²/plant, but exceeded the control variant by 112.4 cm²/plant (Fig. 3).

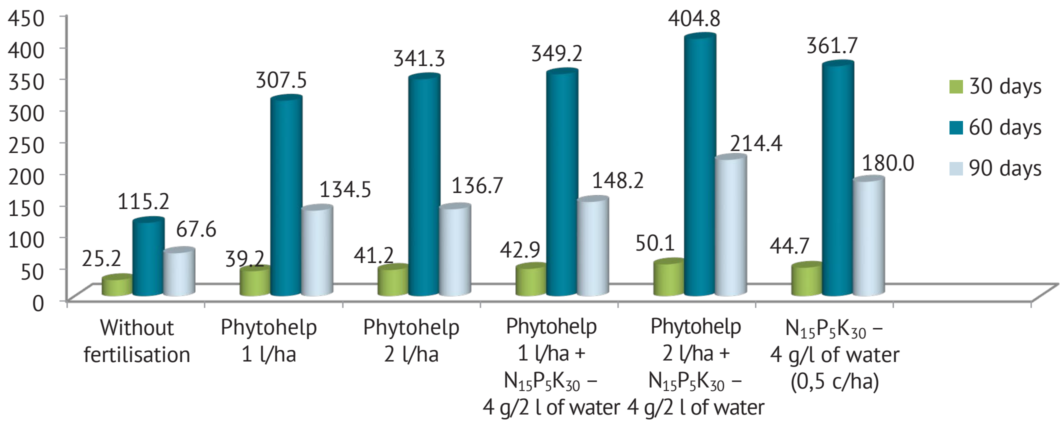


***Figure 3.*** *Leaf blade area depending on the method of fertilisation with biological product and complex mineral fertiliser, cm2/plant after 30, 60, 90 days after spring regrowth*

***Source:*** *author's development*

Leaf area index is a complex indicator that reflects the area of plant leaves per unit area of soil. Thus, with the combined application of the biological product Phytohelp at a rate of 1 and 2 l/ha, foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 l of water or 0.5 c/ha, and the bioadhesive Liposam at a rate of 1 l/ha, the increase to the control variant was 0.86-1.07 m². When fertilising with biological preparations Phytohelp at a rate of 1-2 l/ha and Liposam at a rate of 1 l/ha, the increase in leaf index was 0.7-0.84 m². This indicator exceeded the control by 0.9 m² in the variant where foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 l of water or 0.5 c/ha and Liposam bioadhesive at a rate of 1 l/ha was used (Fig. 4).

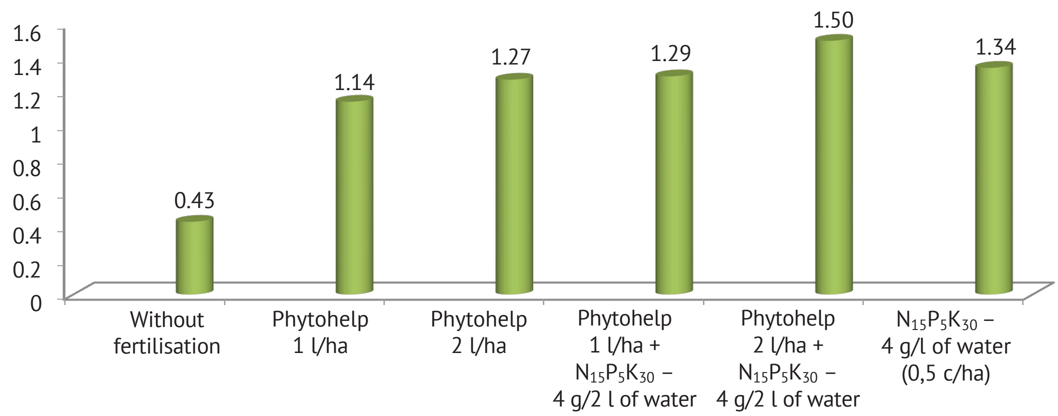


***Figure 4.*** *Leaf surface index of winter garlic variety Lyubasha 60 days after germination depending on the method of fertilisation with biological product and complex mineral fertiliser (2017-2019), m²*

***Source:*** *author's development*

Analysing the results of research on the structure of the yield of winter garlic variety Lyubasha, it can be noted that the increase in bulb weight directly depends on the rate of fertilisation with biological products and mineral fertiliser. Thus, in 2017, the average bulb weight in the control variant was 20.0 g, and in the variant with the use of the biological preparation Phytohelp at a rate of 1-2 l/ha and the bioadhesive Liposam at a rate of 1 l/ha – 54.5-55.4 g, respectively. The best results were obtained with the combined application of the biological product Phytohelp at a rate of 1 and 2 l/ha, foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 l of water or 0.5 c/ha and Liposam bioadhesive at a rate of 1 l/ha – 5.5 g in both variants. When using foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 l of water and Liposam bioadhesive at a rate of 1 l/ha, this indicator exceeded the control by 35.4 g. In 2018, the weather conditions for growing winter garlic were less favourable, but the control prevailed by 9.2-9.5% in the variant with the use of the biological preparation Phytohelp at a rate of 1-2 l/ha and the bioadhesive Liposam at a rate of 1 l/ha. With the combined application of the biological preparation Phytohelp at a rate of 1 and 2 l/ha, foliar feeding with mineral fertilizer Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water, this indicator exceeded the control variant by 10.4-11.6%, and in the variant with foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water and Liposam bioadhesive at a rate of 1 l/ha – by 9.2%. In 2019, a positive dynamics of the effect of biological products and mineral fertiliser on the weight of winter garlic bulbs of the Lyubasha variety was noted. In areas where joint fertilisation with the biological product Phytohelp was used at a rate of 1 and 2 l/ha, together with foliar fertilisation with the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water, the bulb weight was 55.4-56.4 g, respectively. On winter garlic crops, where the biological product Phytohelp was applied at a rate of 1 and 2 l/ha with foliar application of Drip Fert $N_{15}P_5K_{30}$+ME mineral fertilizer at a rate of 4 g/2 l of water, a lower bulb weight was observed, but they exceeded the control by 25.9 and 28.4 g. In the variant with the use of foliar fertilisation with mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water and bioadhesive Liposam at a rate of 1 l/ha, the bulb weight was 56.4 g, which exceeded the variant without fertilisation by 14.2% (Fig. 5).

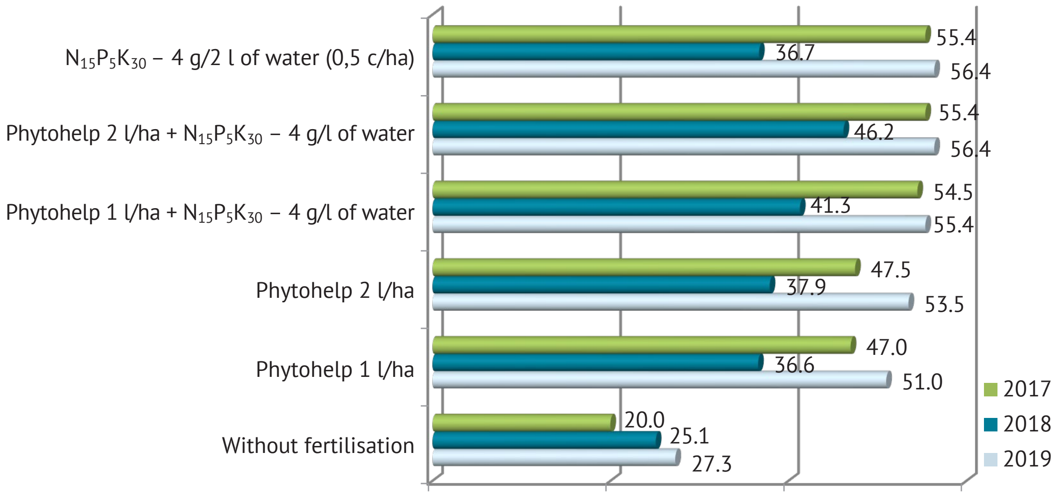


***Figure 5.** Weight of winter garlic bulb of Lyubasha variety depending on the method of fertilisation with biological product and complex mineral fertiliser (2017-2019), g*

***Source:** author's development*

On average, over the years of research, the highest yield of winter garlic variety Lyubasha was obtained with the combined application of the biological preparation Phytohelp at a rate of 1 and 2 l/ha, foliar fertilisation with the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water or 0.5 c/ha and the bioadhesive Liposam at a rate of 1 l/ha – 17.9 and 19.5 t/ha, an increase over the control was 9-10.6 t/ha. Biological preparations Phytohelp at a rate of 1-2 l/ha and Liposam at a rate of 1 l/ha contributed to an increase of 7.7-8.2 t/ha of winter garlic. The use of foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 litres of water or 0.5 c/ha and Liposam bio-sticker at a rate of 1 l/ha resulted in an increase in yield to 18.1 t/ha, while the increase in the control plots was 9.1 t/ha.

In 2017, in the first decade of July, the commercial bulbs of winter garlic variety Lyubasha were harvested, with yields exceeding the control by 2.4 and 2.8 times. In 2018, the highest productivity indicators were obtained in the variant with the combined application of the biological product Phytohelp at a rate of 1 and 2 l/ha and the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water or 0.5 c/ha, and the bioadhesive Liposam at a rate of 1 l/ha – 15.3 and 17.1 t/ha. In other experimental variants, the yield was 4.3-4.7 t/ha higher than in unfertilised plots. In 2019, weather conditions were more favourable for the formation of structural elements. These indicators were higher and the increase to the control ranged from 8.8 to 10.8 t/ha (Table 1).

***Table 1.*** *Yield of winter garlic variety Lyubasha depending on the method of fertilisation with biological product and complex mineral fertiliser t/ha*

| Fertilisation | Year | | | average | + - control |
|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | | |
| No fertilisation (control) | 7.4 | 9.3 | 10.1 | 8.9 | - |
| Phytohelp – 1 l/ha | 17.4 | 13.6 | 18.9 | 16.6 | 7.7 |
| Phytohelp – 2 l/ha | 17.6 | 14.0 | 19.8 | 17.1 | 8.2 |
| Phytohelp – 1 l/ha + $N_{15}P_5K_{30}$ – 4 g/2 l of water | 20.2 | 15.3 | 20,5 | 17.9 | 9.0 |
| Phytohelp – 2 l/ha + $N_{15}P_5K_{30}$ – 4 g/2 l of water | 20.5 | 17.1 | 20.9 | 19.5 | 10.6 |
| $N_{15}P_5K_{30}$ – 4 g/2 l of water (0.5 c/ha) | 17.4 | 13,6 | 18.9 | 18.1 | 9.1 |
| *$HIP_{05}$* | 0.808 | 0.614 | 0.881 | 0.788 | |

***Source:*** *author's development*

Various biochemical processes and moisture evaporation occur in the tissues of winter garlic bulbs, which leads to a decrease in their weight. According to the results of the study, it was found that the greatest weight loss was observed in the first weeks after harvesting – up to 24.8%. This is due to the loss of moisture accumulated during the growing season. Thus, with the combined application of the biological product Phytohelp at a rate of 1 and 2 l/ha, foliar feeding with the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water and the bioadhesive Liposam at a rate of 1 l/ha, the loss of bulb weight 2 weeks after harvesting was 19.9 and 24.8%. In the variant where the biological product Phytohelp was used at a rate of 1-2 l/ha and the bioadhesive Liposam at a rate of 1 l/ha, this indicator was 15.8-16.7%. When applying foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 litres of water, the bulb weight decreased by 15.8%. The harvested crop from unfertilised areas also recorded a weight loss of 7.3% (Fig. 6).

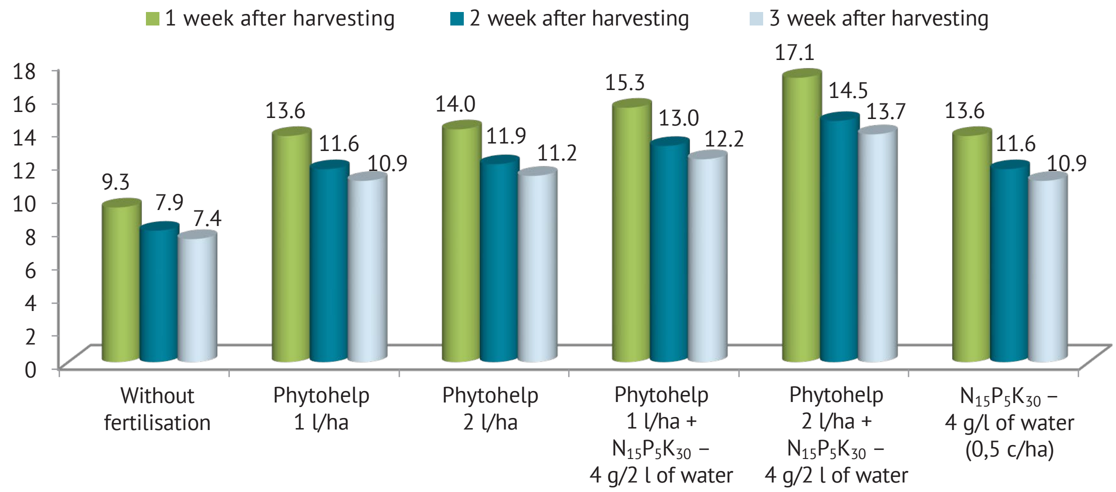


***Figure 6.*** *Productivity of winter garlic variety Lyubasha depending on the method of fertilisation with biological product and complex mineral fertiliser 1, 2, 3 weeks after harvesting, t/ha*
***Source:*** *author's development*

Three weeks after harvesting, a further decrease in the weight of the bulbs of winter garlic variety Lyubasha was recorded. With the combined application of the biological product Phytohelp at a rate of 1 and 2 l/ha, foliar feeding with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 l of water and Liposam bioadhesive at a rate of 1 l/ha, the bulbs decreased by 15.9-19.9%. When using the biopreparation Phytohelp at a rate of 1-2 l/ha and the bioadhesive Liposam at a rate of 1 l/ha, the losses were 12.6-13.3%. In the variant where foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 l of water was applied, the weight of garlic decreased to 12.6%, and in the control variant – by 5.8%.

## DISCUSSION

The results of this study provide scientific support to scientists to create an environmentally friendly technology for growing crops by applying organic fertilisers. These technologies provide for the efficient use of resources and contribute to the sustainable development of agriculture and industrial production. The use of organic fertilisers helps to avoid negative environmental impacts and maintains biodiversity. However, crop yields depend not only on climatic conditions but also on soil fertility. Y. Ma *et al.* (2023) argue that organic fertilisers, such as composts, humus or green manure, are a natural source of nutrients that contribute to soil enrichment. They help to support healthy microorganisms in the soil, such as bacteria and fungi, which help to retain nutrients and improve soil quality, as well as increase the organic carbon content. This is in line with the study conducted, where the effect of fertiliser on the vegetative growth of garlic parameters is positive.

Scientists A. Degwale *et al.* (2016) found that in Northwestern Ethiopia, before planting garlic, local application of vermicompost to the rows at a rate of 2.5-5 t/ha allowed to obtain a yield increase of 3 to 10%. In the same region, according to scientists F.T. Kenea & F. Gedamu (2018), after applying vermicompost at a rate of 2.5-7.5 t/ha, a larger assimilation surface area of garlic was obtained (17.6-35.4%), while both bulb weight (2.8 to 5.9%) and yield (15.9-38.7%) increased. A similar situation can be observed in this study, when fertilising with the biological product Phytohelp at a rate of 1 and 2 l/ha, foliar fertilisation with mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water and bioadhesive Liposam at a rate of 1 l/ha 60 days after spring regrowth, a larger leaf area of 349.2-404.8 $cm^2$/plant and a yield increase (average for three years) of 9.0 and 10.6 t/ha were observed. According to the phenological observations, a direct dependence on the rate of application of biological products was established. The average number of leaves in 30 days after spring regrowth varied between 4.2-5.1 pcs./plant, providing an assimilation surface of 25.2-50.1 $cm^2$/plant.

According to N. Hu *et al.* (2023), garlic yield had a positive correlation with TOC (Total Organic Carbon), DOC (Dissolved Organic Carbon) and POC (Particulate Organic Carbon). The increase in garlic production was facilitated by the increase in TOC, POC and DOC content, and the treatment with 1/3OF + 2/3NF organic fertilisers increased the garlic yield by 37.2 and 15.3%, respectively, compared to N0 and NF. The study shows that fertiliser application regimes can directly affect total soil organic carbon and labile organic carbon components, thereby affecting the organic carbon associated with aggregates. Aggregates with a particle size of 0.5-2 mm played an important role and had a positive effect on garlic yield. Analysing the results, it can be said that the application of organic fertilisers has the potential to increase the organic carbon content of the soil and also the yield of garlic. These conclusions are in line with those of H. Zhao *et al.* (2018), who showed that the combined use of organic and chemical fertilisers can improve soil structure and promote the aggregation of more soil particles.

X. Zhang *et al.* (2019) found that the best choice for increasing soil carbon sequestration and maize yields based on long-term experiments is organic fertiliser, which completely replaces chemical fertilisers. However, the nitrogen in organic fertilisers is mainly in the form of organic nitrogen. The needs of crop production are not fully met because the release of organic nitrogen and the supply of effective nitrogen to plants are slow. L. Zhang *et al.* (2023) found that the use of nitrogen fertilisers increased corn yields by 50.64%, $N_2O$ emissions by 64.39%, and $NH_3$ evaporation by 69.25%, respectively. Feeding winter garlic variety Lyubasha with nutrients from the biological product Phytohelp and mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME contributed to an increase in plant vegetative mass and bulb weight, and had an impact on yield. Something similar was noted in the work of V. Palamarchuk *et al.* (2024).

Having analysed the productivity indicators of winter garlic, it was noted that favourable weather conditions in 2019 contributed to the highest yield in all variants, except for the control 10.1 t/ha. The highest yields were collected from the plots where the combined fertilisation with the biological product Phytohelp at a rate of 1 and 2 l/ha, foliar fertilisation with the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME at a rate of 4 g/2 l of water and the bioadhesive Liposam at a rate of 1 l/ha were applied. O. Ulianych & V. Yatsenko (2018) found that the Sofiyivskyi garlic variety (multi-clove form) requires a maximum rate of biohumus of 5 t/ha, which increased the yield by 3.6 t/ha. For the Prometheus variety (small-toothed form), by increasing the weight of the tooth and increasing their number, the bulb weight also increases. In order to obtain a high yield, the optimal rate is considered to be 3-5 t/ha. G. Yarovyi & V. Kuzmenko (2013) noted in their work that the highest technical efficiency against tomato pathogens, namely 43.6-59.5%, was obtained in the variant where a mixture of biological products with plant growth regulators was used: Vermistim + Azotophyte and Bioglobin + Azotophyte.

In summary, most studies demonstrate the significant potential of organic fertilisers to improve soil fertility, conserve biodiversity and increase crop yields. The use of biological products and organic fertilisers is an effective strategy aimed at sustainable productivity growth and environmental sustainability in agriculture.

## CONCLUSIONS

The influence of the biological product Phytohelp and its combined use with the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME on the growth, development, formation and quality of winter garlic variety Lyubasha under drip irrigation was studied. According to the phenological observations, it was found that the highest rates were in the variants with the combined use of the biological product Phytohelp at a rate of 1-2 l/ha, Drip Fert $N_{15}P_5K_{30}$+ME – 4 g/2 l of water and the bioadhesive Liposam at a rate of 1 l/ha. The height of plants in the phase of intensive growth and development was 56.7-64.2 cm, which is 11.0-18.5 cm higher compared to the control. There was also a greater number of leaves per plant (7.5-8.0), which made it possible to obtain a larger leaf surface area – 349.2 and 404.8 cm$^2$/plant. In the variant where the biological product Phytohelp and the bioadhesive Liposam were applied at 2/1 and 1/1 l/ha, the plant height exceeded the control by 24.5-25.0%, the number of leaves was 6.8-7.4 pieces, and the assimilation surface area was 307.5-341.3 cm$^2$/plant. The use of foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser at a rate of 4 g/2 l of water contributed to an increase in height by 23.8%. The number of leaves was 7.3 pcs./plant, and the leaf surface area was 361.7 cm$^2$/plant. The use of foliar fertilisation with Drip Fert $N_{15}P_5K_{30}$+ME mineral fertiliser contributed to the production of winter garlic (18.1 t/ha) and an increase in yield (9.1 t/ha). The introduction of the biological product Phytohelp with Liposam adhesive at a dose of 2/1 and 1/1 was ineffective, but the yield increase was 8.2 and 7.7 t/ha. The yield was maximum when the biological product Phytohelp was applied together at a dose of 2 l/ha and the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME (4 g/2 l of water or 0.5 c/ha) with the adhesive Liposam (1 l/ha) – 19.5 t/ha, which is 1.7% more than in the control. When fertilising with the biological product Phytohelp at a dose of 2 l/ha and the mineral fertiliser Drip Fert $N_{15}P_5K_{30}$+ME (4 g/2 l of water or 0.5 c/ha) with the adhesive Liposam (1 l/ha), the yield increase was 9.0 t/ha, which is 1.6% more than in the control variant. Thus, the use of biological products and mineral fertiliser are effective methods for fertilising winter garlic. They have a positive effect on the height, number of leaves per plant and assimilation surface area, which helps to increase yields and improve plant quality. However, many mechanisms of interaction between plants and biological products in different soil and climatic conditions have not been identified. Also, the effect of biological products of different concentrations on plants and the environment has not been studied in more detail, which may be a prospect for further research.

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None.

## CONFLICT OF INTEREST

None.

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# Ефективність застосування біопрепаратів та мінеральних добрив на посівах часнику озимого в умовах Правобережного Лісостепу України

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**Анотація.** У статті представлено результати трирічних досліджень ефективності впливу біопрепарату Фітохелп, мінерального добрива Drip Fert $N_{15}P_5K_{30}$+МЕ та біоприлипач Липосам на структуру врожаю часнику озимого сорту Любаша в умовах краплинного зрошення. Актуальність досліджень обумовлена пошуком нових підходів до розробки технологічних прийомів вирощування часнику озимого із урахуванням конкретних умов нестійкого зволоження Лісостепу. Метою написання статті є встановлення оптимальних доз та співвідношення між ними для досягнення підвищення якості та врожайності часнику озимого. Дослідження було проведено на дослідному полі кафедри овочівництва національного визначеного внеску України Уманського національного університету садівництва на чорноземі опідзоленому важко суглинковому у 2017-2019 рр. В результаті було доведено, що в умовах Правобережного Лісостепу України на чорноземі опідзоленому за краплинного зрошення більшу урожайність отримано на ділянках за сумісного застосування біопрепарату Фітохелп нормою 1-2 л/га, мінеральне добриво Drip Fert $N_{15}P_5K_{30}$+МЕ та біоприлипач Липосам у нормі 1 л/га. Це дозволило отримати приріст до контрольного варіанту 9,0-10,6 т/га відповідно. Використовуючи біопрепарат Фітохелп та біоприлипач Липосам у нормі 2/1 та 1/1 л/га, одержано врожай 16,6-17,1 т/га, де надбавка до контролю становила 7,7-8,2 т/га. Встановлено вплив позакореневого підживлення мінеральним добривом Drip Fert $N_{15}P_5K_{30}$+МЕ (4 г/2 л води або 0,5 ц/га) на врожайність часнику озимого. Приріст до контролю становив 1,6 %. Результати проведеного дослідження можуть бути корисними для сільськогосподарських підприємств та фермерів, які займаються вирощуванням часнику та інших культур

**Ключові слова:** сорт; ріст; розвиток; цибулина; урожайність

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