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Formation of sunflower hybrid productivity by resource saving cultivation technologies in southern Ukraine

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Abstract. The implementation of resource-efficient technology in contemporary agricultural production enhances the productivity and efficiency of sunflower farming while mitigating environmental harm. The research aimed to examine the impact of various tillage techniques on sunflower farming in southern Ukraine. A field study was undertaken from 2021 to 2023 at the Educational and Research Centre of Mykolaiv National Agrarian University to achieve this objective. The research established that traditional tillage yields the lowest density of the topsoil (0-10 cm), signifying good soil aeration. At the same time, no-till cultivation is characterised by the highest soil density, but it helps to increase the reserves of productive moisture at all depths. Before sunflower harvesting, the no-till moisture content was 134 mm in the 0-100 cm layer, which is 26 mm more than in conventional

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tillage. The study showed that plant height and vegetative mass growth of sunflowers were higher than no-till in all growth stages. In the phase of two pairs of true leaves, the height of the plants under no-till was 16.8 cm, and during flowering – 176.2 cm. The growth of vegetative mass in the phase of two pairs of true leaves under no-till reached 135 g/m^2 and in the phase of seed formation – 1,380 g/m^2. The leaf area index under no-till was the highest in all phases of sunflower growth, in the flowering phase it was 4.8 m^2/m^2, which is 10% higher than under conventional tillage (4.2). The chlorophyll content was also the highest under no-till and in the flowering phase at 46 (SPAD units). In addition, the sunflower yield under conventional tillage was 3.56 t/ha, under minimum tillage – 3.85 t/ha, and no-till was the highest at 3.95 t/ha. The practical value of the study is to provide scientifically based recommendations for agricultural enterprises on the choice of the optimal method of soil cultivation, which can increase the competitiveness of Ukrainian sunflowers on the world market

Keywords: yield; soil cultivation; agrophysical parameters of soil; plant growth and development; vegetative mass

INTRODUCTION

The sustainable utilisation of natural resources is becoming increasingly critical in the context of population expansion and climate change. Population growth puts additional pressure on agriculture, increasing demand for food, fodder crops and raw materials for industry. At the same time, climate change is leading to a decrease in the availability of water resources, soil degradation and an increase in the frequency of extreme weather events such as droughts, floods and hurricanes. This makes it more difficult to ensure stable yields and increases risks for the agricultural sector (Coêlho *et al.*, 2022).

The rational use of natural resources such as water, soil, energy and fertilisers are becoming a key factor in ensuring the sustainable development of agriculture. Adapting agriculture to climate change requires a comprehensive approach. M. Duca *et al.* (2022) assert that employing hybrids resistant to adverse environments might markedly enhance plant resilience to extreme weather events. Agricultural practices, such as improving soil structure and its ability to retain moisture, can reduce the negative impact of climate change on crop yields. Risk management strategies development can assist in coping with unpredictable climate change and ensure the resilience of agricultural systems. Such strategies include developing plans for droughts or other abnormal weather events, as well as applying new technologies and farming methods.

The development of precision agriculture, including the use of drones and sensor technologies, contributes to more efficient resource management and cost reduction. Research in the field of agronomy and ecology allows for the development of new ways of cultivating soil, fertilising and managing water resources, which contributes to the resilience of agricultural systems (Casali *et al.*, 2022). According to S.I. Haruna & N.V. Nkongolo (2019) and B. Basile *et al.* (2021), resource-saving technologies can improve farm efficiency. In sunflower production, these technologies may encompass new hybrids distinguished by elevated yields, resilience to adverse environments, illnesses, and pests, as well as the efficient utilisation of available resources.

Sunflower is one of the most popular oilseeds in Ukraine, used to meet domestic needs and in exporting products. S. Kalenska *et al.* (2020) underscore the necessity of implementing resource-efficient growing practices in contemporary agricultural production, which enhance sunflower yield while mitigating environmental detriment. Among these technologies is no-till cultivation, which helps to preserve its structure and improve water retention properties. I. Kolosok (2022) believes that the use of no-till not only reduces the time and resources spent on tillage but also helps preserve moisture in the soil, which is especially important in arid climates. Precision agriculture systems, which use GPS navigation, drones, sensors and analytical software to collect and analyse data on soil, plant and weather conditions, can help determine exactly where and when to apply fertiliser or water to maximise resource efficiency and reduce costs. Following O. Kovalenko *et al.* (2024), mulching is also an effective element of cultivation technology, which involves covering the soil surface with organic or inorganic materials. Mulching not only helps to retain moisture, which is critical to ensuring crop stability but also reduces erosion, which helps to maintain soil fertility.

The implementation of resource-efficient technology improves the efficacy of sunflower cultivation and markedly diminishes the ecological footprint of agricultural output, which is crucial for the sector's sustainable development through resource conservation and the promotion of enduring productivity. Nevertheless, current research predominantly emphasises general energy-saving principles and inadequately considers their adaptation to particular regional conditions, such as the hot, low-humidity summers of southern Ukraine, which significantly impact sunflower cultivation and necessitate comprehensive energy-efficient solutions. The present research aimed to examine the impact of different tillage technologies on sunflower agriculture by evaluating the effects of various soil cultivation methods on agrophysical parameters, the growth and development of sunflower plants, and overall crop yield.

MATERIALS AND METHODS

From 2021 to 2023, a field experiment was carried out at the Educational and Research Centre of Mykolaiv National Agrarian University to investigate resource-efficient sunflower growing techniques with the P64HE133 hybrid. The studies were conducted on southern chernozem soil characterised by a neutral pH (6.8-7.2), elevated humus content (123-125 g/kg), and sufficient concentrations of nitrates, phosphate, and potassium. Sunflowers were planted at a density of 50,000 seeds per hectare while soil temperatures ranged from 8 to 10°C, succeeding winter wheat as the preceding crop. The 320 m^2 study area, comprising a 90 m^2 survey plot, was replicated thrice and evaluated three soil cultivation techniques: traditional ploughing to 25 cm followed by harrowing and shallow cultivation to 5-10 cm, minimal tillage employing disc harrows to a depth of 10-15 cm, and no-till, which preserves plant residues on the surface to mitigate erosion and enhance moisture retention. Laboratory and field observations were employed to evaluate plant growth, development, and yield under various growing strategies.

The research assessed the agrophysical properties of the soil, specifically the density of the topsoil, employing the M.A. Kachinsky method (Feketa, 2015), at intervals of 10 cm to a depth of 30 cm, and evaluated soil moisture using the thermostat-weight technique, measuring moisture content at various depths every 10 cm up to 100 cm through drying at 105°C. To evaluate the impact of different tillage methods on the growth and development of sunflower plants, regular measurements of plant height and vegetative mass growth were made in the following phases of sunflower growth and development: two pairs of true leaves, budding, flowering and seed formation. A metric ruler was used to measure the height of the plants, starting from the base of the stem to the top of the plant. This method was used to accurately track changes in plant height over time. To determine the vegetative mass, plant samples were collected, weighed the fresh weight and calculated for the average value for each variant.

Two key metrics were used to assess the photosynthetic activity of sunflowers under the influence of different tillage methods: leaf surface index and photosynthetic potential. To measure the leaf surface index, a portable leaf index analyser LI-COR LAI-2200C (LI-COR Biosciences, USA) was used. A portable device SPAD-Plus (Konica Minolta, Japan) was used to determine the photosynthetic potential. Harvest accounting was conducted with the continuous harvesting method on the designated plot, then converting the results to hectares. The data underwent processing via the multivariate analysis of variance (MANOVA) method, executed using Microsoft Excel and Statistica 10. The results were deemed statistically significant if the probability value (P) was less than or equal to 0.05, as assessed by the Student's T-test. The study was conducted following the requirements of the Convention "On Biological Diversity" (1992), as well as safety conditions.

RESULTS

Soil cultivation techniques profoundly impact soil structure, hydrology, and aeration, thus influencing plant growth and development. The study revealed that standard, minimal, and no-till methods differentially affected soil density at various depths (Fig. 1). Conventional tillage resulted in the lowest density of 1.1 g/cm^3 in the upper 0-10 cm layer, signifying effective loosening and enhanced soil structure, whereas density increased to 1.25 g/cm^3 at 20-30 cm due to diminished tillage practices. Minimal tillage led to a marginally elevated top-layer density of 1.13 g/cm^3, which increased to 1.33 g/cm^3 in deeper layers, indicating reduced soil aeration. No-till methods demonstrated the highest densities, recording 1.21 g/cm^3 in the surface layer and rising to 1.36 g/cm^3 at a depth of 20-30 cm, attributed to the accumulation of organic residues and the absence of mechanical disturbance. These variances illustrate the impact of diverse tillage practices on the agrophysical properties of soil, hence affecting total agricultural production.

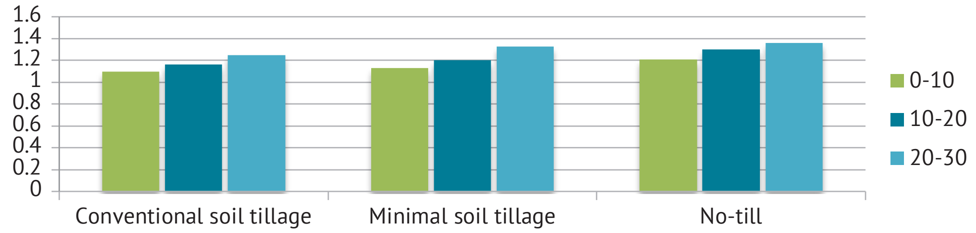

Figure 1. *Impact of ploughing techniques on soil density prior to sunflower harvest, g/cm*^{3} *(average for 2021-2023)*
Source: *compiled by the authors*

Soil moisture reserves are essential for the growth and development of crops, such as sunflowers. Soil moisture is influenced by numerous ways, with soil cultivation practices being particularly significant. The no-till approach has demonstrated superior efficacy in retaining soil moisture, hence enhancing plant growth, particularly under conditions of inadequate moisture. Consequently, the soil moisture before to harvesting sunflowers employing no-till in the 0-100 cm layer was 135 mm, exceeding minimum tillage by 9 mm and conventional tillage by 25 mm (Fig. 2).

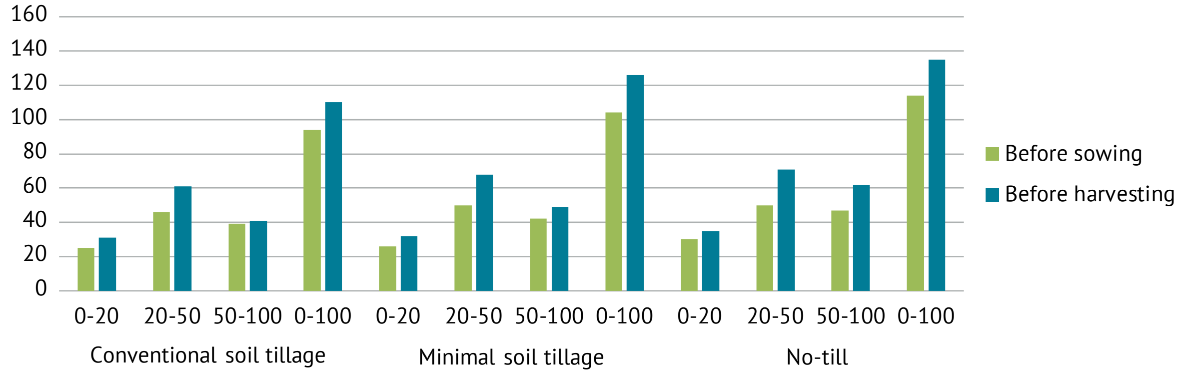

Figure 2. *Productive soil moisture reserves depending on cultivation methods, mm (average for 2021-2023)*
Source: *compiled by the authors*

The height of plants is an important metric of their growth and development, which affects the yield and general condition of crops. In this context, analysing the height of sunflower plants at different stages of their development is critical for assessing the effectiveness of different tillage methods. Table 1 shows the results of sunflower plant height measurements for three different tillage methods: traditional, minimal and no-till.

Table 1. *Growth in height of sunflower hybrid plants, depending on soil cultivation methods, cm (average for 2021-2023)*

Growth and development phase	Conventional soil tillage	Minimal soil tillage	No-till
Two pairs of real leaves	15.2	15.5	16.8
Budding	55.4	56.1	58.7
Blooming	170.8	172.3	176.2

Source: *compiled by the authors*

The height of the sunflower in the phase of two pairs of true leaves was the lowest for all treatments, but no-till provided the highest (16.8 cm) compared to the traditional (15.2 cm) and the lowest (15.5 cm). This shows the potential of no-till to improve early plant development. In the budding phase, the height of the plants under no-till reached 58.7 cm, which is the highest among the three methods. This is a sign of better plant development, which is supported by the optimal conditions provided by no-till. Plant height at flowering was also the highest for no-till (176.2 cm), confirming that no-till not only supports early development but also promotes plant growth in later stages. This demonstrates the positive impact of no-till on plant growth and a possible increase in yields.

Vegetative mass growth is a critical metric for assessing the effectiveness of agronomic practices, as it reflects plant development, health and productivity potential. The results of measurements of vegetative mass growth of sunflower plants under three different tillage methods show that in the phase of two pairs of true leaves, the mass growth was the lowest for all tillage options, but no-till provided the highest rate – 135 g/m^2 compared to traditional (120 g/m^2) and minimum (125 g/m^2) tillage. This shows the advantage of no-till in ensuring better plant development. In the budding and flowering phases of sunflower, the growth of vegetative mass under no-till reached 445 and 1,005 g/m^2, respectively, indicating that no-till contributes to a more efficient accumulation of vegetative mass in the middle stage of plant development. In the phase of seed formation, the growth of vegetative mass under no-till reached 1,380 g/m^2, which is 80 and 55 g/m^2 higher than under conventional and minimum tillage, respectively (Table 2).

Table 2. *Growth of vegetative mass of sunflower hybrid, depending on soil cultivation methods, g/m2 (average for 2021-2023)*

Growth and development phase	Conventional soil tillage	Minimal soil tillage	No-till
Two pairs of real leaves	120	125	135
Budding	400	420	445
Blooming	950	970	1,005
Seed formation	1,300	1,325	1,380

Source: *compiled by the authors*

Thus, in the phase of two pairs of true leaves, no-till influenced the formation of the leaf surface index at the level of 0.4 m²/m², which was higher than in conventional tillage (0.3 m²/m²) and minimal tillage (0.35 m²/m²). During budding, the no-till leaf surface index was 3.5, while in conventional tillage it was 3 and while minimum tillage – 3.3. During the flowering phase of no-till, the leaf surface index was 4.8, which was higher than conventional tillage (4.3) and minimum tillage (4.5). In general, the data show that no-till has a positive effect on the growth of the sunflower hybrid, providing the highest leaf area indexes at all growth stages. This shows that reducing soil disturbance through no-till can lead to improved crop growth and productivity (Fig. 3). Thus, no-till is the most effective for increasing the leaf area index in all phases of sunflower growth. But it is worth noting that minimal tillage also shows a positive impact on plant development compared to conventional tillage.

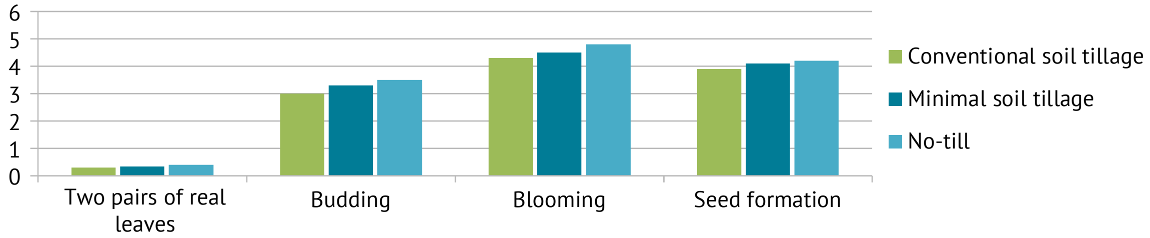

Figure 3. *Leaf area index of sunflower hybrid depending on soil cultivation methods, m²/m² (average for 2021-2023)*
Source: *compiled by the authors*

The chlorophyll content, assessed by the SPAD index as a measure of photosynthetic efficiency, was utilised to examine the impact of various soil cultivation methods on photosynthetic processes and overall plant health during critical growth stages. The research indicated that in the budding phase, no-till farming produced the greatest chlorophyll content, surpassing conventional tillage by 4.7 and minimal tillage by 3.4%. Minimal tillage exhibited a 1.3% increase in chlorophyll content relative to conventional tillage, signifying a moderate improvement in photosynthetic activity and plant health under reduced soil disturbance procedures. Using no-till, the chlorophyll content in the flowering phase of sunflower was the highest, exceeding conventional cultivation by 4.0 and minimum tillage by 2.8%. However, at the stage of sunflower seed formation, photosynthetic activity decreased (Fig. 4).

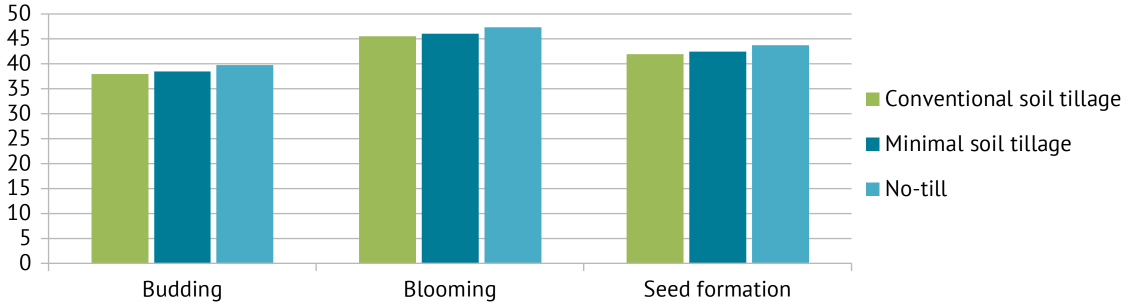

Figure 4. *Chlorophyll content in the leaves of sunflower hybrid depending on soil cultivation methods, SPAD units (average for 2021-2023)*
Source: *compiled by the authors*

The study findings demonstrate that no-till cultivation is the most effective method for enhancing sunflower photosynthetic activity across all growth phases, as indicated by the highest SPAD index compared to minimal and traditional tillage. Minimal tillage also positively affects photosynthetic efficiency, though to a lesser extent, while traditional tillage results in the lowest SPAD index. Additionally, the tillage method significantly impacts sunflower yields, with conventional tillage averaging 3.56 t/ha, minimal tillage achieving 3.85 t/ha, and no-till producing the highest average yield of 3.95 t/ha from 2021 to 2023. These findings highlight the superior performance of no-till practices in both plant health and crop productivity.

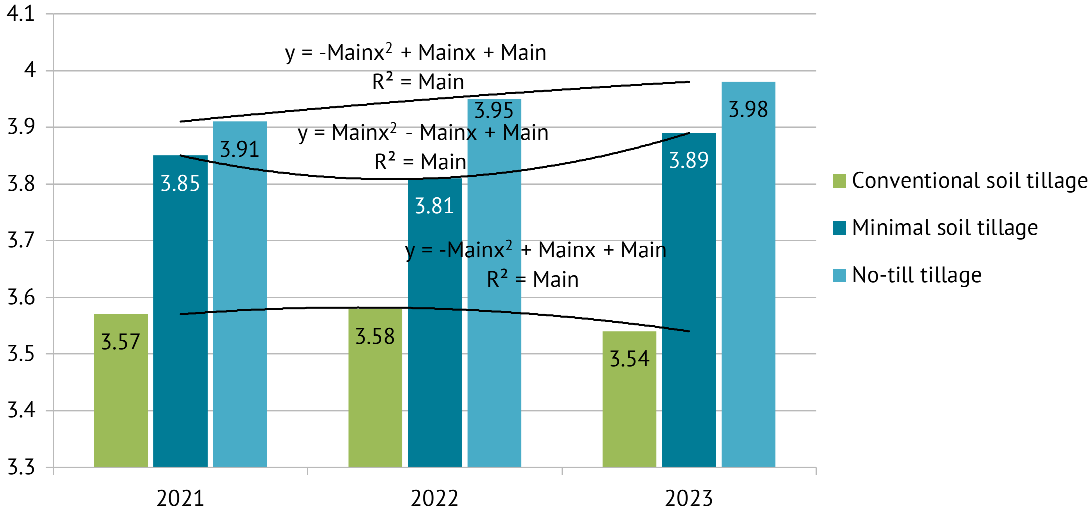

Figure 5. *Sunflower hybrid seed yield depending on cultivation methods, t/ha*
Source: *compiled by the authors*

In general, the results of the study show that no-till is the most effective way to improve the growth and development of sunflowers, including plant height, vegetative mass growth, leaf area index and photosynthetic potential. This method provides optimum conditions for plant development, preserves productive soil moisture and increases sunflower yields, making it recommended for use in southern Ukraine as a resource-saving sunflower cultivation technology.

DISCUSSION

Awareness of the necessity for sustainable production has increased, necessitating ongoing enhancement of agronomic techniques. The amalgamation of scientific inquiry, cutting-edge technologies, and effective resource management is increasingly vital to this process (Howell *et al.*, 2015). Most authors, including D.D. Avgoustaki & G. Xydis (2020) and O. Sydiakina & M. Ivaniv (2023), agree that the formation of sunflower hybrids productivity with the use of resource-saving technologies is a critical aspect of modern agricultural production. These technologies help to increase the productivity of sunflower hybrids by improving the conditions for their growth and development. They ensure optimum soil moisture and nutrient levels, which are critical to achieving high yields.

In addition, the results of numerous studies by scientists confirm that the use of resource-saving technologies leads to an increase in yields and product quality (Perea-Moreno *et al.*, 2018). According to V. Radić *et al.* (2021), the introduction of such technologies not only improves the physical and chemical properties of the soil but also contributes to an increase in microbiological activity, which in turn improves the availability of nutrients for plants. Importantly, this approach helps to preserve soil moisture, which is a critical factor in a changing climate, increasing the resistance of sunflower hybrids to drought and other stressful conditions.

The use of resource-saving technologies in agricultural production can lead to a significant reduction in energy costs, such as fuel for tillage, and reduce the need for chemical fertilisers. This can be achieved by optimising tillage processes, using energy-efficient equipment and precision farming. The findings of B. Li *et al.* (2022) affirm that optimising energy and material resource costs positively influences the economic efficiency of agricultural production, resulting in enhanced profits for agricultural producers and greater market competitiveness. In addition, reducing the cost of resource-saving technologies leads to a reduction in the overall environmental burden, as it reduces greenhouse gas emissions, and soil and water pollution, and helps to preserve biodiversity and ecosystem services. Thus, the use of resource-saving technologies in agricultural production can be beneficial not only for agricultural producers but also for the environment (Nardón *et al.*, 2021).

It should be noted that resource-saving technologies help improve soil quality by reducing erosion, preserving organic matter and improving its structure. As confirmed by Ya. Tsymbal *et al.* (2022), the use of mulching and no-till helps to preserve moisture, improve aeration and reduce the need for additional erosion control measures, which was also confirmed in the present study. This creates optimal conditions for plant growth, which in turn increases their productivity. According to the results of V. Gamayunova & A. Panfilova (2020), resource-saving technologies reduce the incidence of plant diseases by 30 and pests by 25% compared to traditional cultivation methods. This highlights the effectiveness of conservation practices in increasing overall plant resilience, which is associated with improved moisture retention, improved soil structure and optimised conditions for crop growth and development. Researchers such as A. Ozturk *et al.* (2022) and A.U. Jan *et al.* (2022), emphasise the need to optimise tillage technologies, especially in the southern regions. In these areas, where drought management and effective soil moisture conservation are critical, the right choice of cultivation methods can significantly improve crop production.

The results obtained show that no-till promotes plant height growth and increases vegetative mass. O. Tsyliuryk *et al.* (2021) also emphasise that no-till improves root development and promotes more efficient use of water and nutrients, which in turn leads to an increase in total biomass. However, I. Demir (2020) noted that in certain conditions, no-till can lead to a slowdown in initial plant growth. This is due to the limited access to certain nutrients that conventional tillage usually provides. Thus, although no-till demonstrates advantages in the long run, it is necessary to account for possible initial difficulties and adjust technological approaches to the specific conditions and needs of agricultural production.

The results of this study are consistent with the findings of V. Giannini *et al.* (2022), who noted that no-till improves its structure and aeration, which contributes to a more even distribution of the plant root system. This, in turn, increases their ability to absorb nutrients and moisture, which is a key factor in increasing photosynthetic activity. The authors also noted that reduction of mechanical impact on the soil with no-till reduces stress on plants, which contributes to better growth and increased yields. As such, despite the numerous benefits of resource-saving technologies, certain challenges should be considered. Following R. Puttha *et al.* (2023), even though no-till and other resource-saving methods can significantly improve soil quality and reduce resource costs, their implementation can be fraught with difficulties. These technologies require careful management of crop residues, which can accumulate on the soil surface and can lead to problems with disease and pest control, which contributes to their spread, and require additional measures to maintain plant health. In addition, the introduction of resource-saving technologies often involves the use of specialised equipment and technologies that may not be economically feasible for small farms or those who are just beginning to adapt to new methods. The cost of such equipment and the need for additional knowledge and skills to use it effectively can be a barrier for some agricultural producers (Domaratskiy *et al.*, 2023).

Thus, based on scientific research and analysis, the implementation of energy-efficient technology in sunflower production is a fundamental component of sustainable agricultural development. These technologies facilitate the conservation of natural resources, mitigate environmental degradation, and enhance the economic efficiency of agricultural output. The successful adoption of resource-saving technologies necessitates a holistic approach, encompassing meticulous planning and financial backing to guarantee the establishment of all requisite circumstances for their optimal utilisation.

CONCLUSIONS

The study demonstrated that soil cultivation methods significantly affect its density and water management, as well as the development and growth of sunflower plants. Conventional tillage resulted in the lowest density in the upper layer (0-10 cm), at 1.1 g/cm^3, signifying effective aeration and enhanced soil structure in this stratum. No-till had the greatest soil density, specifically 1.21 g/cm^3 in the 0-10 cm soil layer, and at a depth of 20-30 cm, the density attained 1.36 g/cm^3. A reduction in tillage intensity resulted in an augmentation of productive moisture stores at all depths. Prior to sunflower harvesting utilising no-till methods, the soil moisture within the 0-100 cm layer measured 135 mm, above that of traditional tillage by 25 mm (110 mm).

The examination of sunflower plant height indicates that at the stage of two pairs of true leaves, the height of plants under no-till was 16.8 cm, surpassing that of traditional tillage (15.2 cm) and minimum tillage (15.5 cm). During the flowering of sunflowers, the height of the plants under no-till was 176.2 cm. The growth of the vegetative mass of sunflower in the phase of two pairs of true leaves under no-till was 135 g/m^2, which is higher than under traditional (120 g/m^2) and minimum (125 g/m^2) treatments. In the phase of seed formation, the growth of vegetative mass under no-till reached 1,380 g/m^2, which exceeded the metrics of traditional (1,300 g/m^2) and minimum (1,325 g/m^2) treatments.

The study determined that no-till is the most effective for increasing the leaf surface index and chlorophyll content in sunflower leaves at all stages of their development. No-till provides the highest leaf area index (0.4-4.8) and chlorophyll content (34.5-47.3) compared to conventional (0.3-4.3 and 32.5-45.5 respectively) and minimum tillage (0.35-4.5 and 33-46 respectively). Minimal tillage also shows a positive effect on plant development compared to conventional tillage, although to a lesser extent than no till. The limitations of the study were determined by only one climate region, which may limit the generalisability of the results. Further research should address the effectiveness of no-till in different climatic zones to determine its efficiency.

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CONFLICT OF INTEREST

None.

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Формування продуктивності гібридів соняшнику за ресурсозберігаючими технологіями вирощування в умовах півдня України

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Анотація. Впровадження ресурсоефективних технологій у сучасному сільськогосподарському виробництві підвищує продуктивність та ефективність вирощування соняшнику, одночасно зменшуючи шкоду для навколишнього середовища. Метою дослідження було вивчення впливу різних способів обробітку ґрунту на вирощування соняшнику на півдні України. Для досягнення цієї мети з 2021 по 2023 рік було проведено польове дослідження в Навчально-науковому центрі Миколаївського національного аграрного університету. Дослідження показало, що традиційний обробіток ґрунту забезпечує найнижчу щільність верхнього шару ґрунту (0-10 см), що свідчить про добру аерацію ґрунту. Водночас, безвідвальний обробіток (no-till) характеризується найбільшою щільністю ґрунту, але сприяє збільшенню запасів продуктивної вологи на всіх глибинах. Зокрема, перед збиранням соняшнику no-till вологість становила 134 мм у шарі 0-100 см, що на 26 мм більше порівняно з традиційним обробітком. Дослідження продемонструвало, що висота рослин та наростання вегетативної маси соняшнику були вищими за no-till у всіх фазах росту. У фазі двох пар справжніх листків висота рослин при no-till становила 16,8 см, а під час цвітіння – 176,2 см. Наростання вегетативної маси у фазі двох пар справжніх листків за no-till досягало 135 г/м^2, а у фазі утворення насіння – 1380 г/м^2. Індекс листкової поверхні за no-till був найвищим у всіх фазах росту соняшнику, зокрема у фазі цвітіння він становив 4,8 м^2/м^2, що на 10 % більше порівняно з традиційним обробітком (4,2). Вміст хлорофілу також був найвищим за no-till, і у фазі цвітіння становив 46 (одиниці SPAD). Крім того, врожайність соняшнику за традиційного обробітку ґрунту становила 3,56 т/га, за мінімального – 3,85 т/га, а за no-till була найвищою, і сягала 3,95 т/га. Практична цінність дослідження полягає у наданні науково обґрунтованих рекомендацій для сільськогосподарських підприємств щодо вибору оптимального способу обробітку ґрунту, що може збільшити конкурентоспроможність українського соняшнику на світовому ринку

Ключові слова: врожайність; обробіток ґрунту; агрофізичні показники ґрунту; ріст і розвиток рослин; вегетативна маса

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Prerequisites for innovative development of livestock and agriculture through the integration of agricultural production and environmental safety

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Abstract. A multi-year analysis of the state of the livestock sector in the period before the outbreak of war in 2022 is important for the post-war recovery of Ukraine's regions. The purpose of the research was to identify the factors of losses in the production of livestock products, methods and means of integrated development. The generally accepted methods in zootechnology were followed, the study was conducted over a thirty-year period (1991-2021) in accordance with the stages of research work number: 0121U113933 of 18.11.2021. It was found that the number of cattle decreased by 8.4 times, and cows – by 5.2 times. Gross milk production decreased by 2.7 times, and beef and veal production – by 4.5 times. Improving the genetic potential of livestock, feeding, and housing contributed to an increase in cow productivity by 2,842 kg on average in the region and by 4,693 kg at the enterprises. As of 01.01.2021, 5 stud farms of the Ukrainian Black-and-White dairy breed were established with a population of 12,369 heads, including 4,647 cows, with a milk yield of 9,749 kg in 2020. The profitability of milk production in 2019 was 20.6%, while cattle breeding for meat was unprofitable (-27.1%). Many farms turn manure into compost and apply it to the soil for ploughing. Between 1991 and 2021, the Kharkiv region lost the potential of the dairy industry, the number of cattle decreased, with the largest decline in 1991-2001 (6.54 times). Milk production decreased by 2.7 times and beef and veal production by 4.5 times, with the main "drop" occurring between 1990 and 2010 (by 2.7 and 4.5 times respectively). The average annual milk yield per cow in the region from 1990 to 2020 increased by 2,840 kg and in 2020 amounted to 5,821 kg. Practical value: the article is the first to provide a long-term analysis of the state of the cattle breeding industry before the outbreak of hostilities in Ukraine, taking into account technological, organisational and economic aspects

Keywords: organic fertilisers; humus; soil; restoration of fertility; milk; beef

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INTRODUCTION

The successful functioning and development of each individual production and social unit of society depends on its ability to provide itself with food, first and foremost. One of the most challenging issues in ensuring a high standard of living is the production and supply of milk and meat. At the same time, it is important to preserve the environment and maintain soil fertility. Restoring the number of cattle in the post-war period is important in terms of increasing the production of high-quality milk and beef meat, taking into account modern technologies for breeding, feeding and housing animals.

Increasing cows' milk production helps to solve environmental problems. US scientist J.K. O'Hara (2023) investigates the intensity of greenhouse gas emissions from milk production. The higher the productivity of animals, the less greenhouse gases are produced in the intestines and the less they are released into the environment. The researchers D.V. da Silva *et al*. (2024) tried to propose and determine the net environmental performance of different milk production systems. A case study of a closed composting farm located in South-Eastern Brazil was chosen as a baseline scenario. The results and benefits of the ecosystem were aggregated and converted into monetary units per kg of milk. The semi-closed systems had the worst environmental performance compared to milk production on the farm where composting was applied.

The intensive development of each individual branch of the agricultural sector of the economy and balanced entrepreneurship, as well as in the complex of a large region, should be based on the principles of preserving, improving and strengthening production resources. It is on these principles that land and its agricultural land should be used, because it is not only a platform for living beings, but from the point of view of the economic category, land is the main means of production and requires rational use. Scientists from China, J. Chang *et al*. (2018), point out that rational land use in karst areas can increase the productivity of water and fertiliser use. They propose that agricultural land on sloping areas should be converted to forested areas with moderate grazing, while agricultural land on flat areas should adopt a grain-forage and grain-soybean rotation to meet the needs of a growing population and ensure economic development.

Selection and breeding work plays an important role in increasing animal productivity. Scientists L. Khmelnychyi & B. Karpenko (2023) note that the use of linear classification in the breeding process of dairy cattle to determine the breeding value of cows is a fairly effective means of objectively determining the breed characteristics of the exterior type. The presence of a correlation between the final score and the level of milk production will contribute to the efficiency of selection in the indirect selection of animals for these traits.

An important factor in animal productivity is well-balanced feeding and the use of effective innovative techniques. Researchers M.M. Wright *et al*. (2024) show that adding rapeseed cake to grain mixtures can improve milk production and increase milk fat and protein yields. In addition, there are no milk yield benefits when some barley is replaced with maize in a wheat-barley mix fed to cows grazing on.

L. Cesarini *et al*. (2024) analysed and forecast changes in agriculture at a national scale, which is essential for developing strategies to ensure food security and stability of the entire agri-food chain. This is often challenging as data is usually sparse and long detailed reports are rarely available, but researchers have tried to develop some models to forecast monthly milk production in France, Germany and Italy using climatic and economic variables from open datasets as inputs.

Over the last 30 years (1991-2021) covered by the research, the use of mineral fertilisers in soils has decreased tenfold, and organic fertilisers by 5-7 times, while at the same time, humus has been leached from the soil through erosion and nutrient removal with the harvest. According to O. Drebot *et al*. (2024), special attention should be paid to the issues of economic activity to balance environmental and economic factors on the basis of social relations, which necessitates the restructuring of land and the structure of sown areas of major crops, taking into account the regional characteristics of the general phytosanitary state of the cenosis of a particular region, weather and climatic, relief and soil conditions. Scientists I. Shumyhai *et al*. (2023) point to a biogeochemical imbalance of molybdenum in the agricultural landscapes of the Forest-Steppe zone of Ukraine, where a lack of the element in the soil was found. Technogenic migration in the soil cover is manifested by its increased dispersion. O. Mamenko *et al*. (2021) focus on the emergence of biogeochemical endemics. This has been significantly affected by the ruthless ploughing of land in both Ukraine and Kharkiv region, high energy consumption, disruption of ecological balance, reduced soil fertility, and the decline of livestock production. Under such extreme conditions, the number of cattle decreased by 8.4 times, milk production – by 2.2 times, and meat production – by 2.2 times. The authors highlight the attempts to find a way out of the crisis, but restoring soil fertility and raising cows is a long-term endeavour.

The purpose of the research was to identify the causes and factors of losses in the production of livestock products in Kharkiv region, to determine methodological principles and methods, means of integrated development of livestock and agriculture through mutually necessary sectoral components of agricultural progress.

MATERIALS AND METHODS

This study analyses the state of livestock and agriculture in the Forest-Steppe zone of Ukraine. A 30-year period of time was analysed – from 1991 to 2021, the last three ten-year periods. The dynamics of cattle numbers in general and by categories of farms in Kharkiv region, milk and beef production per capita, along with livestock numbers, gross and average productivity data, were studied, and the contribution of the livestock sector to the development of crop production and soil fertility in Kharkiv region was calculated. Statistical data are taken from the State Statistics Service of Ukraine (n.d.). The authors worked with the data from the annual reports of breeding plants in printed format, so it is not possible to provide an electronic link. When taking average samples of feed, milk, and organic waste, the methods generally accepted in zootechnical practice were followed, the method of ecological monitoring of ecosystems was used, and the study was conducted in accordance with the stages of the research work State Registration Number: 0121U113933 (Fig. 1).

Registration card for research and development work

State Registration Number: 01210113933
Public Date of Registration: 18-11-2021
Status of the performer: 17 Chief Executor

Figure 1. *Registration card for research and development work*
Source: *Ukrainian Institute of Scientific and Technical Expertise and Information (n.d.)*

The analysis was based on the scientists' own research and international scientific publications. The scientific and economic experiments were conducted in cattle-breeding enterprises of the Forest-Steppe zone of Ukraine, whose biogeocenoses are subject to increased anthropogenic pressure near industrial cities, oil and gas production and processing sites, and major motorways. The experiments were conducted on dairy cows of the Ukrainian Black-and-White dairy breed with different types of feeding: silage-silage-concentrate feeding, silage-silage, silage-root crops and silage-hay feeding, respectively. Animals were selected by the method of analogues for live weight and milk production and divided into three groups: the first control group and the second and third experimental groups. To improve the quality, environmental safety of cow's milk and cow productivity, the main feeding ration for the experimental groups was balanced with a specially developed vitamin and mineral premix. An experiment was also conducted on calves in the dairy period. Laboratory analysis of selected samples of plant and animal origin for the content of macro- and microelements, including heavy metals, was carried out by atomic absorption spectrophotometry (AAS-30 spectrophotometer, Germany), which gives a minimum error in sample analysis. The quality and environmental safety of milk was monitored in accordance with DSTU 3662:2018 (2019), as well as the requirements of international quality standards (Regulation of the European Parliament..., 2004). The following data were also used for the analysis: State Enterprise... (n.d.), State Register of Breeding Subjects... (2021). The monographic method, method of analysis and synthesis, empirical and comparative methods were used in writing the paper. The calculation was carried out in the STATISTICA software package version 10.0.

RESULTS

While in 1991 Kharkiv region was ranked 4th in Ukraine by cattle and 5th by cows, in 2021 it was ranked 8th and 11th, respectively. The decline in cattle numbers has been a long-standing problem in Ukraine due to the lack of an effective government support programme. That is, the loss of cows, which is the main means of production, reached 80.9% (Table 1).

Table 1. *Dynamics of the number of cattle and % of the total in Ukraine by categories of farms in the Kharkiv region (as of 1.01, thousand heads – from 1991 to 2021)*

Groups of livestock	Unit of measurement	Years					2021 to 1991, %
		1991	2001	2011	2015	2021	
In farms of all categories							
Total cattle	heads	1,274.6	466.2	194.8	192.1	151.9	11.9
	%	5.18	4.95	4.33	4.95	5.28	
including cows	heads	415.0	217.3	100.5	92.7	79.3	19.1
	%	5.00	4.39	3.82	4.10	4.32	
At enterprises							
Total cattle	heads	1,203.8	338.4	96.8	96.9	79.9	6.6
	%	5.71	6.72	6.34	7.40	7.92	

Table 1, Continued

Groups of livestock	Unit of measurement	Years 1991	2001	2011	2015	2021	2021 to 1991, %
including cows	heads	371.9	133.4	39.9	37.3	32.3	8.7
	%	6.01	7.48	6.775	7.05	7.62	
In the farms							
Total cattle	heads	-	3.6	4.0	4.7	3.8	105.6
	%	-	3.51	4.20	4.50	3.46	
including cows	heads	-	1.4	1.6	1.8	1.7	121.4
	%	-	3.91	4.20	4.81	3.90	
In the households							
Total cattle	heads	70.8	127.8	98.0	95.2	82.5	116.5
	%	2.00	2.91	3.30	3.70	3.86	
including cows	heads	43.1	83.9	60.6	55.4	46.8	108.6
	%	1.97	2.70	2.94	3.20	3.19	

Notes: *% of total livestock in Ukraine*
Source: *developed by the authors*

It is worth noting that with the outbreak of full-scale aggression, in the first months of the war, the dairy industry suffered the greatest losses (Bal-Prylypko *et al.*, 2024). After the "shock period", industrial farms in the frontline and near-frontline zones tried to save themselves as best they could. A certain number of animals died. Those who could do something moved their livestock to safer areas in the central and Western regions. That is why in critical regions, including Kharkiv region, dairy farms reduced their livestock by 47.3% (to 17.4 thousand), in Sumy region – by 5.2% (to 25.6 thousand), and in Chernihiv region – by 4.1% (37.9 thousand). The number of cattle increased in Ternopil region, with an increase of 17.5% (16.1 thousand), Odesa region – 14.5% (6.3 thousand), Ivano-Frankivsk region – 12.2% (4.6 thousand). According to the State Register (2021), as of 1 December 2022, the largest number of cattle was concentrated in Poltava (54.1 thousand), Cherkasy (43.1 thousand) and Chernihiv (37.9 thousand) regions. In general, according to the Unified State Register of Animals, there were 1.98 million cattle in Ukraine at the beginning of 2023. The largest number of cattle was in Vinnytsia region (154.6 thousand), Poltava region (151.9 thousand) and Cherkasy region (130.1 thousand). As of 1 July 2024, the number of cattle in the Unified State Register of Identified and Registered Animals was 1,867,858 heads (State Enterprise..., n.d.).

According to preliminary data from the Ministry of Agrarian Policy and Food of Ukraine, as of 1 April 2024, 2 million 330.5 thousand cattle were kept in the household and industrial sector, including 1 million 263.8 thousand cows. Compared to March 2024, the number of cattle increased by 76 thousand heads (+3%), and the number of cows increased by 3.3 thousand heads (+0.3%). Compared to April 2023, the number of cattle decreased by 172.4 thousand heads (-7%), including 91.1 thousand heads (-7%) of cows. About 39% of animals are kept at industrial enterprises, while 61% are kept in households. Many farmers are keeping cows in wartime conditions and are experiencing a shortage of working capital. The cost of keeping animals is becoming more expensive, as are the costs of feed preparation, diesel fuel and electricity, and profitability is decreasing. Injured animals have to be culled. Production costs are rising much faster than prices for finished products, as people have low purchasing power. The reduction of pasture and agricultural land due to mine and shell contamination remains a challenge. Nevertheless, in 2024, the decline in the number of cattle slowed markedly compared to 2023, and the time for some stabilisation is coming. Moreover, compared to the previous year, the number of cattle in households in Kharkiv region increased by 1% (The number of cattle..., 2024).

In 2020, total milk production in Kharkiv region decreased to 469.9 thousand tonnes, or 2.7 times (-800.7 thousand tonnes compared to 1990). Beef and veal production (in slaughter weight) also decreased, except for households. During the research period, it was found that investments in improving the genotype of dairy herds, more efficient breeding, more intensive milk production technologies, rational feeding, and comfortable housing conditions ensured an increase in milk yield in Kharkiv region to 7,698 kg. The main breed here is the newly created Ukrainian Black-and-White dairy breed, which has a high milk yield potential. There are five breeding plants of this breed in the region, and as of 01.01.2021, there were 12,369 heads, including 4,647 cows, with a milk yield of 9,749 kg each, which is twice as high as the regional average for farms of all categories (State Register of Breeding Subjects..., 2021). However, the loss of a significant number of cows and the lack of regulation in the production sector led to a decrease in gross milk production and a shortage of milk per capita for the population of Kharkiv region (Table 2).

Table 2. *Dynamics of milk and meat production per capita in Ukraine and Kharkiv region, kg*

Region	Unit of measurement	Years 1990	2000	2010	2015	2020	2020 to 1990, %
Production of all types of milk, kg							
Ukraine	kg %	472.3 100	257.4 54.5	245.2 95.3	247.8 101.1	221.9 89.5	47.0
Kharkiv region	kg %	397.6 100	182.8 46.0	169.1 92.5	192.5 113.8	177.6 92.2	44.7
Production of all types of meat (in slaughter weight, kg)							
Ukraine	kg %	84.0 100	33.8 40.2	44.9 103.0	54.2 120.7	59.3 109.4	70.6
Kharkiv region	kg %	71.3 100	28.6 40.1	30.1 105.2	34.6 115.0	33.1 95.7	46.4
Beef and veal production (in slaughter weight, kg)							
Ukraine	kg %	38.7 100	15.3 39.5	9.3 60.8	8.9 95.7	8.2 92.1	21.2
Kharkiv region	kg %	31.7 100	11.6 36.6	8.2 70.7	8.5 103.7	8.6 101.2	27.1

Notes: *% to the previous period*
Source: *developed by the authors*

Feed costs for the production of 1 tonne of live weight gain of cattle, 1 tonne of milk and one head of cattle in enterprises were within the traditional range and only in recent years (2018-2020) have increased significantly, with the main reason being feed quality (Table 3).

Table 3. *Feed costs for the production of 1 centner of cattle growth in enterprises, centner of feed per unit*

Region	Feed of all kinds 2010	2015	2018	2019	2020	of which are concentrated 2010	2015	2018	2019	2020	2020 to 2015 (all types / of them concentrated), %
Ukraine	15.69	14.80	12.06	13.95	12.84	4.47	4.93	5.79	6.65	6.12	81.8 / 136.9
Kharkiv region	14.68	15.36	13.73	14.19	13.37	4.20	5.23	6.51	6.51	6.52	91.1 / 147.1
Region to Ukraine, %	93.6	103.8	113.8	101.7	104.1	94.0	106.1	112.4	98.0	101.0	
Feed costs per cent of milk production in enterprises, centner of feed per unit											
Ukraine	1.18	1.00	0.86	0.89	0.84	0.37	0.41	0.48	0.49	0.46	71.2 / 124.3
Kharkiv region	0.98	1.02	0.87	0.87	0.83	0.35	0.44	0.49	0.49	0.47	84.7 / 134.2
Region to Ukraine, %	83.0	102.0	101.2	97.8	98.8	94.6	107.3	102.1	100.0	102.2	
Feed consumption per 1 head of cattle in enterprises, centner of feed per unit											
Ukraine	26.73	26.46	29.19	29.59	28.78	17.95	19.41	24.37	24.89	24.20	107.7 / 134.8
Kharkiv region	28.94	31.88	36.16	36.35	36.24	18.16	19.36	24.94	25.53	25.44	125.2 / 140.2
Region to Ukraine, %	119.2	120.5	123.9	122.8	125.9	101.2	99.7	102.3	102.8	105.1	

Source: *developed by the authors*

The period of the last 10 years (2010-2020 in the dynamics by years) was chosen for the analysis of feed costs (Table 3). The costs per 1 centner of cattle growth in the region's enterprises were lower than in Ukraine only in 2010, and then they grew and in 2020 increased to 4.1% of the average for Ukraine. There was no significant difference between the figures for Ukraine and Kharkiv region and between the years of the study period in terms of feed costs per 1 cent of milk production at milk production enterprises. However, the cost of feed per head of animals in the region was higher (the difference reached 25.9%, 5.1 in 2020), and feed costs have increased significantly over the past three years (2018-2020) (Ukraine = +34.8, Kharkiv region = +40.2 for feed).

The share of cattle in the Kharkiv region kept in farms of all categories in the national total varied from 5.18 (1991) to 5.28% (2021), including the number of cows – from 5.00 to 4.32%. In 2021, according to the State

Statistics Service of Ukraine (n.d.), Ukraine produced 8.72 million tonnes of milk, which is 5.9% less than in the previous year. At the same time, agricultural enterprises produced 2.75 million tonnes (0.4% less), and households produced 5.97 million tonnes (-8.2%). Poltava, Vinnytsia and Khmelnytsky regions became the leaders in milk production, although milk production in these regions also decreased compared to the previous year. Luhansk, Donetsk and Zaporizhzhia regions produced the least amount of milk. The productivity of the dairy herd in all categories of farms increased by 1.7 times on average in Ukraine and by 2.1 times in Kharkiv region. The most significant increase in cow productivity was in enterprises – by 2.5 and 2.6 times, respectively. Of all the categories of farms in the Kharkiv region, enterprises produce the most milk. In 2020, 52.1% of total gross milk production was produced by enterprises, which is 8.87% of the national production (Table 4).

Table 4. *Dynamics and share of milk and meat production of cattle in the total production in Ukraine by categories of farms in Kharkiv region from 1990 to 2020*

Types of enterprises	Unit of measurement	Years 1990	2000	2010	2015	2020	2020 to 1990, ±
		Milk production					
Farms of all categories	ths. tonnes	1,270.6	539.6	467.2	524.5	469.9	-800.7
	%	5.18	4.26	4.15	4.94	5.07	
Enterprises	ths. tonnes	1,133.0	279.4	175.2	232.6	244.8	-888.2
	%	6.08	7.62	7.90	8.71	8.87	
Private households	ths. tonnes	137.6	260.2	292.0	291.9	225.1	+87.5
	%	2.34	3.72	3.23	3.67	3.46	
Farms	ths. tonnes	-	2.3	6.5	10.6	9.0	+389
	%	-	3.39	5.80	5.98	4.02	
		Beef and veal production (in slaughter weight, thousand tonnes)					
Farms of all categories	ths. tonnes	101.5	34.4	22.7	23.2	22.7	-78.8
	%	5.11	4.56	5.31	6.04	6.57	
Enterprises	ths. tonnes	94.6	14.6	5.5	5.4	6.1	-88.5
	%	5.23	4.78	5.25	5.76	7.19	
Private households	ths. tonnes	6.9	19.8	17.2	17.8	16.6	+9.7

Notes: *% of total production in Ukraine*
Source: *developed by the authors*

Beef and veal production (in slaughter weight) in 2020 was almost 4.5 times lower in all categories of farms in the region compared to 1990. By category of farms, the share of gross production produced by enterprises is 7.19% and by households – 6.37%. The most objective and economically justified indicator of cattle productivity is the milk yield of cows (Table 5).

Table 5. *Average annual milk yield per cow, kg*

Region	Index	Years 1990	2000	2010	2015	2020	2020 to 1990, %
		Farms of all categories					
Ukraine	kg	2,863	2,359	4,082	4,644	5,129	179.1
	%	100	82.4	173.0	113.8	110.4	
Kharkiv region	kg	2,979	2,137	4,560	5,483	5,821	195.4
	%	100	71.7	213.7	120.2	106.2	
		At enterprises					
Ukraine	kg	2,941	1,588	3,975	5,352	6,634	225.6
	%	100	54.0	250.3	134.6	124.0	
Kharkiv region	kg	2,975	1,689	4,413	6,302	7,698	258.8
	%	100	56.8	261.3	142.8	122.2	
		At private households					
Ukraine	kg	2,637	2,960	4,110	4,497	4,666	105.2
	%	100	139.9	108.0	108.0	105.2	
Kharkiv region	kg	3,017	3,059	4,660	4,937	4,545	150.6
	%	100	101.4	152.3	105.9	92.1	

Notes: *% to the previous period*
Source: *developed by the authors*

Investments in the development of the dairy industry in enterprises over the past decade (2010-2021) have created more opportunities to improve genetic potential, apply intensive production technologies, improve feeding, and create more comfortable conditions. As a result, the average annual milk yield per cow in Ukrainian enterprises increased to 6,634 kg, and in the region – to 7,698 kg, which is more than in households by 1,968 and 3,153 kg. However, as of 01.01.2021, the number of cows kept in Ukrainian enterprises has significantly decreased and amounts to only 25.3%, and to 40.7% of the total in the region. A new Ukrainian Black-and-White dairy breed is being introduced in Kharkiv region. There are five breeding plants in the region that are engaged in the improvement of cattle of this breed with a total number of 12,369 heads of breeding cattle as of 1 January 2021, including 4,647 heads of cows. According to the annual reports of breeding plants for 2020, the milk yield per cow is 9,749 kg, which is almost twice as high as the average for farms of all categories in the region (190.1%). Gradually, from year to year, the livestock sector (especially meat production) in the country is not profitable, as evidenced by the level of profitability of production at the enterprises of the region (Table 6).

Table 6. *The level of profitability of milk and meat production at enterprises*

Types of products	Years							
	1990	2000	2012	2015	2016	2017	2018	2019
Milk	32.2	-6	1.8	12.7	18.6	26.9	16.1	20.6
Cattle for meat	20.6	42.3	-28.3	-16.9	-23.2	3.4	-17.7	-27.1

Source: *developed by the authors*

The production of cattle meat has led to a critical state of the industry due to a decrease in the number of livestock and production volumes (Kopytets & Voloshyn, 2020). Volatility in purchase prices for livestock products, low purchasing power of the population, imperfect import regulation and financial and credit policy in the agricultural sector, as well as unregulated relations in the areas of production, harvesting, processing and trade have led to the decline of the industry. In Ukraine and in Kharkiv region, due to the decline in gross livestock production, milk and meat production per capita lags far behind physiological standards (380 kg of milk and 80 kg of meat) and continues to decline (Table 7).

Table 7. *Dynamics of milk and meat production per capita in Ukraine and Kharkiv region, kg*

Region	Unit of measurement	Years					2020 to 1990, ±
		1990	2000	2010	2015	2020	
Production of all types of milk, kg							
Ukraine	kg	472.3	257.4	245.2	247.8	221.9	-250.4
	%	100	54.5	95.3	101.1	89.5	
Kharkiv region	kg	397.6	182.8	169.1	192.5	177.6	-220.0
	%	100	46.0	92.5	113.8	92.2	
Production of all types of meat (in slaughter weight, kg)							
Ukraine	kg	84.0	33.8	44.9	54.2	59.3	-24.7
	%	100	40.2	103.0	120.7	109.4	
Kharkiv region	kg	71.3	28.6	30.1	34.6	33.1	-38.2
	%	100	40.1	105.2	115.0	95.7	
Beef and veal production (in slaughter weight, kg)							
Ukraine	kg	38.7	15.3	9.3	8.9	8.2	-30.5
	%	100	39.5	60.8	95.7	92.1	
Kharkiv region	kg	31.7	11.6	8.2	8.5	8.6	-29.1
	%	100	36.6	70.7	103.7	101.2	

Notes: *% to the previous period*
Source: *developed by the authors*

While from 1990 to 2010, the production of milk and meat of all kinds per capita continued to decline, from 2010 to 2015, milk production per capita increased by 2.6 kg on average in Ukraine and by 23.4 kg in the region, in 2020, compared to 2015, milk production decreased by 10.5% on average in Ukraine and by 9.2% in the region, and is 58.4 and 46.7% of the physiological norm, respectively.

As for the production per capita of all types of meat, from 2015 to 2020, it increased by 5.1 kg in Ukraine and decreased by one and a half kilograms in the region, and in 2020 it was 67.8% of the normative indicators on average in Ukraine and 41.4% in the region. Of all the types of meat, beef and veal are the least produced per person in the country (8.2 kg), which is only 21.2% of the 1990 figure, and in Kharkiv region (8.6 kg and 27.1%, respectively). A particular threat to livestock farming is posed by the government's attempt to meet domestic demand for meat and dairy products through imports. This actually brings the country closer to the critical point of national food security, but the loss of soil fertility is very dangerous.

Over 30 years, the gross production of bedding manure has decreased by 8.4 times, while the area of agricultural land has remained virtually unchanged. Cows processed feed into milk, and the production of organic fertilisers from them has also decreased significantly (by 5.2 times) over such a long period, but this is much less than the total number of cattle. However, in enterprises, organic production decreased by 15 times (including 12.1 times from cows). In 2020, households and farms produced organic matter steadily and returned 60% of the total volume of bedding manure production to land. A decrease in cattle numbers and a decrease in animal consumption of bulk (hay, haylage) and an increase in concentrates in the diet resulted in a loss of organic fertiliser production as soil fertility deteriorated.

During the stall period (210 days), the manure output per cow is 7 tonnes, but during the so-called grazing period (155 days), cows in Kharkiv region are kept tied up, and the average annual manure production reaches 12 tonnes per cow (5 tonnes on average for young cattle). Of the total feed fed to cattle, 60% is absorbed, 5% is lost, and 35% is excreted as excrement, which, together with the remains of uneaten feed and bedding material, forms manure. Manure contains nutrients that are essential for plant life, and it contains 50-70% of nitrogen, which is absorbed by plants after mineralisation in the first year of application to the soil and is the starting material for humus formation. Manure is divided into bedding, semi-liquid, liquid and slurry based on its moisture content. Only cow bedding manure (winter wheat straw), which is the most suitable for obtaining 20% of humus organic matter, was used in the calculations of manure yield and the following results were obtained (Table 8).

Table 8. *Dynamics of bedding manure production in farms of Kharkiv region for the period 1991-2021 (thousand tonnes)*

Groups of livestock	Years					2021 to 1991	
	1991	2001	2011	2015	2021	%	times
Beef and veal production (in slaughter weight, kg)							
Total from cattle	10,834	3,963	1,656	1,633	1,292	11.9	8.4
including cows	4,980	2,604	1,206	1,112	952	19.1	5.2
In enterprises							
Total from cattle	10,232	2,876	823	825	680	6.6	15.0
including cows	4,464	1,601	480	448	388	8.7	12.1
In farms							
Total from cattle	-	31	34	40	32	5.6	
including cows	-	16.8	19.2	21.6	20.4	21.4	
In households							
Total from cattle	637	1,150	882	857	743	+16.6	
including cows	560	1,092	788	720	608	+8.8	

Source: *developed by the authors*

Between 1991 and 2021, the production of manure from cattle in all categories of farms decreased by 8.8 times, including 5.2 times from cows. The main reason is a significant decrease in the number of livestock. This was most noticeable in enterprises, while in farms and households it increased, but their total percentage was only 7.4%. In other words, the decrease in organic fertiliser production in Kharkiv region was influenced by a decrease in the number of producers, a trend that coincided with changes in Ukraine as a whole. And this most basic of the most powerful production assets has different quality indicators even within individual areas of one settlement, let alone an entire farm, a separate district, region, or country. This happens depending on how the land is managed. Long-term barbaric use of land for high yields leads to its depletion, impoverishing it of nutrients, especially its most valuable component – humus. The land is not capable of synthesising this fertiliser on its own; this function is performed by soil biota based on specific raw materials – organic and mineral substances, mostly secondary livestock products, and primarily ruminant manure.

DISCUSSION

For various reasons, it is quite difficult for agricultural producers in Ukraine to maintain, let alone increase, the number of cattle and ensure the production of milk and meat. Between 1991 and 2021, scientists and practitioners were looking for effective ways to not only increase animal productivity but also improve the quality and environmental safety of milk, and much was achieved. Much attention was paid to animal feeding, breeding and selection, improving cattle keeping conditions, and environmental safety. In 2022, the hostilities caused significant losses to the agricultural sector throughout Ukraine, with cattle farms in the frontline regions of the Forest-Steppe zone of Ukraine and the regions that were occupied, including Kharkiv region, suffering the most. In 2023-2024, the situation stabilised somewhat, but the number of cattle in the region decreased by almost 50%. In the second half of 2024, hostilities continued in the Kharkiv region, so there is no hope for a rapid improvement in the livestock sector. Mine contamination of agricultural land complicates the situation with field work, production of high-quality crops and animal feed, and the reduction in cattle numbers has led to a decrease in the application of organic fertilisers to the soil.

It is important to analyse the current situation in the livestock sector, take into account the accumulated scientific and practical experience and prepare for the post-war recovery of the industry, increase in the number of animals and their productivity, and production of environmentally safe milk and beef meat based on the introduction of innovative technologies and international experience. Manure composting is one of the most effective ways of processing manure, which is used in various countries where cattle are kept. Scientists X. Zheng *et al*. (2022) emphasise that anaerobic digestion and composting of manure are increasingly attracting attention due to the increase in organic fertiliser production and environmental safety. Composting is an ideal way to utilise the nutrients in animal manure. To reduce soil contamination with heavy metals, especially such hazardous metals as cadmium and lead, researchers recommend that agricultural producers take a holistic approach by producing both compost and biogas, which is very important in the context of the energy crisis and environmental protection. Heavy metal pollution from man-made and military impacts threatens animal and human health due to their high bioavailability, cumulative nature and migration in the trophic chain.

Scientists from China, H. Wang *et al*. (2013), examined samples of feed and manure for heavy metals on livestock farms. It was found that zinc and copper in animal feed ranged from 15.9 to 2,041.8 and 392.1 mg/kg, respectively, while mercury, arsenic, lead, and chromium in all feeds were below 10 mg/kg. The concentration of copper, zinc, arsenic, and chromium in animal feed and manure had a positive correlation, but cadmium, mercury, and lead were not statistically correlated between the content in feed and manure. The highest concentrations were found for copper and zinc in both feed and organic waste from different animal species, including dairy cattle. The authors also emphasise that the content of heavy metals in organic waste from dairy animals has only increased over time, which means that it poses an environmental risk of soil pollution. Researchers M. Xiang *et al*. (2021) note that the increase in the content of heavy metals in the soil is due to a violation of the norms for applying organic fertiliser from livestock waste if animals were fed feed containing hazardous ecotoxicants. Heavy metals pose a significant threat to agricultural production. Soil contamination can pose a potential environmental risk, and crop contamination can already pose a risk to human health.

Y. Xu *et al*. (2019) also note that livestock manure tends to be contaminated with heavy metals, as large amounts of the mineral elements copper and zinc are added to the feed, which are heavy metals but biogenically important for the animal body. A large amount of these elements is released into the soil with organic waste. Elevated concentrations of copper and zinc in cattle manure were found in different regions of the country and varied significantly. Scientists from the United Kingdom, F.A. Nicholson *et al*. (1999), also emphasise the environmental hazards of heavy metal contamination of feed and manure. Other scientists (Tao *et al*., 2020) took samples of feed and analysed the content of cadmium, chromium, arsenic, and mercury using atomic absorption spectrophotometry. The researchers conclude that systematic environmental monitoring of the concentration of heavy metals in animal feed, implementation of feed management and bioremediation strategies to reduce the impact of heavy metals is important, which should be taken into account in the post-war period on farms not only in Kharkiv region but also in other regions where cattle are kept and milk and meat are produced.

Nutrients from organic fertilisers obtained after composting cattle manure are used by plants in the first, second and third year after application. The increase in livestock numbers in the post-war period will lead to an increase in organic waste, which will lead to an increase in organic matter application to the soil and litter manure will be effective as fertiliser for industrial and fodder crops, including sugar, fodder beet, corn for silage and grain, rapeseed, sunflower, soybeans and other crops. The application of organic fertilisers for fodder crops to be used as feed in dairy cows' diets should be standardised with due regard to the content of heavy metals. Since the accumulation of pollutants in the soil will eventually lead to increased accumulation in plants grown, feed for dairy cows or animals raised for meat, followed by rapid entry into milk and accumulation in muscle tissue. In the more environmentally stressed regions of Ukraine's Forest-Steppe zone, more organic fertilisers can be used for industrial crops such as sunflower, rapeseed, and sugar beet, but avoiding over-application.

Scientists from India emphasise that milk plays a key role in human nutrition, especially for children, due to its content of protein, vitamins, and calcium, which contribute to cognitive development, but the risk of potential hazards of heavy metals in milk due to environmental exposure and the intake of toxic metals from animal feed has attracted not only their attention but also the attention of scientists around the world (Alam *et al.*, 2024). They studied seasonal fluctuations in the quantitative intake of heavy metals cadmium, chromium, and lead by dairy cows in the South Indian metropolis of Bengaluru. The analyses of the samples revealed the content of pollutants in feed, milk, and organic waste. The study covered thirty-nine dairy farms in urban and suburban areas. Significant concentrations of heavy metals were found in organic cattle waste, while cow's milk was safe. At the same time, there was a risk of re-contamination of the soil by organic fertiliser with high concentrations of toxic metals.

Farmers often face the question of how to run their farms: conventional or organic farming. Plant-based production of organobiological products in Ukraine is more developed than animal-based production, which requires significant investment (Pysarenko *et al.*, 2019). The choice can significantly affect the financial performance of the farm and the impact on the environment. Norwegian scientists R. Bang *et al.* (2024) compare the profitability of conventional and organic cattle systems, taking into account the characteristics of farms, feed production, feed quality, milk quotas, livestock housing capacity, etc. and conclude that if feed is of good quality, easily accessible, but livestock production cannot be expanded due to the maximum number of animals kept, milk quota restrictions, organic farming can displace conventional farming. Gross profit is maximised by conventional farming. Researchers emphasise the crucial role of feed production capacity and quality in relation to the available milk quota and infrastructure when considering the transition from conventional to organic farming. In other words, in the future, as a guideline for farmers, the environmentally friendly organic-biological type of farming should be more widely implemented. The organisation of environmentally safe milk production in terms of heavy metal content on cattle farms in different countries of the world under the influence of natural and anthropogenic factors remains relevant (Özbay *et al.*, 2023).

After the end of the war, the restoration of the livestock sector in Kharkiv region and Ukraine as a whole should be based on innovation, taking into account the integration of crop and livestock production components in combination with the preservation of the environment and its components of atmospheric air, soil, water, and living organisms. High-quality, environmentally friendly crop and livestock products, especially milk and beef meat produced in both conventional and organic farms, will have a competitive advantage in the market.

CONCLUSIONS

Over the past 30 years (1991-2021), the Kharkiv region has lost the potential of the dairy industry and the number of cattle has decreased by 8.4 times, including cows – by 5.2 times, the most significant reduction in the total number of cattle occurred in 1991-2001 (by 6.54 times), including cows (by 4.1 times). Due to the reduction in production resources, there was a decrease in milk production (-800 thousand tonnes or 2.7 times) and beef and veal production (in slaughter weight) (-78.8 thousand tonnes or 4.5 times), with the main "drop" occurring in the period 1990-2010 (2.7 and 4.5 times respectively). Enterprises suffered the most among all categories of farms. Despite the decline in gross milk production, the average annual milk yield per cow in the region increased by 2,840 kg (2.0 times or 195%) from 1990 to 2020 and reached 5,821 kg in 2020. The most significant increase in cow productivity (+4,693 kg) occurred in enterprises (from 2,975 kg to 7,698 kg). Cow productivity increased due to breeding, the use of intensive technologies, improved feeding and housing conditions on farms in the region. The reduction in the number of cattle, and cows in particular, led to a decrease in gross production of organic fertilisers (manure) by 8.8 times, including 5.2 times from cows themselves. Despite a significant increase in milk yields, the downward trend in organic production was similar in Kharkiv region enterprises, as well as in farms of all categories in Ukraine. In developing the dairy farming sector in the post-war period, it is necessary to increase the number of cattle, as there is no more effective measure to obtain organic fertilisers and prevent the crisis of degradation of Ukrainian black soil and produce environmentally friendly products in an integrated agricultural production system. Further research could be aimed at analysing the quality and environmental safety of cow's milk and beef produced.

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CONFLICT OF INTEREST

None.

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Передумови інноваційного розвитку скотарства та землеробства за рахунок інтеграції складових аграрного виробництва і екологічної безпеки

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Анотація. Багаторічний аналіз стану галузі скотарства в період до початку війни 2022 року має важливе значення для післявоєнного відновлення регіонів України. Мета дослідження: встановити чинники втрат під час виробництва продуктів скотарства, методи, засоби інтегрованого розвитку. Було дотримано загальноприйнятих методів в зоотехнії, дослідження проведено за тридцяти річний період (1991-2021 роки) відповідно до етапів виконання науково-дослідної роботи номер: 0121U113933 від 18.11.2021 року. Встановлено, що поголів'я великої рогатої худоби зменшилося у 8,4 раза, корів – у 5,2 раза. Знизилося валове виробництво молока – у 2,7 раза, яловичини і телятини – у 4,5 раза. Поліпшення генетичного потенціалу поголів'я, годівлі, утримання сприяло підвищенню продуктивності корів в середньому по області на 2842 кг, у підприємствах – на 4693 кг. На 01.01.2021 створено 5 племзаводів української чорно-рябої молочної породи з поголів'ям 12369 голів, у тому числі 4647 корів, надоєм за 2020 рік 9749 кг. Рентабельність виробництва молока за 2019 рік становила 20,6 %, вирощування великої рогатої худоби на м'ясо виявилося збитковим (-27,1 %). Багато господарств перетворюють гній на компост, який вносять під оранку ґрунту. З 1991 по 2021 роки у Харківській області відбулася втрата потенціалу молочної галузі, поголів'я великої рогатої худоби зменшилося, найбільше скорочення припало на 1991-2001 роки (у 6,54 раза). Зменшилося виробництво молока у 2,7 раза та яловичини і телятини у 4,5 раза, основне «падіння» відбулося в період 1990-2010 роки (в 2,7 та 4,5 раза відповідно). Середньорічний надій на одну корову в середньому по області з 1990 по 2020 рік зріс на 2840 кг і в 2020 році становив 5821 кг. Практична цінність: у статті вперше зроблено багаторічний аналіз стану галузі скотарства до початку бойових дій в Україні з урахуванням технологічних та організаційно-економічних аспектів

Ключові слова: органічні добрива; гумус; ґрунт; відновлення родючості; молоко; яловичина

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Sanitary and hygienic assessment of the welfare of Ukrainian Black-and-White cattle breedy

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Abstract. Dairy farming is one of the most important areas in the agricultural sector, which regularly provides the country's population with valuable nutritionally and hygienically safe food products. However, for proper functioning and ensuring a high level of animal productivity, it is essential to take into account such elements as maintaining a consistently high level of sanitary and hygienic conditions in livestock premises, as well as optimising feeding and housing conditions. The purpose of the study was to evaluate different ways of keeping cattle in terms of sanitary and hygienic conditions, taking into account the physiological state of cows. The study was based on zootechnical and breeding records for the previous years of the enterprise's operation. The research data were calculated using MS Excel 2013. The results of the study indicate that the air in those livestock buildings where dairy cows were kept next to dry cows on a tether had the highest percentage of carbon dioxide at 6 am (0.32%), then during the day this figure decreased to 0.19% and increased again closer to the evening and night time, during which period its value was 0.28%. This indicates that the efficiency of the ventilation system is imperfect in the above method of cattle housing. In addition, the air contamination with microorganisms during the day in different ways of keeping animals had quite clear changes. This is due to the fact that it is during the day that all the most significant technological processes of milk production take place, and this in turn automatically leads to an increase in the number of microorganisms in the air. Thus, taking into account the study of microclimate parameters (air composition, the number of microorganisms in the air, the amount of water vapour), the best option is to separate cows during the dry period from the dairy herd into a specially isolated section equipped with combined boxes, with a free-standing method of housing, which

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will provide better conditions for keeping dry cows. Thus, compliance with cow housing standards will reduce healthcare costs, increase life expectancy, improve animal welfare and contribute to higher milk production

Keywords: technology; containment methods; relative humidity; carbon dioxide; ammonia content; microbial contamination

INTRODUCTION

Intensification of agriculture and dairy farming in general, as well as maintaining its stable sustainability over a significant period of time, is one of the key points for the effective development of the country's economic potential in the agricultural sector.

According to M.R.H. Rakib *et al*. (2020), the financial efficiency of dairy farming is a close consolidation of the following elements: high efficiency of the agricultural process, maximum productivity of the use of production resources, a positive correlation between the obtained labour costs and increased profitability of production by obtaining a large number of high-quality agricultural products. This, in turn, is not possible without creating optimal conditions for keeping cows, providing them with comfortable climate and microclimate conditions depending on their physiological state.

A. Shevchenko & O. Petrenko (2020) argue that if an environment is not created for animals that meets all zoohygienic and veterinary and sanitary standards, it will be impossible to obtain the highest possible level of productivity from them and maintain good health. According to S. Brodovsky (2021), in cows that are record holders in terms of milk production and calf birth, if the relevant microclimate parameters are not met, the resistance of the immune system and the resistance of the body as a whole begins to decrease sharply, and as a result, causes various diseases, the development of pathological processes, and in the most severe cases, even the death of animals.

M. Zakharenko *et al*. (2023) also point out that in order to prevent the occurrence of diseases and subsequently obtain the maximum number of dairy products and solve a number of other pressing issues that will arise as a result of the work, it is necessary to know and strictly adhere to the basic tenets of animal health, respond in a timely manner to any deviations and solve them correctly. Particular attention should be paid to the study of the environment in which the animals are kept and at the same time to take all necessary measures to improve the health of the cow herd.

According to R. Bleizgys *et al*. (2023), one of the important conditions for keeping cows is to ensure the necessary microclimate parameters in the barn. At the same time, elevated temperature and humidity in the room can cause heat stress in cows, which negatively affects their physiological state and productivity, and can even cause a deterioration in the quality of milk produced. In addition, according to C. Kipp *et al*. (2021), an increase in humidity and temperature in barns leads to an increase in greenhouse gas emissions.

Monitoring of data in the world practice of dairy farming shows that a number of authors cite non-compliance with the recommendations of standards for animal welfare indicators and the creation of comfortable microclimate conditions for animals. For example, G.E. Dahl *et al*. (2020) report that indoor temperature, humidity and ventilation conditions do not always meet the standards and are often the cause of heat stress in summer, especially in dry cows and cows during calving. In turn, C.B. Tucker *et al*. (2021) found that unfavourable conditions, including poor ventilation, insufficient gas exchange, heat and rain, lead to the accumulation of large amounts of harmful gases in the air and contribute to microbial contamination of the air.

Creating comfortable conditions during late pregnancy in dry cows is beneficial for both the cow and the developing calf. And violation or non-compliance with sanitary and hygienic standards of keeping such animals has a number of negative consequences, not only for the cow itself, but also for calves that will be in unsatisfactory conditions during intrauterine development. Therefore, the issue of studying the welfare of pregnant cows during dry periods does not lose its relevance, which aroused interest in assessing the conditions of keeping Ukrainian Black-and-White cows during dry periods in the Southern region of Ukraine.

LITERATURE REVIEW

In the conditions of agricultural enterprises, cattle can be kept in quite different ways and systems. The main methods include tethered and untethered, and among the housing systems there are four main types – fattening grounds, walking and non-walking, and pasture systems. Therefore, depending on the above methods and systems, appropriate climate and microclimate conditions should be created in the premises where animals are kept, depending on their age and physiological condition.

According to M.R. Mondaca (2019) and D. Lovarelli *et al*. (2020), housing in a free-range system usually takes place either on deep bedding or can be replaced by housing on a slotted floor. When cows are kept tethered, floor space is an important issue, with 1.7-2.1 m^2 per animal always being allocated. When cattle are kept untethered, the area of the animal's location increases, which in turn leads to an increase in the motor activity of cows, according to the standards, the area ranges from 3 to 7 m^2 per animal. Feeding is provided either through a feed trough or a feed table. In this case, the feeding front per head should be at least 70 cm.

G.E. Dahl *et al*. (2020) found that the importance of such an important issue as microclimate from a veterinary and sanitary point of view can vary significantly depending on the systems and methods of housing. Thus, in the premises where animals are kept in the untethered system, the ambient temperature is the lowest compared to other systems and is 6-8°C. Of all the age and sex groups of animals, young animals are the most sensitive and vulnerable to cold, which can cause diseases. Therefore, the temperature indicators for them are the highest, reaching 12-18°C. For tethered housing, the room temperature is between 8-12°C.

Both temperature and humidity levels in livestock housing are quite broad concepts. Typically, the optimum humidity level should be 75%, with a permissible limit of 85%. R.F. Cooke (2019) found that air composition and air quality in barns is also important in creating good cow welfare. One of the most common elements of the air environment in livestock buildings is ammonia. Ammonia is a colourless gas characterised by a strong pungent odour and is highly irritating to mucous membranes. It is most often found in the air in the form of carbon dioxide, nitrogen dioxide and nitric acid salts. It is released into the atmosphere through the decay of substances with a high nitrogen content, and penetrates the soil from various manure storage facilities and industrial enterprises. In livestock buildings, the main source of ammonia is nitrogen-containing substances that undergo decomposition (faeces and urine). Studies have shown that extremely high levels of ammonia can be detected in poorly functioning sewage and ventilation systems, as well as in places where animals are crowded in tethered housing.

A. Shuliar *et al*. (2020) believe that if all sanitary and hygienic standards are met at a high level in livestock buildings: manure is removed and disposed of in a timely manner, sewage and ventilation systems operate systematically, and a consistently clean floor is maintained, then the ammonia content in the air can be reduced to a minimum. S. Voitenko & I. Zheliznyak (2019) confirmed that the permissible ammonia content for cowsheds is a fairly broad concept and has a close correlation between the age and physiological state of the animal. For example, adult cattle are fully formed in terms of growth and development and are more resilient, so a level of up to 20 mg/m^3 is a satisfactory indicator for them. Young cattle are more vulnerable and sensitive, so this value is lower for them and is up to 10 mg/m^3.

Another important element found in the air environment is hydrogen sulphide. This type of gas is the most harmful and often causes the death of animals due to the toxicity of waste on the farm. It spreads extremely quickly over the ground and indoors and reaches its peak concentration in manure storage areas. According to M. Maasikmets *et al*. (2015), the most dangerous feature of hydrogen sulphide is that it causes paralysis of the nerve cells in the nose, leading to a suppression of the sense of smell. At higher concentrations, loss of consciousness occurs quickly enough, and death can occur in a few minutes. However, even a short stay in an environment filled with hydrogen sulphide results in a slow reaction, which can result in death of a person or animal from pulmonary edema in 24 hours.

Thus, the assessment of the conditions of keeping Ukrainian Black-and-White cows using different methods will help to identify the best sanitary and hygienic criteria and factors of keeping, which in turn will allow to manage the indicators related to the welfare of dairy cattle, and as a result, will improve the health of cows and directly affect the level of their milk production.

MATERIALS AND METHODS

The research was carried out in the conditions of the State Enterprise "Plemreproductor 'Stepove", Mykolaiv district, Ukraine, in the period 2023-2024. To achieve the task, three groups of Ukrainian Black-and-White cows were formed, which were in the period of dryness. In further work, 10 animals were selected for the experiment, and in each group, the comparison was formed according to the principle of analogue pairs.

The experimental groups differed in the way they were kept, with the control group cows being kept on a tether next to lactating cows. For the cows of the first experimental group, a tethered method of housing with separate sections was used. Animals of the second experimental group were kept in a separate section without tethering in combined boxes.

In the premises where cattle were kept, the microclimate parameters were studied every ten days in three sections, this work was carried out with a frequency of four times a day, with an interval of 6 hours. The time of material collection was as follows: at 6 am, at 12 pm, at 6 pm, at 12 am. For a clearer analysis and more detailed coverage of the results of the work carried out, biometric data processing was carried out using MS Excel 2013 according to the methodology of S. Kramarenko *et al*. (2019).

The rules for handling animals in the experiment fully complied with European legislation (Council Directive of the European Union No. 98/58/EC, 1998; Nalon & Stevenson, 2019). The protocol of the experiment on blood sampling from cows was approved by the local bioethics committee of Mykolaiv National Agrarian University, Ukraine, in accordance with the Good Clinical Practice (GCP) for the protection and humane treatment of experimental animals.

RESULTS

Investigating the level of humidity in livestock buildings where cattle are kept, it can be observed that the data obtained are quite different. For example, when dry cows are kept on a tether together with lactating cows, the humidity level varied slightly during the day and slightly exceeded the norms (Demchuk *et al*., 2006). When animals were kept on a tether in a specially designated separate section, as well as when they were kept in combine cubicles without ties in an isolated section, the level of relative humidity was much lower and did not exceed the values established by the norm (Table 1).

Table 1. *Relative humidity level of livestock premises in different ways of keeping cows, %*

Method of keeping	Time of the day				The average indicator
	6 am	12 pm	6 pm	12 am	
Tethered (together with cows during lactation)	82.9 ± 2.21	87.9 ± 2.20	88.0 ± 2.05	84.3 ± 2.58	85.77 ± 2.26
Tethered (in a separate section)	68.9 ± 1.00	72.1 ± 1.01	72.4 ± 1.28	68.6 ± 1.21	70.50 ± 1.13
Untethered (in a separate section with combined boxes)	64.4 ± 1.54	69.3 ± 1.53	69.8 ± 1.80	65.7 ± 1.51	67.30±1.59

Source: *authors' development*

In the daytime (from 6 am to 12 pm), when animals were kept tethered, the relative humidity increased quite significantly, while remaining steadily at the same level until 6 pm, and only after that it decreased by 3.8%. This point can be explained by the fact that it is during this period of time that physiological processes of urine and faeces excretion are actively taking place, as well as the intensive process of air gas exchange, since animals are one of the main sources of water vapour in the room. It is also during this period that the main production and technological processes take place. Relative air humidity during the day in the livestock premises where cows were kept in a separate section with combined boxes without tethering was 18.2-18.6% lower compared to animals kept on a tether next to the milking cows. The company also studied the carbon content in the air of livestock premises depending on the way cows are kept. Thus, it was found that the highest level of CO_2 was observed when dry cows were kept together with dairy cows (Table 2).

Table 2. *Carbon dioxide content in the air of the premises in different ways of keeping cattle, %*

Method of keeping	Time of the day				The average indicator
	6 am	12 pm	6 pm	12 am	
Tethered (together with cows during lactation)	0.32 ± 0.022	0.19 ± 0.012	0.19 ± 0.008	0.28 ± 0.020	0.25 ± 0.015
Tethered (in a separate section)	0.18 ± 0.007	0.12 ± 0.006	0.12 ± 0.005	0.23 ± 0.009	0.16 ± 0.006
Untethered (in a separate section with combined boxes)	0.22 ± 0.009	0.14 ± 0.007	0.15 ± 0.003	0.22 ± 0.006	0.18 ± 0.006

Source: *authors' development*

The air in the room where the dairy cows were kept next to the dry cows had the highest carbon dioxide level at 6 am (0.32%). During the day, it gradually decreased to 0.19%, and in the late afternoon and at night it increased again to 0.28%. One of the main reasons for these changes is that when cows of different physiological groups (dairy and dry cows) are kept, the efficiency of the ventilation system is relatively unsatisfactory.

In the second method of cow housing, the average carbon content was 0.16%, which was the best indicator and was characterised by somewhat stable values during the day – 0.12% from 12 pm to 6 pm. It slightly increased at 6 am to 0.18% and reached its maximum value at 12 am – 0.23%. This is probably due to the low mobility of animals and their rest period at this time. The third method of keeping cows in combined boxes revealed average carbon dioxide values of 0.18%, which were characterised by dynamics during the day. The highest level was observed, again at 6 am and at 12 am – 0.22%. At the same time, during the day, from 12 pm to 6 pm, the carbon level fluctuated between 0.14 and 0.15%.

An important indicator that characterises the sanitary condition in the livestock building and is also important when assessing the operation of the sewage system is the concentration of ammonia in the air. Studies have shown that the method of keeping cattle did not significantly affect the ammonia content in the air (Table 3).

Table 3. *Ammonia content in livestock premises in different ways of keeping cows, mg/m³*

Method of keeping	Time of the day				The average indicator
	6 am	12 pm	6 pm	12 am	
Tethered (together with cows during lactation)	23.0±1.08	16.6±1.05	15.9±0.65	22.9±0.90	19.6±0.92
Tethered (in a separate section)	20.2±0.67	14.8±0.93	15.3±0.56	22.4±0.79	18.2±0.74
Untethered (in a separate section with combined boxes)	18.7±0.62	14.8±0.74	13.9±0.83	24.0±0.75	17.8±0.74

Source: *authors' development*

In the study of the tethered method of keeping cattle in stalls together with dairy cows, despite the fact that the concentration of ammonia in the air was quite fluctuating, it was within normal limits, and the only exception was the night period (from 12 am to 6 am) when the ammonia content in the air exceeded the maximum permissible level – 22.9-23.0 mg/m³. When dry cows were kept in a separate section with combined boxes without being tethered, the concentration of ammonia in the air reached its lowest values during the day, during the active period of animals (from 12 pm to 6 pm) – 13.9-14.8 mg/m³. Under the tethered method, when dry cows were kept in separate sections, the ammonia content in the air was average, and its highest concentration occurred during the period of reduced cow activity, i.e. at night – 20.2-22.4 mg/m³. At the same time, during the day, this indicator fluctuated at the level of 14.8-15.3 mg/m³. This is due to the lower air mobility in the barn when animals are resting than during their physical activity and during the main production processes.

As of 2024, one of the least studied issues in livestock farming is the study of the level of air pollution by microorganisms, which has aroused interest in studying this aspect as an important indicator of animal welfare. A significant role in this issue is given to the study of the main technological processes, such as feeding and watering animals, milking, ventilation system operation, as well as the quality of building materials used for stalls and floors, as they affect the degree of contamination of livestock premises with various microorganisms (Table 4).

Table 4. *The level of microbial contamination of indoor air depending on the way cows are kept, thousand microbial bodies/m³*

Method of keeping	Time of the day				The average indicator
	6 am	12 pm	6 pm	12 am	
Tethered (together with cows during lactation)	74.5±1.31	82.2±1.41	83.0±1.29	77.1±1.27	79.2±1.32
Tethered (in a separate section)	36.2±0.81	40.2±1.00	41.2±0.76	35.6±0.70	38.3±0.82
Untethered (in a separate section with combined boxes)	33.5±1.25	35.8±1.13	36.2±0.94	29.8±1.03	33.8±1.08

Source: *authors' development*

The research results clearly show that the level of microbial contamination of the air in livestock premises during the day, where animals were kept in different ways, had significant fluctuations. Thus, the lowest contamination was recorded in the air of those rooms where cows were kept untethered in a separate section equipped with combined boxes. The highest values were observed during the day – 35.8-36.2 thousand/m³, i.e. during the hours of the highest activity of cows. In the mixed housing of dry cows with lactating cows in a tethered manner, this indicator was the highest and averaged 45.4 thousand/m³ more cells compared to animals kept separately in combined boxes. Comparing the microbial contamination of the air in the rooms where dry cows were kept in an isolated section in a tethered manner, it should be noted that there were 13.5% fewer microorganisms in the room compared to the first variant of housing.

Thus, the results obtained give grounds to assert that the analysis of sanitary and hygienic conditions of cows is the basis for the creation of an integrated system for assessing the welfare of dairy cows on the farm, which will take into account the biological component of technological processes and create such conditions that will fully correspond to the physiological state of the animal, its health status and provide comfort, which in combination will affect the high level of milk production.

DISCUSSION

Increasingly, global practice pays great attention to assessing the welfare of dairy cows and creating comfortable living conditions for them that are in line with natural ones. Even in 2017, the issue of comfortable conditions for dairy cows was considered in the European Parliament in a report by the Directorate-General for Internal Policy, which noted that the welfare of dairy cows is considered the second biggest problem of animal welfare in the EU (Broom, 2017). Therefore, most scientists, for example, I. Halachmi *et al*. (2019), believe that there is an urgent need to improve the conditions of cows on farms. A.R. Frost *et al*. (1997) and F. Napolitano *et al*. (2009), when assessing the welfare of farm animals, pay attention to three important aspects – "How well does the animal's body function physiologically, how well does the animal feel, and do the given living conditions correspond to the animal's natural environment?". But here, too, the authors' opinions differed. Thus, scientists T. Jóhannesson & J.T. Sørensen (2000) and L.M. Leliveld & G. Provolo (2020) have different interpretations as to which of these problems is the most important and universally recognised. At the same time, E. Galán *et al*. (2018) and X. Wang *et al*. (2018) believe that none of these three issues can fully address all aspects related to animal welfare.

According to L.M. Leliveld & G. Provolo (2020), it is not possible to create ideal conditions for the animal, as in tethered housing, dairy cows will have a lower risk of injury, lameness and hoof diseases, but at the same time they will be limited in movement and social contact, and thus they will somehow have poor welfare that does not correspond to natural conditions. Studies by M. Bagath *et al*. (2019) and M. Besler *et al*. (2021) show that keeping animals in cool, damp, insufficiently ventilated rooms with drafts leads to a decrease in their productivity by up to 15%, an increase in feed consumption by 12-35%, which leads to a 2-3-fold increase in morbidity. An inappropriate microclimate also affects the general condition of the livestock building, its durability and thermal conditions in the building. At air temperatures above 25°C, cows eat less, and their milk yield and weight gain decrease. The most unfavourable combination of parameters is a set of high temperatures with high humidity (over 80%) and low air exchange. In this case, cattle may experience so-called heat stress. Relatively high humidity prevents animals from releasing heat into the environment by evaporation from the body surface. If the indoor air is heavily polluted due to low air exchange, the humidity will usually be high. Such conditions lead to the increased development and spread of bacteria and viruses. Relatively high humidity also requires more bedding, as the area is difficult to keep dry. Wet indoor surfaces also shorten the life of the building and increase maintenance costs in winter.

One of the indicators of animal welfare is the assessment of the composition of the air in cowsheds, as excessive levels of harmful gases have a negative impact on the animal's body. One of these gases is ammonia. Experimental studies by R. Bleizgys & I. Bagdoniene (2016) showed changes in ammonia concentration and the factors that most affect it in different periods of the year. Thus, according to the authors, the process of ammonia evaporation from manure is influenced by many different and interrelated factors, among which temperature and air ventilation intensity are the most critical. An increase in temperature leads to an exponential increase in ammonia emissions, while the dependence of emissions on air velocity is best expressed by a second-degree polynomial.

Particulate matter in the air can be a potential risk factor for human and animal health. For example, E. Galán *et al*. (2018) studied the concentration of particulate matter and the concentration of harmful gases in the air during the free-range housing of cows. The authors found correlations between indoor particulate matter, concentrations of harmful gases and other microclimate parameters. There were clear seasonal variations between measurements in summer and winter. Particulate matter (all fractions) and CO_2 concentrations were higher and ammonia concentrations were lower in winter.

M. Maasikmets *et al*. (2015) consider hydrogen sulphide to be another important harmful gas found in livestock buildings. H_2S is produced during anaerobic manure decomposition as a result of mineralisation of organic sulphur compounds, as well as the reduction of oxidised inorganic sulphur compounds such as sulphate by sulphur reducing bacteria. Higher manure sulphate content leads to higher H_2S emissions. The reduced content of sulphurous compounds and volatile fatty acids also contributes to the production of odours that can cause negative physical and psychological reactions in animals and humans.

Thus, a study on dairy welfare on dairy farms should be evaluated for at least two main reasons: to identify unsatisfactory housing conditions and to eliminate them, as they affect the health of the animal. This will generally contribute to the production of more and better quality products.

CONCLUSIONS

It was found that in the premises where pregnant dry cows were kept together with dairy cows, the air humidity during the day did not fall within clearly established norms. Significantly lower values of relative air humidity in livestock premises were found when cows were kept in a separate section with combined boxes. At the same time, higher humidity values were observed during the day during the greatest physiological and motor activity of cows, because it is during this period of time that intensive gas exchange and physiological processes of urine and faeces excretion occur. Also, the effect of the method of keeping dry cows on the carbon and ammonia content in the air was found to be ambiguous. Thus, the best carbon levels were observed in the tethered method when cows were kept in separate sections, while lower ammonia values were inherent in the untethered method in a separate section with combined boxes. The lowest concentration of harmful gases in both housing methods was observed during the day, when animals were actively moving and the main technological processes were taking place, which contributed to air circulation in the room.

The air contamination with microorganisms under different methods of keeping during the day had significant changes. This is due to the fact that most of the technological operations and milk production processes at the enterprise take place during the daytime, which actually lead to an increase in the number of microorganisms in the air. And, accordingly, they have a much greater impact on this indicator than at night, when animals are resting and no technological operations are taking place. A comprehensive assessment of the sanitary and hygienic conditions for the welfare of Ukrainian Black-and-White dairy cows showed that it is not desirable to keep animals of different physiological groups, namely lactating and dry cows, in a mixed way in one room. Thus, to improve cow welfare, it is necessary to comprehensively assess the conditions of cow housing, climate and microclimate in the building and create conditions where animals feel comfortable and natural. After all, only a healthy animal that is free from stress and in conditions close to natural ones is able to realise its potential for high milk production. The prospect of further research on this topic may be the creation of comprehensive models of cow welfare depending on the method, housing system and physiological state of the cows, which will help to improve not only their health but also prevent the occurrence of stressful phenomena in animals and influence the level and quality of milk production.

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CONFLICT OF INTEREST

None.

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Санітарно-гігієнічна оцінка добробуту великої рогатої худоби української чорно-рябої породи

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Анотація. Молочне скотарство є одним з найважливіших напрямків в агропромисловому секторі, який на регулярній основі дає можливість постачати населенню країни цінні в харчовому та безпечні в санітарно-гігієнічному плані продукти харчування. Але для належного функціонування та забезпечення високого рівня продуктивності тварин обов'язковим аспектом є врахування таких елементів, як: підтримання стабільно високого рівня санітарно-гігієнічних умов у тваринницьких приміщеннях, а також оптимізація умов годівлі та утримання корів. Мета дослідження – оцінка різних способів утримання великої рогатої худоби за санітарно-гігієнічними умовами з урахуванням фізіологічного стану корів. Для проведення дослідження було використано дані зоотехнічного та племінного обліку за попередні роки роботи підприємства. Дані досліджень було обчислено за допомогою програми «MS Excel 2013». Результати досліджень вказують, що повітря в тих тваринницьких приміщеннях, де дійні корови утримувалися поруч з сухостійними на прив'язі, мало найвищий відсоток рівня вуглекислого газу саме о 6-й годині ранку (0,32 %), в подальшому протягом доби цей показник зменшувався до 0,19 % і знову зростав ближче до вечірнього та нічного періоду часу, в цей період його значення дорівнювало 0,28 %. Це вказує на те, що за наведеного способу утримання великої рогатої худоби ефективність роботи системи вентиляції є недосконалою. Окрім того, забрудненість повітря мікроорганізмами протягом доби при різних способах утримання тварин мала достатньо кількісні зміни. Це пов'язано з тим, що саме в день відбуваються всі найбільш значні технологічні процеси виробництва молока, а це в свою чергу автоматично призводить до підвищення кількості мікроорганізмів в повітрі. Таким чином, враховуючи дослідження параметрів мікроклімату (склад повітря, чисельність мікроорганізмів в повітрі, кількість водяної пари), найкращим варіантом є відокремлення корів в період сухостою від дійного стада в спеціально ізольовану секцію, яка оснащена комбінованими боксами, з безприв'язним способом утримання, що забезпечить кращі умови утримання сухостійних корів. Тож, дотримання норм утримання корів має зменшити витрати на їх охорону здоров'я, збільшити тривалість життя, покращити добробут тварин і буде сприяти більш високій молочній продуктивності

Ключові слова: технологія; способи утримання; відносна вологість; вуглекислий газ; вміст аміаку; мікробне забруднення

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Study of structural and kinematic characteristics of an energy-efficient oil press

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Abstract. The technological process of vegetable oil production requires significant energy costs, while the introduction of new technologies requires investment, which is a challenge for small and medium-sized enterprises in the current environment. This makes it important to introduce energy-efficient equipment in the conditions of these enterprises, which does not require significant investments. The article was concerned with improving the technological process of pressing oilseeds by introducing an energy-efficient oil press into the technological process and studying its structural and kinematic characteristics. In the context of the study, the determination of the physical and mechanical properties of raw materials, methods of theoretical mechanics and solid mechanics, calculation of structural elements of technological equipment for processing oilseeds were used. The necessity and expediency of theoretical analysis and experimental research are substantiated. The main regularities of oil separation from the crushed mass are determined. The study of physical and mechanical characteristics, size and weight parameters of seeds and crushed mass allowed to substantiate the main kinematic and design parameters of the screw press. The principle of operation of an energy-efficient screw oil press is described. The design of the press is improved by a steam sprayer installed in the receiving hopper under the threaded rollers, which is equipped with a steam generator, which makes it possible to carry out moisture-thermal treatment with steam within one device. The proposed constructive solution includes: determination of the coefficient of friction of seeds on an inclined plane, study of the components of the crushed mass obtained with the help of an energy-efficient oil press, and theoretical aspects of oilseed pressing. A study of the design and operating parameters of the screw press has been carried out, namely: determination of the screw press productivity, use of an energy-efficient press for oil separation makes it possible to improve the quality of the technological process, determination of the press

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power consumption and its efficiency. It has been concluded that the improved design solution of the press meets the modern requirements for oil production machines. The use of the proposed constructive solution will reduce oil losses during pressing, which will significantly increase the efficiency of the process, reduce operating costs and promote the development of oil production in small and medium-sized oilseed enterprises

Keywords: screw shaft; crushed mass; density; pressure; technological process; productivity; oil yield

INTRODUCTION

The oil and fat industry is one of the leading sectors in the food industry. Its main products are vegetable oil (edible and technical), and additional products are proteins for food and feed. Vegetable edible oil is used both in its pure (unchanged) form and as a component of various products (margarine, cooking fat, mayonnaise, etc.). Technical oil is used to produce fatty acids and oxidised oil. In turn, fatty acids are used in the chemical industry to make soaps and detergents (household and industrial), while oxidised oil is used in the production of drying oils, varnishes and paints. Some types of vegetable oils are used as solvents for medicines and in the production of cosmetics. Oilcakes and meals, which are waste products from the processing of many oilseeds, are a valuable high-protein concentrated feed for farm animals. More than 50 sunflower species are cultivated in Ukraine, and when developing new varieties, the aim is to change the chemical composition of the seeds and reduce the content of the fruit coat (seed hulling). Sunflower occupies a predominant place among oilseeds in the Mykolaiv region, which led to the choice of the research area, which concerned the operation of press equipment for processing sunflower seeds and the possibility of using a certain design for processing other oilseeds.

The authors P. Rajkhowa & Z. Kubik (2021) studied the level and development of processing enterprises, in particular for the processing of vegetable raw materials. In their work, they concluded that increasing the level of mechanisation of the agro-industrial complex, in particular farms and small industrial enterprises, has a positive impact on the involvement of labour reserves in economic development. The article analyses the use of agricultural machinery, in particular, water-lifting equipment, tractors, agricultural machinery and equipment for processing crop production. It has been found that the impact of increasing the level of mechanisation of farms reduces the demand for hired labour and has a positive impact on the participation of women in agricultural labour, which is relevant in the context of constraints.

Researchers A.E. Obayelu & S.O. Ayanshina (2020) note that processing enterprises need an effective approach, in particular, compliance with the principles of food security and the transition to sustainable food systems. L. Lytovchenko (2022) notes that the use of waste-free production, namely the further processing of husks, the use of cake or meal for feed purposes, contributes to the development of sustainable production and helps enterprises to receive additional profit. A study conducted by M. Hamulczuk *et al.* (2021) shows that Ukraine is one of the world's leading countries in the production and export of sunflower oil. However, the key trend is towards integration into the European Union markets, which requires the development of various forms of enterprises and investments.

Researchers S. Balaji & S. Chandrasekar (2023) note that vegetable oil can be used as an alternative to mineral oil and used in a certain proportion with mineral oil for insulation and cooling medium in a transformer. In turn, P.A. Kandhan *et al.* (2023) note that the use of a mixture of saturated and unsaturated vegetable oil is a promising solution for the insulation of high-voltage liquid dielectrics. They studied such characteristics as viscosity, flash point, and pour point. Scientists I. Zakharov *et al.* (2019) presented the results of a study of the quality of sunflower seed processing using an improved line. The mechanical and technological parameters of the processed raw materials, in particular the concentration of oil in sunflower seeds, are presented. The team of authors P. Osadchuk *et al.* (2022) developed an experimental setup with an ultrasonic generator for the purification of sunflower oil under the action of an ultrasonic field, the paper presents the technological parameters of the process of sunflower oil purification by ultrasonic treatment.

V. Shevchuk & O. Sukach (2018) described in detail the study of the mechanical and technological properties of oilseeds, in particular for ellipsoidal seeds. The main attention was paid to rapeseed and the design of the oilseed huller. The authors developed technical solutions for oilseed processing and presented the design dependencies of the outlined structures, in particular, the interaction of the hulling rollers with the seeds and the dependence of their gap and diameter. The authors of S. Wang *et al.* (2022) developed a simulation modelling method for the comprehensive description and construction of a discrete element model for non-spherical particles for sunflower seeds using computer digital modelling technology. This study is relevant for identifying the sowing characteristics of sunflower seeds, but studies of the size and mass characteristics of seeds conducted using mathematical modelling can also optimise processing processes.

Many researchers pay attention to the quality characteristics of oil as a finished product, in particular, A. Sudhakar *et al*. (2023) provided a detailed report on chemical studies, chromatography, carried out in the field of assessing the falsification of edible oils, as well as methods for detecting and combating counterfeiting. Researchers Z. Ye & Y. Liu (2023) studied the fatty acid composition of rapeseed and the impact of the technological process of its processing on the properties of the oil. However, in the context of evaluating the finished product, it is important to assess the quality of the feedstock, identify the correlations between the physical and mechanical properties of the raw materials that are processed and the influence of the design and operating parameters of the equipment, which is the focus of this study.

The aim of the study was to intensify the pressing of sunflower seeds on a screw press and substantiate its design and kinematic parameters based on theoretical and experimental studies, technical and technological solutions that can significantly improve the efficiency of the process of separating oil from sunflower seeds. The analysis of literature sources on the state of vegetable oil production has identified the following tasks, the solution of which was necessary to achieve the research goal:

- describe the features of the proposed constructive solution of an energy-efficient oilseed press;
- to present the design and kinematic characteristics of an energy-efficient oil press;
- to conduct laboratory tests on the physical and mechanical characteristics of raw materials processed by the oil press.

MATERIALS AND METHODS

The study was carried out on the basis of the proposed design of an energy-efficient oil press, the peculiarity of which is that a steam generating device was introduced into the press design, which affects the intensification of the oil separation process and increases its yield and reduces the pressure on the material on the working bodies, which will extend their service life (Fig. 1).

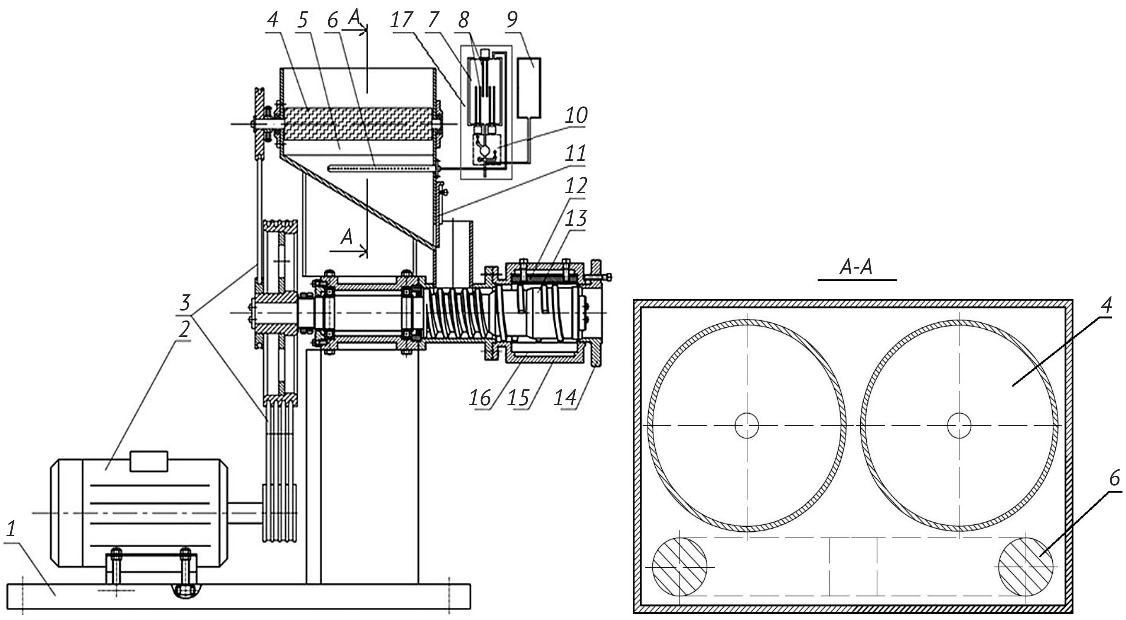

Figure 1. *Energy-efficient oilseed press with steam generator for moisture heat treatment*
Notes: *1 – frame; 2 – electric motor; 3 – V-belt transmission; 4 – threaded rollers; 5 – hopper; 6 – steam spray; 7 – heat exchanger; 8 – tubular electric heater; 9 – expansion tank; 10 – hydraulic groups; 11 – valve; 12 – tension wedge; 13 – auger; 14 – nut; 15 – perforated cylinder; 16 – perforated panels; 17 – steam generator*
Source: *N. Dotsenko et al. (2023)*

The most common varieties (hybrids) of sunflower seeds typical for cultivation in the Southern zone of Ukraine are: Alianze (RPG 406), Alamo (RT 933), Altsion, Arena, B-206, B-306, Visit, Hetman F1, Lan 26, Megasan (Makarchuk, 2022). The research was conducted on the seed varieties listed in Table 1.

Table 1. *Sunflower seed characteristics*

Variety	Dimensions, mm			Length to width ratio, L/a	Weight of 1,000 seeds, g	Fat content, %
	Length, L	Width, a	Thickness, b			
Alianze (RPG 406)	9.0	5.1	4.3	1.8	53	47.8
Arena	9.5	5.0	4.2	1.9	51	50.7
Visit	9.8	5.5	4.5	1.8	63.3	52.8
Hetman F1	10.0	5.4	4.4	1.9	55.5	49

Source: *developed by the authors*

In the course of studying the mechanical and technological properties of seeds, their frictional properties were also investigated. The friction angles of seeds on the following surfaces were determined: galvanised steel, white tin, sheet steel (rolled), and technical rubber. To confirm the theoretical assumption that pressure depends on material density, the setup shown in Figure 2 was used.

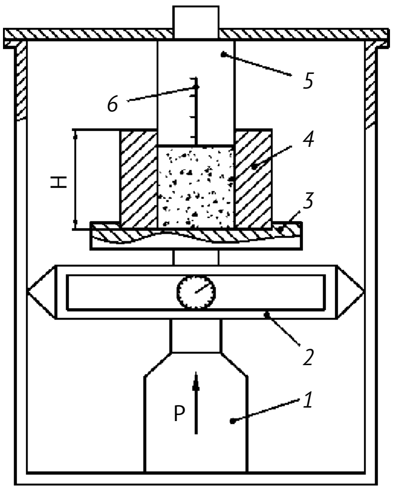

Figure 2. *Diagram of the device for determining the pressing pressure and pressing operation*

Notes: *1 – hydraulic jack; 2 – exemplary dynamometer; 3 – glass; 4 – matrix; 5 – punch; 6 – metric scale*

Source: *developed by the authors*

The main physical, mechanical and technological properties of sunflower seeds are shape, size, absolute and volumetric weight, density, and moisture content. The methodology is based on well-known guidelines and specific experimental conditions. Statistical methods of research and mathematical processing were used to separate natural changes from random indicators (Bortz, 2005).

To characterise the general population (all seeds under study) by discrete variation traits, sample statistical observation was applied on the basis of each value of trait X_i. The extreme values are denoted as X_{min} i X_{max}.

The total number of samples n for each of the traits was taken to be at least 50. In this case:

$$n = \sum_{i=1}^{n} l(i). \quad (1)$$

The statistical series of the feature X was divided into a number of classes N_k of $N_k = 10$, while $n \geq 50$. The class was calculated as:

$$t = \frac{X_{max} - X_{min}}{N_k}. \quad (2)$$

The boundaries for any k-th class were defined as:

- lower boundary: $X_{k-1} = X_{min} + t \cdot (k - 1)$;
- upper boundary: $X_k = X_{k-1} + t$.

Relative frequency of observations for any k-th class:

$$P_k = \frac{n_k}{n}, \quad (3)$$

where n_k – the number of options that fall into the k-th class.

The check was carried out according to the formula:

$$\sum_{k=1}^{N} P_k = 1. \quad (4)$$

The average arithmetic value of a feature across classes:

$$X_{k.avr} = \frac{(X_{k-1} + X_k)}{3}. \quad (5)$$

Formula for calculating the average value:

$$X_a = \sum_{k=1}^{N} X_{k.avr} \cdot P_k. \quad (6)$$

The estimate of the spread of the values of the random variable X around the average value of X_a was determined by the formula for the mean square of the deviation (variance) S:

$$S = \sum_{k=1}^{N} (X_{k.avr} - X_a) \cdot P_k. \quad (7)$$

To compare the spread of values near the centre of the distribution and a random variable, the standard deviation is determined σ:

$$\sigma = \sqrt{S}, \quad (8)$$

as well as the coefficient of variation or variability of the trait v:

$$v = \left(\frac{\sigma}{X_{avr}}\right) \cdot 100\%; \quad (9)$$

$$\rho = \pm\left(\frac{\sigma}{X_a \cdot \sqrt{n}}\right) \cdot 100\%. \quad (10)$$

The error rate (error) of the experiment, determined by formula (10), should not exceed 4.0%. The size and weight characteristics of seeds include: seed length L, mm; seed width a, mm; seed thickness b, mm; seed weight m, mm; absolute weight M, g; seed density ρ, kg/cm^3. Size and weight characteristics were determined by caliper SHC-1 (country of origin: Ukraine) with a scale division price of 0.05. The experiment was repeated 100 times. The absolute weight of seeds was determined by calculation:

$$m = \frac{M}{z}, \quad (11)$$

where z – the number of seeds in a random sample; M – the mass z of seeds.

For bulk materials, it is convenient to use the bulk density (kg/m^3), which depends on the actual density of the material particles and the voids between them:

$$\rho_H = (1 - \varepsilon) \cdot \rho_p, \quad (12)$$

where ε – the porosity; ρ_p – the density of the particle material, kg/m^3.

Porosity is defined as the ratio of the volume of pores V_p (m^3) in a loosely packed, uncompacted material to the volume of the entire loosely packed material V (m^3), i.e.:

$$\varepsilon = \frac{V_p}{V}. \quad (13)$$

RESULTS

Determination of the coefficient of friction of seeds on an inclined plane. One of the main physical and technological properties of seeds is their friction properties. The frictional properties of sunflower seeds are determined by the coefficients of external and internal friction, the indicator of which is the angle of natural slope. The calculation scheme of the device for determining the friction properties of seeds, and in particular for determining the static and dynamic friction coefficients, is shown in Figure 3. If a body is placed on an inclined plane, it will move downward under the action of its own weight $\vec{P} = m\vec{g}$ with constant acceleration $\vec{a}$, the normal reaction $\vec{N}$ of the inclined plane and the friction force F_{fr}, directed upward along the inclined plane, opposite to the body's motion. At $F_{fr} = f \cdot N$, where f – the friction coefficient. According to the basic law of dynamics:

$$m\vec{a} = \vec{P} + \vec{N} + \vec{F}_{fr}. \quad (14)$$

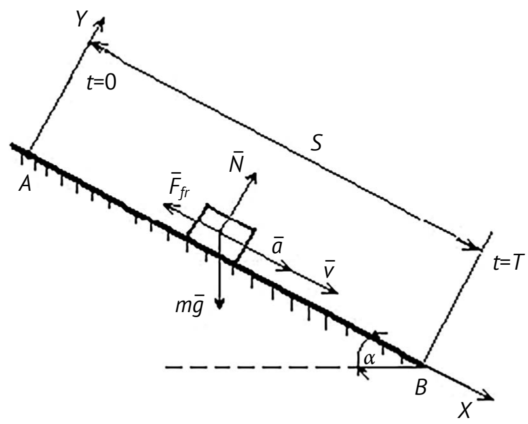

Figure 3. *Calculation scheme of the device for determining the dynamic coefficient of friction*
Source: *developed by the authors*

By projecting both parts of this vector equation onto the selected fixed coordinate axes, the differential equations of motion of a body on a rough inclined plane are obtained:

$$m\ddot{x} = mg \cdot sin\alpha - fN; \quad (15)$$

$$m\ddot{y} = -mg \cdot cos\alpha + N. \quad (16)$$

Since $y = 0$, then, accordingly, $\ddot{y} = 0$, and therefore from the differential equation (16) is determined:

$$N = mg \cdot cos\alpha. \quad (17)$$

Substituting this value of the normal response into equation (15) and reducing this equation by m, obtained:

$$a = \ddot{x} = g(sin\alpha - f \cdot cos\alpha) = const. \quad (18)$$

That is, the body is moving at an equally accelerated rate. Integrating this equation, obtained:

$$v = \dot{x} = g(sin\alpha - f \cdot cos\alpha)t + C_1. \quad (19)$$

Substituting the initial conditions into equation (18): $t = 0$, $v = v_0 = 0$, since the body motion is equally accelerated, $C_1 = 0$, and so on:

$$v = \dot{x} = g \cdot t \cdot (sin\alpha - f \cdot cos\alpha). \quad (20)$$

Integrating equation (20) and substituting the initial conditions into the resulting equation:

$$s = x = g \cdot t \cdot (sin\alpha - f \cdot cos\alpha) \cdot \frac{t^2}{2}. \quad (21)$$

Equation (16) is the law of motion of a body (material point) on a rough inclined surface. Solving equation (21) with respect to the friction coefficient f:

$$f = \frac{1}{cos\varepsilon}\left(sina - \frac{2s}{gt^2}\right) = tga - \frac{2s}{gt^2 \cdot cosa}. \quad (22)$$

Denoting the path travelled by the body in time $t = T$ from position A to position B by S, obtained the calculation form for determining the friction coefficient f:

$$f = tga - \frac{2S}{gT^2 \cdot cosa}. \quad (23)$$

The values of the friction coefficients cannot be determined by direct measurements, so the sliding angles were determined. The friction surfaces used were plates made of galvanised steel, white tin, rolled sheet steel and industrial rubber. When studying sliding friction, seeds were placed on an inclined plane of the device, with a sample of the material under study fixed on it. The inclined plane was raised to an angle φ, at which the seed began to move. The sliding friction coefficient f was determined by the formula:

$$f = tg(\varphi). \quad (24)$$

The angles and coefficients of seed sliding on the materials under study are presented in Table 2.

Table 2. *Sliding angles and friction coefficients of sunflower seeds*

Variety	Moisture content, %	Friction surfaces							
		Galvanised steel		White tin		Sheet steel (rolled)		Technical rubber	
		φ	f	φ	f	φ	f	φ	f
Alianze (RPG 406)	5	32.62	0.64	30.54	0.59	31.38	0.61	36.5	0.74
Arena	7	33.42	0.66	31.38	0.61	32.21	0.63	37.23	0.76
Visit	6	33.02	0.65	30.96	0.60	31.79	0.62	36.87	0.75
Hetman F1	8	33.82	0.67	31.8	0.62	32.62	0.64	37.6	0.77

Source: *developed by the authors*

Thus, the results of Table 2 show that the surface material has a negligible effect on the coefficient of friction of seed sliding. When sunflower seeds slide on a galvanised strip, the sliding friction coefficient ranges from 0.64 to 0.67; on a white tin strip – from 0.59 to 0.62; on a rolled strip – from 0.61 to 0.64; on a rubber strip – from 0.74 to 0.77.

Study of the components of the shredded mass. Theoretical studies have allowed to obtain calculations that reflect an idealised sunflower processing process, and therefore require experimental confirmation. Three areas of the pressing process have been experimentally identified: in the first area, the density of sunflower seeds increases within 500-600 kg/m^3; in the second area, the density increases from 500 to 650 kg/m^3 in proportion to the increase in pressure; in the third area, from 650 kg/m^3 with a rapid increase in pressure. The mathematical processing of the experimental results (Fig. 4) made it possible to determine the values of the coefficients (c) and (m), which characterise the effect of density, elasticity, size, and shape of seeds and allow theoretical calculation of the specific work by pressing. The probability of comparing the experimental and theoretical values of the specific work by pressing is within 5% (0.05).

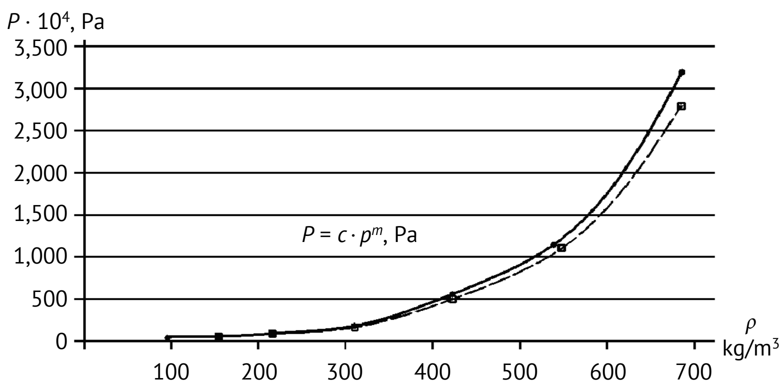

Figure 4. *Dependence of pressing pressure P on mint density*

Source: *developed by the authors*

Alignment of the experimental data with the theoretical curve allowed to establish that the relationship between the pressing pressure and the density of sunflower seeds is expressed by the following empirical relationship:

$$P = c \cdot p_m, \quad (25)$$

where P – the pressing pressure, Pa; ρ – the seed density, kg/m^3; c, m – coefficients.

The values of the coefficients (25) for sunflower are presented in Table 3.

Table 3. *Experimental values of the coefficients c and m*

Condition of sunflower seeds	c	m
Whole seeds	$1.76 \cdot 10^{-13}$	6.66
Crushed seeds (mint)	$3.3 \cdot 10^{-32}$	11.84

Source: *developed by the authors*

Determining the performance of a screw press. The working body of the screw is a screw that rotates in a fixed casing. In order to determine the design parameters of the working body, the movement of the material along the screw surface in the pressing zone is considered. Screw surfaces are formed as a trajectory from the movement of a straight line around and along a certain axis. The helical line described by any point of the line is called the directrix, or guide of the helical surface. The axial dimension that corresponds to the rise of the formed point in one revolution is the pitch of the helical line. A helical line is called regular if the forming point moves around and along a certain axis uniformly at a constant speed.

If a regular helical line corresponding to the outer cylinder with diameter D of the screw (Fig. 5) at a length of one step H onto a plane is turned, a right triangle ABC with a base equal to the length of the expanded circle of the cylinder πD and a height equal to the step of the helical line is fromed. This triangle is called a step triangle. The angle α made by the expanded helical line and the cylinder base is called the helical line rise angle. From the experience of many screw devices, it is known that material moves in a helical manner with variable speed in the axial and radial directions, depending on the distance of the material particles to the screw axis, the coefficient of friction and the pressure. The movement of the material along the screw surface of the screw can be conditionally represented as the movement of a number of unconnected individual particles with rather small gravitational forces. Under the assumption, each particle of material moves along its own helical line of the screw surface, the sweep of which is the hypotenuse of a step triangle.

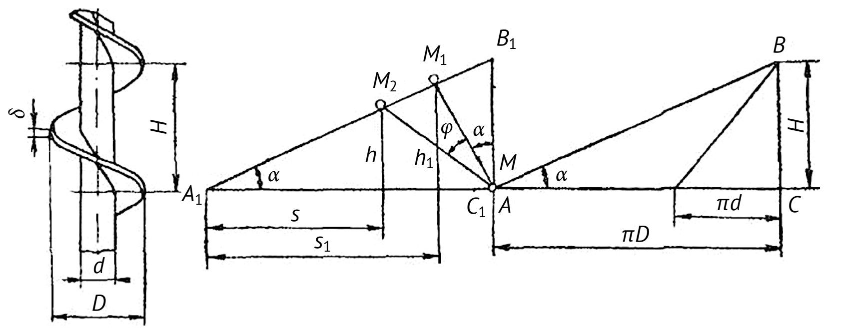

Figure 5. *Determining the screw parameters*

Source: *developed by the authors*

In the absence of friction between the screw surface (the expanded helical line AB) and a particle M of the transported material, the latter moves perpendicular to this surface, always in contact with it. With one rotation of the screw, the material particle in the axial direction passes the path h_1 and ends up at the point M_1.

$$h_1 = H \cdot cos^2\alpha. \quad (26)$$

In the presence of friction between the particle and the screw surface, the particle M will move at a friction angle φ to the normal C_1M_1 of the helical line and in one revolution of the screw will be at point M_2, having travelled in the axial direction the path:

$$h = H \cdot \frac{cos\alpha \cdot cos(\alpha+\varphi)}{cos\varphi} = H \cdot cos\alpha(cos\alpha - tg\varphi \cdot sin\alpha), \quad (27)$$

where H – the screw pitch of the screws; α – the angle of inclination of the screw lines; φ – the friction angle.

When the screw rotates, the material particles do not move in a straight line, but in helical lines – along and around the screw axis, which results in a decrease in their movement in the axial direction ($h < H$). This reduction can be accounted for by the coefficient K_o of lag or the coefficient k_b of rotation of the material particles, the analytical dependencies for which follow from the previously discussed scheme (Fig. 5).

Excluding friction forces:

$$k_0 = \frac{H-h_1}{H} = sin^2\alpha = \frac{\pi D - S_1}{\pi D} = k_b. \qquad (28)$$

Taking into account friction forces:

$$k_0 = \frac{H-h}{H} = sin^2\alpha + 0.5 \cdot f \cdot sin2\alpha = \frac{\pi D - S}{\pi D} = k_b, \qquad (29)$$

where $f = tg\varphi$ – the coefficient of friction of the material particles on the screw surface of the screw.

Since the pressed material is plastic-viscous and adhesive, the coefficient of friction is the coefficient of internal friction determined from the condition of particle bonding when the material layers are displaced. Thus, the movement of the product particles in the screw device can be accounted for by the displacement coefficient:

$$k = 1 - k_0 = cos^2\alpha - 0.5fsin2\alpha. \qquad (30)$$

The axial displacement of the material particles ranges from h at the periphery to 0 at the point where the helical line angle is $\alpha_0 = (90° - \varphi)$. In the context of practical calculations, the average value is assumed:

$$\alpha_{aver} = 0.5(\alpha_D + \alpha_d), \qquad (31)$$

where α_D – the angle of rise of the helical line on the periphery of the screw ($\alpha_D = arctg\frac{H}{\pi D}$); α_d – the angle of rise of the helical line on the screw shaft ($\alpha_d = arctg\frac{H}{\pi d}$).

The diameter d of the screw shaft must be greater than the maximum permissible diameter d_{np}, determined from the condition:

$$d_{np} = \frac{H}{\pi}tg\varphi. \qquad (32)$$

Taking into account the above, the productivity (kg/h) will be:

$$Q = 600 \cdot V_j \cdot p_j \cdot \omega \cdot K_s \cdot K_V \cdot (1 - K_b) \cdot K_y \cdot K_p, \; j = 1, 2, ..., n, \qquad (33)$$

where V_j – the theoretical volume of muscle per coil, m^3; ρ_j – the density of muscle per coil, kg/m^3 ($p_j = p_f \varepsilon_j$); $\rho_f = 450$ – the density of muscle in the feed zone, kg/m^3; ε_j – the degree of muscle compression on the coil ($\varepsilon_j = (1 + j)^{1.45}$); ω – the angular speed of the screw, rad/s ($\omega = \frac{\pi \cdot n}{30}$); n – the number of revolutions; $K_s = 2$ – the coefficient of muscle compaction; $K_V = 0.86$ – the coefficient of utilisation of the inter-twist volume; $K_b = 0.64$ – the coefficient for reverse movement; K_y – the coefficient of the oilseed (for sunflower $K_y = 1$, for flax $K_y = 0.5$); K_p – the coefficient that takes into account the mode of operation of the press (for single-stage pressing $K_p = 1$).

The design scheme of the screw press is shown in Figure 6. Before that, the theoretical volume of the pulp, m^3, is determined:

$$V_j = \frac{Q}{600 \cdot p_j . \omega \cdot K_S \cdot K_V \cdot (1 - K_b) \cdot K_y \cdot K_p}. \qquad (34)$$

On the other hand, the volume V_j is determined by the formula:

$$V_j = (\pi/4)(D_j^2 - d_j^2)[L_j - (ib_1 + b_2)/2cosa_j], \qquad (35)$$

where D_j – the inner diameter of the sump cylinder at section j, m; d_j – the diameter of the hub of the j-th screw turn, m; L_j – the length of the j-th turn, m; b_1, b_2 – the thickness of the coil in normal section along the outer and inner diameters of the screw, respectively, m; $i = 1, 2$ – the number of screw turns; α_j – the angle of the screw line along the average diameter, degree ($a_j = arctg\frac{Dj - dj}{t_j}$); t_j – the coil pitch, m.

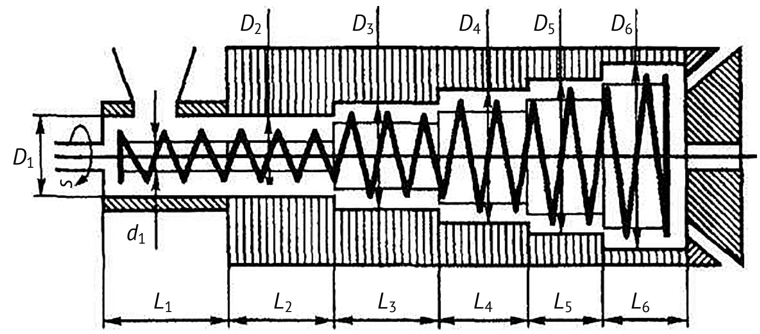

Figure 6. *Design diagram of a screw press*

Source: *developed by the authors*

By equating the right-hand sides of expressions (34) and (35), taking into account the above design relations, the equation is obtained from which the diameters D_j of the sections of the zeier cylinder are determined:

$$\frac{Q}{600 \cdot p_j \cdot \omega \cdot K_s \cdot K_V \cdot (1-K_b) \cdot K_y \cdot K_p} = (\pi/4) \cdot \left[D_j^2 - (D_j^2 - 0.025)\right] \cdot \left[1.08D_j - (ib_1 + b_2)/\ 2cos\alpha_j\right]. \quad (36)$$

Muscle pressure in the inter-turn space of the j-th screw turn, Pa:

$$p_j = 2.52a\varepsilon_j^{5.5}\, e^{0.022B}, \quad (37)$$

where $\alpha = 0.006$ – the empirical coefficient; $B = 4...5$ – the moisture content of the muscle, %.

With the calculated capacity, the screw parameters can be determined. The screw line pitch is equal to (0.7-0.8)*D*. At smaller values of the screw line pitch, the material may be torn off the inner surface of the device body due to the predominance of the screw surfaces of the screw above it, as a result of which the material will only rotate with the screw. Areas of the inner cylindrical surface of the housing:

$$F_H = \pi D \cdot (H - \delta); \quad (38)$$

$$F_W = \frac{1}{4\pi}(\pi DL - \pi dl + H^2 ln\frac{D+2L}{d+2l}), \quad (39)$$

where l and L – the scans of the helical lines corresponding to the shaft and screw diameters, m.

$$l = \sqrt{H^2 + (\pi d)^2}; \quad (40)$$

$$L = \sqrt{H^2 + (\pi D)^2}. \quad (41)$$

The axial force is calculated from the expression:

$$S = 0.392n \cdot (D^2 - d^2) \cdot P_{max}, \quad (42)$$

where n – the number of screw strokes; P_{max} – the maximum pressure developed by the screw press.

Knowing the axial force, the stress on the shaft can be calculated:

$$\sigma_s = \frac{S}{F}, \quad (43)$$

where F – the cross-sectional area of the screw shaft.

The last turn of the screw must be designed for strength. The greatest bending moment in a steel screw turn will be on the inner contour of the plate and will be equal:

$$M_F = \frac{P_{max} \cdot D^2}{32} \cdot \frac{1.9 \cdot 0.7\alpha^{-4} - 1.2\alpha^{-2} - 5.2ln\alpha}{1.3 \cdot 0.7\alpha^{-2}}. \quad (44)$$

Highest stress (equivalent):

$$\sigma = \pm\frac{6M_F}{\delta^2}, \quad (45)$$

where $a = D/d$ – the ratio of diameters.

Determining the power consumption of the press and its efficiency. The power (kW) required to drive the screw shaft of the press is determined by the formula:

$$N = N_0 \cdot Q, \quad (46)$$

where $N_0 = 0.045...0.055$ – the specific energy consumption for pressing oil in single-stage screw presses, kWh/kg.

The press efficiency is determined by the formula:

$$\eta = \frac{G + (M_C - \frac{M_C \cdot O}{100})}{G + O_P + (M_C - \frac{M_C \cdot O}{100})}, \quad 47)$$

where G – the amount of cake produced over a certain period of time (15-20 minutes), kg; M_C – the amount of crude unrefined oil produced over the same period of time as cake, kg; O_P – the amount of mill cake collected in the press collector over the same period of time, kg; O – the sediment in the oil supplied for refining, % by weight.

Practice shows that with proper preparation of the muscle for pressing and the screw presses in good working order, the efficiency is 0.94-0.96.

DISCUSSION

The technological process of oilseeds processing includes the following stages: preparation of raw materials (cleaning seeds from impurities, sorting, drying); extraction of mint – this operation is preceded by hulling (separation of husks), separation of the hull (separation of the "undershell"), crushing of the hulled kernel; oil extraction using one of the known methods. The resulting oil is subjected to preliminary purification, refining and sent for storage. The seed mass entering storage and processing is a heterogeneous mixture that includes both seeds and impurities that enter the mass during harvesting, temporary storage in the field and during transportation. The authors L.M. Alvarez-Gonzalez & I.J. Perea-Barrios (2023) point out that a large amount of impurities leads to moisture and seed deterioration, wear and tear of machine working parts, and a decrease in the subsequent oil quality.

The seed mass often contains metal impurities, primarily ferromagnetic ones (iron, steel, cast iron). Electromagnetic separators are used to remove them. The team of authors V. Shebanin *et al*. (2019) concluded that the efficiency of cleaning machines depends on the observance of a number of conditions during their operation. Seed flow into the machine should be uniform – underloading or overloading of the machine is unacceptable. If the machine is overloaded, the separation of impurities will be low, and if it is underloaded, seeds may get into impurities (in case of aerodynamic separation). The thickness of the seed layer on the machine sieve should not exceed 15 mm. The sieve installed in the machine must be selected according to the size of the most typical impurities and seeds. When the sieves are properly selected, the seeds should cover 2/3 of the total working length of the sieve. The angle of the sieve should ensure equal speeds of seed passing through the sieve and leaving the sieve. The sieve surface must be maintained in good technical condition (without dents, tears), systematically cleaned of debris using mechanical brushes or manually. The air flow rate must be adjusted so that no cleaned seeds come out with light debris and, at the same time, that heavy debris is also free of seeds. The processing should be done separately, as this will result in a higher yield of extra virgin oil.

The post-harvest stage involves bringing the seeds to moisture content standards (the exception is cottonseed, which sometimes has a moisture content 5…6% below the critical level when it arrives for processing and needs to be moistened before it can be processed). Prepared in accordance with the existing requirements, the raw material is sent for dehulling (separation of the hull from the kernel). In today's oilseed production facilities, dehulling is an important stage of the technological process. For this process, beater or centrifugal dehulling machines are usually used, with the former operating by breaking the hulls against the drum and drum beats, and the latter by hitting the drum beats once due to centrifugal forces. Technological standards allow the content of unshredded seeds to be up to 5%, and chaff – up to 3%. During the shucking process, the seeds are dehulled to form a hull, which includes the whole and crushed kernel, undershell and husk, and then threshed out on aspiration seeding machines. The hulled seeds are sent to the next technological operation – kernel grinding, which is aimed at obtaining an intermediate product called mint, which is obtained using rolling machines. The authors V. Shevchuk & O. Sukach (2018) note that rollers with grooves on the surface are used for primary and coarse grinding. The final grinding is carried out on rollers with smooth surfaces. The rotation speed of the rollers can be the same or different. The degree of grinding is regulated by changing the distance between the rollers. In terms of known methods, the mechanical method is one of the most common and most frequently used in oilseed processing plants. At the same time, the current study found that the process of compression of the pulp by pressing promotes oil separation and at the same time compacts the solid particles of the initial bulk material to form the cake. The process of compaction of the press material leads to the fact that the particles of the cake come closer together and the surface layers of oil are compressed. With a further increase in pressure on the material, the oil release virtually stops, despite the fact that some oil still remains in the middle of the material. The plastic properties of the pulp with high moisture content do not allow for the maximum pressure required for a given press design.

The authors of P.P. Ugarte-Espinoza *et al*. (2021) note that in the case of overdried pulp, the maximum possible pressure developed by the press is lower than that required for the appearance of the specified properties in the pulp. If the equipment is started up after a long shutdown, the cake should be fed into the press in a small amount until the press is fully heated and reaches thermal equilibrium with the cake and the heat losses of the press to the environment when the heated finished product (oil and cake) is removed from it. The main purpose of pressing the cake before extraction, or its full (final) pressing, is to obtain the maximum amount (80-90%) of pressing oil. The main working body of screw presses is the screw shaft. It consists of an axis, pressure coils and intermediate rings. All forging presses are equipped with stepped shafts. The screw shaft moves the material to be pressed with oil separation in the die cylinders. The mill cylinders consist of a set of mill plates. In the case of the pressing process, the following technological operations are carried out in the sequence shown below. The product obtained after rolling is fed into a fryer and then pressed using screw presses for complete oil separation, or so-called expeller presses. In the oilseed press industry, expellers are used for both single and complete oil separation in combination with fork presses. An expeller of the EP type is installed in a set with a three-chamber fryer. When the expeller is used in a double pressing scheme, the screw shaft has a rotation speed of 5-6 rpm. The capacity of the EP-type expeller with a double pressing scheme (FP-EP) for sunflower seeds is 20 tonnes per day, or 7-8 tonnes of oil cake with an oil content of 4-5%. The oil mills built in previous years, along with others, use the mechanical screw press MP-21, which can process 32 tonnes of sunflower seeds per day. This is a double-acting press, as it combines preliminary and final (complete) oil separation. The unit consists of a fryer, a vertical screw shaft that acts as a for-press, a horizontal screw shaft that acts as an expeller, a vibrating screen, a filter tank, pumps and an oil cooling system. The pulp prepared in the roaster is first fed for preliminary pressing into a vertical sieve drum with a vertical screw shaft installed in it. The design solution proposed in the results of this study allows combining hydrothermal treatment and pressing operations, which will reduce equipment costs, metal consumption and energy consumption, which is especially important in small industrial enterprises.

Based on the principle that the time spent by the muscle in each stage of the press tract is equal to the difference between the internal volume of the zener and the volume of the shaft (i.e., free space) divided by the volume of muscle passing through it per unit time. The authors of H. Jianjun *et al*. (2021) note that rheological dependencies indicate that one cannot be limited to only one of them to describe the behaviour of elastic-viscoplastic bodies, since the variety of structural and mechanical properties makes the deformation process quite complex. The proposed constructive solution of an energy-efficient screw press using a steam generator that treats raw materials with steam allows to significantly reduce the complexity of the deformation process, reducing the wear of the press working parts. The article by M. Mursalykova *et al*. (2023) is devoted to modelling the pressing process using an experimental screw press for the production of safflower oil in small processing enterprises. The problem of pressing the liquid phase from the dispersed material is described and solved. The proposed methodology for theoretical calculation of the pressing process allows determining the optimal parameters and pressing safflower oil. Taking into account the design solution of the oil press used for sunflower processing proposed in this paper, it should be noted that due to the fact that the oil moves through channels of variable cross-section and different shapes at a variable speed, the pressure on the liquid phase (hydrodynamic head) along the screw shaft also changes.

The authors of I.B. Muhammad *et al*. (2021) determine that the failure of a short drive shaft of a palm oil screw press is caused by fatigue crack formation, which was safe from stresses due to their concentration in its keyed areas. The plastic fracture observed on the surface of the shaft was found to be a result of the continuous rotational motion and the loading and unloading effect of the central drive system of the shaft. Therefore, the use of a steam generating device will reduce the stress on the screw and increase its service life. The authors Z. Barati *et al*. (2022) note that the total pressure and its radial and axial components are considered as the average values of the pressure on the oil and helium phases of the muscle. Practically, it is important to consider the change in total pressure and its components that occur along the screw shaft, since they affect the efficiency of oil pressing during pressing and the design of the presses themselves. The presented research on an energy-efficient oil press confirms the importance of an integrated approach to solving the issue of optimising the kinematic and structural parameters of screw presses for the oil industry. It is necessary to take into account the geometric parameters of the working chamber, the kinematic parameters of the equipment and the physical and mechanical properties of the seeds of the crop to be processed. Variations in the geometric characteristics of the working chamber or pressing elements of the equipment affect the ratio of pressure distribution and friction inside the chamber, and, consequently, the extraction efficiency and final oil yield. Thus, some physical and mechanical properties of oil-containing raw materials, in particular sunflower seeds, such as the coefficient of external friction, density, and pressure, are considered. Resistance to the movement of the material through the chamber is determined by the density of the pulp, the shape and distribution of the material is affected by lateral pressure and other factors. Kinematic parameters, such as the angular speed of the screw and linear speeds of movement, determine the material movement rate, which affects the time of contact between the raw material and the press working bodies and, accordingly, the quality and efficiency of oil extraction. To confirm the theoretical assumptions, experimental studies of the physical and mechanical characteristics of raw materials at all stages of the process are required. Such studies will help to correct the discrepancies between theory and practice and offer effective means of levelling them.

CONCLUSIONS

Oilseeds and their processed products, such as vegetable oil, cake, meal, and husk briquettes, are an important sector of the Ukrainian processing industry. To improve the efficiency of the technological process of oilseeds processing, the design and kinematic characteristics of an energy-efficient oil press were studied. A constructive solution of a screw press equipped with a steamer is presented, which allows to increase the oil yield due to the moisture-thermal treatment of mint, which is implemented in a single device. The physical and mechanical characteristics of sunflower seeds, which are typical for cultivation in the South of Ukraine, have been investigated. The coefficients of friction of sunflower seeds on an inclined plane, which affects the quality of their processing, were determined. Also, the components of the crushed mass were studied, on the basis of which the dependence of the pressing pressure on the density of the crush is presented. The calculation of the geometric parameters of the screw is presented. Based on these characteristics, the performance of the screw press, its capacity and efficiency were determined. Based on the data presented, it was concluded that the geometric parameters of the zeer chamber have the greatest impact on the pressing process. It is also necessary to take into account the physical and mechanical properties of the raw material entering the press. Kinematic parameters have a significant impact on the efficiency of an energy-efficient screw press. The presented theoretical dependencies can be used to calculate the technological process and select the most optimal parameters for its implementation. The theoretical analysis provides the initial data for understanding how the sunflower processing process proceeds. However, in order to optimise and implement this process in practice, it is necessary to conduct theoretical research, which can be attributed to the prospects for further research. This will allow to provide recommendations for improving the efficiency and cost-effectiveness of the oilseed processing process.

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CONFLICT OF INTEREST

None.

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Дослідження конструктивних і кінематичних характеристик енергоефективного олійного пресу

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Анотація. Технологічний процес виробництва рослинної олії потребує значних витрат на електроенергію, в той час як впровадження нових технологій потребує інвестицій, що в сучасних умовах є викликом для малих та середніх підприємств. Це спричиняє актуальність впровадження енергоефективного обладнання в умовах зазначених підприємств, що не потребує значних капіталовкладень. Стаття присвячена вдосконаленню технологічного процесу пресування олійної сировини шляхом впровадження в технологічний процес енергоефективного олійного пресу та дослідження його конструктивних та кінематичних характеристик. В контексті дослідження використовувалося визначення фізико-механічних властивостей сировини, методи теоретичної механіки та механіки твердого тіла, розрахунок конструктивних елементів технологічного обладнання для переробки олійної сировини. Обґрунтовано необхідність та доцільність проведення теоретичного аналізу та експериментальних досліджень. Визначено основні закономірності відокремлення олії з подрібненої маси. Дослідження фізико-механічних характеристик, розмірно-масових параметрів насіння і подрібненої маси дозволили обґрунтувати основні кінематичні і конструктивні параметри шнекового пресу. Викладено принцип роботи енергоефективного гвинтового олійного пресу. Конструкція пресу удосконалена паророзпилювачем, встановленим у приймальному бункері під нарізними валками, який комплектується парогенератором, що дає змогу здійснювати волого-термічну обробку парою в межах одного пристрою. Для запропонованого конструктивного рішення викладено: визначення коефіцієнту тертя насіння на похилій площині, здійснено дослідження компонентів подрібненої маси, отриманої за допомогою енергоефективного олійного пресу та представлено теоретичні аспекти пресування насіння олійних культур. Здійснено дослідження конструктивних і режимних параметрів шнекового пресу, а саме: визначення продуктивності шнекового пресу, використання енергоефективного пресу для відокремлення олії дає можливість поліпшити якість виконання технологічного процесу, визначення витрат потужності пресу та його коефіцієнт корисної дії. Підсумовано, що вдосконалене конструктивне рішення пресу відповідає сучасним вимогам, що ставляться до машин по виробництву олії. Використання запропонованого конструктивного рішення дозволить знизити втрати олії під час пресування, що значно підвищить ефективність процесу, дозволить знизити експлуатаційні витрати та сприятиме розвитку виробництва олії в умовах малих та середніх олійних підприємств

Ключові слова: шнековий вал; подрібнена маса; щільність; тиск; технологічний процес; продуктивність; вихід олії

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Economic assessment of the impact of climate change on agriculture in Albania and Ukraine

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Abstract. This study aimed to provide a comparative analysis of the impacts of climate change on the agricultural sector in Albania and Ukraine, with a focus on identifying key challenges and opportunities for adaptation. The study analysed statistical data from 2010 to 2023 on climate change and its impact on agriculture and assessed the consequences. The results of the study showed that changes in temperature regimes are a key factor that directly affects agriculture. An increase in average annual temperatures leads to a change in the growing season of plants, which has both positive and negative consequences. Changes in precipitation patterns are another key mechanism of climate change impact on agriculture. Reduced precipitation and frequent droughts can lead to significant crop losses, requiring the introduction of irrigation systems and other water-saving technologies. Economic risks associated with climate change are a serious challenge for agriculture. Reduced yields, higher production costs and the need to adapt to new conditions can threaten the stability of farms, especially small ones. The analysis for Albania showed that rising temperatures and decreasing precipitation pose challenges for agriculture, particularly for cereal and vegetable production. In Ukraine, with its large area of arable land, there is scope to compensate for the decline in yields by expanding the area under cultivation, but investment in new irrigation technologies and agronomic practices is needed to improve efficiency. Both countries face the need to introduce new plant varieties, modernize irrigation systems, and develop agricultural innovation and precision farming. Effective adaptation strategies, including international cooperation and support for research, are key to ensuring the sustainability of the agricultural sectors in both countries. The findings of the study can be applied in practice to government agricultural support programmes and international climate change adaptation projects

Keywords: temperature regime; water resources; productivity; investments in infrastructure; comparative analysis

INTRODUCTION

Climate change is a major global challenge that affects agriculture, a key sector for food security and economic stability, by altering critical climatic factors such as temperature and precipitation, resulting in reduced production in the short and long term. Impacts vary across geographical boundaries. In Albania and Ukraine, unique climatic conditions and agricultural practices lead to specific manifestations. Albania is facing rising temperatures, changing precipitation patterns and increasingly frequent severe weather events such as droughts and floods, which have a significant impact on crop yields and vital water resources required for agricultural

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activities. Ukraine has huge agricultural resources and is among the world's largest grain exporters. Nevertheless, the agricultural industry faces serious challenges related to climate change, including higher average annual temperatures, reduced precipitation in some areas, and increased extreme weather events. These challenges require adaptation measures to maintain exceptional agricultural productivity and competitiveness in the global market.

The significance of the study stems from the need to assess the economic impacts of climate change on the agricultural industry in Albania and Ukraine in order to develop effective adaptation measures to changing climatic conditions. Although each country has its own characteristics and obstacles, the main common factor is that climate change affects the ability of the agricultural sector to guarantee sustainable food production. The potential consequences of this could be significant for the economies, social progress and food security of countries.

G.S. Malhi *et al*. (2021) studied the global impact of climate change on agriculture, focusing on changes in grain productivity. They found that rising temperatures can lead to a decrease in wheat yields in regions where temperature increases are not accompanied by increased precipitation. D. Müller & M. Hofmann (2022) conducted a study on the example of Southern European countries, including Albania, and concluded that the decline in precipitation and the increase in the frequency of droughts pose significant challenges to the production of olive oil and other traditional crops. A. Skrypnyk *et al*. (2021), in turn, focused on Ukraine, where he analysed the impact of climate change on grain production. Authors concluded that, despite the increase in the growing season, a decrease in precipitation in the southern regions of Ukraine could significantly reduce yields without proper irrigation. N. Khan *et al*. (2021) studied adaptation strategies in agriculture, emphasizing the importance of integrating modern agricultural technologies, such as the use of drought-resistant plant varieties. S. Skendžić *et al*. (2021) noted in their work that climate change contributes to the spread of new pests and diseases that can threaten crop production, and stressed the need to develop new plant protection products. N.T.L. Huong *et al*. (2019) also conducted a study on the economic impact of climate change on agriculture and concluded that climate change will lead to the need for significant investment in irrigation systems to maintain sustainable agricultural production. E. Zhllima *et al*. (2022) analysed climate risks for agriculture in Albania. They found that the Mediterranean climate of the region is becoming more arid, which leads to a reduction in fruit crop yields. A.A. Chandio *et al*. (2020) studied the impact of climate change on the economy of the agricultural sector and pointed to the growing risks for corn and sunflower production. Authors noted that without adaptation measures, significant losses in yield and profitability are possible. A. Raza *et al*. (2019) studied the global impacts of climate change, in particular the impact on agricultural prices. The authors highlighted that climate change has the potential to result in increased food prices. The study conducted by R. Anderson *et al*. (2020) highlighted the need of international collaboration and knowledge sharing across nations in developing adaptation methods for agriculture in response to climate change.

The examination of researches indicates that climate change exerts a substantial influence on agriculture. Consequently, it becomes imperative to formulate and execute adaptation measures that are designed to mitigate risks and guarantee the sustainable growth of the agricultural industry. While prior research has made a substantial contribution to comprehending the influence of climate change on the agricultural sector, there are numerous areas that have not been well investigated. A notable deficiency exists in the thorough comparative examination of the effects of climate change on agriculture in two nations characterised by distinct meteorological circumstances and economic frameworks, namely Albania and Ukraine. Furthermore, there is a lack of focus on evaluating the economic consequences of climate change on specific crops that are crucial for both nations. The purpose of the study was to perform a comparative examination of the influence of climate change on agriculture in Albania and Ukraine, with an emphasis on pinpointing particular obstacles for important cereal crops.

MATERIALS AND METHODS

In order to study the impact of climate change on agriculture in Albania and Ukraine, a range of materials and methods were used, including both qualitative and quantitative data. Primary sources of information consist of statistical data, published climate reports and agronomic research. The study of climate change impacts on agriculture in Albania and Ukraine involved a thorough examination of climate data, crop yields and production in both countries. To study climate change, authors used data from the Climate Change Knowledge Portal (n.d.a; n.d.b), which covers average annual temperatures and precipitation in Ukraine and Albania. Specifically for this study, changes in average annual temperature and precipitation were analysed for the period from 2010 to 2022. The graphical display of these data allowed to identify the main trends in climate change in both countries.

A statistical analysis of the yields of several crop groupings was used to evaluate the influence of climate change on agricultural productivity. For Albania, data were obtained from Food and Agriculture Organization (n.d.) and National Institute of Statistics of Albania (n.d.). In Ukraine, data from the State Statistics Service of Ukraine (n.d.) were used. The information included yields from 2016 to 2022 in Albania and 2023 in Ukraine for different types of crops, such as cereals, vegetables, fruits, and industrial crops. In addition, data on production volumes of these crops from 2016 to 2023 were collected. The data analysis allowed to assess how changes in climate conditions have affected crop yields and production in both countries. Analysis methods included correlation analysis to determine the relationship between climate change and yields, as well as regression analysis to determine possible directions for future changes in crop production.

Furthermore, significant focus was given to the examination of advancements in irrigation, agronomy, and agronomic techniques that enhance the ability of agricultural produce to withstand influences from climate change. The study examined contemporary irrigation systems, the use of drought-tolerant crop types, and the use of sophisticated agronomic practices to mitigate the effects of unfavourable climatic conditions. To study the economic impact of climate change, authors took into account aspects such as adaptation costs, reduced profitability and risks associated with extreme weather conditions. The economic impact assessment included an analysis of changes in production costs, in particular the costs of irrigation systems and crop protection, as well as the impact on farm profitability. In particular, the costs of adopting new technologies, such as drip irrigation systems, and changes in agricultural prices were considered. The study also conducted a comparative analysis of the effects of climate change on agriculture in Albania and Ukraine. This encompassed an examination of the various meteorological conditions and their influence on agricultural output in both nations, taking into account the particularities of agricultural methods and economic circumstances.

RESULTS

Climate change presents substantial obstacles to agriculture, the industry most reliant on natural environments, by impacting it through intricate and varied processes that encompass both direct and indirect consequences on production. Influential variables such as increasing temperatures modify the periods of plant growth, which may lead to higher yields in certain areas but often result in reduced production due to heat stress and increased insect activity, especially in dry climates (Aragón *et al.*, 2021). Alterations in precipitation patterns have a second in importance effect on agriculture; decreased rainfall and more frequent droughts result in decreased crop yields necessitating water conservation techniques, while excessive or uneven precipitation can lead to flooding and soil erosion, so adversely affecting agricultural production (Siddig *et al.*, 2020).

Changes in the frequency and intensity of extreme weather events, such as hurricanes, floods and droughts, are another crucial mechanism of climate change impacts. Such events can lead to sudden crop losses, infrastructure damage and significant economic losses. The increasing frequency of extreme weather events creates additional risk for farmers and forces them to look for new risk management strategies, such as crop insurance or the introduction of climate-resistant plant varieties. In addition, climate change is affecting water resources, which are critical for agriculture. Changes in the water balance can lead to water shortages, especially in regions where water is already a limited resource. This is forcing farmers to look for new approaches to water management, such as reducing water consumption or adopting more efficient irrigation technologies.

The phenomenon of climate change poses many risks to the agricultural sector, with both immediate and long-term consequences for agricultural production. A clear threat to agriculture is the reduction in yields of major crops. Climate change, characterized by higher temperatures, reduced precipitation and more frequent extreme weather events, poses challenges to maintaining traditional production levels. Another significant risk is the change in geographical areas of agricultural production. Due to climate change, some regions may become unsuitable for growing certain crops. For example, in regions where olives or grapes were previously successfully grown, the conditions may become too harsh for these crops due to rising temperatures and decreasing rainfall (Shahzad *et al.*, 2021). This may lead to the need to change the specialization of regions, which in turn requires significant investments in new infrastructure, changes in growing technologies and adaptation of farmers to new conditions. Climate change also increases the risk of pests and diseases. Warming may help to expand the habitat of some pests that were previously restricted to warmer regions.

Economic risks associated with climate change are among the most serious challenges facing modern agriculture. These risks not only affect the profitability of agricultural production, but can also threaten the stability and viability of farms, especially small ones. The main economic challenges posed by climate change include higher production costs, reduced profitability, the need to adapt to new conditions, and the risk of farm retrenchment (DeFries *et al.*, 2019). Increased costs of agricultural production are one of the most obvious consequences of climate change. For example, farmers are forced to invest in irrigation systems to provide water for crops in drought conditions. The cost of installing and maintaining such systems can be significant, especially for small farms (Kolstad & Moore, 2020). The introduction of new agricultural practices, such as climate-resilient plant varieties or tillage methods, also requires additional financial resources. In addition, farmers are forced to spend more money on protecting plants from pests and diseases, which are becoming more prevalent as temperatures rise and rainfall patterns change. The cost of pesticides, herbicides, and other plant protection products is rising, which significantly increases the cost of production. In some cases, this may require farmers to implement integrated crop protection systems, which requires additional knowledge and skills, as well as even greater financial investment.

Reduced yields due to climate change are another serious economic risk. Fluctuations in plant growth period, reduced rainfall and increased incidence of severe weather events lead to uncertainty in agricultural production. Farmers may face volatility in yields from year to year, making their income unpredictable. Declining yields directly affect the profitability of farms, especially those that are already operating at the margins of profitability (Ray *et al.*, 2019). This can have catastrophic consequences for small farmers who do not have the financial reserves to overcome such losses. In the face of low profitability, many farmers may be forced to leave agriculture or change their specialization. This is especially true for small farms that do not have sufficient resources to invest in new technologies and adaptation measures. For example, farmers who produce certain crops may find that these crops are no longer economically viable due to climate change (Ojo & Baiyegunhi, 2020). This may force them to switch to other activities, which in turn may lead to the loss of traditional agricultural practices and knowledge. In addition, it is important to recognize that farm closures resulting from economic problems can have significant socio-economic consequences. A reduction in agricultural production as a result of fewer active farmers can lead to higher food prices and increased food insecurity. The depletion of farms can negatively affect rural populations by reducing employment opportunities and incomes in geographic areas already facing economic challenges (Guth *et al.*, 2020).

Thus, economic risks associated with climate change pose a serious threat to the agricultural sector. Increased production costs, lower yields and reduced profitability could force many farmers to leave agriculture, with far-reaching consequences for food security and economic stability. To address these challenges, effective strategies to adapt and support farmers are needed, including through financial assistance, educational programmes and the development of new agricultural technologies. Agriculture in Albania is an important factor in economic development and employment. Currently, the sector accounts for about 18.6% of the country's gross domestic product (GDP) and employs more than 40% of the population. In addition, agricultural and food products make up a significant share of exports, accounting for 11.3% of the total (National Institute of…, n.d.). However, Albania, as a country with a developed agricultural sector, faces many challenges posed by climate change, which requires a deep understanding and appropriate adaptation strategies. Albania has a diverse climate, ranging from Mediterranean to continental, which determines the cultivation of different crops. Climate change, such as frequent droughts in summer and increased rainfall in autumn and spring, can cause significant fluctuations in crop yields. This, in turn, leads to unpredictability in production volumes, which creates risks for farmers and may lead to higher agricultural prices. Figure 1 shows changes in average annual temperature and precipitation.

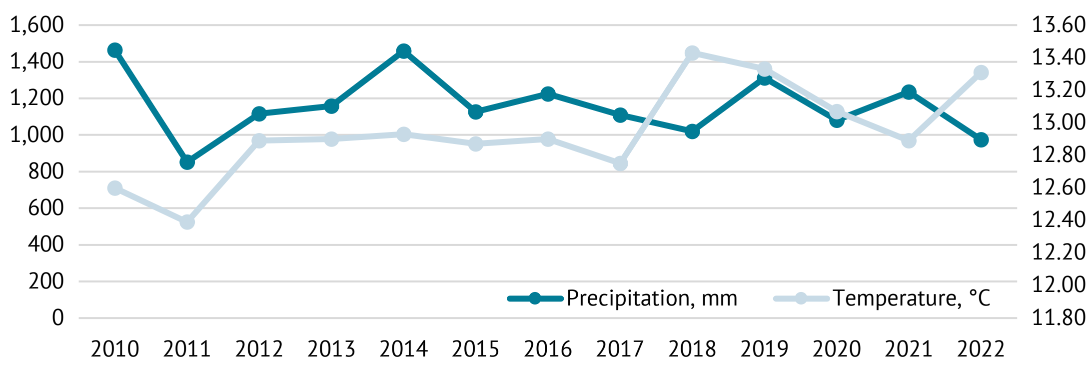

Figure 1. *Dynamics of climate change in Albania from 2010 to 2022*
Source: *developed by the author based on data from the Climate Change Knowledge Portal (n.d.a)*

The average annual temperature in Albania for the period from 2010 to 2022 showed a gradual increase. While in 2010 the average temperature was 12.6°C, in 2022 it reached 13.31°C. This temperature increase is a sign of global warming, which can have a significant impact on the country's agriculture. Changes in precipitation are another critical factor that has a direct impact on agriculture. Figure 1 shows significant fluctuations in precipitation. Particularly noteworthy are the recent years: from 2019 to 2022, there has been a decline in precipitation, most notably in 2022, when the amount of precipitation was only 973.69 mm. This decline can pose serious challenges for farmers, including the need for increased irrigation costs and lower yields. Table 1 shows the yields of different crop production groups.

Table 1. *Crop yields in Albania from 2016 to 2022, t/ha*

Product groups	2016	2017	2018	2019	2020	2021	2022
Cereals	4.7	4.8	4.8	5	5.2	5.1	5.2
Citrus fruits	27.8	29.6	38.5	35.8	37	37.8	39.7
Fibre crops	0.39	0.39	0.38	0.38	0.39	0.39	0.4
Fruit	22.9	22	22.3	22.6	22.7	23.8	24
Oilseeds (oilcake)	1.02	0.81	0.92	0.87	0.84	0.8	0.92
Oilseeds (oil)	0.56	0.52	0.55	0.46	0.6	0.5	0.69
Root vegetables and tubers	24.6	25.1	26.2	25.6	26.3	24.9	26.5
Sugar crops	30.4	33.8	39.2	38.1	32.2	32.3	32.3
Nuts	4.8	4.7	4.1	4.2	4.4	4.3	4.9
Vegetables	27.3	28.1	27.7	28.4	28.5	29.1	29.6

Source: *developed by the author based on data from the Food and Agriculture Organization (n.d.)*

Agriculture in Albania shows changes in the yields of different crops, which can be attributed to various agronomic, technological and climatic factors. Despite the negative changes in climatic conditions, positive trends and stability are observed in most crops, which indicates the effectiveness of agronomic practices, while the decline in yields of certain crops may indicate the need for additional research and adaptation strategies. Table 2 shows the volume of crop production.

Table 2. *Crop production in Albania from 2016 to 2023, thousand tonnes*

Product groups	2016	2017	2018	2019	2020	2021	2022	2023
Cereals	698.4	701.7	678.2	666.1	684	691.4	690.8	701.3
Vegetables	1,129.1	1,151.9	1,166.3	1,258	1,295.7	1,338.2	1,357.8	1,384.5
Potatoes	238.3	249.8	254.5	260.7	254.8	258.9	262.7	274.2
White beans	25	21.2	24.5	24.8	25.8	22.4	21.8	23.3
Industrial crops	-	32.7	30.8	33.7	30.1	27.3	24.5	23.4
Medicinal crops	10.6	12.8	12.5	12.9	14.4	16	16.4	17.8
Feed	6,144	6,688.6	7,050.1	7,115.2	7,170.5	7,054	7,138.8	6,940.3
Fruit trees	261	262.6	274.3	272.6	273.7	287.2	295.4	281.9
Olives	99	107.8	117.6	98.3	131.9	110.2	157.7	117.6
Citrus fruits	40	41	45.5	46.9	49.2	50.5	55.1	56.7
Grapes	205.1	202.9	189.8	189.8	199.1	212	211.2	179.7

Source: *developed by the author based on National Institute of Statistics of Albania (n.d.)*

The agricultural commodity production in Albania has exhibited either growth or stability, suggesting the efficacy of climate change adaptation strategies and the conservation of the nation's agricultural capacity. Nevertheless, certain commodities, including industrial crops and grapes, are seeing a decrease in productivity, underscoring the necessity for additional study and the adoption of novel approaches to sustain their competitiveness.

At the macroeconomic level, climate change impacts Albania's international economic operations. Given the significance of agriculture as an export industry, any decrease in crop production could result in a decrease in the nation's ability to export. This can potentially have an adverse effect on Albania's trade balance, further augmenting its reliance on food imports and exacerbating the country's economic stability. Furthermore, an increase in pricing for agricultural commodities on the local market can result in inflation, therefore adversely affecting the buying power of the populace.

The agricultural industry in Ukraine, which constitutes a significant portion of the national economy (7.8% of GDP), is facing a growing and complex challenge posed by climate change (State Statistics Service..., n.d.). Given its status as a major global producer and exporter of grains and oilseeds, Ukraine relies heavily on consistent meteorological conditions to maintain its agricultural output. Nevertheless, climate change, characterised by the observation of elevated average yearly temperatures, altered precipitation patterns, and a heightened occurrence of severe weather phenomena, can exert a substantial influence on the productivity of agricultural land and the economic viability of farms. Figure 2 illustrates variations in mean yearly temperature and precipitation.

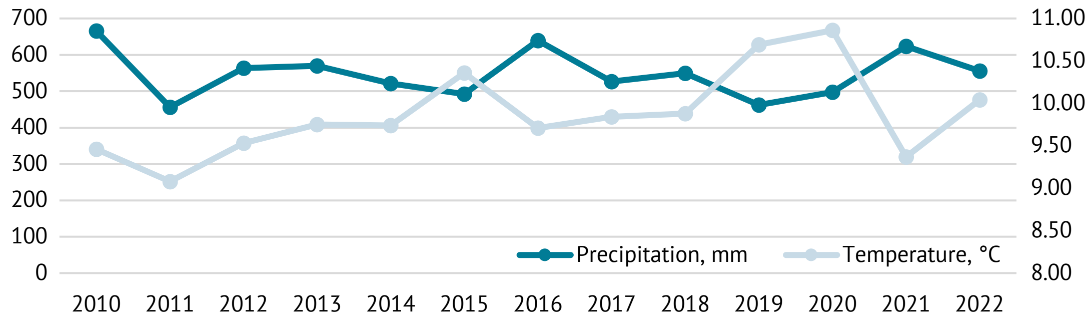

Figure 2. *Dynamics of climate change in Ukraine from 2010 to 2022*
Source: *developed by the author based on data from the Climate Change Knowledge Portal (n.d.b)*

The mean annual temperature in Ukraine has exhibited a progressive upward trend, rising from 9.46°C in 2010 to 10.86°C in 2020, and then seeing a minor decline to 10.04°C in 2022. The observed pattern suggests a general increase in temperature, which can have both beneficial and detrimental effects on agriculture. Elevated temperatures can enhance the productivity of heat-tolerant crops and extend their cultivation regions towards the northern regions. Nevertheless, an over rise in temperature could also result in heightened evaporation and in turn, droughts, therefore adversely impacting agricultural output, particularly in the southern parts of Ukraine. Substantial variations in precipitation were observed throughout the research period. The inequitable allocation of rainfall is a significant obstacle for agriculture, since both the overall quantity of precipitation and its variation over the growing season are crucial factors. The yields of several agricultural production groups are presented in Table 3.

Table 3. *Crop yields in Ukraine from 2016 to 2023, t/ha*

Product groups	2016	2017	2018	2019	2020	2021	2022	2023
Cereals and pulses	4.61	4.25	4.74	4.91	4.25	5.39	4.58	5.52
Factory sugar beet	48.2	47.5	50.9	46.1	41.6	47.9	54.1	52.5
Sunflower	2.24	2.02	2.3	2.56	2.02	2.46	2.16	2.45
Potatoes	16.6	16.8	17.1	15.5	15.7	16.6	17.4	17.7
Vegetable crops	21.1	20.8	21.4	21.4	20.7	21.5	20	20.9
Cultures fruit and berry	10.2	10.3	12.8	10.8	10.6	11.7	11.6	11.9

Source: *developed by the author based on data from the State Statistics Service of Ukraine (n.d.)*

The dynamics of crop yields in Ukraine from 2016 to 2023 indicates a significant impact of climate change on the agricultural sector. The fluctuations in yields of different crops highlight the need to adapt to new climatic conditions, introduce new technologies, and more precisely plan agronomic measures to minimize risks and maintain the productivity of the Ukrainian agricultural sector. Table 4 shows the volume of crop production.

Table 4. *Crop production in Ukraine from 2016 to 2023, thousand tonnes*

Year	2016	2017	2018	2019	2020	2021	2022	2023
Cereals and pulses	66,088	61,917	70,057	75,143	64,933	86,010	53,864	59,772
Factory sugar beet	14,011	14,882	13,968	10,205	9,150	10,854	9,942	13,130
Sunflower	13,627	12,236	14,165	15,254	13,110	16,392	11,329	12,760
Potatoes	21,750	22,208	22,504	20,269	20,838	21,356	20,900	21,359
Vegetable crops	9,415	9,286	9,440	9,688	9,653	9,935	7,512	8,297
Fruit and berry crops	2,007	2,048	2,571	2,119	2,024	2,235	1,995	1,996

Source: *developed by the author based on data from the State Statistics Service of Ukraine (n.d.)*

Ukraine's agricultural sector is subject to significant fluctuations in the production of different crops, which is due to climate change as well as economic and political factors. The decline in 2022 is mainly due to the outbreak of war in Ukraine. Successful adaptation of the agricultural sector to new conditions requires the introduction of innovative technologies, improvement of agronomic practices and consideration of all possible risks.

Despite their differences in climate, geography, agricultural organisation, and economic development, Ukraine and Albania both rely significantly on the agricultural industry. The Mediterranean climate of Albania, situated in the southern region of Europe, is distinguished by moderate winters and scorching, arid summers. As of 2024, the nation is experiencing escalating temperatures and erratic precipitation, resulting in a notable surge in the vulnerability to drought and a reduction in readily available water supplies. These modifications exert a substantial influence on the agricultural outputs and efficiency of crops, particularly those that are exceptionally responsive to fluctuations in the water equilibrium, such as grains and vegetables. For example, cereal production in Albania has shown some stability, but climate variations could have a significant impact on future yields. Water scarcity also threatens orchards and vineyards, requiring the introduction of new irrigation systems and adaptive technologies. This requires an increase in the costs of introducing new technologies for irrigation and water management. In particular, farmers are forced to invest in efficient irrigation systems, which increases production costs. This can have a negative impact on profitability, especially for small farmers, who often do not have access to sufficient finance. Agricultural products make up a significant portion of Albania's exports. A decline in yields could affect the country's export potential, which in turn would affect foreign trade and economic growth. A decline in production of major export crops such as citrus could also reduce foreign exchange earnings from exports.

As one of the largest agricultural countries in Europe, Ukraine faces other challenges. Climate change in Ukraine, including an increase in average annual temperature and reduced precipitation in some regions, is leading to soil degradation, lower yields and overall agricultural productivity. This is particularly acute in the southern and eastern regions of the country, which face frequent droughts. However, unlike Albania, Ukraine has a larger area of arable land, which allows it to compensate for the decline in yields by expanding its sown areas. On the other hand, climate change also causes uneven distribution of precipitation, which leads to flooding in some regions and, as a result, crop losses. This requires significant investment in irrigation technologies, new agronomic practices and improved soil cover. However, large agricultural companies have more resources to implement such technologies than small farmers. Ukraine's agricultural sector is of great importance to the country's economy, particularly for exports. Climate change could reduce production of major crops, which would negatively impact export revenues and economic stability. Decreased yields of grain and oilseeds could lead to higher prices for products on the domestic market and increased import costs.

Both countries encounter difficulties associated with the necessity to adjust to changes in climatic circumstances. The aforementioned activities encompass the implementation of novel crop cultivars that exhibit enhanced drought tolerance, the upgrading of irrigation infrastructure, and the advancement of agro-innovation and precision farming technology. Furthermore, it is crucial to underscore that climate change in both nations not only entails adverse repercussions, but also presents novel prospects for the advancement of the agricultural industry (Shahini *et al.*, 2023). As an illustration, alterations in the duration of the growing season can enable the growth of novel crops that were not previously customary in these areas. Statistical analysis has demonstrated that climate change will exert a substantial influence on the agricultural industries of both nations. However, the magnitude and nature of this influence differ based on the accessible resources, structural characteristics of the agricultural sector, and the economic conditions in each country.

Adaptation of agriculture to climate change is a key task for ensuring sustainable food production and maintaining economic stability (Cui, 2020). The decline in yields of cereals, vegetables and citrus fruits in Albania requires the urgent implementation of efficient irrigation systems (Shahini *et al.*, 2024). Modernization of irrigation infrastructure, including the introduction of drip irrigation and rainwater storage, will reduce water losses and increase the efficiency of agronomic practices. It is also critical to improve agronomic practices, including the use of drought-resistant plant varieties, crop rotation and soil cover to preserve moisture. The development of climate monitoring systems will help farmers to respond to weather changes in a timely manner and adjust agronomic practices. Education and training of farmers, investment in research and support for innovative technologies are also key factors for successful adaptation.

In Ukraine, adaptation requires improving water management by introducing modern irrigation systems, such as rainwater storage tanks and technical solutions for water reuse. Agronomic technologies, such as crop rotation, climate-resistant varieties and precision farming, will help improve yields and reduce costs. It is also important to maintain soil quality through no-till farming and the use of organic fertilizers. Investing in research and supporting innovations, such as new agronomic practices, will help farmers adapt to changing conditions. Financial support and insurance programmes can help farmers cope with economic losses due to climate change.

The combined suggestions for Albania and Ukraine encompass international collaboration to exchange knowledge and technologies, enhance infrastructure such as water storage systems and transportation networks, and formulate measures to mitigate risks linked to severe weather events. The adaptation of agriculture to climate change is an intricate and diverse process that necessitates a unified strategy and the active involvement of all sectors of society. The adoption of these suggestions will contribute to mitigating the adverse impacts of climate change, so guaranteeing the sustainable growth of the agricultural industries in both nations.

DISCUSSION

The study on the effects of climate change on agriculture in Albania and Ukraine revealed that these countries encounter distinct problems arising from both the overall pattern of global warming and particular characteristics of their local environments. Variations in temperature are a primary determinant impacting agriculture in both nations. The rise in mean yearly temperatures in Albania and Ukraine is a clear indication of the global warming phenomenon, which can manifest in both beneficial and detrimental effects on agricultural output. On one side, increasing temperatures might enhance the productivity of heat-tolerant crops and broaden their suitable growing regions. Yet, excessive warming can result in heightened evaporation and, as a result, droughts, which pose a significant threat to agriculture in the southern parts of Ukraine. This necessitates the implementation of novel agricultural technology and adjustments, such as the use of effective irrigation strategies. B. Qian *et al.* (2019) studied the impact of climate change on wheat and corn production in the central regions of Canada. Their results showed that the increase in average temperatures had a positive impact on yields, especially in areas previously considered cool for growing these crops. Y. Yue *et al.* (2019) pointed out that due to the warmer climate, wheat began to ripen better, and the growing season was extended, which led to an increase in the amount of harvest. However, in contrast to their findings, the current study showed that in Eastern Europe, particularly in regions with a more continental climate, rising temperatures have a negative impact on wheat yields.

The study carried out by M.F. Cardell *et al.* (2019) examined the effects of climate change on viticulture in key European countries, specifically Italy, Spain, and France. An investigation revealed that higher average temperatures result in reduced acidity of grapes, therefore influencing the flavour and chemical makeup of wine. The present findings somewhat align with these results, as they also demonstrate that increasing temperatures impact the quality of crops. Nevertheless, the present investigation concentrated on cereals, namely wheat, whereby rising temperatures exert an adverse influence.

The study showed significant fluctuations in precipitation levels, which is a serious challenge for agriculture, as not only the total amount of precipitation but also its distribution over the growing season is crucial. In Albania, the decrease in rainfall in 2022 posed serious challenges for farmers, forcing them to increase irrigation costs and struggle with low yields. In Ukraine, the uneven distribution of precipitation makes it difficult to predict yields and requires more precise planning of agricultural practices. Y. Ding *et al.* (2020) studied the impact of climate change on rice production in the regions of China. Their study showed that the main factor affecting rice yields is a change in precipitation, not temperature. S. Hussain *et al.* (2020), in turn, noted that an increase in rainfall intensity, especially during the monsoon season, contributes to an increase in rice yields by 10-12%. However, during periods of reduced rainfall, yields drop sharply due to a lack of water for irrigation. This contrasts with current results, where rising temperatures are the main factor affecting crop yields in Eastern Europe. The current study indicates that even with sufficient precipitation, rising temperatures lead to negative effects such as droughts and heatwaves, which significantly reduce yields.

Another crucial factor to consider is the variations in the frequency and severity of severe weather phenomena. The occurrence of droughts, floods, and storms in Albania and Ukraine is on the rise, thereby amplifying the vulnerabilities faced by farmers. Consequently, there is a need to devise novel risk management approaches, such as the implementation of crop insurance and the cultivation of plant selections that are resilient to climate change. D. Beillouin *et al.* (2020) examined the effects of severe weather phenomena on agricultural land in Europe. They found that frequent droughts and heat waves, which have become more common from 2000s, significantly reduce the yields of various key crops in the regions. This is comparable to the current results, which also indicate that frequent droughts in Eastern Europe have a negative impact on yields. However, unlike the author, where he noted that perennial crops were affected, the current study refers to a decline in yields of annual cereals.

The results showed that higher production costs, lower yields and reduced profitability could lead many farmers to abandon agriculture, with far-reaching consequences for food security and economic stability. The rising cost of agricultural production requires farmers to adopt costly adaptation technologies such as irrigation systems and new agricultural practices. The economic consequences of climate change on the agricultural sector worldwide, specifically on the cultivation of various crops in different geographical areas, were examined by R. Dellink *et al.* (2019). Their study demonstrated that as a result of climate change, namely the escalation of temperatures and the reduction of rainfall, farmers have seen an average revenue loss of 15-20%. A.M. García *et al.* (2019), in turn, noted that farmers are forced to spend more money on irrigation systems and sun protection, which leads to higher production costs and, consequently, lower profits. The current results also demonstrate the economic ramifications of climate change on the agricultural industry, with a focus on reduced yields and productive capacity, resulting in financial losses caused by diminished revenues from product sales.

The decline in yields caused by climate change has particularly affected Ukraine, which has seen a significant drop in grain and oilseed production. Consequently, the country's export capacity has declined, potentially resulting in adverse consequences for its trade balance and economic stability. Moreover, the influence of climate change on agricultural yields and output volumes was investigated by M. Kalkuhl & L. Wenz (2020). Their research demonstrated that increasing temperatures and alterations in precipitation patterns resulted in a decline in agricultural productivity in various parts of the nation. A. Ortiz-Bobea *et al.* (2021) observed that a rise in the occurrence of severe weather phenomena, such as typhoons and intense precipitation, results in increased crop losses and crop damage, so diminishing total production. This is consistent with the current results, which also found a decrease in yields due to rising temperatures.

In both countries, there are changes in the geographical areas of crop production, requiring significant investments in new infrastructure, changes in cultivation technologies and adaptation of farmers to new conditions. For example, in Albania and Ukraine, climate change may make some regions unsuitable for growing certain crops, leading to a need to change the specialization of the regions.

Overall, the analysed results confirm the significant and multifaceted impact of climate change on agriculture, while highlighting regional peculiarities that should be taken into account when adapting agricultural practices. Overall, successful adaptation of agriculture to climate change requires innovative technologies, improved agronomic practices and consideration of all possible risks. This requires significant financial resources, education, and government support to ensure the resilience of the agricultural sector in a changing climate.

CONCLUSIONS

The main mechanisms of climate change impacts on agriculture include changes in temperature, which can both increase and decrease yields depending on the region, as well as changes in the amount and pattern of precipitation, which in some cases leads to lower yields due to droughts or soil erosion. In particular, Albania is experiencing a gradual increase in average temperature and a decrease in precipitation, which poses additional challenges for the agricultural sector, requiring the implementation of adaptation measures such as expanding irrigation systems or using climate-resistant plant varieties.

Being a major producer and exporter of grains and oilseeds, Ukraine is also confronted with substantial obstacles created by climate change. Increasing temperatures and shifting precipitation patterns have a direct impact on crop production, namely on grain and oilseed yields, as verified by comprehensive data analysis. Alterations in precipitation patterns and increasing temperatures need the adjustment of agricultural methods, including the strategic organisation of agricultural activities to align with the changing climatic circumstances.

Furthermore, the research revealed that the economic hazards linked to climate change provide a significant peril to agriculture in both nations. Escalated production expenses, diminished crop outputs, and the necessity to adopt novel technologies may result in decreased profitability of farms and potentially a decline in their population. Consequently, this could maybe result in adverse effects on both food security and economic stability.

Nevertheless, notwithstanding the obstacles, the research also emphasises prospects for the agricultural industry to thrive in response to climate change. For instance, alterations in the duration of the growing season might enable the growth of novel crops that were not previously characteristic to certain geography. Advancements in cutting-edge technology, such precision agriculture, together with substantial investments in research and training for farmers, are crucial.

Hence, the research has demonstrated the necessity of adopting adaptation measures to guarantee the long-term viability of food production and economic stability in response to climate change. Specifically, this encompasses the upgrading of irrigation infrastructure, enhancement of water management practices, adoption of climate-resistant agricultural types, and provision of financial and instructional assistance to farmers.

The study's limitations include the use of data that may not comprehensively represent all facets of climate change and its effects on agriculture, owing to the scarcity of accessible literature. Additional investigation should prioritise the intensive observation of the enduring consequences of climate change on many facets of the agricultural industry and the formulation of novel adaptation measures, taking into account the incorporation of innovative technologies and predictive models.

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None.

CONFLICT OF INTEREST

None.

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Економічна оцінка впливу зміни клімату на сільське господарство в Албанії та Україні

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Анотація. Метою цього дослідження було проведення порівняльного аналізу впливу зміни клімату на сільськогосподарський сектор в Албанії та Україні, з акцентом на визначенні ключових викликів та можливостей для адаптації. У дослідженні було проаналізовано статистичні дані з 2010 по 2023 рік щодо зміни клімату та її впливу на сільське господарство, а також оцінено наслідки. Результати дослідження показали, що зміни температурних режимів є ключовим фактором, який безпосередньо впливає на сільське господарство. Підвищення середньорічних температур призводить до зміни вегетаційного періоду рослин, що має як позитивні, так і негативні наслідки. Зміна режиму опадів є ще одним ключовим механізмом впливу зміни клімату на сільське господарство. Зменшення кількості опадів та часті посухи можуть призвести до значних втрат врожаю, що вимагатиме впровадження систем зрошення та інших водозберігаючих технологій. Економічні ризики, пов'язані зі зміною клімату, є серйозним викликом для сільського господарства. Зниження врожайності, зростання виробничих витрат і необхідність адаптації до нових умов можуть загрожувати стабільності фермерських господарств, особливо малих. Аналіз для Албанії показав, що підвищення температури та зменшення кількості опадів створюють виклики для сільського господарства, особливо для виробництва зернових та овочів. В Україні, з її великими площами орних земель, є можливість компенсувати зниження врожайності за рахунок розширення посівних площ, але для підвищення ефективності потрібні інвестиції в нові технології зрошення та агрономічні практики. Обидві країни стикаються з необхідністю впровадження нових сортів рослин, модернізації іригаційних систем, а також розвитку сільськогосподарських інновацій та точного землеробства. Ефективні стратегії адаптації, включаючи міжнародне співробітництво та підтримку наукових досліджень, є ключовими для забезпечення сталості сільськогосподарських секторів обох країн. Результати дослідження можуть бути застосовані на практиці в державних програмах підтримки сільського господарства та міжнародних проєктах з адаптації до зміни клімату

Ключові слова: температурний режим; водні ресурси; продуктивність; інвестиції в інфраструктуру; порівняльний аналіз

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Adaptive variability of early potato in the Forest-Steppe of Ukraine

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Abstract. The purpose of this study was to investigate the dynamics of early potato yield formation at 40 days depending on the weather conditions of the research years and the adaptive potential of early potato cultivars. During 2018-2024, 10 cultivars of early potatoes common in the Forest-Steppe zone were investigated in the field (Uman, 48°46′N, 30°14′E). To analyse the results obtained, the study employed generally accepted methods of field and genetic-statistical research. During the study, the number and weight of marketable tubers in the bush, the dynamics of crop formation on the 40th day after germination, and the strength of the correlation between yield and rainfall were investigated. As a result of the data obtained, the most promising cultivars were identified for early potato harvest in the Forest-Steppe region of Ukraine. It was found that this climatic zone is best suited

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to the cultivars Bazaliia, Tornado and Madison with a yield of 11.0-11.7 t/ha and a large weight of marketable tubers – 58-60 g. In the full ripeness phase, the most productive cultivars were Madison – 37.2 t/ha (+18.6 t/ha of control), Tornado – 34.7 t/ha (+16.1 t/ha of control), Duma and Bazaliia – 31.4 and 32.2 t/ha, respectively (+12.8 t/ha 13.6 t/ha of control, respectively). The study found that the Tornado and Madison cultivars form the largest number of marketable tubers in the bush. Analysis of the semi-ratio of plasticity and stability parameters contributed to the grouping of cultivars into intensive ones (Sanibel, Radomysl, Duma, Bazaliia and Madison had indicators $bi > 1$, $\sigma^2 d > 0$ and plastic (Povin, Vzirets, Skrabnytsia, Bernina and Tornado). As a result of the study, the most productive potato cultivars for early production were identified, which will ensure the stable development of the vegetable growing industry in the Forest-Steppe zone of Ukraine, and the calculated statistical models will allow predicting and directing the programming of potato yields

Keywords: early harvest; stability; plasticity; environmental variation; genetic variation

INTRODUCTION

In modern environment, the development and implementation of environmentally friendly, resource-saving technologies for growing crops, including potatoes, is of particular significance. This is cause by the fact that potatoes are one of the most popular food crops in Ukraine, with high demand. It is planned to increase the efficiency and competitiveness of vegetable production by providing the population with high-quality, affordable products. The key task in developing zonal cultivation technologies is to select potato cultivars.

According to FAOSTAT (n.d.), about a tenth of the world's agricultural land is suitable for potato cultivation, but in other areas, the possibility of obtaining consistently high yields is limited by various factors. The conclusions drawn by R. Ilchuk *et al*. (2023) suggest that potatoes are a major crop characterised by high adaptability, plasticity and potential productivity. It is cultivated in 130 countries and is considered a strategically important product. M. Furdyha (2022) notes the advantage of potatoes compared to other crops in their ability to generate high productivity in a wide range of agricultural systems.

A. Bombik *et al*. (2023) note that modern progress in potato production is possible due to the introduction of new promising high-yielding cultivars, their seed production on a virus-free basis, improvement of adaptive potato production technologies based on biologisation, energy and resource saving in the conditions of an adaptive landscape economically justified farming system. M. Ostrenko *et al*. (2020) pointed out that the most relevant and practically significant aspects of potato growing are expanding the range of high-yielding early cultivars, considering consumer demand and farm specialisation. According to L. Korol *et al*. (2023), it becomes clear that special attention is paid to food and table cultivars with yellow or creamy flesh and high palatability. There are also cultivars of interest for industrial processing with a high starch content and certain technological qualities, as well as for feed use with a high dry matter and starch content.

From the findings of R. Nicolao *et al*. (2023), it is known that despite the large number of potato cultivars available, there is a need for new cultivars that have high productivity yields at low inputs, resistance to diseases and pests, and resistance to environmental stresses such as high or low temperature, drought and salinity. The researchers also noted that, if possible, potato cultivars should also have improved nutritional properties. To achieve this goal, it is necessary to develop, introduce and select cultivars that are well-adapted to concrete soil and climatic conditions.

R.M. Gutaker *et al*. (2019) stated that the spread of potatoes outside their native range required considerable adaptation to new environments, specifically moving crops along latitudinal gradients. In these cases, geographical expansion required the adaptation of plant development to a different day length and temperature. In case of a short day in Europe, potato tuberisation would only occur on short days in late autumn accompanied by frosts. Therefore, overcoming the dependence of a short day for tuberisation was probably the crucial adaptation to European conditions. Modern potato cultivars behave as facultative short-day plants because tuberisation occurs during the long day, but tuber differentiation is still accelerated after the plants are moved to shorter day lengths.

A. Chindi *et al*. (2020) noted that the adaptability of crops can vary depending on the climate zone, and therefore it is important to conduct site-specific adaptation trials to identify suitable cultivars. Accordingly, an adaptation trial of potato cultivars was conducted in the central highlands of Ethiopia to assess the performance and adaptability of introduced and improved cultivars in different potato agroecologies. The findings showed that plant height, number of stems, average number of tubers, and average tuber weight varied substantially between cultivars, and their yields ranged within 19.44-30.08 t/ha.

Earlier studies have shown that the key characteristics that determine high potato yields are adaptive capabilities, the number of stomata per unit leaf area, and the content of photosynthetic pigments (Laisina *et al.*, 2021). The quantitative value of these parameters, together with the number of tubers and the average tuber weight, helped to determine the differentiation of plants by the degree of yield. S.A. Jennings *et al.* (2020) concluded that considering the increasing significance of potatoes globally, there is a growing need to understand the impact of dynamic climate change on potato production. Temperature and precipitation can be limiting factors, as potatoes require a temperate climate and are inhibited by temperatures above 33°C and require more than 500 mm of precipitation during the growing season for high yields.

Due to the shift of climatic zones, the movement of the Steppe to the North of Ukraine and the geopolitical situation in Ukraine since 2022, the purpose of this study was to select early (young) potato cultivars for specific soil and climatic conditions and to investigate their adaptive and productive potential.

MATERIALS AND METHODS

The experiments were conducted in 2018-2024 in the city of Uman (coordinates: 48°46′N, 30°14′E). The study included 10 cultivars of early potatoes, which are particularly common in the Forest-Steppe zone. All studies conducted followed the provisions of the Convention "On Biological Diversity" (1992). The soil of the experimental field was podzolised heavy loamy chernozem with a humus horizon 40-45 cm thick and a humus content of 1.5%; pH (salt) – 6.65; hydrolytic acidity – 2.6 mg equivalents/100 g, soil saturation with bases – 90-95%, the indicator of the sum of absorbed bases – 24.6 mg equivalents/100 g. The focus of the study was on the investigation of the impact of weather conditions, specifically, the amount of precipitation during the growing season of potato plants. The data in Table 1 suggest that the most moisture-supplied growing season was in 2020, 2023 and 2024. According to the Uman Weather Station, these years were also characterised by an even distribution of precipitation by month, namely in May and June, which contributed to a high yield.

Table 1. *Amount of precipitation during the growing season of early potato plants*

Month	Year						
	2018	2019	2020	2021	2022	2023	2024
IV	17.5	22.4	21.0	49.9	57.7	129.6	55.0
V	18.3	35.6	101.0	56.4	22.4	42.4	103.0
VI	82.4	69.8	70.4	104.7	36.3	15.8	180.0
VII	92.9	33.8	21.4	89.8	28.1	92.5	92.5
Σ	211.1	161.6	213.8	300.8	144.5	280.3	430.5

Source: *data from the Uman Weather Station*

The study involved 10 cultivars of early potatoes (Skarbnytsia, Bazaliia, Bernina, Madison, Tornado, Povin, Duma, Radomysl, Vzirets, Sanibel), with the Skarbnytsia cultivar as the control, as it is the most tested in the Forest-Steppe zone. Tubers were planted in the second decade of April according to the scheme of 70 × 35 cm (40.8 thsd plants/ha). The area of the test plot was 25 m^2, replicated four times. The biometric measurements (leaf area of plantations, number of stems, number of marketable tubers per bush) and the dynamics of yield formation (at 40 and the phase of complete tops' death) were carried out using generally accepted methods (Bondarenko & Yakovenko, 2001; Ukrainian Institute of Plant Variety Expertise, 2016; Bondarchuk *et al.*, 2019).

Genetic and statistical processing of the results. Most methods for assessing adaptive capacity are based on the use of regression analysis, the mathematical model of which was developed by K.W. Finlay & G.N. Wilkinson (1963) and supplemented by S.A. Eberhart & W.A. Russell (1966). To systematise the obtained findings, the ranking of cultivars was used according to the ratio of the parameters of plasticity (bi) and stability $\sigma^2 d$:

1) $bi < 1, \sigma^2 d > 0$ – shows a better result under adverse conditions, unstable;

2) $bi < 1, \sigma^2 d = 0$ – shows a better result under unfavourable conditions, stable;

3) $bi = 1, \sigma^2 d = 0$ – responds well to improving conditions, stable;

4) $bi = 1, \sigma^2 d > 0$ – responds well to improving conditions, unstable;

5) $bi > 1, \sigma^2 d = 0$ – shows best results under favourable conditions, stable;

6) $bi > 1, \sigma^2 d > 0$ – shows best results under favourable conditions.

Therewith, a cultivar with $bi > 1$ is classified as highly plastic (relative to the average group), and with $1 > bi = 0$, it is classified as conditionally low plastic. Stability coefficient – $\sigma^2 d$, the lower it is, the more stable the genotype is.

The genotype homeostasis parameter (*Hom*) was determined according to the following formula:

$$H_{om} = \frac{\overline{X}^2}{\sigma}, \quad (1)$$

where $\overline{x}$ – the arithmetic mean of the genotype; σ – the generalised standard deviation.

The breeding value of a genotype was calculated using the following formula:

$$(S_c) = \bar{X} \cdot \frac{\bar{X}_{lim}}{\bar{X}_{opt}}, \quad (2)$$

where $\overline{X}$ – the arithmetic mean of the genotype; $\overline{X}_{lim}$ – the arithmetic mean of the limited (minimum) value of the trait; $\overline{X}_{opt}$ – the arithmetic mean of the optimum (maximum) value of the trait.

To avoid a linear artefact in the regression coefficient, a multiplicative coefficient (*MC*) was determined to compare the variability of the trait. The higher the numerical value of the coefficient, the more volatile the trait is:

$$MC = \frac{\overline{X}i + bi \cdot yi}{Xi}, \quad (3)$$

where $\overline{X}i$ – the average value of the studied trait in the *i*-th cultivar; *bi* – the linear regression coefficient of the *i*-th cultivar; *yi* – the average value for all averages for all cultivars *yi* for each *j*-th experiment point (year).

Environmental plasticity index:

$$EPI = \frac{\left(\frac{YV_1}{ATV_1} + \frac{YV_2}{ATV_2} + \dots + \frac{YV_n}{ATV_n}\right)}{n}, \quad (4)$$

where YV_1, YV_2... YV_n – the values of the trait in the genotype in different years of testing; ATV_1, ATV_2... ATV_n – the average trait values of the cultivars in each of the experimental variants.

The absolute adaptability coefficient (*AAC*) of genotypes was determined according to the following formula:

$$AAC = \frac{(XiC \cdot 100 \cdot Xm)}{100}, \quad (5)$$

where *XiC* – the average yield of the cultivar over the years of testing; *Xm* – the multi-year average yield of the cultivar.

Stress resistance and compensatory capacity of cultivars were calculated according to A.A. Rossielle & J. Hemblin (1981):

$$SR = Y_{min} - Y_{max}; \quad (6)$$

$$CC = \frac{Y_{min} + Y_{max}}{2}, \quad (7)$$

where Y_{min} and Y_{max} – the minimum and maximum values of the cultivar trait.

The results were statistically processed using the arithmetic mean (x) and standard deviation (SD) calculated using Microsoft Excel 2019. Correlations were calculated using Statistica 12 software. The Chaddock scale was used to qualitatively assess the correlation coefficients. The results of the correlation studies were presented graphically, as the graphical method plays an essential role in statistical research, where the interrelationships of phenomena and processes in the movement of dynamics indicators are studied. For this, a correlation field was used, which reflects the statistical relationship between the measurement results. A visual analysis of the correlation field allows qualitatively assessing the shape, direction and closeness of the relationship. The form is determined by the type of correlation field: if a straight line can be drawn through the correlation field, the form of the relationship is linear, otherwise it is non-linear.

In the experiments, the phenotypic, genotypic and environmental variability of cultivars was determined (Burton & DeVane, 1953; Shing *et al.*, 1993) using the formulas (8-13).

Genetic variance:

$$\sigma_G^2 = \frac{CM_p - CM_e}{r}, \quad (8)$$

where CM_p – the generalised root mean square value of the population trait; CM_e – the generalised root mean square error; *r* – the number of repetitions.

Environmental variance:

$$\sigma_A^2 = CM_e. \quad (9)$$

Phenotypic variance:

$$\sigma_F^2 = \sigma_G^2 + \sigma_A^2. \quad (10)$$

Genotypic variation coefficient:

$$CVG = \frac{\sqrt{\sigma_G^2 \cdot 100}}{\overline{X}}. \quad (11)$$

Phenotypic variation coefficient:

$$CVF = \frac{\sqrt{\sigma_F^2 \cdot 100}}{\overline{X}}. \quad (12)$$

Environmental variation coefficient:

$$CVA = \frac{\sqrt{\sigma_A^2 \cdot 100}}{\overline{X}}. \quad (13)$$

RESULTS AND DISCUSSION

Reports by FAOSTAT (n.d.) show that one of the reasons for the low efficiency of potato production in Ukraine was the falling behind of the agro-industrial complex in terms of global agro-technological advance. At the same time, potato growing in Ukraine has switched to an adaptive landscape farming system in the modern market economy. According to FAO (2024), potatoes are on the list of crops whose production has been fairly stable over the period of economic reforms in Ukraine: the area under cultivation is 505 thsd ha, the gross harvest is 20.9 mn t, and the average yield is 41 t/ha higher than the global average yield of 20.0 t/ha.

An evaluation method that allows for the analysis of stability and plasticity parameters is a significant step in breeding programmes and provides more accurate information about the adaptive potential of a genotype. This approach allows determining the effect of genotype, environment and their interaction (GEI) on yield, as well as identifying stable and high-yielding populations in trials.

Analysing the cultivars according to the trait "number of marketable tubers", it can be observed that the variation over the years was noticeable from 4.1 pcs/plant in 2022 in the Sanibel cultivar to 10.4 pcs/plant in 2024 in the Madison cultivar. The maximum number of tubers was formed in 2020, 2021, 2023 and 2024, where the average cultivar index ranged within 7.0-7.6 pcs/plant. The variation in this indicator was within 11-19%, with the most stable being Madison and the least stable being Sanibel and Radomysl. The impact of weather conditions during the years of research was substantial. The lowest variation was in 2024 – 16%, and the highest was in 2019 – 29%.

The largest number of marketable tubers per plant over the years was formed by the cultivars Bazaliia (5.5-8.3 pcs.), Duma (5.9-9.6 pcs.), Tornado (6.7-9.8 pcs.) and Madison (7.9-10.4 pcs.). To achieve high crop productivity, a ratio of *CVG/CVA* ≥ 1 is required. The study shows that environmental variation (*CVA* = 23.7%) outweighed genetic variation (*CVG* = 5.4%), suggesting a significant dependence of potato genotypes on environmental conditions. Ratio of *CVG/CVA* = 0.23, which indicates that the unstable weather conditions of the Forest Steppe were not favourable enough for the formation of marketable potato tubers (Table 2).

Table 2. *Dynamics of the number of tubers per bush, pcs., and average weight of marketable tubers, g (2018-2024)*

Cultivar	2018	2019	2020	2021	2022	2023	2024	*Xmed*	*SD*	*CV*, %	Tuber weight, g
Povin	5.9	4.4	6.0	4.9	4.2	4.6	5.9	5.1	0.72	14	33.0
Skarbnytsia (C)*	4.7	4.9	6.1	5.7	3.9	5.2	5.9	5.2	0.71	14	39.0
Vzirets	5.4	4.9	6.2	6.0	4.4	5.9	6.9	5.7	0.79	14	38.0
Sanibel	5.1	5.1	7.2	6.2	4.1	6.4	7.6	5.9	1.15	19	44.0
Radomysl	5.6	5.1	8.0	6.8	4.6	6.7	7.8	6.4	1.23	19	56.0
Bernina	7.2	6.5	9.2	7.6	5.6	7.8	7.5	7.3	1.03	14	46.0
Bazaliia	8.2	7.8	5.5	8.1	6.5	7.8	8.3	7.5	0.97	13	52.0
Duma	7.8	7.5	9.6	8.5	5.9	7.2	7.8	7.7	1.06	14	55.0
Tornado	7.2	9.1	6.7	9.8	7.8	8.6	8.5	8.2	1.00	12	58.0
Madison	8.5	10.3	7.9	9.1	7.8	9.8	10.4	9.1	1.00	11	60.0
Xmed	6.5	6.6	7.2	7.3	5.5	7.0	7.6	6.8			48.0
SD	1.30	1.92	1.31	1.51	1.42	1.50	1.24	1.28			8.9
CV, %	20	29	18	21	26	22	16	19			19
LSD_{05}	0.37	0.33	0.37	0.36	0.28	0.33	0.39	0.35			2.69
σ_G^2								0.1			
σ_A^2								2.6			
σ_F^2								2.7			
CVG, %								5.4			
CVF, %								24.3			
CVA, %								23.7			
CVG/CVA								0.23			

Notes: ** – control*
Source: *developed by the authors*

The largest average weight of marketable tubers (over 50 g) was formed by the cultivars Bazaliia, Duma, Radomysl, Tornado and Madison, which exceeded the control cultivar Skarbnytsia by 13-21 g. The dynamics of the early potato harvest by year showed that the weather conditions in 2020, 2021 and 2024 were the most favourable, with the average yield of 9.7, 10.6 and 15.9 t/ha. The analysis of the variability of this trait showed that the cultivars Bazaliia, Tornado and Madison had an average variation – *CV* = 23-24%, and all other cultivars had a significant variation – *CV* = 26-30%. The analysis by year showed that in 2019, 2022 and 2024, the yield variation between cultivars was low – 7-10%, while in all other years the variation was average – 11-18%.

On average over the years, only two cultivars produced lower yields than the control – Povin and Vzirets, with yields of 8.5 and 8.8 t/ha, which is 3.9 and 1.0% less than the control, or 0.3 and 0.1 t/ha, respectively. No significantly lower yields were recorded. All other cultivars had yields significantly higher than the control by 0.6-2.9 t/ha, or 7.2-32.2%. The most productive cultivars were Duma, Radomysl, Bazaliia, Tornado and Madison – 10.0-11.7 t/ha (Table 3).

Table 3. *Dynamics of early potato harvest, t/ha (2018-2024)*

Cultivar	2018	2019	2020	2021	2022	2023	2024	*Xmed*	*SD*	*CV*, %
Povin	7.1	7.7	7.9	7.7	6.1	8.6	14.6	8.5	2.58	30
Vzirets	7.3	8.4	8.3	8.1	6.4	8.4	14.6	8.8	2.47	28
Skarbnytsia (C)*	7.3	8.5	8.7	8.4	6.3	8.1	14.8	8.9	2.54	29
Sanibel	8.5	8.5	8.2	12.1	6.4	7.8	15.1	9.5	2.79	29
Bernina	7.5	9.0	9.0	10.8	7.2	8.5	15.1	9.6	2.50	26
Duma	10.0	7.8	8.2	11.2	7.6	8.6	16.7	10.0	2.98	30
Radomysl	7.8	9.1	11.2	11.2	7.3	8.8	16.5	10.3	2.90	28
Bazaliia	9.6	9.3	11.7	11.4	7.7	10.4	16.8	11.0	2.69	24
Tornado	11.9	9.4	12.4	12.1	8.0	11.0	17.1	11.7	2.66	23
Madison	10.7	10.0	11.7	13.0	8.1	11.2	17.4	11.7	2.71	23
Xmed	8.8	8.8	9.7	10.6	7.1	9.1	15.9	10.0		
SD	1.59	0.68	1.69	1.76	0.71	1.17	1.07	1.10		
CV	18	8	17	17	10	13	7	11		
LSD_{05}	0.45	0.45	0.50	0.54	0.36	0.47	0.81	0.51		
σ^2_G								1.0		
σ^2_A								8.4		
σ^2_F								9.5		
CVG, %								10.2		
CVF, %								30.8		
CVA, %								29.1		
CVG/CVA								0.35		

Notes: ** – control*
Source: *developed by the authors*

The statistical analysis showed that environmental variation (*CVA* = 29.1%) was superior to genetic variation (*CVG* = 510.2%), suggesting that the productivity of potato genotypes significantly depends on the environmental conditions of cultivation. Ratio of *CVG/CVA* = 0.35 and suggests that the climatic conditions of the Forest Steppe are favourable, but the biological potential of potato cultivars is not entirely fulfilled.

The genetic-statistical analysis of the yield of genotypes showed that the cultivars Vzirets, Skarbnytsia and Bernina were the most stable ($\sigma^2 d$). The study revealed that the cultivars Sanibel, Radomysl, Duma, Bazaliia and Madison had indicators of plasticity $bi > 1$ and stability $\sigma^2 d > 0$, which suggests their better results under favourable growing conditions, but they turned out to be unstable. The other cultivars had $bi < 1$ and

$\sigma^2d > 0$, suggesting their ability to produce better results in unfavourable conditions, but they were also unstable.

Sanibel, Radomysl, Duma, Bazaliia and Madison cultivars can be classified as intensive in terms of plasticity (*bi*), while all other cultivars are classified as plastic. The cultivars were very evenly distributed in terms of homeostasis from 1.5 to 2.9, which confirms the stability or, on the contrary, the plasticity of a particular cultivar. The Tornado and Madison cultivars were distinguished by their high breeding value (*Sc*) and compensatory capacity (*CC*). The cultivars Radomysl, Duma, Bazaliia, Tornado, and Madison were distinguished with a high coefficient of adaptability – *AAC* was 1 and greater (Table 4).

Table 4. *Parameters of adaptability of early potato cultivars by yield, t/ha (2018-2024)*

Cultivar	*Xmed*	*σ²d*	*bi*	*Hom*	*Sc*	*MC*	*EPI*	*SR*	*CC*	*AAC*
Povin	8.5	1.61	0.96	1.5	6.2	2.12	0.85	-9	10	0.85
Vzirets	8.8	1.57	0.92	1.6	6.4	2.05	0.88	-8	11	0.88
Skarbnytsia (C)*	8.9	1.59	0.96	1.7	6.5	2.08	0.89	-9	11	0.89
Sanibel	9.5	1.67	1.01	1.9	6.9	2.07	0.95	-9	11	0.95
Bernina	9.6	1.58	0.94	1.9	7.0	1.99	0.96	-8	11	0.96
Radomysl	10.0	1.73	1.09	2.1	7.3	2.09	1.00	-9	12	1.00
Duma	10.3	1.70	1.09	2.2	7.5	2.06	1.02	-9	12	1.03
Bazaliia	11.0	1.64	1.02	2.6	8.0	1.93	1.10	-9	12	1.10
Tornado	11.7	1.63	0.97	2.9	8.5	1.83	1.18	-9	13	1.17
Madison	11.7	1.64	1.03	2.9	8.6	1.88	1.18	-9	13	1.17

Notes: * – *control*
Source: *developed by the authors*

The analysis of the averaged data over the years of research showed that the highest yield was recorded for the Madison cultivar, which reached 37.2 t/ha. Compared to the control cultivar Skarbnytsia, which yielded 18.6 t/ha, the Madison cultivar yielded 18.6 t/ha more, which is a 100% increase. The Tornado potato cultivar also showed a high yield of 34.7 t/ha, which was 16.1 t/ha higher than the control. The Duma and Bazaliia cultivars had slightly lower yields of 31.4 and 32.2 t/ha, respectively, but still outperformed the control by 12.8 and 13.6 t/ha.Phenotypic stability revealed a clear pattern: with increasing yields, the stability of the trait also increased. Thus, cultivars Radomysl, Madison and Bazaliia showed both high yields and stability of this trait (Fig. 1).

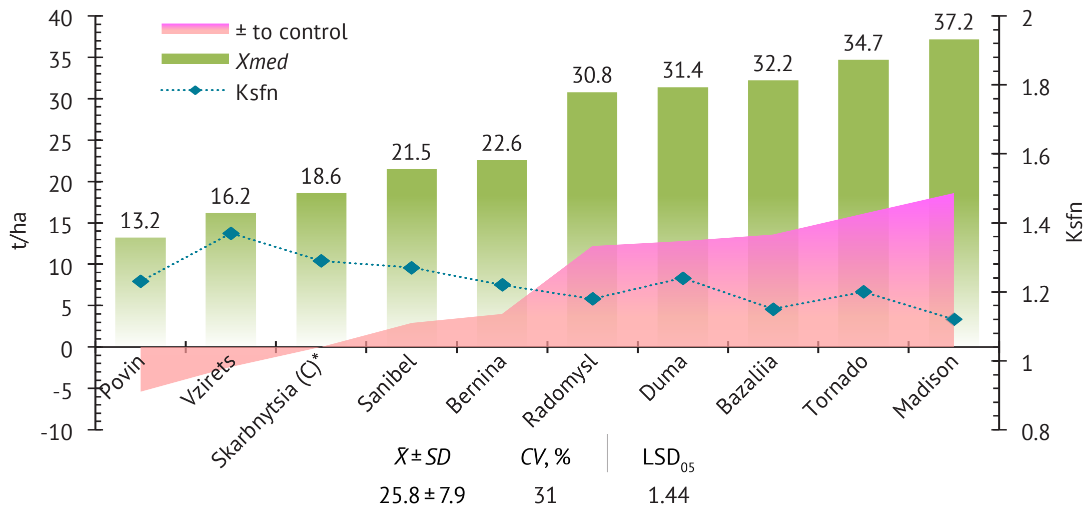

Figure 1. *Yield of early potato cultivars in biological ripeness (after complete death of tops)*
Notes: * – *control*
Source: *developed by the authors*

The study helped to establish the fact that the share of early harvest is 31.5-64.6% of the crop after the tops have completely died off. It was found that the more productive the cultivar is in the phase of complete tops' death, the smaller is the share allocated to the early harvest. As a result of statistical calculations, a strong correlation was found on the Chaddock scale between the yield of early production and the amount of precipitation during the growing season of potato plants – $r = 0.8577$ and the total yield and the amount of precipitation – $r = 0.7595$. Considering the statistical reliability of the equations, the corresponding dependence is presented graphically in Figure 2.

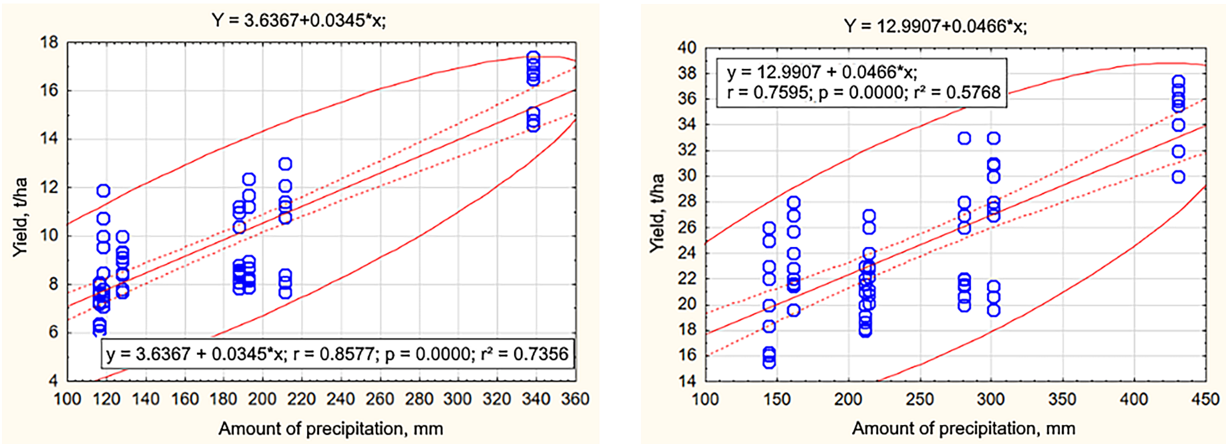

Figure 2. *Statistical models of potato yield dependence on the amount of precipitation*
Source: *developed by the authors*

The data obtained suggest that the difference in the number of tubers per plant is a genetic trait of the plant and is subject to a noticeable environmental influence. The findings of this study are in line with the data obtained by T.E. Eaton *et al.* (2017) and A. Khan *et al.* (2019), who noted that the number of tubers depends on genotype and environmental conditions. The findings of this study showed a significantly higher influence of environmental conditions than the genotypic component ($CVG = 5.4\%$, $CVA = 23.7\%$, while the ratio $CVG/CVA = 0.23$). D. Kumar *et al.* (2004) and C.K. Patel *et al.* (2008) also noted that tuber weight is more genotype-dependent and heritable.

Considerable standard deviations are unambiguous evidence of the significant influence of the environment on the investigated traits of potato cultivars. F. Elfnesh *et al.* (2011) reported a significant effect of environment on the performance of potato genotypes. These data are also consistent with the data presented in the current study: high SD scores (0.68-1.76), high coefficient of ecological variation ($CVA = 29.1\%$) and a low ratio between $CVG/CVA = 0.35$ for early harvest, suggest a significant influence of environmental conditions on the productivity of potato cultivars. T. Abebe *et al.* (2012) reported a considerable effect of genotype and genotype × environment interaction on the productivity of 25 potato cultivars. W. Mohammed (2016) and M. Nasiruddin *et al.* (2017) reported analogous results in their studies.

M. Ostrenko *et al.* (2020) noted that the early yield of young potato tubers depended on varietal characteristics and ranged from 12.8 t/ha in the Skarbnytsia cultivar at 60 days after germination to 21.0 t/ha at full ripeness. The findings of the present study reflect comparable dynamics: the Skarbnytsia cultivar had an early potato yield of 8.9 t/ha at 40 days, and 18.6 t/ha after complete tops death, while in India, the tuber yield at 60 days was 18.52 t/ha (Deshmukh *et al.*, 2018).

According to the findings of this study, environment and genotype had an impact on tuber weight. According to G. Habtamu *et al.* (2016), tuber weight is strongly influenced by potato genotype, as well as management practices (cultivation), seed quality, or agro-ecological conditions. T.E. Eaton *et al.* (2017) also reported this. According to A. Borivskyi (2016), the variation in the total yield of early potato cultivars ranged within 26.0-31.0 t/ha. L. Korol *et al.* (2023) report potato yields of 16.8-31.9 t/ha and an adaptability coefficient of 0.72-1.27, which to some extent coincides with the findings of the present study. The obtained findings confirmed the previous ones and showed the adaptability of cultivars at 0.85-1.17. As a result of the discussion, comparable patterns of productivity formation of different potato cultivars in various soil and climatic conditions were revealed and a substantial intervarietal difference in productivity parameters was confirmed.

CONCLUSIONS

It was found that without adapting the farm to climate change by selecting cultivars, it is impossible to achieve high potato productivity. The investigation of the level of adaptability of different cultivars of early potatoes to the soil and climatic conditions of the Forest-Steppe helped to identify cultivars that allow procuring an early harvest of marketable tubers – Sanibel, Radomysl, Duma, Bazaliia and Madison. It was found that these cultivars provided yields of 9.5-11.7 t/ha 40 days after germination. The number of marketable tubers in the bush, which ranged on average from 5.1 pcs/plant in the Povin cultivar to 9.1 pcs/plant in the Madison cultivar, and their weight, which ranged within 33.0-60.0 g, influences the high yield. The cultivars that formed an increased number of marketable tubers in the bush were Bernina, Bazaliia, Duma, Tornado and Madison, and cultivars with a larger mass of marketable tubers were Bazaliia, Duma, Radomysl, Tornado and Madison. The analysis of the averaged data showed that the highest yields were recorded for the Madison cultivar, which reached 37.2 t/ha (+100%), compared to the standard cultivar Skarbnytsia, which yielded 18.6 t/ha. Phenotypic stability revealed a clear pattern: with increasing yields, the stability of the trait also increased. Thus, the cultivars Radomysl, Madison and Bazaliia showed both high yields and stability of this trait. Statistical studies contributed to the ranking of cultivars into two groups: Sanibel, Radomysl, Duma, Bazaliia and Madison cultivars had plasticity parameters $bi > 1$ and stability $\sigma^2 d > 0$, which suggests their better productivity under favourable growing conditions, although they were unstable. Other cultivars had $bi < 1$ and $\sigma^2 d > 0$, which indicates their high productivity in unfavourable conditions, although they were also unstable. The conducted genetic and statistical analysis showed a strong ecological variation (*CVA*) of the traits under study, which suggests a strong dependence of potato cultivars productivity on growing conditions and was confirmed by the correlation analysis of the dependence of yield on moisture supply – $r = 0.8577$. Prospects for further research lie in the possibility of growing seed potatoes of the studied cultivars with optimisation of the elements of growing technology (drip irrigation, mulching).

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CONFLICT OF INTEREST

None.

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Адаптивна мінливість картоплі ранньої у Лісостепу України

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Анотація. Метою було передбачено дослідити динаміку формування врожайності картоплі ранньої на 40 добу залежно від погодних умов років досліджень та адаптивний потенціал ранньостиглих сортів картоплі. Упродовж 2018-2024 рр. у польових умовах (м. Умань, 48°46′N, 30°14′E) досліджено 10 поширених в зоні Лісостепу сортів картоплі ранньостиглої. Для аналізу отриманих результатів використано загальноприйняті методи польових і генетико-статистичних досліджень. Під час проведення досліджень вивчено кількість і масу товарних бульб в кущі, динаміку формування врожаю на 40 добу після появи сходів та силу кореляційного зв'язку між врожайністю і сумою опадів. У результаті одержаних даних визначено найбільш перспективні сорти для отримання раннього врожаю ранньої картоплі у Лісостепу України. Встановлено, що даній кліматичній зоні найбільше відповідають сорти Базалія, Торнадо, Медісон з врожайністю 11,0-11,7 т/га та великою масою товарної бульби – 58-60 г. У фазу повної стиглості найбільш врожайними виявилися сорти Медісон – 37,2 т/га (+18,6 т/га контролю), Торнадо – 34,7 т/га (+16,1 т/га до контролю), Дума і Базалія – 31,4 і 32,2 т/га (+12,8 і 13,6 т/га до контролю). Дослідженнями встановлено, що сорти Торнадо і Медісон формують найбільшу кількість товарних бульб в кущі. За результатами аналізу співвідношення параметрів пластичності й стабільності проведено групування сортів на інтенсивні (Санібель, Радомисль, Дума, Базалія і Медісон мали показники $bi > 1$, $\sigma^2 d > 0$ і пластичні (Повінь, Взірець, Скарбниця, Берніна і Торнадо). У результаті проведених досліджень визначено найбільш продуктивні сорти картоплі на ранню продукцію, що забезпечать стабільний розвиток галузі овочівництва в зоні Лісостепу України, а розраховані статистичні моделі дозволять прогнозувати і програмувати врожайність картоплі

Ключові слова: ранній врожай; стабільність; пластичність; екологічна варіація; генетична варіація

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Role of agriculture in the development of Ukrainian socio-economic potential

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Abstract. The agricultural sector is key to the development of the Ukrainian economy, especially in times of war, as it helps to maintain the standard of living of its citizens. In this regard, the interaction between the sector and society is relevant to the study. The study aimed to assess the relationship between certain metrics of living standards and agricultural output. The study addressed the role of the agricultural sector in Ukraine and its origins. In addition, a detailed analysis was carried out in the context of existing problems separately for livestock and crop production. The study further substantiated the connection between the agricultural sector and the social well-being of the rural population of Ukraine due to the sector's ability to create a significant number of jobs. Using correlation and regression analysis, the study concluded that agricultural output does indeed affect the standard of living of the local population, particularly the gross domestic product per capita. The results show that an increase in agricultural production directly contributes to economic growth, reinforcing the importance of this sector in Ukrainian long-term development strategy. The study also showed what the long-term development of the agricultural sector in Ukraine should be in the long term, and what actions should be taken to achieve these goals, by the state. The findings of the study can be used to formulate state policy in the agricultural sector in the context of the impact on the social component of the country

Keywords: international trade; crop production; animal husbandry; infrastructure; finance

INTRODUCTION

Agriculture in Ukraine is substantial in the social sphere, providing jobs for a large part of the population, especially in rural areas where it is the main source of income. It also helps to support the livelihoods of rural communities while preserving national identity and traditions. In addition, the agricultural sector ensures national food security, which is the basis for the stable development of society. Thus, it is not only the basis for the economic development of a country but also a significant factor in ensuring a high standard of living, especially in Ukraine. Moreover, such support is especially important in times of war. In wartime, farmers actively

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support local communities by providing humanitarian aid and increasing social cohesion. Large companies often give to both the military and other citizens, often selflessly. In this regard, the impact of this kind of activity requires more detailed research and analysis of the impact of the agricultural sector on the social development of the local population.

I. Tomashuk & Ye. Borboliuk (2023) analysed the role of the agricultural sector in ensuring food security in Ukraine. The scientists noted that to ensure global food security, it is necessary to stop Russian aggression against Ukraine and return to the occupied territories. This includes defending Ukraine with international support, assisting in demining and land restoration, providing soft loans to farmers, attracting investors to rebuild infrastructure, introducing modern technologies in agriculture to increase exports, modernising logistics, including railways, and ensuring safe maritime exports of agricultural products. Although all these actions are difficult to implement in a time of war, the state should strive to do so to ensure the effective recovery of the nation in the future. B. Starchak (2023) also assessed the role of the agricultural sector in the development of the Ukrainian economy. The author described the role of the sector, in the context of national international relations, in ensuring food security. The need to upgrade material and technical support was also mentioned. O. Zghurska *et al*. (2022), in turn, assessed the possibilities of digitalising the sector. The researchers noted that most large agricultural holdings in Ukraine are actively investing in and implementing digital solutions, with a clear upward trend in the adoption of such innovative technologies. This study also noted that, despite the positive impact of digital technologies on the development of this sector, the country has an overall low level of their implementation, which requires increased efforts in several key areas: development of digital platforms, production and food security forecasting, optimisation of production sites, use of predictive analytics, sectoral planning and improvement of digital competencies of specialists. A. Ivanko *et al*. (2022) identified four key components of the agricultural-industrial complex – agriculture, industry, processing and secondary stages such as storage, transport and maintenance – that ensure its functioning. The study concluded that organisational and economic mechanisms of development should be considered as a set of economic levers and organisational measures aimed at influencing and stimulating the agricultural-industrial complex. It integrates various components into the system of economic relations and includes functions such as redistribution, planning, control and innovation. The effectiveness of this mechanism, in turn, is achieved through the symbiosis of its organisational and economic components. I. Petrunenko *et al*. (2021) addressed the peculiarities of the development of small farms in the agricultural-industrial complex of Ukraine. The scientists noted that the role of such enterprises is critical, in ensuring food and nutrition security and employment in rural areas. In this regard, such companies are substantial in ensuring the sustainable development of enterprises. The role of agrarians in the context of military operations was addressed by L. Boiko & V. Boiko (2023). Scientists noted that local producers recognise the need to use all available resources to maintain their businesses and jobs in the face of military operations while increasing agricultural production to ensure national food security. To achieve a better level of profitability, they proposed an introduction of measures such as preferential purchases of agricultural products, value-added tax refunds, additional insurance guarantees for farmers and minimum tariffs to minimise transport costs.

Thus, while the current economic literature pays much attention to the development of agriculture in Ukraine in general, little attention is paid to the impact of this sector on the social welfare of the population. In this regard, the study aimed to investigate how agriculture affects the welfare of the Ukrainian population.

MATERIALS AND METHODS

As part of the study, the impact of the agricultural sector on the well-being of the local population was assessed. In this regard, the impact of real agricultural output on real minimum and average wages, as well as gross domestic product per capita, was assessed. Notably, real prices were addressed, as the analysis would have shown incorrect data without accounting for inflation. Two approaches were used to estimate real gross domestic product, agricultural output, and minimum and average prices. The first approach: data was used in UAH, including a reduction from inflation level. Another approach was to first estimate the level of the metric in US dollar terms and then find the real level for the US dollar value, accounting for the inflation.

The dependence of the metrics was assessed by finding the correlation between the metrics and the regression equation. To check whether there is indeed a correlation between the data, an assessment was made using three main metrics: F-significance, P-value (for both regression values: dependent and independent variables) and R^2 adjusted. F-significance is used in the context of regression analysis to assess the statistical significance of a regression model. It shows whether the model variables are significant in predicting the dependent variable. If the F-Significance within the study was less than 0.05, the model was considered adequate, and therefore really shows a certain level of dependence between the selected metrics. R^2 adjusted, or adjusted coefficient of determination, is a modified version of R^2, which is a correlation metric. It shows how much of the variation in the dependent variable is explained by the model. This study will not define the threshold at which the model will be rejected, but an R^2 adjusted value of +-0.6 is desirable. The P-value, in turn, is a key metric in statistical analysis used to test hypotheses. The P-value shows the probability that the observed results could have occurred by chance if the null hypothesis is true. The null hypothesis for this test is as follows: H_0 – the values of the dependent/independent variable are not random, there is a relationship between them. For this study, if the P-value is less than 0.05, then agricultural output (the independent variable) is considered to have an impact on the level of wages (minimum or average) or the level of gross domestic product (GDP) (the dependent variable).

The main information was taken from the website of the State Statistics Service of Ukraine (n.d.a.; n.d.b), namely the level of gross agricultural output and GDP per capita in the country, and the MinFin website (Inflation index…, 2024), which estimates the level of inflation, as well as the level of average and minimum wages. The study included the period from 2008 to 2023 since there was no information on agricultural output before 2008. Information as of 2024 is also not available for most metrics.

RESULTS

The agro-industrial complex (AIC) is substantial in the development of Ukrainian socio-economic potential, as it is one of the main sectors of the national economy. It includes the production, processing and marketing of agricultural products and ensures national food security. Given Ukrainian fertile land and favourable climate, the country has a high potential for growing various crops such as grains, oilseeds, sugar beet, vegetables and fruits. Ukraine is one of the world's leading grain exporters and holds a significant position in the global market for the export of sunflower oil and other agricultural products. The agricultural sector ensures national food security, which is the basis for the stable development of society; it is also an important source of income for a large part of the population, especially in rural areas, where agricultural activities are often the main source of employment. It is also worth noting that agriculture is also a major source of income for the country through the export of agricultural products: Ukraine has traditionally held leading positions in the global market for the export of grains, oilseeds and other agricultural products, which strengthens the country's economy and contributes to GDP growth. In addition, the development of the agro-industrial complex contributes to the investment attractiveness of Ukraine, which attracts investors to develop agricultural infrastructure, technologies and processing, which is especially important in times of war when the country needs new investments to ensure its functioning (Kyrylenko *et al.*, 2018).

The current state of the Ukrainian agricultural sector is characterised by significant achievements in the production and export of agricultural products, but it also faces numerous challenges that require further reforms and support. Ukraine remains one of the world's leading exporters of grain crops, in particular wheat, corn and barley. Crop production is dominated by large agricultural holdings that use modern technologies and machinery to cultivate land, which ensures high yields and competitiveness of their products on the global market. At the same time, small and medium-sized farms are also actively developing, although they often face problems with access to finance, technology and markets (Ilieva *et al.*, 2022; Castillo *et al.*, 2024). Livestock farming, which is also an important component of the agricultural sector, is in a more difficult situation. Despite modernisation efforts, the sector remains less developed than crop production. There has been a decline in livestock numbers, particularly in pig and dairy farming, due to high maintenance costs, problems with veterinary services and difficulties in marketing products. In addition, logistical problems such as disruptions in supply chains and access to ports also have a significant impact on Ukrainian export opportunities. At the same time, the agricultural sector faces numerous challenges, including volatile global markets, insufficient technological equipment, logistical problems, access to finance and restrictions due to military operations in part of Ukraine. To overcome these challenges, production modernisation, technological innovation, infrastructure development, and management efficiency improvement are required (Rose *et al.*, 2021; Mendes *et al.*, 2022). Comprehensive measures are also needed, including government support, attracting foreign investment, infrastructure development, and the introduction of modern technologies (Borko, 2024). Support for small and medium-sized businesses in the agricultural sector remains necessary to ensure the sustainable development of the agricultural-industrial complex (Taoumi & Lahrech, 2023).

The social aspect of agricultural development in Ukraine is an important component of the overall development of the agricultural sector and plays a key role in shaping the welfare of the rural population, supporting rural communities and preserving national identity. This aspect covers a wide range of issues, including living standards, employment, social infrastructure, educational opportunities, and demographic change (Nowack *et al.*, 2021). Agriculture is one of the largest sectors of the Ukrainian economy, employing a significant proportion of the population. Despite urbanisation and migration to cities, agriculture remains the main source of income for many rural families. However, employment in this sector is declining due to mechanisation, automation and other technological changes, leading to job losses. Rural residents often face certain challenges, such as lower incomes compared to urban residents, limited access to quality healthcare and education, and poorer living conditions. At the same time, agriculture can provide the population with home-grown food, which partially compensates for lower cash incomes. During the war, farmers in Ukraine played a significant role in ensuring a better standard of living for the local population by producing and supplying food, which is vital in a crisis (Skydan *et al.*, 2023).

One of the most relevant modern concepts is the ecological-social economy. It is also represented in Ukraine. This approach is focused on ensuring sustainable development of the agricultural sector, preserving the environment and improving the quality of life of residents. Ecological-social agriculture includes a range of initiatives and practices that aim to support environmentally friendly production, conserve biodiversity, increase social responsibility and promote the development of rural communities. In Ukraine, in particular, organic farming (the use of natural methods of growing plants and animals without the use of synthetic pesticides, herbicides and chemical fertilisers), agroforestry (planting forest belts, creating water resources and protecting rural ecosystems) and biodiversity conservation (restoring native plant and animal species) were particularly widespread before the full-scale invasion. As for the social component – this includes the development of local communities, participation in the creation of educational programmes to raise public awareness among the population, and a greater role for farmers in the context of social responsibility. To assess the impact of agriculture on the social well-being of the local population in Ukraine, high correlations between certain variables characterising the level of agricultural sector output and the welfare of the population were determined. The data for these metrics are shown in Tables 1 and 2.

Table 1. *Correlation data for agricultural output, average and minimum wages, and GDP, adjusted for inflation and denominated in UAH*

Value	Real agricultural levy adjusted for inflation	Real minimum salary adjusted for inflation	Real average salary adjusted for inflation	Real GDP per capita adjusted for inflation
Real agricultural levy adjusted for inflation	1	0.626217	0.680948	0.564906
Real minimum salary adjusted for inflation		1	0.962936	0.873101
Real average salary adjusted for inflation			1	0.938112
Real GDP per capita adjusted for inflation				1

Source: *compiled by the authors based on State Statistics Service of Ukraine (n.d.a; n.d.b) and Inflation index... (2024)*

Table 2. *Correlation data for agricultural output, average and minimum wages, and GDP denominated in US dollars and adjusted for inflation*

Value	Real gross agricultural production adjusted for inflation and at the US dollar exchange rate	Real minimum salary adjusted for inflation and in US dollar terms	Real average salary adjusted for inflation and in US dollar terms	Real GDP per capita adjusted for inflation and at the US dollar exchange rate
Real gross agricultural production adjusted for inflation and at the US dollar exchange rate	1	0.569914	0.689151	0.582423
Real minimum salary adjusted for inflation and in US dollar terms		1	0.903796	0.743557
Real average salary adjusted for inflation and in US dollar terms			1	0.924816

Table 4, Continued

Value	Real gross agricultural production adjusted for inflation and at the US dollar exchange rate	Real minimum salary adjusted for inflation and in US dollar terms	Real average salary adjusted for inflation and in US dollar terms	Real GDP per capita adjusted for inflation and at the US dollar exchange rate
Real GDP per capita adjusted for inflation and at the US dollar exchange rate				1

Source: *compiled by the authors based on State Statistics Service of Ukraine (n.d.a; n.d.b) and Inflation index... (2024)*

Following Tables 1 and 2, even after adjusting for inflation, a significant number of metrics have a very high inflation rate, at almost 0.6, which suggests a significant relationship between them. Nevertheless, adjusted inflation is a more substantial factor. This data and other metrics (P-Value and F-Significance) for each of the regression models are shown in Table 3.

Table 3. *The main regression metrics for the six equations constructed*

Value	Depicted in UAH			
	F-Significance	P-Value Y	P-value X	R^2
Minimum wage	0.0095	0.9159	0.0095	0.3487
Average wage	0.0037	0.2383	0.0037	0.4254
GDP level	0.0226	0.0491	0.0226	0.2705
Value	Depicted in US dollars			
	F-Significance	P-Value Y	P-value X	R^2
Minimum wage	0.0212	0.6596	0.0212	0.3248
Average wage	0.0031	0.3423	0.0031	0.4749
GDP level	0.0179	0.1591	0.0179	0.3392

Notes: *selected metrics in the equation were used as the dependent variable Y, while agricultural output was used as the independent variable X*

Source: *compiled by the authors based on State Statistics Service of Ukraine (n.d.a; n.d.b) and Inflation index... (2024)*

Following Table 3, only one of the six regression equations that were estimated turned out to fit the conditions chosen in the study – the dependence of GDP on agricultural output (nominated in UAH and adjusted for inflation). The other metrics also showed a certain level of dependence on each other, but most often do not match the P-value for metric X, even though F-Significance indicates that all the models are adequate. This inflation equation is constructed below, within the framework of Formula (1):

$$y = 0.061x + 5148, \quad (1)$$

where y – dependent variable (GDP per capita); x – independent variable (agricultural output).

Following Formula 1, if agricultural output increases by 1 million UAH, GDP per capita increases by 0.061 UAH, or 6.1 kopiykas; if agricultural output increases by 1 billion UAH, GDP per capita increases by 61 UAH, and so on. Thus, it is possible to conclude that there is a certain link between the level of agricultural development and welfare metrics in Ukraine, especially the level of GDP per capita. This suggests that the agricultural sector should become one of the main sectors that the state will address when formulating long-term policies to achieve a better level of economic development and social welfare.

In times of war, the development of the agricultural sector is closely linked to ensuring food security and attracting foreign exchange earnings to the country. After the end of the war, the main areas of agricultural development should be aimed at restoring production capacity, modernising technologies, and attracting investment in infrastructure to rebuild the sector. Special attention should be devoted to the development of small and medium-sized enterprises, given their role in ensuring economic stability in the regions.

After the war, Ukrainian agriculture should address innovative development and global expansion. With the relative advantages that characterise the Ukrainian agricultural sector, local products are extremely competitive on the global stage. Therefore, it is necessary to ensure access to international markets through integration with global logistics systems, as well as to strengthen cooperation with international partners to promote Ukrainian agricultural products. In the post-war period, the state should play a leading role in creating favourable conditions for the development of the sector by providing support to farmers, stimulating investment and ensuring the stability and security of agricultural activities. Only in this case, especially at the initial stage, will it be possible to achieve significant success in restoring the sector and spreading its products globally.

DISCUSSION

The current study describes the role that agriculture plays in ensuring the effective development of Ukraine, both in the context of economic and social development. The role of agriculture in national development was also described by A. Devlet (2021). The scientist noted that it is necessary to ensure the development of agriculture in modern conditions to solve pressing problems related primarily to food security. In addition, it was noted that in the current environment, the sector faces significant challenges that prevent it from operating efficiently and smoothly, such as droughts or other environmental factors that affect yields. The current study did not focus on the food security component, but it is also relevant in the context of ensuring the long-term well-being of the country, as well as its strategic security.

The current study focuses on the current manifestations of the eco-social economy in Ukraine. This approach and its impact on social transformation and environmental sustainability was also evaluated by S. Nicli *et al.* (2020). Scientists have noted that ecosocial agriculture is characterised by a holistic approach that integrates the needs of people, communities and nature. Initiatives under this approach often go beyond organic farming, preserving local crop varieties and promoting biodiversity. Its three pillars include addressing social needs through inclusive agriculture, fostering local co-operation and using natural resources responsibly to protect the environment. Social agriculture is deemed as a social innovation that can create new local conditions of well-being. Its implementation requires support from the authorities, appropriate policies, and funding for such opportunities offered by various programmes, including the European Union. According to scientists, eco-social agriculture has the potential to benefit disadvantaged people and society, contributing to regional sustainability and restructuring society to ensure both social and environmental well-being. The paper emphasised the interconnectedness of social, cultural and political spheres with strong local and regional networks and community-based decision-making. The possibilities of using social agriculture were also addressed by F. Sgroi (2022). The author emphasised that social agriculture is a concept that is aligned with multifunctional small and medium-sized farming and focuses on achieving a better level of community development rather than profit-making by farmers. Social agriculture employs agricultural resources to provide therapeutic, educational and social services, especially for vulnerable groups such as individuals with physical disabilities, mental hospital patients and ex-prisoners. These initiatives are organised at the local level and are more cost-effective than traditional public services. The study contrasts the two business models: the first is based on neoclassical economic theory, which prioritises profit maximisation, and the second is based on the Tagliavia farm approach, which is grounded in social doctrine, emphasising solidarity and the common good. The study highlights that while both models help achieve socially important goals, their underlying principles differ. The neoclassical model focuses on transforming inputs into outputs, while the social doctrine values social interdependence and the collective good. Accordingly, in the context of achieving the goals and benefits for the state, the second approach will be more effective. Given the conclusions reached in the present study regarding the usefulness of this approach for the long-term development of the country, as well as the results obtained by other scientists, it is possible to formulate recommendations on how the state should involve farmers in this area. However, it will only be possible to introduce such activities after the war is over.

An approach to agricultural development based on the concept of societal vision was presented by J. Helfenstein *et al.* (2022). The study showed a new approach to assessing the sustainability of agricultural development by comparing societal visions (i.e., those that address the values of society, priorities and long-term goals of the nation) in the Royce Valley, Switzerland. The case study demonstrated the potential of using public vision as a forecasting tool to improve regional governance. The current study also showed that during the war, Ukrainian farmers were quite active in supporting both the local population and the military. Given this, it is possible to conclude that Ukrainian farmers are quite responsible in terms of understanding the importance of state and citizen support. However, the state should also support farmers to enable them to develop, especially in times of war.

The current study also describes that one of the most pressing problems in agricultural development is the lack of significant adoption of innovative technologies on local farms. Other scholars have also addressed this component in overcoming climate-related problems and achieving a better standard of living for the local population and compliance with moral and ethical standards. The concept of Agriculture 5.0 was addressed by K.D. Bissadu *et al*. (2024). The scientists noted that its main goal is to address certain global issues, such as population growth, climate change and population ageing. This concept uses the latest technologies, such as artificial intelligence, Big Data, the Internet of Things, etc. Scientists believe that their use to ensure a better level of development of innovative technologies can achieve much better results in the context of achieving the goals of sustainable development in general and improving people's living standards in particular. In turn, the possibilities of using the latest technologies to solve various kinds of problems were assessed by E.D. Lioutas *et al*. (2021). The scientists noted that the use of digital technologies has both potential and shortcomings. The use of the latest technologies in this area creates new social, ethical, political, cultural and environmental problems. While digital tools are regarded as potential solutions to the global food problem, they also lead to the need to make complex trade-offs that require careful analysis to avoid serious consequences for society. Thus, the conclusions drawn by the scientists above are indeed relevant to the general problems in the context of the development of innovative technologies in agriculture.

CONCLUSIONS

Small and medium-sized crop farmers are crucial for inclusive agricultural development but often face limited access to finance, technology and markets. The livestock sector is also experiencing difficulties, especially in pig and dairy farming, due to high costs, inadequate veterinary services and logistical problems. Despite these obstacles, the sector continues to grow and agriculture remains the main sector for job creation. The study demonstrated that the current needs of the agriculture sector include the need for policies that support rural communities, improve social infrastructure, and ensure equitable access to education and healthcare. The concept of eco-social agriculture, which emphasises sustainable practices and social responsibility and offers a promising way to balance economic growth with environmental protection and social development, was also discussed.

The study also showed the correlation between agricultural production and the welfare of the Ukrainian population, in terms of gross domestic product per capita. The results show that an increase in agricultural production directly contributes to economic growth, reinforcing the importance of this sector in Ukrainian long-term development strategy. To fully realise the potential of the sector, comprehensive measures are needed, including government support, the introduction of modern technologies, infrastructure development, and the promotion of small and medium-sized enterprises. Further study should address possible effective ways to attract investment in the industry for its development (development of state support mechanisms, use of donor funds, etc.). The main limitation of this paper is the low amount of available data for analysis and comparison, which rendered an analysis of the interaction between the agricultural sector and the welfare of the population in sufficient detail impossible.

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CONFLICT OF INTEREST

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Роль агропромислового комплексу в розвитку соціально-економічного потенціалу України

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Анотація. Агропромисловий комплекс є основним для розвитку економіки України, особливо в умовах війни, оскільки дозволяє підтримувати рівень життя громадян. У зв'язку з цим, взаємодія між сектором та соціумом є актуальною для дослідження. Ціллю роботи стало оцінити взаємозв'язок між окремими показниками, що вказують на рівень життя населення, та випуском продукції сільського господарства. У дослідженні було розглянуто роль аграрного сектору в Україні та його витоки. Крім того, детальний аналіз був проведений в контексті існуючих проблем окремо для сфери тваринництва та рослинництва. Надалі було обґрунтовано зв'язок агропромислового сектору із соціальним благополуччям сільського населення України, зокрема у зв'язку з можливістю сфери створювати значну кількість робочих місць. За допомогою кореляційного та регресійного аналізу було зроблено висновок стосовно того, що розвиток аграрного сектору дійсно впливає на рівень життя місцевого населення, зокрема – на валовий внутрішній продукт на душу населення. Отримані результати свідчать про те, що збільшення сільськогосподарського виробництва безпосередньо сприяє економічному зростанню, посилюючи важливість цього сектору в довгостроковій стратегії розвитку України. Також в рамках дослідження було показано, яким має стати довгостроковий розвиток агропромислового комплексу в Україні в довгостроковій перспективі, та які дії мають бути виконані для досягнення поставлених цілей, зокрема з боку держави. Висновки, отримані в рамках дослідження, можуть бути використані для формування державної політики в сфері аграрного сектору в контексті впливу на соціальну складову країни

Ключові слова: міжнародна торгівля; рослинництво; тваринництво; інфраструктура; фінанси

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