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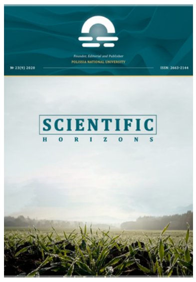

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Effect of chicken infectious bronchitis vaccine on morphogenesis and differentiation of cells in caecal tonsils

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Abstract. The study of the chickens' immune system morphofunctional state allows assessing critical periods of their development and the body as a whole, as well as the effectiveness of vaccine prevention methods. The purpose of this study was to identify morphological and immunohistochemical changes in the caecal tonsils of chickens aged 8, 20, 40, 90, 110 days for vaccine prevention of infectious bronchitis. During the study, the following research methods were used: cytological, histological, immunohistochemical, morphometric, light-optical, statistical. Histological preparations

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of caecal tonsils of poultry aged 8, 20, 40, 90, 110 days of vaccinated and unvaccinated groups were analysed and studied. Up to 20 days of age, no lymphoid nodules were detected in the caecal tonsils of chickens, both vaccinated and non-vaccinated groups. Histological and morphometric studies were conducted, which showed that vaccination of poultry accelerates the development of lymphoid formations in the early stages of the postnatal period of ontogenesis, especially in chickens aged 20 days, which is manifested by an increase in the number and size of lymphoid nodules of caecal tonsils relative to the control group. Immunohistochemical studies have established that the placement and accumulation of T-lymphocytes with markers CD4⁺, CD8⁺, as well as B-lymphocytes (CD20⁺) and CD45RA⁺ cells in caecal tonsils, namely in lymphoid nodules and diffuse accumulation of lymphoid cells, depend on the age of chickens and multiplicity of vaccinations. It was proved that in chickens aged 8 days, the number of T-lymphocyte subpopulations with surface markers CD4⁺, CD8⁺ prevailed over CD45RA⁺ and CD20⁺. With the increase in the number of immunizations (after three-fold vaccination against infectious bronchitis of chickens), immunocytometric studies indicated that in vaccinated chickens aged 40 and 90 days, there was a clear increase in the number of mature B-lymphocytes by 1.58 and 1.37 times, respectively. Considering the fact that the number of CD8⁺ lymphocytes in vaccinated chickens aged 40 days was 1.49 times greater than the number of CD4⁺ cells, this led to a sharp decrease in the immunoregulatory index of the caecal tonsils, which must be factored in when carrying out preventive vaccinations

Keywords: poultry; histological changes; lymphoid formations; T-lymphocytes; B-lymphocytes; vaccine prevention

INTRODUCTION

Chicken infectious bronchitis virus (IBV) is a coronavirus that reduces meat and egg production in poultry (Gallardo, 2021; Chandrasekar *et al.*, 2023). The CIB virus has been known since 1930, but even now, it causes significant economic damage to farms (Bande *et al.*, 2017; Legnardi *et al.*, 2020). Live and inactivated vaccines are used to prevent infectious bronchitis, but due to the emergence of IBV new strains, the risk of this disease outbreak increases (Bhuiyan *et al.*, 2021). The prevalence of the CIB virus is growing rapidly (Karimi *et al.,* 2019). Infectious bronchitis has three forms: respiratory, nephroso-nephritic, and reproductive (Guralska *et al.*, 2019; Zhang *et al.*, 2020). External factors that reduce the immune response also affect production parameters. Many factors, including infectious ones, cause immunosuppression in poultry (Gimeno & Schat, 2018; Nair, 2022; Schat & Skinner, 2022).

Poultry farming is the most intensive and fast-growing industry among other livestock production. Presently, it has expanded considerably due to the demand for both meat and eggs (Stamilla *et al.*, 2020). Vaccination is used in poultry farms to prevent infection, reduce morbidity and mortality (Habibi *et al.,* 2017; Yang *et al.,* 2023). According to Stamilla *et al.* (2020), vaccination is a vital step to maintain the necessary biosecurity, especially in the first weeks of poultry life. However, repeated vaccinations significantly inhibit the body's immune functions (Kaab *et al.,* 2018). Vaccines are often used repeatedly, and this, as a result, causes immune stress disorder. Mass use of vaccines, specifically against infectious bronchitis, is to some extent ineffective and can lead to ineffective vaccination (Jordan, 2017). Despite the fairly widespread use of vaccination against infectious bronchitis, this disease causes considerable economic damage to poultry farms (Icochea *et al.*, 2023). M.W. Jackwood and D.H. Lee (2017) argue that the use of live attenuated vaccines for immunization affects the genetic profile of chicken infectious bronchitis strains. According to the results of the study, the use of the vaccine has a weak reactogenic effect (Asrutdinova *et al.,* 2020). And yet, even though there may be outbreaks of the disease in immunized poultry, vaccination is still one of the key methods of preventing infectious bronchitis in chickens (Ali *et al.,* 2023). For vaccine prevention of infectious bronchitis in chickens, it is necessary to first consider the immunosuppressive effect of vaccines on the poultry body (Guralska & Budnik, 2020).

Logvinova & Oliyar (2021) indicate the need to consider the morphogenesis of the lymphoid structures of the intestine of poultry during intensive poultry farming. The gastrointestinal tract plays a major role in immune homeostasis (Ahluwalia *et al.,* 2017; Nochi *et al.,* 2018). Peripheral organs of the immune defence of birds include lymphoid tissue associated with the mucous membrane of the digestive canal (Montalban-Arques *et al.,* 2018). It occupies one of the prominent places in the system of the immune defence organs of birds (Mazurkevych, 2017). The intestine-associated lymphoid tissues of the digestive tract, which consist of lymphoid cells contained in Peyer's patches, caecal tonsils, and also in the own lamina of the intestinal mucosa, are quite well-developed in the bird's body. The cacecal tonsils consist of an aggregated mass of lymphocytes and form numerous nodules (Abd El-Wahab *et al.,* 2017). They trigger a protective immune response against both bacterial and viral pathogens (Alqazlan *et al.,* 2021). The caecal tonsils are analogous in structure to Peyer's patches, have the appearance of two large lymphoid aggregates and are located at the border between the caecum and rectum (Abd El-Wahab *et al.*, 2017). These lymphoid formations are secondary lymphoid tissue that takes part in humoral immune responses (Nnadozie *et al.,* 2019). Lymphoid formations that are located in the digestive organs of poultry protect the body from foreign antigens (Khomich *et al.,* 2021).

The immune formations of the poultry caecum are quite well-developed. The area of the caecal tonsils contains a significant amount of lymphoid tissue (Mazurkevych, 2017). Morphologically, two types of lymphoid tissue are found in them: diffuse (T-zone) and nodular (B-zone) (Nnadozie *et al.*, 2019). Lymphoid tissue is present in the mucosa and submucosa of the caecal tonsils (Mazurkevych, 2017). Lymphoid formations of the digestive system support the genetic constancy of the internal environment of the body (Khomich *et al.,* 2021).

The caecum is constantly exposed to bacterial or other antigens. Therefore, cochlear lymphoid formations play an important role in the immunological response to foreign microorganisms. Cellular immune responses in lymphoid formations are a prerequisite for humoral responses, the deficiency of which in birds in the first weeks of life is associated with the immaturity of T- and B-lymphocytes (Junior *et al.*, 2018). In caecal formations, under the antigen, lymphocytes turn into effector cells, the secretory substances of which determine the development of cellular and humoral immunity (Mazurkevych, 2017). The study of basic structures is a necessary condition for understanding the physiology and immunomorphology of immune defence organs (Ayman *et al.,* 2021). According to Thomrongsuwannakij *et al.* (2021), before using vaccines, it is necessary to investigate the immune status of chickens.

The purpose of this study was to establish the immunocytological and histological features of the formation of caecal tonsils in chickens for vaccine prevention against infectious bronchitis. Objectives of the study: to establish cyto- and histological features of the chickens caecal tonsils during vaccination; to determine the content, localization, and quantitative ratio of subpopulations of $CD8^+$, $CD4^+$, $CD20^+$, CD45RA-lymphocytes of the chickens caecal tonsils during vaccination.

MATERIALS AND METHODS

For the study, Hisex Brown cross chickens of the same age were selected, which were kept at the branch "Solotvyn poultry farm" of the limited liability company "Zelenyi Val" in the village of Stary Solotvyn, Berdichevskyi district, Zhytomyr region. The poultry was divided into two groups: control (intact) and experimental (vaccinated).

Histological studies were performed in the educational-scientific clinical-diagnostic laboratory of the Polissia National University. Histological material was the caecal tonsils of chickens aged 8, 20, 40, 90 and 110 days selected from the control and experimental groups.

Anatomical examination included slaughter and exsanguination of chickens, preparation and removal of organs. Histological studies were carried out according to generally accepted methods of tissue fixation and production of histological tissue sections. For histological examination, caecal tonsils of chickens were selected, which were fixed in a 10-12% aqueous solution of neutral formalin for 48 hours, then washed with tap water for 24 hours, dehydrated with ethyl alcohol of increasing concentration (40%, 50%, 70%, 96%, 100%) followed by pouring in paraffin. Histosections were made on a sled microtome, which were subsequently stained with haematoxylin and eosin, as well as according to the Van Gieson method.

Immunohistochemical studies revealed T-lymphocytes in caecal tonsils: helpers and cytotoxic cells with $CD4^+$ and $CD8^+$ surface markers, respectively; mature B-lymphocytes ($CD20^+$), as well as naïve T-helpers, B-lymphocytes and monocytes ($CD45RA^+$). Monoclonal antibodies were used for this purpose. For better visualization, the histosections were additionally stained with Mayer's haematoxylin (DAKO, Denmark).

A Primo Star light microscope (Carl Zeiss, Germany) and Image Scope software were used for the morphometric study of caecal tonsils of chickens. The immunoregulatory index (IRI) was determined – the $CD4^+$:$CD8^+$ ratio. For microphotography, a digital camera mounted in a Primo Star microscope (Carl Zeiss, Germany) was used. Statistical processing of the study results was performed using the Statistica 6.0 software (StatSoft Inc., USA). Fischer's F-criterion was used to assess statistical significance. The difference between the obtained data was recognized as probable at $P<0.05$.

During the research, the "General Ethical Principles of Experiments on Animals" (Reznikov, 2003) were observed, which is consistent with the Law of Ukraine No. 3447-VI "On the Protection of Animals from Cruelty" dated 10.16.2012 (Law of Ukraine No. 3447-IV, 2006) and the Provisions of the "European Convention for the Protection of Animals Used for Experimental and Other Scientific Purposes" (European Convention, 1986), as well as the Declaration on the Humane Treatment of Animals (Universal Declaration, 2007).

RESULTS AND DISCUSSION

Histological examination of the caecum revealed that the histoarchitectonics of the chickens experimental group organ practically does not differ from the control one. Notably, no lymphoid formations were observed in the control and experimental chickens aged 8 days in their own plate of the caecum mucosa. However, in chickens aged 20 days (with repeated vaccination), the lymphoid tissue was diffuse clusters of lymphoid cells and lymphoid nodules (LN) were also detected, the average diameter of which increased 1.13 times in the experimental and control chickens and amounted to 59.8±2.44 μm ($P<0.05$), respectively (Fig. 1). This indicated the LN hyperplasia in the poultry of the experimental group due to antigenic stimulation.

Therewith, in chickens of this age in the experimental group, a slight increase in the number of lymphocytes in the caecum submucosal base was observed, especially B-lymphocytes and plasmocytes with a low content of macrophages, with a considerable number of lymphocytes concentrated in the area of the caecal tonsils (CTs).

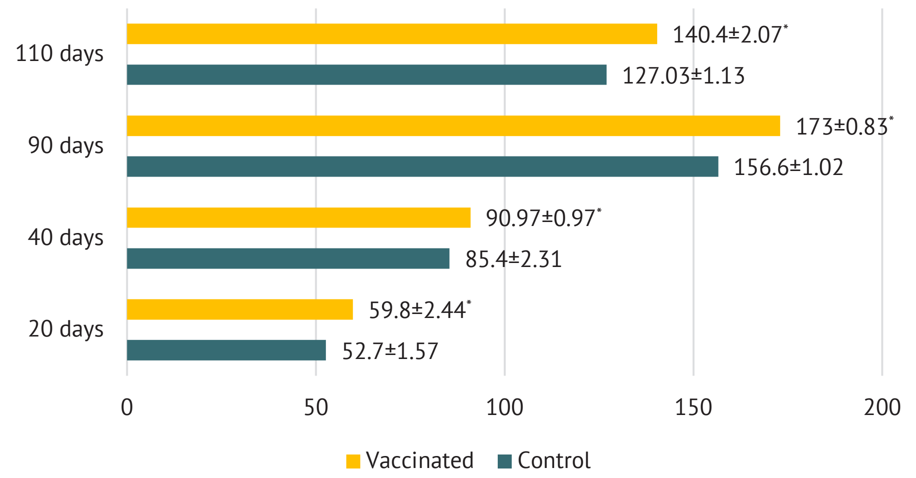

Figure 1. *Diameter of vaccinated chickens' caecal tonsils lymphoid nodules, μm*
Note: ** – P<0.05 for chickens in the control group*
Source*: compiled by the authors*

The detected hyperplasia of lymphoid nodules (Fig. 2) in the CTs area of the experimental group chickens occurred regardless of the vaccine administration method. That is, the systemic course of the processes that took place was noted. The submucosal base of the caecum was infiltrated by lymphocytes, and as the number of antigenic stimulations increased, an intense plasmocytic reaction occurred in the intestinal wall. The chickens after the first vaccinations were dominated mainly by plasmoblasts, as well as immature plasmocytes. In poultry aged 90 and 110 days, the main plasma cells were already mature plasmocytes.

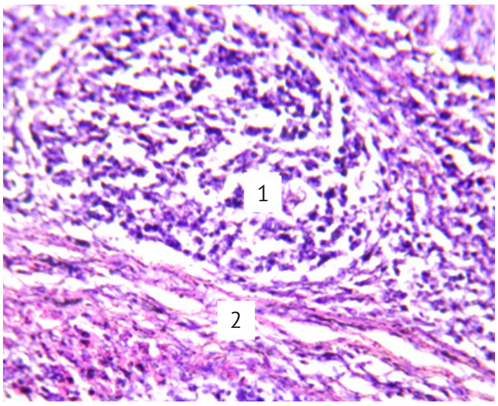

Figure 2. *Fragment of the microscopic structure of the vaccinated chicken aged 40 days caecal tonsils: 1 – lymphoid nodule; 2 – trabecula*
Note*: Haematoxylin and eosin. ×400*
Source*: photographed by the authors*

Lymphoid cells and macrophages were detected in the submucosal base of chickens aged 40 and 90 days in the experimental group. Lymphocyte accumulations were insignificant. Therewith, the presence of LN wrapped in collagen fibres was noted (Fig. 3).

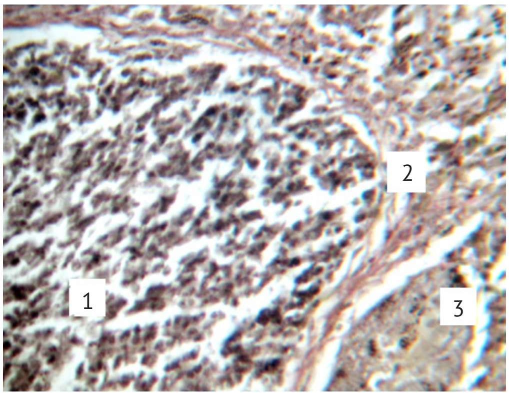

Figure 3. *Fragment of the microscopic structure of the caecal tonsils of a vaccinated chicken aged 40 days: 1 – lymphoid nodule; 2 – trabecula; 3 – crypt*
Note: *The Van Gieson's stain. ×400*
Source*: photographed by the authors*

Analysis of cytomorphometric results indicated that in the experimental group of chickens aged 40 days, the amount of LN was 12.06±0.38 pcs., while in the control – 10.83±0.28 pcs. (Fig. 4). The LN diameter in vaccinated chickens aged 40 days also significantly increased by 1.07 times (P<0.05) and was 90.97±0.97 μm (Fig. 1).

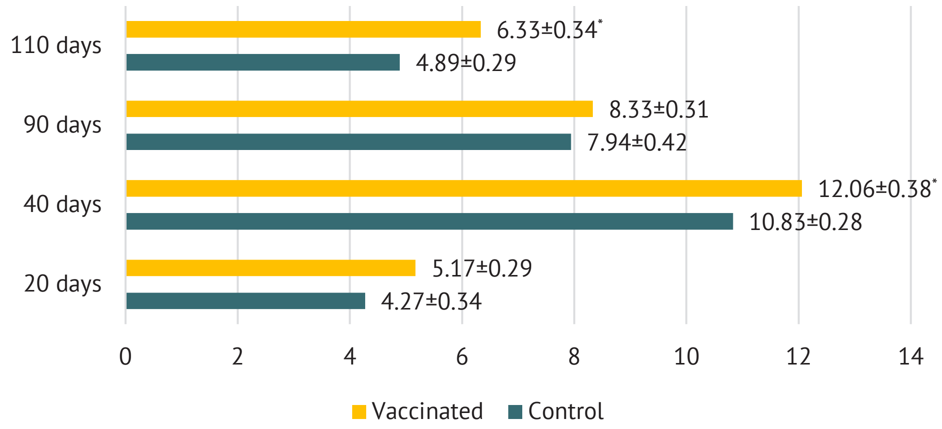

Figure 4. *Number of lymphoid nodules of the vaccinated chickend caecal tonsils, pcs.*
Note: ** – P<0.05 for chickens in the control group*
Source*: compiled by the authors*

Similar cyto- and histoarchitectonics of CTs lymphoid nodules were observed in experimental chickens aged 90 and 110 days. Moreover, there was a stable predominance of the number and size of CTs nodules in vaccinated chickens over the control ones, as evidenced by the presented histometric studies.

During the immunohistochemical analysis of CTs in experimental chickens compared to control ones, an increase in the processes of formation and differentiation of lymphocytes with $CD4^+$ and $CD8^+$ markers, which provide a cellular immune response, as well as $CD20^+$, which form the antibodies, was observed. According to the results of immunohistochemical studies, it was established that T-lymphocytes ($CD4^+$) in the CTs area of vaccinated chickens aged 8 days are located in the mucous membrane. They form small clusters that are located near the crypts. On individual preparations of the CTs of chickens aged 20 and 40 days of the experimental group, these T-lymphocytes are localized singly in the places where the crypts are located (Fig. 5).

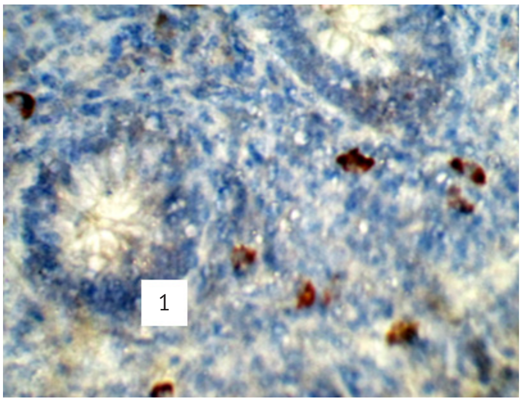

Figure 5. *$CD4^+$ lymphocytes in the caecal tonsils of a vaccinated chicken aged 20 days: 1 – crypts*
Note: *Histopreparations using monoclonal antibodies. ×600*
Source*: photographed by the authors*

The presence of lymphocytes was also noted in the intestinal villi (Fig. 6). In chickens of older age groups, after vaccination, T-lymphocytes with surface markers $CD4^+$ had an analogous location as in a poultry aged 40 days, and they also formed clusters in lymphoid nodules.

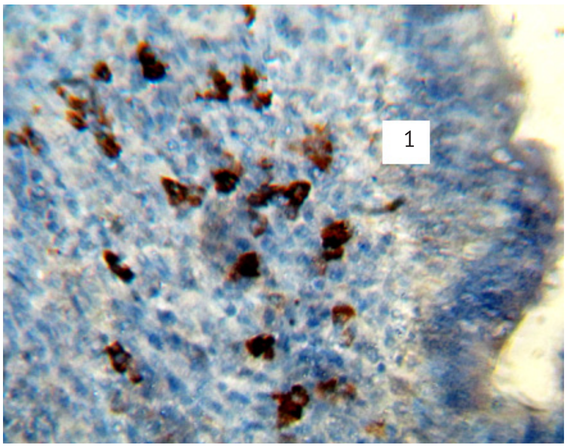

Figure 6. *$CD4^+$ lymphocytes in the caecal tonsils of vaccinated chicken aged 40 days: 1 – villi*
Note: *Histopreparations using monoclonal antibodies. ×600*
Source*: photographed by the authors*

Analysis of the quantitative study of lymphocyte subpopulations in CTs showed clear cytomorphometric manifestations of changes in $CD4^+$ lymphocytes in vaccinated chickens compared to control ones. Thus, in experimental chickens aged 8 days, an increase ($P<0.05$) in the number of T-helpers was observed by 1.19 times compared to the control. Analogous results regarding the increase in the number of $CD4^+$ lymphocytes were also observed in experimental chickens of a different age (Fig. 7).

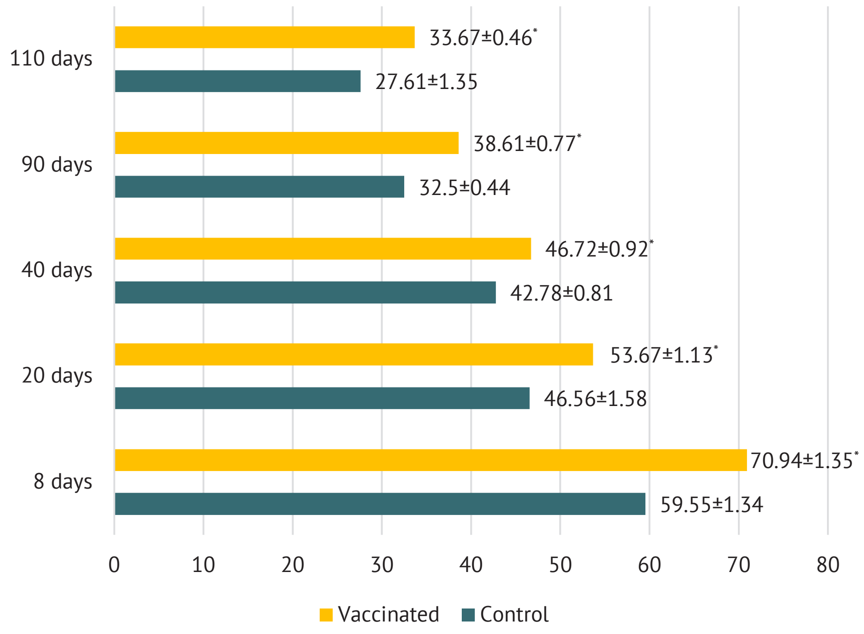

***Figure 7**. The number of CD4⁺ lymphocytes in caecal tonsils of vaccinated chickens, pcs.*
***Note:** * – P<0.05 for chickens in the control group*

The results of immunohistochemical studies indicate that the placement of CD8⁺ lymphocytes in the CTs area of vaccinated chickens aged 8 and 20 days is analogous to the control group. A part of lymphocytes with CD8⁺ surface markers in the CTs of chickens aged 40 days, after threefold vaccination, is diffusely located in the mucous membrane (Fig. 8), while other cells form clusters in lymphoid nodules. In vaccinated chickens aged 90 and 110 days, subpopulations of lymphocytes with CD8⁺ clusters in lymphoid nodules form clusters of 4-10 cells on their periphery.

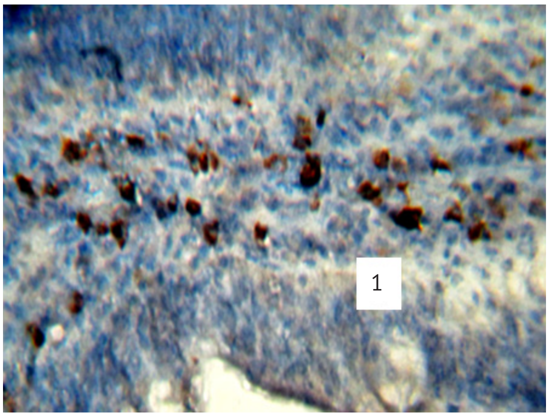

***Figure 8.** CD8⁺– lymphocytes in the caecal tonsils of a vaccinated chicken aged 40 days: 1 – villi*
***Note:** Histopreparations using monoclonal antibodies. ×600*
***Source**: photographed by the authors*

Subpopulations of lymphocytes with CD45RA⁺ clusters in the CTs area of chickens aged 8 and 20 days are individually localized between crypts and in a diffuse cluster of lymphoid cells, their small number was also noted in the villi. In addition, CD45RA⁺ lymphocytes were found in almost every lymphoid nodule of vaccinated chickens aged 40, 90, 110 days. Such cells were also found in the apical region of the epithelial cell cytoplasm, the villi stroma, and the mucosa's own plate (Fig. 9).

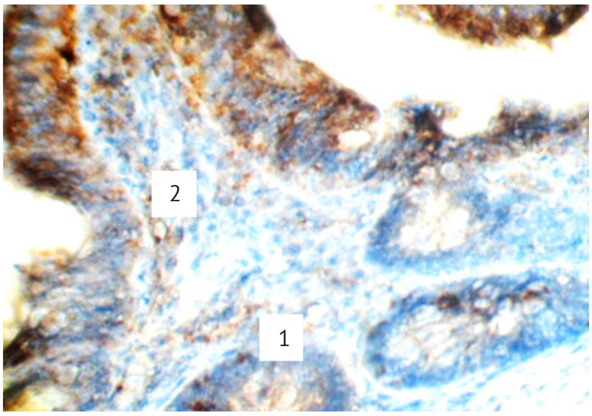

***Figure 9.** CD45RA⁺ lymphocytes in the caecal tonsils of a vaccinated chicken aged 90 days: 1 – crypt; 2 – villi*
***Note:** Histopreparations using monoclonal antibodies. ×400*
***Source**: photographed by the authors*

According to the results of studies, it was found that the number of cytotoxic cells (CD8⁺) in the CTs area of experimental chickens with an increase in the frequency of vaccination changed. Therewith, vaccinated chickens of different age periods showed their growth (Fig. 10).

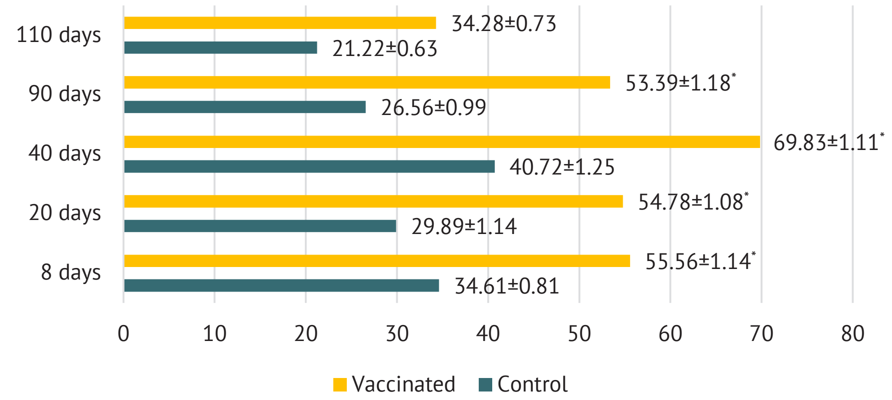

Figure 10. *Number of CD8S⁺ lymphocytes in the caecal tonsils of vaccinated chickens, pcs.*
Note: ** – P<0.05 for chickens in the control group*
Source*: compiled by the authors*

The growth of CD8⁺ lymphocytes also affected the immunoregulatory index of the CTs of the experimental poultry. This indicator significantly decreased (P<0.05) in all age groups relative to the control (Fig. 11).

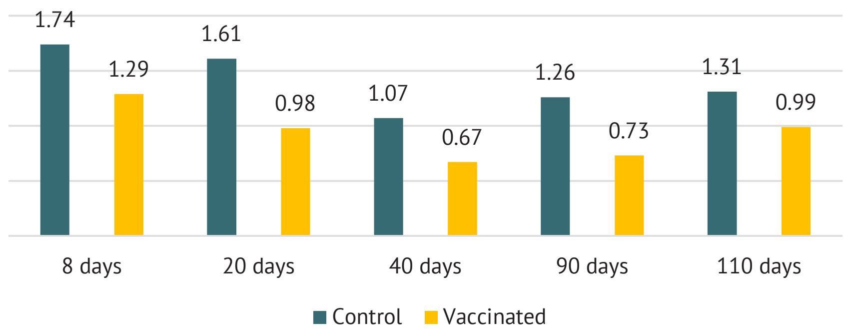

Figure 11. *Immunoregulatory index in the amygdala of vaccinated chickens*
Source*: compiled by the authors*

Cytomorphometric studies also established a significant (P<0.05) increase in the number of cells of the CD45RA⁺ subpopulation after three- and five-fold vaccination against CIB compared to non-vaccinated ones. At the same time, in vaccinated chickens aged 8, 20, and 90 days, only a tendency to an increase in the number of CD45RA⁺ cells was observed compared to the control (Fig. 12).

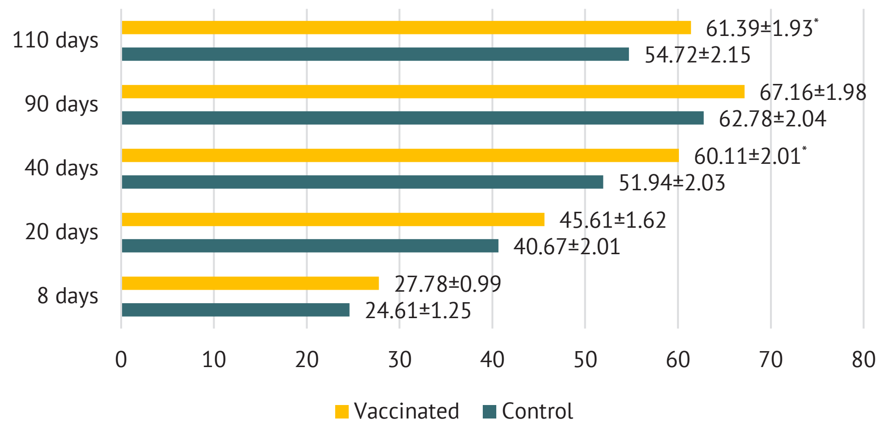

Figure 12. *Number of CD45RA⁺ lymphocytes in the caecal tonsils of vaccinated chickens, pcs.*
Note: ** – P<0.05 for chickens in the control group*
Source*: compiled by the authors*

In the CTs of vaccinated chickens, a significant increase in the number of CD20+ cells (mature B-lymphocytes) was noted, the presence of which was observed in all structural elements, including the mucous membrane, villous stroma, around the crypts, diffuse lymphoid tissue, and in the LN. Furthermore, in chickens aged 20 and 40 days (after two- and threefold vaccination), B-lymphocytes were detected in the apical region of the cytoplasm of columnar epithelial cells of the epithelial plate of the mucous membrane, as well as in LN. In experimental chickens aged 90 and 110 days, mature B-lymphocytes were localized in LN, the cytoplasm of columnar cells that formed crypts, and a significant number were located in the interfollicular lymphoid tissue (Fig. 13).

At the same time, in vaccinated chickens of all age groups, the number of CD20+ cells increased significantly ($P<0.05$) compared to intact ones (Fig. 14).

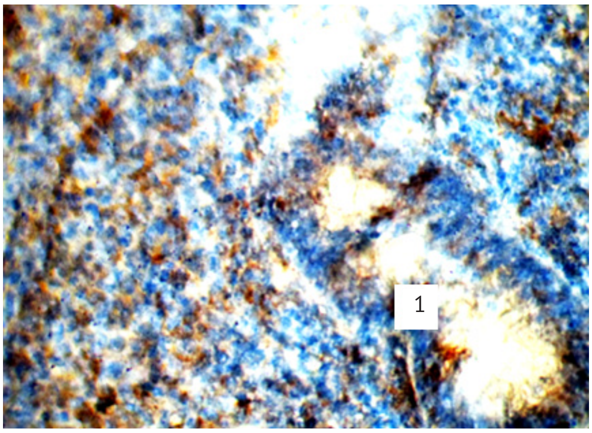

Figure 13. *CD20+ lymphocytes in caecal tonsils of a vaccinated chicken aged 110 days: 1 – crypt*
Note: *Histopreparations using monoclonal antibodies. ×600*
Source*: photographed by the authors*

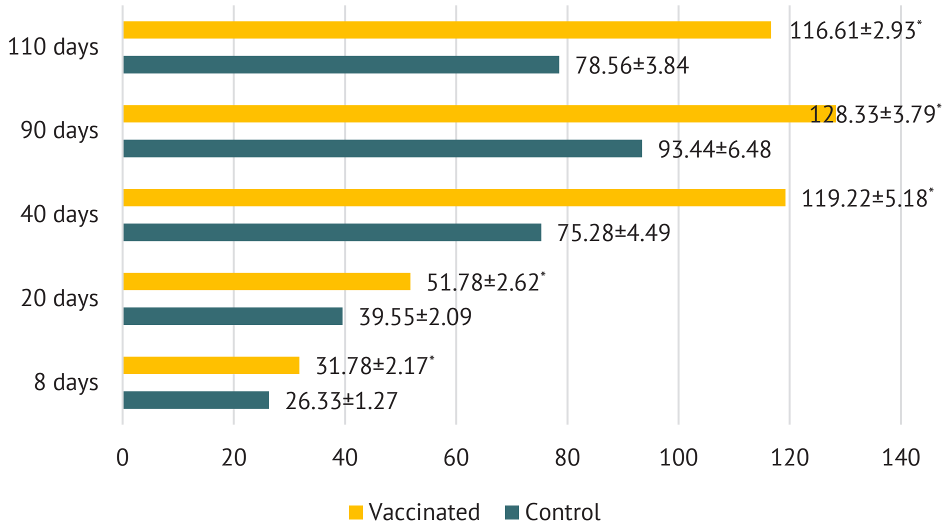

Figure 14. *Number of CD20+- lymphocytes in the caecal tonsils of vaccinated chickens, pcs.*
Note: ** – P<0.05 for chickens in the control group*
Source*: compiled by the authors*

According to the results of histological studies of the caecal tonsils in chickens aged up to 20 days, there were no lymphoid nodules, only diffuse lymphoid tissue was noted, which indicates their functional immaturity. These results confirm the data of B. Song *et al.* (2021) that the immune system of chickens is not developed until 34 days of age. Studies on the morphological characteristics of chickens caecal tonsils at the cellular and tissue levels to some extent complement the data of other authors. The detected postvaccinal morphofunctional changes in the chicken organ depended on the frequency of immunization and their age. According to N. Nagy *et al.* (2022), T-lymphocytes in the tonsils are located mainly in the interfollicular space, but some of them are also in the germinal centres. After hatching, the number of lymphocytes increases, CTs are observed already in the second week of life, and they increase with age. The composition includes specialized epithelium, subepithelial zone, lymphoid nodules and interfollicular areas. In the subepithelial zone, apart from plasma cells, there are also CD4+ and CD8+ lymphocytes, and the interfollicular T-cell-dependent zone consists mainly of CD4+ (Nagy *et al.*, 2022). U. Ayman *et al.* (2021) in chickens aged 1 day, only a small infiltration of lymphocytes was detected in the area of caecal formations; however, in chickens aged 14 days, they already noted the presence of lymphoid nodules, whereas in chickens aged 28 days, encapsulated lymphoid nodules and diffuse lymphoid tissue in the lamina propria and submucosal layer. Caecal tonsils of chickens acquire morphofunctional maturity gradually up to 35 days of life (Udoumoh *et al.*, 2021).

The study results complement the data of A. Hussein and A. Reshag (2019), which indicate that the caecal tonsils contain many B cells. Results of immunohistochemical studies by V. Khomich *et al.* (2021) indicated that the highest number of mature B lymphocytes was observed in poultry aged 180 days. According to the results of the study B. Song *et al.* (2021), the highest levels of specific cellular immunity components, namely the activity of T- and B-cells proliferation, are observed from 30 to 34 life days of broiler chickens. According to A. Hussein and A. Reshag (2019) the size of the caecal tonsils increases with age. In poultry aged 2 months, the presence of mature B-lymphocytes was clearly noted. In Hisex Brown chickens, according to research results, the highest indicators of T-lymphocytes with surface markers $CD4^+$ $CD8^+$ were noted precisely at the age of 40 days, while the indicators of mature B-lymphocytes ($CD20^+$) – at the age of 90 days.

To estimate humoral immunity, it is necessary to consider the level of T-lymphocytes with the surface marker $CD4^+$. $CD4^+$ and $CD8^+$ lymphocytes can have suppressive activity (Dai *et al.*, 2021). According to Lee *et al.* (2019), $CD4^+$ lymphocytes act as regulatory T cells.$CD8^+$ is particularly important for antigen recognition (Liu *et al.*, 2020). According to the study results of E. Aston *et al.* (2019), when immunizing chickens against CIB, the amount of $CD8^+$ lymphocytes grows in relation to unvaccinated poultry. M. Dai *et al.* (2021) point out the importance of cytotoxic T cells in the immune response specifically to the chicken infectious bronchitis virus. These data are confirmed in our research results because starting from the 20-day age of chickens, the number of $CD8^+$ lymphocytes prevailed over $CD4^+$ lymphocytes in caecal tonsils. Thus, if in vaccinated chickens aged 40 days the number of lymphocytes in the CTs with surface markers $CD8^+$ was 69.83±1.11 pcs., then $CD4^+$ lymphocytes – 46.72±0.94 pcs. Based on the results of immunocytochemical studies by R. Zegpi *et al.* (2019), vaccination can induce elevated levels of $CD4^+$ lymphocytes, $CD8^+$ lymphocytes. The presence of CD8 lymphocytes is clearly expressed in young poultry (Hussein & Reshag, 2019). When investigating the cell clusters, results were obtained that indicated a certain dynamics in the development of the immune response, which depended on the age of the poultry, the frequency of vaccination, and the characteristics of the organ under study. Any infection can destroy post-vaccination defences and adversely affect the immune system.

The T-system of poultry is involved in the formation of the immune response and regulates its duration (Hussein & Reshag, 2019). Although an increased number of $CD4^+$, $CD8^+$ T-cells was observed in the peripheral blood during viral infections, according to M. Dai *et al.* (2021), their role, functions, and biological significance are still understudied. An increase in the ratio of $CD4^+/CD8^+$ in the thymus of chickens was observed in the studies of T. Kannan *et al.* (2017): at four weeks to 0.67 and at eight weeks of age to 0.72. According to our research, the ratio of $CD4^+/CD8^+$ in the CTs of vaccinated chickens at 40 days of age was 0.67, and at 90 days it was 0.73. Therewith, K. Acevedo-Villanueva *et al.* (2021) did not note substantial changes in the ratio of $CD4^+/CD8^+$ in CTs of immunized and intact poultry.

The investigation of the immune system organs morphology helps fully understand the immunology of poultry (Nagy *et al.,* 2022). As indicated by T. Mazurkevych *et al.* (2022), it is by determining both the quantitative and qualitative composition of the immune protection organs lymphoid cells subpopulations that the immune status of an animal can be determined at different age periods. Understanding the morphology of caecal tonsils in poultry is particular importance because they perform a protective function (Saleh *et al.*, 2022).

Thus, as a result of the conducted studies, data were obtained indicating the feasibility of using immunohistochemical methods to determine the immune state in vaccinated chickens against infectious bronchitis.

CONCLUSIONS

During histological examination of experimental chickens' aged 110 days caecal tonsils, the size of lymphoid nodules decreases, which may indicate physiological involution. Thus, if at the age of 90 days in vaccinated chickens the nodule diameter was 173±0.83 μm, then at the age of 110 days this indicator decreased to 140.4±2.07 μm. In the control group of chickens, this indicator was 156.6±1.02 μm and 127.03±1.13 μm, respectively.

Immunohistochemical studies of caecal tonsils helped establish the localization and number of lymphocytes with $CD4^+$, $CD8^+$, $CD45RA^+$ and $CD20^+$ differentiation clusters in the structural elements of the organ, which directly depended on the age of the poultry and the frequency of vaccination. Thus, by the age of 20 days, T-lymphocytes with surface markers $CD4^+$ (T-helpers), $CD8^+$ (cytotoxic cells) dominated over mature B-lymphocytes ($CD20^+$).

In vaccinated chickens aged 40 and 90 days, there was a considerable dominance of cytotoxic cells over T-helper cells. Therefore, in the 40-day age of experimental chickens, the number of CD8+ lymphocytes in caecal tonsils was 69.83±1.11 units, and $CD4^+$ lymphocytes – 46.72±0.94 units. As a result, this was reflected in a decrease in the immunoregulatory index of the organ, which in this age period had the lowest indicators and amounted to 0.67.

As the analysis of the immunocytomorphometric study showed, a significant increase in mature B-lymphocytes ($CD20^+$) and naïve T-helpers, B-lymphocytes, and monocytes ($CD45RA^+$) was noted in vaccinated chickens aged 40, 90 and 110 days, both in relation to the previous age groups and to control group. Thus, in control chickens aged 90 days, the number of lymphocytes with the surface marker CD20+ was 93.44±6.48 units, while in vaccinated chickens this indicator reached 128.33±3.79 units. It follows from this that stimulation of the immune system through vaccines affects the growth of mature B cells, and the increase in the number of CD45RA+ can indicate the presence of an active immune response in the body of the poultry.

In the future, it is planned to conduct a histochemical study of the immune defence organs of chickens for comparative characterization of morphological features.

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CONFLICT OF INTEREST

None.

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Вплив вакцини проти інфекційного бронхіту курей на морфогенез та диференціацію лімфоїдних клітин сліпокишкових мигдаликів

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Анотація. Вивчення морфофункціонального стану органів імунної системи курей дає можливість оцінити критичні періоди їх розвитку та організму в цілому, а також ефективність методів вакцинопрофілактики. Метою дослідження було виявлення морфологічних та імуногістохімічних змін сліпокишкових мигдаликів курей 8, 20, 40, 90, 110-добового віку за вакцинопрофілактики інфекційного бронхіту. В ході роботи використано методи дослідження: цито-, гістологічні, імуногістохімічні, морфометричні, світлооптичні, статистичні. Проаналізовано та досліджено гістологічні препарати сліпокишкових мигдаликів птиці віком 8, 20, 40, 90, 110 діб вакцинованої та невакцинованої групи. До 20-добового віку курей, як вакцинованої, так і невакцинованої групи, лімфоїдних вузликів в ділянці сліпокишкових мигдаликів не виявлено. Було проведено гістологічні та морфометричні дослідження, які показали, що вакцинація птиці прискорює розвиток лімфоїдних утворень на ранніх етапах постнатального періоду онтогенезу, особливо у курей 20-добового віку, що проявляється збільшенням кількості та розмірів лімфоїдних вузликів сліпокишкових мидаликів стосовно контролю. Імуногістохімічними дослідженнями було встановлено, що розміщення та скупчення Т-лімфоцитів з маркерами $CD4^{+,}$ $CD8^{+}$, а також В-лімфоцитів ($CD20^{+}$) та клітин-$CD45RA^{+}$ у сліпокишкових мигдаликах, а саме у лімфоїдних вузликах та дифузному скупченні лімфоїдних клітин залежать від віку курей та кратності вакцинації. Було доведено, що у курей 8-добового віку переважала кількість субпопуляцій Т-лімфоцитів з поверхневими маркерами $CD4^{+,}$ $CD8^{+}$ над $CD45RA^{+}$ та $CD20^{+}$. Із зростанням кількості проведених імунізацій (після трьохкратної вакцинації проти інфекційного бронхіту курей) імуноцитометричними дослідженнями показано, що у вакцинованих курей віком 40 та 90 діб відбулось чітке зростання кількості зрілих В-лімфоцитів у 1,58 та 1,37 рази відповідно. Зважаючи на те, що у вакцинованих курей 40-добового віку кількість $CD8^{+}$-лімфоцитів переважала у 1,49 рази за кількість $CD4^{+}$-клітин, це призвело до різкого зниження імунорегуляторного індексу сліпокишкових мигдаликів, що необхідно враховувати при проведенні профілактичних щеплень

Ключові слова: птиця; гістологічні зміни; лімфоїдні утворення; Т-лімфоцити; В-лімфоцити; вакцинопрофілактика

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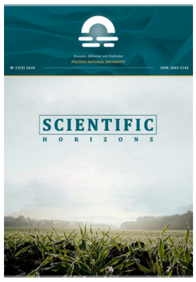

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Creation of potato hybrids (*Solanum tuberosum*) progeny with high field resistance against phytophotorosis

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Abstract. The creation of new potato varieties with prominent economically valuable properties and comprehensive resistance against the most common diseases is one of the main areas of crop breeding at present. First of all, this is due to the possibility of increasing the gross production of potatoes, improving its economic performance, as well as the tasks of protecting the environment from pesticide pollution, which contributes to a substantial improvement in the environment and obtaining environmentally safe products. The purpose of this study was to identify varieties with a prominent level

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of yield and resistance against potato blight in the western region of Ukraine. The study was conducted using field (assessment of disease development), laboratory, analytical, and mathematical and statistical methods. The paper provides a theoretical substantiation and a new solution to the important scientific task of establishing the specific features of the use of Ukrainian and foreign varieties, intervarietal and multispecies hybrids by parental forms in potato breeding. The study summarized the features of the manifestation of productivity components, quality traits, resistance to potato blight, correlations between economic and valuable traits, selection of new parent forms for intervarietal and interspecies hybridization, nature of high productivity, quality and potato blight resistance of breeding material, and created genetically valuable varieties with great value in potato selection and for agricultural production of Ukraine. Based on this, the possibility and effectiveness of the combination of the transfer of traits to the offspring and their inheritance was proven, which will expand the existing base of initial breeding material for further work on the creation of promising potato varieties of different maturity groups with highly valuable economic traits

Keywords: potato; variety; intersort and interspecific hybrid; descendant; productivity; potato blight; correlation

INTRODUCTION

Different components of the potato gene pool have different adaptive potential, especially those controlled by dominant genes, which are often highly efficient and highly expressed rather than polygenic. This results in different properties that are important for the farm (especially for different varieties), depending on the growing conditions and pathogenic pressure. Therefore, the expressiveness of economically valuable properties in potatoes, samples of cultivated and wild species should be investigated in conditions that are as close as possible to the growing conditions of varieties created based on the gene pool. This is the second stage of working with the gene pool after its introduction. One of the main requirements for the creation and introduction of new competitive potato varieties in modern production is not only their high productivity, but also their resistance to major diseases and pests.

The real prospect of creating potato blight resistant potato varieties becomes possible by introducing the Mexican hexaploid species *S. demissum* into the crossing combination, as the one that carries the main genes of hypersensitivity, while providing full protection of backcross hybrids of *S. demissum* × *ssp. tuberosum*, but only in the first years of their cultivation. Under the pressure of hypersensitivity genes included in the created hybrids, the causative agent of the disease begins to form its new races. Research (Hnitetskyi, 2021) found severe damage to hybrids created with the participation of *S. demissum*, which were previously considered resistant.

Numerous studies (Gryń *et al.*, 2019) led to the creation of an international gene-for-gene system, within which the dominant R-genes of the host plant correspond to certain pathogen virulence genes, and 11 R-genes are known. A potato variety with R-genes or a combination of them stays stable until a common race appears.

However, potato breeding for hypersensitivity did not solve the problem of potato blight. Research (Pánková *et al.*, 2019) indicated that the presence of the R-gene or a combination of both in the genotype of the variety stimulates the selection of suitable fungal races. Their insufficient role becomes noticeable when comparing the degree of resistance of varieties with and without R-genes. Thus, 64% of varieties with R-genes are assigned to the group with a score from 1 point (high) to 5 (medium). The same group includes almost the same number of varieties (62%) without R-genes.

In this regard, increasingly more attention has been paid to field sustainability in recent years. The authors (Whitworth *et al.*, 2019) showed that field resistance is the result of several protective mechanisms: a long incubation period, slow spread of infection on the plant, and reduced sporulation. In plants with high field resistance, damage occurs much later and occurs more slowly; sporulation of the fungus is inhibited. This type of resistance equally protects against all races of potato blight; however, as the disease develops, plants begin to be affected with varying intensity.

Apart from the resistance of potatoes to potato blight, tuber resistance is of great importance, especially recently. As with tops, selection for tuber resistance is based on field resistance, which is controlled by small genes. Inheritance of tuber resistance in the field was studied by (Kelling *et al.*, 2019). Thus, in the offspring from the crossing of resistant original forms, almost all F_1 hybrids had resistant or mildly affected tubers. When crossing resistant and susceptible forms, a small number of hybrids with susceptible tubers were found, but the main part belonged to resistant ones. Crossing of susceptible forms resulted in hatching only single genotypes that were highly resistant to tubers.

Studies (Furdyga, 2022) found that the proportion of highly resistant backcrosses valuable for breeding based on these characteristics was 16.9% and 86.3%, respectively. Analysis of the origin of backcrosses of interspecific hybrids created based on wild species (*S. acaule, S. bulbocastanum, S. phureja, S. demissum, S.andigenum*) established the resistance of hybrids against ring rot, and the sources of resistance to *Ditylenchus destructor Thorne* are wild species *S. acaule, S. andigenum, S. Demissum*.

Tubers of potato varieties should be well stored in the autumn-winter period. It is known that potato blight and fusarium dry rot are among the most harmful and common potato diseases in this period. It is caused by soil fungi of the following species *Fusarium sp.* which are assigned to the *Tuberculariase* genus. They are wound parasites. Fungi penetrate only into tubers injured mechanically and by soil pests. The disease is common wherever potatoes are grown. In terms of harmfulness, it is second only to potato blight (Methodological…, 2018).

Numerous researchers (Díaz *et al*., 2018; Bomok, 2019; Tilahun & Israel, 2021) note that losses from potato blight and dry fusarium rot when grown under optimal conditions can amount to 7.0-23.7%, at elevated temperature and humidity – up to 50%. Apart from losses caused by rotting tubers during storage, potato blight and dry fusarium rot cause a decrease in yield during the growing season. Damage to seed tubers largely leads to crop shortages (up to 26.6%).

Researchers (Sydorchuk *et al*., 2018) state that there are two types of resistance to potato blight: hypersensitivity (vertical or specific) and field (horizontal or general) resistance. Genotypes with hypersensitivity are characterized by a necrotic reaction of infected and neighbouring cells. Plant hypersensitivity is caused by the action of the main independent genes, each of which is activated by a specific race of the fungus. Field resistance is a complex of certain factors that prevent damage to a plant by a pathogen, and its inheritance occurs due to the action of small genes. Both types of resistance appear together in wild potato species *S. demissum*, *S. bulbocastanum*, *S. poliadenium*, *S. stoloniferum*, *S. vernei*, *S. verrucosum*, while non-hybridized pure forms of *S. tuberosum* have only small field resistance genes.

The main purpose of this study was to identify plant varieties that are characterized by a prominent level of yield and resistance to potato blight in the western region of Ukraine.

MATERIALS AND METHODS

Breeding experiments were carried out on the fields of the 4-field crop rotation of the crop selection department of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences in the village of Obroshyne, Lviv district, Lviv region. The predecessor of potatoes was winter cereals, with post-harvest sowing of green manure crops.

The study investigated varieties that were included in the State Register of Plant Varieties (State register…, 2020) and hybrids created based on simple and complex intervarietal crossings and hybrids created based on species: 88.1450 c.2 – with the participation of the species *S. acaule*, *S. bulbocastanum*, *S. phureja*, *S. andigenum*, Aureliia variety; 81.386 c.4 – ((*S. acaule* × *S. bulbocastanum*) × *S. phureja*) × (*S. demissum* × *S. andigenum*); 91.765/15 – with the participation of the species *S. acaule*, *S. bulbocastanum*, *S. phureja*, *S. demissum*, Marko and Volovetska varieties; 90.841 c.2 – with the participation of the species *S. acaule, S. bulbocastanum, S. phureja, S. demissum, S. andigenum*, varieties Poliska rozheva, Lvivianka, Gidra, Gitte; 89.721 c.23 – with the participation of the species *S. demissum, S. bulbocastanum, S. andigenum*, Biloruska 3 variety; 90.674/12 – with the participation of the species *S. acaule, S. bulbocastanum, S. phureja, S. demissum*, Marko and Volovetska varieties; 86.563 c.4 – with the participation of the species *S. acaule, S. bulbocastanum, S. phureja, S. demissum*, varieties Poliska rozheva, Hibrydna 14, Gitte.

Involvement in the breeding work of various raw materials, namely, both cultural varieties and hybrids of interspecies origin, helps create potato varieties with prominent economic value and resistance to various diseases.

S. acaule (2n=48) is self-fertile. Samples of this species have complex resistance to viruses x (extreme), *S, L, Y*, cancer pathotypes, potato nematode (*G. rostochiensis* and *G. pallida*), frost, common scab, oosporosis, alternariosis, ring and brown rot. Tubers contain up to 23% starch and up to 2.8% protein. Easily crossed with wild species and varieties.

S. bulbocastanum (2n=24). Its samples are characterized by high resistance against potato blight, relative resistance against Alternaria, blackleg, potato nematode, rhizoctoniosis, Colorado potato beetle, *X* and *Y* viruses (29, 30, 31).

S. phureja (2p=24). Samples of this species are distinguished by their resistance to potato cancer, Alternaria, scab, black leg, rhizoctoniosis, ring rot, viruses *X, S, M, Y, A, L*, aphids, and nematodes. It has a high content of dry matter and protein.

S. andigenum (2n=48) is self-fertile. Individual specimens of the species are characterized by extreme resistance to viruses *X, Y* and *A*, hypersensitivity and field resistance to potato blight, resistance to potato cancer, common scab, blackleg, alternariosis, potato and stem nematodes, Colorado potato beetle.

S. demissum (2n=72) is self-fertile. Its samples are resistant to viruses *Y* and *L*, characterized by hypersensitivity and field resistance of 290 against potato blight, resistance to cancer pathotypes, potato nematode (species *G. rostochiensis* and *G. pallida*), Colorado beetle and frost, common scab, ring rot, etc. Tubers of individual samples have a high content of starch (22-33%) and protein (2.5-5.4%). It is easily crossed with other species and breeding varieties.

The study was conducted according to generally accepted methods in potato growing (Sygareva, 1986; Kutsenko *et al*., 2002; Trybel & Bondarchuk, 2013; Bondarchuk & Koltunov, 2019), experimental data were processed on a computer using the Microsoft Excel program and methods of (Ehrmantraut, 2018).

RESULTS AND DISCUSSION

The correct selection of parent pairs for hybridization is of crucial importance in the selection for potato blight resistance of potatoes. For this, it is necessary to factor in the degree of resistance against potato blight in particular climatic conditions and the combinational ability for this feature. Comparison of field resistance against potato blight of parent pairs and offspring obtained as a result of crossing, combinations were identified that, both in terms of the average value and the number of hybrids, had different degrees of plant damage by potato blight (Table 1).

Table 1. *The influence of parental forms on the resistance of offspring, obtained based on simple intervarietal crossings, against potato blight*

Combinations of crosses	Resistance of parent forms against potato blight, points			Resistance of offspring against potato blight M±**m**	Correlation coefficient between resistance of parent forms and offspring against potato blight, r	Distribution of genotypes (%) by potato blight resistance classes, score			
	♀	♂	average M±**m**			1-2	3-4	5-7	8-9
Arkhideia x Zakhidna	6.0	7.0	6.5±**0.22**	6.4±**0.43**	-0.026	0	35.7	64.0	0.3
Leleka x Alpinist	5.5	9.0	7.2±**0.74**	8.5±**0.27**	+0.876	0	39.0	50.3	10.7
Alpinist x Teteriv	9.0	8.5	8.7±**0.16**	8.9±**0.23**	+0.781	0	31.4	67.2	1.4
Bahriana x Teteriv	8.5	6.0	7.2±**0.52**	7.3±**0.30**	+0.457	0	46.3	53.2	0.5
Brihantina x Teteriv	6.0	8.5	7.2±**0.16**	7.8±**0.28**	+0.771	0	25.9	72.8	1.3
Teteriv x Bahriana	6.0	8.5	7.2±**0.54**	6.6±**0.42**	-0.703	0	31.0	68.5	0.5
Teteriv x Krynytsia	8.5	7.5	8.0±**0.20**	8.4±**0.21**	+0.486	0	23.0	75.6	1.4
Slava x Pamir	7.5	5.0	6.2±**0.56**	7.5±**0.23**	+0.899	0	31.3	64.9	3.8
Luhovska x Kristal	7.0	5.6	6.3±**0.34**	7.1±**0.24**	+0.580	0	23.8	63.6	12.6

Source: *compiled by the author*

The combinations Alpinist x Teteriv, Leleka x Alpinist, and Teteriv x Krynytsia were the best in terms of resistance to this disease in simple intervarietal crossings. On average, the resistance of parental pairs against potato blight in these combinations was 8.7, 7.2, and 8.0 points, respectively, and in offspring – in the same combinations: 8.9, 8.5, and 8.4 points. The resistance of the offspring to potato blight was associated with the degree of manifestation of this trait in the parent forms.

The correlation between resistance of parent pairs and offspring to potato blight, depending on the combination of crossing, was weak negative, medium, and high positive. A high positive correlation coefficient was noted in the hybrid populations of Leleka × Alpinist, Alpinist × Teteriv, Brihantina x Teteriv, and Slava × Pamir – r=+0.771-+0.899. There was a weak negative correlation coefficient in only one population – Arkhideia x Zakhidna – r=-0.026.

The average percentage of genotypes obtained by simple intervarietal crossings in 9 populations in the resistance class of 3-4 points was 31.9%; 5-7 points – 64.5%, and 8-9 points – 3.6%. The largest number of offspring hybrids – from 50.3% to 75.6% – had a resistance score of 5-7, from 0.5% to 12.6% – 8-9 points, and none of the populations had low resistance to potato blight (1-2 points). We believe that the high field resistance against potato blight of the offspring of the combinations Leleka × Alpinist, Alpinist × Teteriv, Brihantina × Teteriv, Teteriv × Krynytsia is because in the pedigree of one of the parental forms, there were disease-resistant relatives of cultural varieties.

The potato blight resistance of offspring, created by crossing complex intervarietal hybrids, primarily depended on the selection of parental pairs for hybridization. Therewith, both the paternal and maternal forms played an important role. Two previously created hybrids, Sagitta × (Maritta × Igor) and Volovetska × Pamir were used as the maternal form, and Petland Scwajer, Zakhidna, Rakurs, Lybid, Suzorie and Vytok varieties were used as the parental form. The most effective combinations for resistance against potato blight were (Volovets × Pamir) × turn and (Volovets × Pamir) × Suzorie. The average resistance against potato blight in the offspring of these populations was 8.9 and 8.8 points, respectively (Table 2).

Table 2. *Influence of parental forms on the resistance of offspring to potato blight, obtained based on complex intervarietal crosses*

Combinations of crosses	Resistance of parental forms against potato blight, points			Resistance of offspring against potato blight M±**m**	Correlation coefficient between resistance of parental forms and offspring to potato blight, r	Distribution of genotypes (%) by potato blight resistance classes, score			
	♀	♂	average M±**m**			1-2	3-4	5-7	8-9
Sagitta × (Maritta × Igor) × Petland Scwajer	8.0	5.0	6.5±**0.62**	6.8±**0.27**	+0.190	1.2	18.4	75.2	5.2

Table 2, Continued

Combinations of crosses	Resistance of parental forms against potato blight, points			Resistance of offspring against potato blight M±m	Correlation coefficient between resistance of parental forms and offspring to potato blight, r	Distribution of genotypes (%) by potato blight resistance classes, score			
	♀	♂	average M±**m**			1-2	3-4	5-7	8-9
Sagitta × (Maritta × Igor) × Zakhidna	8.0	7.0	7.5±**0.21**	7.9±**0.22**	+0.483	0	21.9	64.4	13.7
Sagitta × (Maritta × Igor) × (Komsomolets × X Naroch)	8.0	7.0	7.5±**0.32**	7.8±**0.21**	+0.361	0	7.5	70.2	22.3
Sagitta × (Maritta × Igor) × Rakurs	8.0	8.5	8.2±**0.15**	8.5±**0.20**	+0.560	0	3.9	61.6	34.5
(Volovetska × Pamir) × Lybid	8.5	7.5	8.0±**0.27**	8.4±**0.22**	+0.638	0	12.4	49.6	38.0
(Volovetska × Pamir) × Suzorie	8.5	8.7	8.6±**0.10**	8.8±**0.12**	+0.189	0	12.7	18.6	68.7
(Volovetska × Pamir) × Vytok	8.5	8.9	8.7±**0.11**	8.9±**0.24**	+0.803	1.8	16.8	38.9	42.5

***Source**: compiled by the author*

Correlation dependence between resistance of parental forms and offspring to potato blight was positive and high in the population (Volovetska × Pamir) × Vytok (r=+0.803), positive and medium – in combinations (Volovetska × Pamir) × Lybid, Sagitta × (Maritta × Igor) × Rakurs (r=+0.560–+0.638), positive and weak – Sagitta × (Maritta × Igor) × Petland Scwajer, (Volovetska × Pamir) × Suzorie and Sagitta × (Maritta × Igor) × (Komsomolets × Naroch) – r=+0.189–+0.361.

The distribution of genotypes according to potato blight resistance classes indicated that 1.2-1.8% of hybrids of the two combinations were characterized by low (1-2 points) resistance against potato blight. The percentage of genotypes with resistance of 3-4 points was 13.4%, 5-7 points – 54.1%, 8-9 points – 32.0% on average across populations.

The combinations (Volovetska × Pamir) × Suzorie, (Volovetska × Pamir) × Vytok were characterized by the highest (8-9 points) resistance to potato blight and the largest (from 38.0% to 68.7%) number of genotypes in the class of 8-9 points, (Volovetska × Pamir) × Lybid.

Analysing the influence of parental forms on the resistance of offspring against potato blight, obtained from backcrossing of complex interspecific hybrids, it was noted that the main part of the source material that was included in hybridization, except for interspecific hybrids 90.841 c.21 and 88.1450 c.2, 86.563 c.4 and variety Lybid was characterized by average resistance against potato blight.

In terms of the resistance of offspring against late blight, obtained based on backcrossing of complex interspecies hybrids, where the second parental form was the Lybid variety, only two populations stood out, the average resistance of hybrids against potato blight in which was 8.8 and 8.5 points. The correlation coefficient between the stability of parental forms and offspring was weak and on average positive (r=+0.253–+0.566). When backcrossing complex interspecific hybrids, 0.7% to 9.4% of genotypes had low resistance against potato blight (1-2 points). The largest (53.3%) percent on average for populations was occupied by genotypes in the resistance class of 5-7 points and 15.6% – in the resistance class of 8-9 points (Table 3).

***Table 3.** Influence of parental forms on the resistance of the offspring obtained by backcrossing complex interspecific hybrids against potato blight*

Combinations of crosses	Resistance of parental forms against potato blight, points			Resistance of offspring to potato blight M±m	Correlation coefficient between resistance of parental forms and offspring to potato blight, r	Distribution of genotypes (%) by potato blight resistance classes, score			
	♀	♂	average M±**m**			1-2	3-4	5-7	8-9
88.1450 c.2 × Chernihivska early	8.0	5.0	6.5±**0.62**	8.2±**0.32**	+ 0.868	1.5	2.5	65.6	30.4
Chernihivska early × 89.721 c.23	5.0	7.0	6.0±**0.55**	6.4±**0.31**	+ 0.367	7.8	50.7	39.3	2.2
Chernihivska early × 90.674/12	5.0	8.0	6.5±**0.61**	7.6±**0.32**	+ 0.598	0.7	40.0	57.0	2.3
Lybid × 90.841 c. 21	7.5	9.0	8.2±**0.31**	8.8±**0.33**	+ 0.566	0	28.4	46.9	24.7
91.765/15 × Lybid	7.5	7.5	7.5±**0.12**	7.7±**0.35**	+ 0.253	9.4	45.8	40.3	4.5
Lybid × 88.1450 c.2	7.5	8.5	8.0±**0.22**	8.5±**0.21**	+ 0.538	0	17.0	59.4	23.6
86.563 c.4 × Lybid	8.5	7.5	8.0±**0.32**	8.6±**0.20**	+ 0.416	1.7	12.4	64.6	21.3

***Source**: compiled by the author*

The manifestation of field resistance against potato blight in the offspring depended on the origin of the potato source material based on which the crossing was carried out. The largest (32.1%) number of hybrids with resistance to potato blight (8-9 points) was obtained in populations when crossing complex intervarietal hybrids, while based on simple intervarietal crossings – only 3.6% and upon backcrossing complex interspecific hybrids – 15.6%, which indicates the possibility of obtaining breeding material resistant to potato blight when parental forms use source material of different origins and different types of crossing. It should be noted that saturating crosses played a role in the effectiveness of intervarietal crossings for obtaining potato blight resistant offspring. Data on the relationship between the resistance of the vegetative mass against potato blight and productivity are presented in Table 4.

Table 4. *Relationship between the resistance of vegetative mass against potato blight and the productivity of offspring of different origins*

Combinations of crosses	Resistance of offspring to potato blight, points M±**m**	Productivity of hybrid populations, g/bush M±**m**	Correlation coefficient between productivity and resistance to potato blight, r
Simple intervarietal crosses			
Archideia × Zakhidna	6.4±**0.43**	524±**29**	-0.116
Leleka × Alpinist	8.5±**0.27**	929±**47**	-0.556
Alpinist × Teteriv	8.9±**0.23**	1,067±**29**	+0.810
Bahriana × Teteriv	7.3±**0.30**	553±**27**	+0.351
Brihantina × Teteriv	7.8±**0.28**	967±**10**	+0.532
Teteriv × Bahriana	6.6±**0.42**	659±**19**	-0.688
Teteriv × Krynytsia	8.4±**0.21**	598±**14**	+0.643
Slava × Pamir	7.5±**0.23**	1,203±**10**	+0.403
Luhovska × Kristal	7.1±**0.24**	1,058±**27**	+0.764
Complex intersort crosses			
Sagitta × (Maritta × Igor) × Petland Scwajer	6.8±**0.27**	433±**48**	-0.196
Sagitta × (Maritta × Igor) × Zakhidna	7.9±**0.22**	565±**11.6**	-0.106
Sagitta × (Maritta × Igor) × (Komsomolets × X Naroch)	7.8±**0.21**	877±**25**	+0.924
Sagitta × (Maritta × Igor) × Rakurs	8.5±**0.20**	695±**48**	-0.538
(Volovetska × Pamir) × Lybid	8.4±**0.22**	622±**39**	-0.254
(Volovetska × Pamir) × Suzorie	8.8±**0.12**	897±**28**	+0.215
(Volovetska × Pamir) × Vytok	8.9±**0.24**	1,026±**25**	+0.670
Backcrossing complex interspecific hybrids			
88.1450 c.2 × Chernihivska early	8.2±**0.32**	676±**28**	+0.768
Chernihivska early × 89.721 c.23	6.4±**0.31**	596±**11**	+0.265
Chernihivska early × 90.674/12	7.6±**0.32**	457±**29**	+0.464
Lybid × 90.841 c. 21	8.8±**0.33**	569±**32**	-0.705
91.765/15 × Lybid	7.7±**0.35**	504±**16**	-0.088
Lybid × 88.1450 c.2	8.5±**0.21**	903±**35**	+0.296
86.563 c.4 × Lybid	8.6±**0.20**	700±**23**	+0.232

Source*: compiled by the author*

The established correlation coefficients between the resistance of vegetative mass to potato blight and productivity indicate independent inheritance of these traits. With different types of crossings used in this study, the correlation coefficients primarily depended on the selection of parental pairs. A high positive correlation between the resistance of the vegetative mass to potato blight and the productivity of offspring was found in combinations involving starting material of different origins in hybridization. Specifically, upon crossing the following varieties: Alpinist × Teteriv, Luhovska × Kristal, Teteriv × Krynitsia, correlation coefficients were r=+0.643-+0.810, complex intervarietal hybrids: Sagitta × (Maritta × Igor) × (Komsomolets × Naroch), (Volovetska × Pamir) × Vytok – r = +0.670-0.924, and complex interspecific hybrid 88.1450 c.2 × Chernihivska early – r=+0.768. In the remaining populations, the relationship between potato blight resistance and productivity was weak, moderately positive, the correlation coefficient was from r=+0.215 to r=+0.532, and weak and moderately negative, the correlation coefficient was from r=-0.088 to r=-0.705.

The largest number of genotypes with high resistance to potato blight (8-9 points) was obtained based on complex intervarietal crossings (32.1%), when backcrossing complex interspecific hybrids (15.6%). The absence of a correlation between potato blight resistance and productivity in a number of combinations indicates independent inheritance and the possibility of combining high indicators of these traits.

Combinations were found in the offspring that combine high resistance against potato blight (7.1-8.9 points) with high productivity (700-1203 g/bush). These include Alpinist × Teteriv, Leleka × Alpinist, Slava × Pamir, Luhovska × Kristal, Sagitta × (Maritta × Igor) × (Komsomolets × Naroch), (Volovetska × Pamir) × Suzorie, (Volovetska × Pamir) × Vytok, Lybid × 88.1450 c.2. Thus, the manifestation of productivity in offspring of different origins depended on the parent pairs and was divided into types: intermediate, heterosism, and depression.

To obtain breeding material with a yield of up to 1,000 g/bush, promising combinations are Leleka × Alpinist, Alpinist × Teteriv, Brihantina × Teteriv, Slava × Pamir, Luhovska × Kristal, Sagitta × (Maritta × Igor) × (Komsomolets × Naroch), (Volovetska × Pamir) × Suzorie, (Volovetska × Pamir) × Vytok, Lybid × 88.1450 c.2. The productivity of offspring created from simple intervarietal crossings was 524 to 1,203 g/bush and exceeded the parental forms by 16.5%, from complex intervarietal crossings – from 433 to 1,026 g/bush, or by 17.6%, from backcrossing of complex interspecific hybrids – 457-903 g/bush, or by 27.2%.

Analysis of the distribution of hybrids by performance classes showed that the percentage of highly productive hybrids primarily depends on the selection of parent pairs and the origin of the source material used in hybridization. In simple intervarietal crossings, the highest percentage (42.0) of offspring with a yield of up to 1,000 g/bush was obtained in the combination of Leleka × Alpinist, in complex intervarietal crossings (45-58%) – in combinations (Volovetska × Pamir) × Vytok, (Volovetska × Pamir) × Suzorie and Sagitta × (Maritta × Igor) × (Komsomolets × Naroch), when backcrossing complex interspecies hybrids (50%) – in combination Lybid × 88.1450 c.2.

The highest average weight of tubers was obtained from simple intervarietal crossings of 101-125 g, the lowest – 48-72 g – from backcrossing of complex interspecific hybrids. The identified combinations that are promising for obtaining high-yielding offspring (700-1,203 g/bush) together with high resistance to potato blight (7.8-8.9 points) are Alpinist × Teteriv, Slava × Pamir, Luhovska × Kristal, Sagitta × (Maritta × Igor) × (Komsomolets × Naroch), (Volovetska x Pamir) × Suzorie, (Volovetska × Pamir) × Vytok, Lybid × 88.1450 p.2.

It was established (Borodai & Parthenyuk, 2018) that potato blight, alternariasis, rhizoctoniosis, bacteriosis, and viral diseases dominate potato plants during the growing season. The share of areas affected by them varied between 6.1-91.5%, and in some regions it reached 100%. The proportion of plants affected by potato blight, alternariasis, and fomosis was 30.0-67.8%, and the development of diseases — 2.1-42.3%. The prevalence and development of other diseases varied within 0.2-5.2 and 0.1-2.1%, respectively.

Scientists (Nevmerzhitska *et al.*, 2019) conducted experiments on the isolation and identification of the species composition of phytopathogens from tubers affected by fusariosis, studying the yield of potato varieties of different maturity groups depending on fusariosis damage during 2019-2020 at PE "Zherm" of Chernyakhiv district of Zhytomyr region and in laboratories of the department of plant protection of the Polish National University. It was found that considerable yield losses were observed in the susceptible temp variety in the variant where potato tubers affected by fusarium rot were used as planting material. Thus, on average, over the years of research from dry fusarium rot, crop losses reached up to 5 t/ha, which is almost 37%. Relatively resistant varieties (Povin, Mavka) also had crop losses, but they did not exceed 4 t/ha. The damage to the planting material by fungi of the genus *Fusarium* had less effect on the productivity of the Povin variety because its yield losses did not exceed 3.7 t/ha, which was only 18.1% compared to the control.

According to V. Martynenko (2016), based on research carried out at the Educational Scientific Production Centre of the V.V. Dokuchaev Kharkiv National Agrarian University resistance to potato blight, based on the study of varieties of the world assortment, it was found that about 40-45% of them are distinguished by field resistance to a certain degree, and the vast majority of them are intervarietal hybrids, where the parent original forms have a sufficiently high resistance score against potato blight.

The analysis of research carried out by scientists made it possible to involve in crossbreeding some potato varieties that stood out with high points of resistance to such harmful diseases as potato blight and fusariosis, namely Slava, Teteriv, Krynytsia, Bahriana, Zakhidna, Luhovska, etc. Some varieties included in the crossbreeding combination were created by breeders of the Institute of Agriculture of the Carpathian Region and the Lviv National University of Nature Management, i.e., in the western region, which is characterized by frequent epiphytotia of a disease such as potato blight, and therefore the hybrid offspring obtained from the crossbreeding was characterized by high resistance scores against potato blight (from 6.6 points) in combination with high productivity (over 500 g/bush).

Some breeding scientists (Kravchenko *et al.*, 2019) claim that the resistance against potato blight of the resulting hybrid generation results in the formation of certain economic traits and culinary parameters in the latter. An increase in the resistance score against potato blight leads to an improvement in these signs.

Scientists (Podhaietskyi *et al*., 2019) revealed the specific effect of crossbreeding components on the germination of hybrid seeds for 5-9 days and the subsequent resistance of plants against potato blight damage. The best results were obtained among seeds with the origin of 86.96s32 × *S. andigenum* – 28.3%. They were quite high in three other populations of this species. The exception was the use of the maternal form of the six-species double backcross hybrid 89.721s81 – 9.2%. In 54.1% of combinations, laboratory seed germination was 90% or more, with the maximum manifestation of Shchedryk × Podoliia hybrid seeds – 96.8%. In another population involving the mentioned maternal form, high results were also obtained – 95.4%.

The obtained research results indicate that carrying out both simple and complex intervarietal crossings, as well as backcrossing of complex interspecific hybrids created involving the species *S. acaule, S. bulbocastanum, S. phureja, S. demissum, S. andigenum* and cultural varieties helps obtain hybrid offspring with high parameters of resistance to potato blight (6.6-8.9 points) with economic and valuable indicators (bush productivity – 457-1,203 g).

The difficulties that scientists face when breeding potatoes for resistance to one of the most harmful diseases – potato blight, and especially when highly virulent and aggressive races of the fungus appear, and the subsequent creation of varieties with high resistance can be overcome, and the selection itself is well-achievable. But for this, it is necessary to constantly replenish the arsenal of breeders with a variety of source material with effective genetic control of this trait and to improve its evaluation methods in relation to the soil and climatic conditions of breeding work.

CONCLUSIONS

The difficulty of involving relatives of cultural varieties in practical selection is based on the specificity of carrying out research on the creation of initial selection material on an interspecies basis, the duration of the process of obtaining primary and secondary interspecies hybrids, their backcrosses, and therefore, the practical absence of the possibility of combining this and the selection area of research in one structural subdivision. The promising use of backcrosses of three- and four-species and, especially, six-species hybrids in breeding practice was proven. According to the methods of creation, they can be backcrosses, offspring from self-pollination, or from crossing hybrids with each other. The high adaptive potential of interspecies hybrid varieties, created from the original selection material according to certain agronomic characteristics, was established.

The nature of the inheritance of resistance to potato blight by offspring was established, and the possibility of combining high indicators of resistance to potato blight and productivity was proven.

Combinations were identified, which are promising for obtaining high-yielding offspring (700-1,203 g/bush) in combination with high resistance to potato blight (7.1-8.9 points): Alpinist × Teteriv, Leleka × Alpinist, Slava × Pamir, Luhovska × Kristal, Sagitta × (Maritta × Igoer) × (Komsomolets x Naroch), (Volovetska × Pamir) × Suzorie, (Volovetska × Pamir) × Vytok, Lybid × 88.1450 c.2.

Using different types of crossings based on complex interspecies and intervarietal hybrids, varieties of Ukrainian and foreign selection, a new genetically diverse selection material was created with a productivity exceeding 1,000 g/bush, a starch content of more than 20.0%, resistance to potato blight of 8.0-9.0 points, high in crude protein, protein, amino acids, vitamin C, low in reducing sugars and nitrates.

Therefore, one of the main factors of breeding work with potato culture in different agro-climatic zones of Ukraine is a sufficient amount of newly created highly productive hybrid material, which enables the breeder to select the best samples with high economic and valuable indicators for further work on the creation of new potato varieties.

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CONFLICT OF INTEREST

None.

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Створення потомства гібридів картоплі (*Solanum tuberosum*) з високою польовою стійкістю проти фітофторозу

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Анотація. Створення нових сортів картоплі з високими господарсько цінними властивостями та комплексною стійкістю проти найбільш поширених хвороб є одним з основних напрямів селекції сільськогосподарських культур на даний час. Насамперед це пов'язано із можливістю збільшення валового виробництва картоплі, покращенню її господарських показників, а також завданнями охорони навколишнього середовища від забруднення пестицидами, що сприяє суттєвому покращенню навколишнього середовища і отриманню екологічно безпечної продукції. Метою цього дослідження було виділити сортозразки з високим рівнем урожайності та стійкості проти фітофторозу в умовах західного регіону України. Дослідження проведено з використанням польових (оцінка розвитку хвороб), лабораторних, аналітичних і математично-статистичних методів. Наведено теоретичне обґрунтування і нове вирішення важливого наукового завдання встановлення особливостей використання батьківськими формами вітчизняних і зарубіжних сортів, міжсортових та багатовидових гібридів в селекції картоплі. Узагальнено особливості прояву складових продуктивності, якісних ознак, стійкості проти фітофторозу, кореляційних зв'язків між господарстько-цінними ознаками, підбору нових батьківських форм для міжсортової та міжвидової гібридизації, характеру високої продуктивності, якості і фітофторостійкості селекційного матеріалу та створено генетично цінні сорти, що має велике значення в селекції картоплі та для сільськогосподарського виробництва України. На основі цього доведено можливість і ефективність поєднання передачі ознак потомству та їх успадкування, що розширить наявну базу вихідного селекційного матеріалу для подальшої роботи щодо створення перспективних сортів картоплі різних групп стиглості з високо-цінними господарськими ознаками

Ключові слова: картопля; сорт; міжсортовий та міжвидовий гібрид; нащадок; продуктивність; фітофтороз; кореляція

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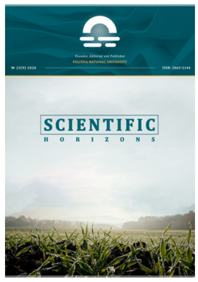

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Forage productivity of combined crops of seed oats, maize, and Sudanese sorghum with white lupine

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Abstract. Research aimed at the accumulation and effective use of nitrogen, its symbiotic fixation from the air by white lupine plants, by selecting the best cereal components, optimizing their ratio and methods of placement when growing in compatible crops under different fertilization systems in the Forest Steppe is insufficient. The purpose of this study was to establish the best cereal components, their ratio and methods of placement with white lupine when sowing in joint crops under different fertilizer systems to produce grass fodder in the Forest-Steppe of

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Ukraine. The following methods were used: field, laboratory, mathematical-statistical, calculation-comparative. It was established that the highest productivity on the background without fertilizers (4.21-4.86 t·ha^{-1} of dry matter) was provided by single-species crops of maize and white lupine, as well as their combined crops, which were formed by continuous row and strip methods, which by 2.60-3.17 t·ha^{-1} of dry matter or 1.8-2.6 times more compared to crops of oats and its mixture with white lupine and by 1.13-1.58 t·ha^{-1} or 1.4-1.5 times more compared to crops of Sudanese sorghum and its mixture with white lupine. Through the accumulation and use of symbiotic nitrogen fixation, the productivity of lupine-oat mixtures increased from 1.90 to 2.70-3.21 t·ha^{-1} of dry mass or 1.4-1.7 times, and that of lupine-sorghum – from 3.17 to 3.43-3.47 or 1.1 times. The most effective ratio of each cereal component to legume in binary intercropping was 25:75% of the sowing rate in single-species agrocenoses when dry biomass productivity was the greatest. Compared to the variant without fertilizers, the most significant (by 1.3-2.0 times) increase in the productivity of all fodder agrocenoses under study was ensured by the application of $N_{45}P_{30}K_{50}$, while the application of $P_{30}K_{50}$ or humigran organic fertilizer at a dose of 250 kg·ha^{-1} – only by 1.2-1.3 times. The research results can be used in the development of scientific and methodological recommendations and the education about the formation of highly productive agrophytocenoses for conveyor production of high-quality grass fodder for animal feeding

Keywords: solid and strip agrocenoses; mineral and organic fertilizers; annual cereals; crude protein; compatible and single-species crops; dry mass; grass fodder

INTRODUCTION

In creating a strong fodder base for animal husbandry in Ukraine, a major role belongs to improving the efficiency of using legumes as a source of cheap symbiotic nitrogen. They are a source of cheap grass fodder (hay, silage, green fodder, artificially dried grass fodder), which is well-balanced in terms of protein, minerals, and vitamins (Demidas & Prorochenko, 2018; Demidas & Galushko, 2018; Kurhak *et al.*, 2020). Improving the efficiency of using cheap symbiotic nitrogen of legumes by enriching them with cereal coenoses is not only an important reserve for increasing fodder production, but is aimed at reducing energy costs, reducing environmental pollution with nitrogen fertilizers, improving soil fertility, etc. The need for fodder production in the Polissia and Forest-Steppe of Ukraine can be provided at least by half through using the potential of perennial and annual leguminous crops when grown in both single-species and combined crops (Kurgak & Karbivska, 2020).

In Western European countries, the dependence of fodder production on mineral nitrogen is also already decreasing by using the potential of leguminous perennial and annual grasses, the need to partially replace mineral nitrogen with symbiotic ones is increasing because the production of nitrogen fertilizers is a very energy-intensive and expensive process, the introduction of elevated doses of mineral nitrogen pollutes the environment, production, and the application of nitrogen fertilizers to fodder lands is insufficient. Therefore, it is not by chance that within the framework of the International Biological Program of UNESCO and the International Society of Soil Scientists, nitrogen fixation, along with photosynthesis, is highlighted as one of the main physiological processes on which the production of agricultural products largely depends. Increasing the use of leguminous perennial and annual grasses in forage production is the most important component of the program for the introduction of energy-saving technologies in the world (Nilsdotter-Linde *et al.*, 2016; Hannaway *et al.*, 2018).

Legumes, thanks to their positive consortial relationships with symbiotrophs (rhizobia), not only feed themselves with symbiotic nitrogen, but also accumulate nitrogen in the soil. This has a positive effect on cereals that grow together with them in phytocenoses (Hetman *et al.,* 2019; Kurgak & Karbivska, 2020).

When creating models of mixtures of annual forage crops, it is necessary that their components are compatible in terms of morphological characteristics and biological features of their growth and development, while simultaneously increasing productivity and improving the quality of feed in terms of crude protein content. These requirements are met by legume and cereal agrophytocenoses (Demidas & Proroshenko, 2018; Kurhak *et al.,* 2020).

The studies of various scientists have developed and recommended legume-cereal fodder agrophytocenoses with a productivity of 5-6 t/ha of fodder units, which ensure the production of high-quality fodder crude materials to produce herbal fodder for animals and the production of ecologically safe animal husbandry products for humans, namely, milk and meat (Hetman *et al.,* 2019; Ratoshniuk, 2020; Dzyubaylo *et al.,* 2020). In this context, it is important to obtain complete feeds from leguminous-cereal mixtures not only of perennial grasses, but also of potential with an expanded assortment and the use of conventional crops and new introducers of annual crops in early intermediate crops and crops involving highly productive drought-resistant late-ripening crops in the chain of green or raw material conveyor. To create stable, highly productive fodder agrocenoses in the conditions of aggravation of arid phenomena in the Northern Forest-Steppe of Ukraine, growing attention is being paid to crops that form high productivity in conditions of a lack of atmospheric precipitation and a deficit of moisture in the soil, namely, maize and Sudanese sorghum, which are characterized by high production potential not only in single-species crops, but also in mixtures. Sudanese sorghum tolerates a lack of moisture in the soil better than low average daily temperatures. Even during frequent dry periods, it generates prominent yields of fodder biomass (Slyusar, 2017; Slyusar & Oksymets 2018).

However, until recently, the issues of the optimal ratio and methods of placing the components of lupine-cereal mixtures under different fertilization systems (organic and mineral) and the influence of these factors on the forage productivity of crops and the quality of grass fodder are still understudied. In the green or raw material conveyor system, it is necessary to substantiate the wider use of lupine-cereal binary mixtures along with oats for sowing drought-resistant corn and sorghum, which is vital in the modern conditions of aggravation of drought phenomena due to aridization of the climate. These are the questions that the present study is aimed at, the results of which are presented in this paper.

The purpose of this study was to establish the features of the formation of one-year highly productive fodder agrophytocenoses with different ratios and methods of placement of cereal components with white lupine when sowing in binary compatible crops under different fertilization systems for conveyor production of highly nutritious grass fodder in the Forest Steppe of Ukraine.

MATERIALS AND METHODS

A study on the fodder productivity of white lupine, oats, maize, and Sudanese sorghum in single-species crops and lupine-cereal mixtures with different ratios and methods of placement under different fertilizer systems (organic and mineral) was conducted during 2016-2018 in the Forest-Steppe zone of Ukraine on dark grey podzolized coarse-pollinated-light loamy soil in the National Research Centre "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine" (Chabany village, Kyiv region). Humus content in the 0-20 cm soil layer is 2.4%; pH (saline) – 5.2; the content of alkaline hydrolyzed nitrogen – 13.1, mobile phosphorus – 17.1 and exchangeable potassium 12.9 mg·100g^{-1} of soil. The depth of the humus horizon is 35-40 cm, and the groundwater occurrence is about 3 m.

The climate of the region where the study was conducted is temperate continental. The average annual air temperature is 6-7°C, while the maximum temperature in the summer months reaches 37-39°C, and the lowest temperature is 36°C in winter. Precipitation averages 480-620 mm per year, and 423 mm during the growing season. Weather conditions during the research years were favourable for the vegetation of perennial grasses. The least favourable year was 2017, when the least precipitation fell during the growing season (335 mm) and when the lowest fodder productivity of all the crops and their mixtures under study was formed. The scheme of the experiment is presented in Table 1.

Table 1. *Experiment scheme*

Sward factor – crops and their mixtures and seed sowing rate, kg·ha^{-1} (%)
White lupine, 300 (100)
Seed oats, 160 (100)
Seed oats, 80 (50) + white lupine, 150 (50) – strip sowing*
Seed oats, 40 (25) + white lupine, 225 (75)
Seed oats, 80 (50) + white lupine, 150 (50)
Seed oats, 120 (75) + white lupine, 75 (25)
Maize, 70 (100)
Maize, 35 (50) + white lupine, 150 (50) – strip sowing*
Maize, 17.5 (25) + white lupine, 225 (75)
Maize, 35 (50) + white lupine, 150 (50)
Maize, 52.5 (75) + white lupine, 75 (25)
Sudanese sorghum, 30 (100)
Sudanese sorghum, 15 (50) + white lupine, 150 (50) – strip sowing*
Sudanese sorghum, 7.5 (25) + white lupine, 225 (75)
Sudanese sorghum, 15 (50) + white lupine, 150 (50)
Sudanese sorghum, 22.5 (75) + white lupine, 75 (25)

Note: ** Strip sowing method with a strip width of 1.5 m. On the remaining agrocenoses, there was a continuous sowing of components in one row with row spacing of 0.15 m. The experiment was conducted on four fertilizer backgrounds: without fertilizers; $N_{45}R_{30}K_{50}$; $P_{30}K_{50}$; Humigran – 250 kg·ha^{-1}*
Source: *compiled by the authors*

Mineral fertilizers were introduced for pre-sowing cultivation in the form of ammonium nitrate, superphosphate, and potassium chloride, while organic fertilizer humigran (granulated vermicompost) was applied to the rows when sowing annual grasses. The area of the sown plot is 30 m^2, the accounting plot is 25 m^2.

The repetition of the experiment was fourfold. Agricultural techniques for growing mixtures were generally accepted for the Right-Bank Forest-Steppe. Pre-sowing soil treatment was carried out with the Europak-600 combined unit to a depth of 6-8 cm, which ensured levelling and crushing of the soil to a fine-grained state.

The crops under study and their mixtures were sown in optimal agrotechnical terms with a mounted Seeder CH-16A in an aggregate with a tractor t-25A in the usual lowercase way with row spacing of 15 cm, including sowing during the formation of strip agrocenoses. The seeding rate of forage crops is consistent with the experiment scheme in the corresponding variants. During sowing, the experiment used zoned varieties of annual crops, mainly selected by the NSC "Institute of Agriculture of the National Academy of Sciences".

Harvest accounting was carried out differentially, as the harvest maturity of the dominant crops of the corresponding agrophytocenoses, namely, the phase of milky maturity of cereals (oats, maize, and Sudanese sorghum) and in the phase of physiological maturity of the seeds in the lower tier of white lupine, continuous mowing of the green mass with accounting area followed by weighing.

Field studies were conducted according to generally accepted methods in feed production (Methods of conducting experiments on feed production, 1994). Harvest accounting was carried out by continuous mowing of biomass in the accounting area at the time of harvesting maturation for harvesting grass fodder in fourfold repetitions, and the determination of the content of dry matter in biomass during harvest accounting was carried out by drying biomass in a drying cabinet at 105°C (DSTU 8044:2015, 2018).

In the dry plant mass, the content of crude protein, crude fat, crude fibre, digestibility of the dry matter of feed was determined *in vitro* – according to the method of infrared spectroscopy per (DSTU 4117:2007, 2008); the content of nitrogen-free extractive substances (NFES) – by calculation (DSTU 4674:2006, 2008). The agrochemical parameters of the soil were determined before starting the experiment in the 0-20-cm layer of the soil according to generally accepted methods, namely: humus – according to Tiurin (DSTU 4289:2004, 2006); nitrogen that is easily hydrolyzed by alkali – according to Cornfield (DSTU 7863:2015, 2018); mobile phosphorus and potassium – according to Kirsanov and Machygin (DSTU 4115-2002, 2004); pH (saline) – potentiometrically (DSTU ISO10390:2001, 2008). Mathematical processing of the obtained experimental performance data in the experiment was carried out according to the method of variance analysis.

RESULTS AND DISCUSSION

The results of the study on the formation of fodder productivity of single-species (white lupine, seed oats, maize, and Sudanese sorghum) and lupine-cereal binary combined crops with different ratios and placement of components upon sowing under different fertilizer options on average for 2016-2018 are presented in Table 2. The analysis of the study results showed that against a background without fertilizers, the productivity of these agrocenoses ranged within 1.90-4.86 t·ha^{-1} of dry matter (mass) and 0.16-0.85 t·ha^{-1} of crude protein. The highest productivity (on the background without fertilizers, 4.21-4.86 t·ha^{-1} of dry matter) was provided by single-species crops of maize and white lupine and their mixtures with continuous row and strip sowing methods, which prevailed over oats and their mixtures with white lupine by 2.60-3.17 t·ha^{-1} of dry matter or 1.8-2.6 times, while Sudanese sorghum and its mixture with white lupine – by 1.13-1.58 t·ha^{-1} or 1.4-1.5 times.

Table 2. *Productivity of mixtures of annual cereal fodder crops with white lupine depending on the ratio and methods of placing components upon sowing*

Crops and their mixtures, seeding rate, kg·ha^{-1} (%)	Fertilizer	Dry mass by year, t·ha^{-1}			Average for 2016-2018		
		2016	2017	2018	Dry mass, t·ha^{-1}	Crude protein, t·ha^{-1}	The share of lupine in the crop, %
1	2	3	4	5	6	7	8
White lupine, 300 (100)	Without fertilisers	4.84	3.63	5.08	4.52	0.88	94
	$N_{45}P_{30}K_{50}$	6.40	4.80	6.72	5.97	1.24	95
	$P_{30}K_{50}$	6.15	4.61	6.46	5.74	1.16	94
	Humigran	5.58	4.19	5.86	5.21	1.07	94
Seed oats, 160 (100)	Without fertilisers	2.04	1.53	2.14	1.90	0.16	–
	$N_{45}P_{30}K_{50}$	3.30	2.48	3.47	3.08	0.29	–
	$P_{30}K_{50}$	2.64	1.98	2.77	2.46	0.21	–
	Humigran	2.49	1.87	2.61	2.32	0.23	–
Seed oats, 80 (50) + White lupine, 150 (50) – strip sowing*	Without fertilisers	3.44	2.58	3.61	3.21	0.45	66
	$N_{45}P_{30}K_{50}$	4.85	3.64	5.09	4.53	0.68	63
	$P_{30}K_{50}$	4.40	3.30	4.62	4.11	0.60	67
	Humigran	4.14	3.11	4.35	3.87	0.58	67
Seed oats, 40 (25) + white lupine, 225 (75)	Without fertilisers	3.40	2.55	3.57	3.17	0.45	68
	$N_{45}P_{30}K_{50}$	4.82	3.62	5.06	4.50	0.70	65
	$P_{30}K_{50}$	4.41	3.31	4.63	4.12	0.61	69
	Humigran	4.10	3.08	4.31	3.83	0.61	69

Table 2, Continued

Crops and their mixtures, seeding rate, kg·ha^{-1} (%)	Fertilizer	Dry mass by year, t·ha^{-1}			Average for 2016-2018		
		2016	2017	2018	Dry mass, t·ha^{-1}	Crude protein, t·ha^{-1}	The share of lupine in the crop, %
1	2	3	4	5	6	7	8
Seed oats, 80 (50) + white lupine, 150 (50)	Without fertilisers	3.04	2.28	3.19	2.84	0.41	55
	$N_{45}P_{30}K_{50}$	4.68	3.51	4.91	4.37	0.68	52
	$P_{30}K_{50}$	4.26	3.20	4.47	3.98	0.59	57
	Humigran	3.88	2.91	4.07	3.62	0.58	56
Seed oats, 120 (75) + white lupine, 75 (25)	Without fertilisers	2.89	2.17	3.03	2.70	0.37	43
	$N_{45}P_{30}K_{50}$	4.52	3.39	4.75	4.22	0.64	41
	$P_{30}K_{50}$	4.02	3.02	4.22	3.75	0.54	44
	Humigran	3.71	2.78	3.90	3.46	0.54	43
Maize, 70 (100)	Without fertilisers	5.21	3.91	5.47	4.86	0.53	–
	$N_{45}P_{30}K_{50}$	9.00	6.75	9.45	8.40	1.02	–
	$P_{30}K_{50}$	6.36	4.77	6.68	5.94	0.68	–
	Humigran	6.87	5.15	7.21	6.41	0.81	–
Maize, 35 (50) + white lupine, 150 (50) – strip sowing*	Without fertilisers	5.03	3.77	5.28	4.69	0.76	43
	$N_{45}P_{30}K_{50}$	7.70	5.78	8.09	7.19	1.19	40
	$P_{30}K_{50}$	6.26	4.70	6.57	5.84	0.93	44
	Humigran	6.29	4.72	6.60	5.87	0.95	44
Maize, 17.5 (25) + white lupine, 225 (75)	Without fertilisers	5.00	3.75	5.25	4.67	0.85	42
	$N_{45}P_{30}K_{50}$	8.33	6.25	8.75	7.78	1.51	38
	$P_{30}K_{50}$	6.00	4.50	6.30	5.60	1.04	45
	Humigran	6.35	4.76	6.67	5.93	1.18	45
Maize, 35 (50) + white lupine, 150 (50)	Without fertilisers	4.70	3.53	4.94	4.39	0.72	36
	$N_{45}P_{30}K_{50}$	8.02	6.02	8.42	7.49	1.32	33
	$P_{30}K_{50}$	5.67	4.25	5.95	5.29	0.89	38
	Humigran	6.01	4.51	6.31	5.61	1.01	38
Maize, 52.5 (75) + white lupine, 75 (25)	Without fertilisers	4.51	3.38	4.74	4.21	0.67	30
	$N_{45}P_{30}K_{50}$	7.69	5.77	8.07	7.18	1.24	27
	$P_{30}K_{50}$	5.53	4.15	5.81	5.16	0.86	31
	Humigran	5.68	4.26	5.96	5.30	0.95	30
Sudanese sorghum, 30 (100)	Without fertilisers	3.40	2.55	3.57	3.17	0.28	–
	$N_{45}P_{30}K_{50}$	6.83	5.12	7.17	6.37	0.64	–
	$P_{30}K_{50}$	4.00	3.00	4.20	3.73	0.35	–
	Humigran	4.33	3.25	4.55	4.04	0.43	–
Sudanese sorghum, 15 (50) + white lupine, 150 (50) – strip sowing*	Without fertilisers	3.72	2.79	3.91	3.47	0.53	53
	$N_{45}P_{30}K_{50}$	6.58	4.94	6.91	6.14	1.02	50
	$P_{30}K_{50}$	4.57	3.43	4.80	4.27	0.68	54
	Humigran	4.55	3.41	4.78	4.25	0.69	54
Sudanese sorghum, 7.5 (25) + white lupine, 225 (75)	Without fertilisers	3.68	2.76	3.86	3.43	0.55	52
	$N_{45}P_{30}K_{50}$	6.34	4.76	6.66	5.92	1.02	48
	$P_{30}K_{50}$	4.33	3.25	4.55	4.04	0.66	55
	Humigran	5.01	3.76	5.26	4.68	0.83	55
Sudanese sorghum, 15 (50) + white lupine, 150 (50)	Without fertilisers	3.69	2.77	3.87	3.44	0.52	46
	$N_{45}P_{30}K_{50}$	6.00	4.50	6.30	5.60	0.92	43
	$P_{30}K_{50}$	4.01	3.01	4.21	3.74	0.59	48
	Humigran	4.73	3.55	4.97	4.42	0.75	48
Sudanese sorghum, 22.5 (75) + white lupine, 75 (25)	Without fertilisers	3.68	2.76	3.86	3.43	0.49	40
	$N_{45}P_{30}K_{50}$	6.35	4.76	6.67	5.93	0.92	37
	$P_{30}K_{50}$	4.34	3.26	4.56	4.05	0.60	41
	Humigran	5.00	3.75	5.25	4.67	0.70	40
LSD_{05}, by factors							
Sward		0.27	0.22	0.29	0.26		
Fertilizer		0.23	0.20	0.25	0.23		
Share of factors, %							
Sward		59	61	63	61		
Fertilizer		41	39	37	39		

Note. ** Strip sowing method with a strip width of 1.5 m. On the remaining agrocenoses, there was a continuous sowing of components in one row with row spacing of 0.15 m*

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

Compared with single-species agrocenoses of cereal crops, the productivity of fodder biomass of lupine-oat mixtures increased from 1.90 t/ha to 2.70-3.21 $t \cdot ha^{-1}$ of dry weight or by 1.4-1.7 times, and of lupine-sorghum – from 3.17 to 3.43-3.47 $t \cdot ha^{-1}$ or 1.1 times. The exception was the productivity of lupine-maize agrocenoses, which did not have an advantage over single-species maize sowing in terms of yield from 1 ha of dry mass. However, in terms of yield from 1 ha of crude protein, lupine-maize agrocenoses prevailed over one-species sowing of maize by 1.3-1.6 times.

According to these data, the best ratio of the cereal component to the legume in the continuous row method of sowing the mixture was 25:75% of the sowing rate in single-species sowing, when the productivity of dry biomass was the highest upon growing white lupine with seeded oats and maize. With this ratio, the productivity of 1 ha of dry biomass and crude protein of these lupine-cereal mixtures increased by 1.1-1.3 times compared to the ratio of cereal to legume component as 75:25%. With the ratio of these components as 50:50%, the productivity of these coenoses occupied an intermediate position. In lupine-sorghum mixtures, an increase in the proportion of the legume component in the ratio during sowing considerably increased productivity in terms of the yield of crude protein from 1 ha.

For the ratio of the cereal component to the leguminous component at 25:75%, the share of white lupine in the harvest was the largest, which varied between 65-69% in the lupine-oat agrocenosis, 38-45% in lupine-maize, and 48-55% in lupine-sorghum, which is 12-26% more than for a ratio of 75:25%. The largest share of the legume component in the harvest was in lupine-oat mixtures, and the smallest – in lupine-maize mixtures.

According to these data, the method of sowing (strip method with a strip width of 1.5 m with alternating placement and continuous sowing in one row of cereal and leguminous components with a ratio of 50:50% of leguminous-cereal mixtures had little effect on the productivity of the fodder agrophytocenoses under study. In most cases, there was a tendency to prefer strip agrocenosis over continuous agrocenosis when growing in compatible lupine crops with oats and maize.

According to the data of this study, the share of the leguminous component in lupine-cereal mixtures decreased by 3-7% from the introduction of N_{45} against the background of $P_{30}K_{50}$. Compared to the option without fertilizers, the most significant (1.3-2.0 times) increase in the productivity of all fodder agrocenoses under study was provided by the application of $N_{45}P_{30}K_{50}$, while the application of $P_{30}K_{50}$ or organic fertilizer humigran at a dose of 250 kg/ha – only by 1.2-1.3 times.

According to these data, the cultivation of cereal crops in mixtures with white lupine, in comparison with single-species sowing of cereal crops in the variant without fertilization, increased the content of crude protein in dry fodder biomass from 8.6-11.1 to 14.0-18.1 or by 5.4-7.0% (Table 3). At the same time, the content of protein and crude fat increased and the content of crude fibre and nitrogen-free extractive substances (NFES) decreased, as well as the digestibility of the dry weight of the feed improved, which increased from 47-54% to 57-61% or by 7-10%. With an increase in the amount of the leguminous component in fodder agrocenoses, the content of crude protein and protein in the dry biomass increased and the content of crude fibre and NFES decreased, as well as the digestibility of the dry mass *in vitro improved*. The highest content of crude protein and protein was characterized by a single-species sowing of white lupine, where they accumulated 19.5% and 17.0% in the dry mass in the version without fertilizers, respectively. Among the fertilizers, the application of $N_{45}P_{30}K_{50}$ had the greatest effect on the accumulation of crude protein and protein. The amount of crude protein in the dry mass of fodder in this case increased by 1.1-1.3% compared to the option without fertilizers.

Table 3. *Chemical composition of mixtures of annual cereal fodder crops with white lupine depending on the ratio and methods of placement of components during sowing, % in dry weight (average for 2016-2018)*

Crops and their mixtures, seeding rate, $kg \cdot ha^{-1}$ (%)	Fertilizer options	Crude protein	Protein	Crude fat	Crude fibre	NFES	Digestibility
		3	4	5	6	7	8
White lupine, 300 (100)	Without fertilisers	19.5	17.0	3.5	23.9	45.9	67
	$N_{45}P_{30}K_{50}$	20.7	18.8	3.1	22.7	46.7	68
	$P_{30}K_{50}$	20.2	18.3	3.0	22.8	47.1	67
	Humigran	20.5	18.5	3.3	22.0	46.3	69
Seed oats, 160 (100)	Without fertilisers	8.6	7.8	3.0	31.0	51.1	47
	$N_{45}P_{30}K_{50}$	9.6	8.6	2.6	28.6	52.2	48
	$P_{30}K_{50}$	8.8	7.8	2.7	28.8	52.7	48
	Humigran	10.1	8.9	2.7	28.5	51.3	49
Seed oats, 80 (50) + White lupine, 150 (50) – strip sowing	Without fertilisers	14.0	12.8	3.3	27.0	48.5	57
	$N_{45}P_{30}K_{50}$	15.1	13.6	2.9	25.7	49.5	58
	$P_{30}K_{50}$	14.6	13.1	2.9	25.8	49.9	59
	Humigran	14.9	13.3	3.0	25.3	48.8	59

Table 3, Continued

Crops and their mixtures, seeding rate, kg·ha⁻¹ (%)	Fertilizer options	Crude protein	Protein	Crude fat	Crude fibre	NFES	Digestibility
		3	4	5	6	7	8
Seed oats, 40 (25) + white lupine, 225 (75)	Without fertilisers	14.5	13.3	3.1	24.6	46.9	64
	$N_{45}P_{30}K_{50}$	15.8	14.1	3.0	23.2	47.6	66
	$P_{30}K_{50}$	15.0	13.6	3.1	23.5	47.8	65
	Humigran	16.3	14.8	3.1	22.9	47.1	67
Seed oats, 80 (50) + white lupine, 150 (50)	Without fertilisers	14.6	13.4	3.3	26.8	45.0	64
	$N_{45}P_{30}K_{50}$	15.9	14.2	3.2	25.4	45.7	65
	$P_{30}K_{50}$	15.1	13.7	3.1	25.6	46.2	65
	Humigran	16.4	14.9	3.3	25.1	45.2	66
Seed oats, 120 (75) + white lupine, 75 (25)	Without fertilisers	14.1	13.3	3.3	24.9	47.1	64
	$N_{45}P_{30}K_{50}$	15.4	14.1	3.3	23.6	47.6	65
	$P_{30}K_{50}$	14.6	13.6	3.3	23.8	48.0	64
	Humigran	15.9	14.8	3.0	23.2	47.6	66
Maize, 70 (100)	Without fertilisers	11.1	10.4	3.4	26.8	49.3	54
	$N_{45}P_{30}K_{50}$	12.4	10.2	3.1	25.9	49.8	55
	$P_{30}K_{50}$	11.6	9.7	3.2	26.0	50.1	55
	Humigran	12.9	10.9	3.1	25.5	49.4	56
Maize, 35 (50) + white lupine, 150 (50) – strip sowing	Without fertilisers	16.3	14.7	3.5	25.4	47.6	61
	$N_{45}P_{30}K_{50}$	16.6	14.5	3.1	24.3	48.3	62
	$P_{30}K_{50}$	15.9	14.0	3.1	24.4	48.6	61
	Humigran	16.2	14.2	3.2	23.8	47.9	63
Maize, 17.5 (25) + white lupine, 225 (75)	Without fertilisers	18.1	16.6	3.7	24.8	42.2	71
	$N_{45}P_{30}K_{50}$	19.4	17.4	3.6	23.6	42.8	72
	$P_{30}K_{50}$	18.6	16.9	3.5	23.8	43.3	72
	Humigran	19.9	18.1	3.4	23.2	42.7	73
Maize, 35 (50) + white lupine, 150 (50)	Without fertilisers	16.6	14.4	3.8	25.9	42.8	69
	$N_{45}P_{30}K_{50}$	17.9	16.2	3.6	24.9	43.2	70
	$P_{30}K_{50}$	17.1	15.7	3.4	25.1	43.8	69
	Humigran	18.4	16.9	3.5	24.5	43.0	71
Maize, 52.5 (75) + white lupine, 75 (25)	Without fertilisers	16.0	14.5	3.6	22.9	46.6	67
	$N_{45}P_{30}K_{50}$	17.3	15.3	3.8	21.6	47.0	69
	$P_{30}K_{50}$	16.6	14.9	3.7	21.8	47.4	68
	Humigran	17.9	16.1	3.6	21.1	46.9	69
Sudanese sorghum, 30 (100)	Without fertilisers	9.0	7.5	3.0	28.0	52.2	48
	$N_{45}P_{30}K_{50}$	10.3	9.3	2.9	27.8	51.7	49
	$P_{30}K_{50}$	9.5	8.8	3.0	28.0	52.0	49
	Humigran	10.8	10.0	3.0	27.4	51.3	50
Sudanese sorghum, 15 (50) + white lupine, 150 (50) (strip sowing)	Without fertilisers	15.3	13.3	3.3	24.0	49.1	58
	$N_{45}P_{30}K_{50}$	16.6	14.1	3.1	25.3	49.2	59
	$P_{30}K_{50}$	15.9	13.6	3.0	25.4	49.6	58
	Humigran	16.2	14.8	3.2	24.7	48.8	60
Sudanese sorghum, 7.5 (25) + white lupine, 225 (75)	Without fertilisers	16.2	14.5	3.1	24.6	45.1	68
	$N_{45}P_{30}K_{50}$	17.5	15.3	3.1	23.1	45.8	69
	$P_{30}K_{50}$	16.7	14.8	2.9	23.2	46.4	69
	Humigran	18.0	16.0	3.4	22.8	45.0	70
Sudanese sorghum, 15 (50) + white lupine, 150 (50)	Without fertilisers	15.5	14.4	3.2	24.9	45.7	67
	$N_{45}P_{30}K_{50}$	16.8	15.2	3.2	23.5	46.3	68
	$P_{30}K_{50}$	16.0	14.7	3.1	23.6	46.9	67
	Humigran	17.3	15.9	3.3	23.2	45.8	69
Sudanese sorghum, 22.5 (75) + white lupine, 75 (25)	Without fertilisers	14.2	12.6	3.0	29.8	47.8	52
	$N_{45}P_{30}K_{50}$	15.5	13.4	2.5	28.6	48.8	53
	$P_{30}K_{50}$	14.7	12.9	2.8	28.7	48.9	52
	Humigran	14.9	13.0	2.9	28.1	48.1	54
Zootechnical norm		14	–	3.5	25-30	–	50-70
LSD_{05}, by factors							
Sward		0.6	0.5	0.2	1.1	1.5	2
Fertilizer		0.5	0.4	0.2	1.0	1.2	2

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

Thus, the patterns of changes in the specific features of the formation of the botanical composition and fodder productivity of lupine-cereal agrophytocenoses, as well as indicators of the chemical composition and digestibility of dry biomass *in vitro*, which were obtained under the researched factors and presented in this paper, confirm the results of earlier studies by various authors. The presented study confirmed the experimental data obtained by Kurgak & Karbivska (2020), as well as Kovtun *et al.* (2020) that the inclusion of leguminous grasses in grass mixtures of perennial and annual crops increases their productivity.

The studies conducted by Ratoshniuk (2020), Holodna (2018) and Holodna & Stolyar (2018) indicate that a prominent positive effect is ensured by inclusion of white lupine in leguminous-cereal mixtures involving seed oats or maize or Sudanese sorghum because white lupine acts as a source of cheap symbiotic nitrogen, provides not only an elevated yield of green mass and hay, but also enriches the fodder with protein, vitamins, amino acids, etc.

Previous studies by Hetman *et al.* (2019), Senyk (2020, 2021) and Kurhak *et al.* (2020) found that the productivity of legume-cereal agrocenoses increases with an increase in the share of the legume component, the amount of which can be adjusted by increasing its share in grass mixtures. This is conditioned upon the fact that, according to these authors, the optimal ratio of legumes and cereals, both in early- and late-maturing mixtures, contributes to more efficient use of moisture, photosynthetically active radiation, soil nutrients, etc.

The study by Senyk (2020) proved that when growing grass mixtures of seeded oats with seeded peas, the highest productivity (7.26 $t \cdot ha^{-1}$ of dry matter) is provided by the ratio of 75% leguminous and 25% cereal components from the norm of sowing seeds in single-species sowing combined with the use of other intensification factors, including fertilizers.

Not only Ukrainian researchers, namely Kurhak *et al.* (2020) and Demidas & Prorochenko (2018), as well as foreign scientists (Hannaway *et al.*, 2018) note that in the conditions of a substantial increase in the cost of mineral nitrogen, the maximum possible use of elements of biologization of feed production due to the increase in the efficiency of the use of symbiotic nitrogen of the best fodder legumes cultures has no alternative. This makes it possible to obtain high productivity (6-8 $t \cdot ha^{-1}$ of dry fodder biomass and more) of fodder land, save 50-300 $kg \cdot ha^{-1}$ of mineral nitrogen, preserve and increase soil fertility, preserve the environment, and produce organic fodder raw materials.

According to Petrychenko *et al.* (2018, 2020), cereal mixtures are inferior in productivity to legumes and cereals. The increase in the yield of green mass on legume-cereal grass mixtures in comparison with cereals on average over the years of research is 6.27 t/ha.

Slyusar (2017) and Slyusar & Oksymets (2018) noted that in the conditions of increasing aridity of the climate, it is advisable to expand the crops of not only perennial, but also annual fodder crops when growing them in mixtures with legumes. Such agrophytocenoses make better use of ecological niches and do not react so sharply with productivity to air drought and lack of moisture in the upper soil layer.

Kurhak *et al.* (2020) and Senyk (2020) proved that the use of leguminous grasses as components of legume-cereal grass mixtures not only increases the productivity of forage land, but also improves the quality of fodder. In comparison with cereal herbage, in this case, the dry mass of feed increases the content of crude protein by 5-9%. At the same time, the amount of protein increases and its amino acid composition improves, primarily in terms of the content of essential amino acids, specifically, the amount of lysine increases, which is quite enough for balanced feeding of cattle. Thanks to legume components in the fodder, the concentration of metabolic energy increases and the content of crude fibre decreases, as well as the digestibility of dry mass improves. At the same time, the mineral composition of the fodder improves, due to an increase in the content of calcium and magnesium and some trace elements.

CONCLUSIONS

On the dark gray soils of the Forest Steppe of Ukraine, the fodder productivity of single-species (white lupine, seed oats, maize, and Sudanese sorghum) and lupine-cereal binary combined crops with different ratios and placement of components when sowing under different options on a background without fertilizers ranges within 1.90-4.86 $t \cdot ha^{-1}$t/ha of dry matter (mass) and 0.16-0.85 $t \cdot ha^{-1}$ of crude protein.

The highest productivity (on the background without fertilizers, 4.21-4.86 $t \cdot ha^{-1}$ of dry matter) is characterized by maize and white lupine in single-species sowing, as well as their combined sowing under continuous row and strip sowing methods. Oats and its mixtures with white lupine in terms of productivity are superior by 2.60-317 $t \cdot ha^{-1}$ of dry matter or by 1.8-2.6 times, and Sudanese sorghum in single-species sowing and its mixture with white lupine – by 1.13-1.58 $t \cdot ha^{-1}$ or 1.4-1.5 times. In comparison with single-species agrocenoses of cereals, the productivity of fodder biomass of lupine-oat mixtures increased by 1.4-1.7 times and lupine-sorghum mixtures – by 1.1 times.

The best ratio of the cereal component to the legume (white lupine) in the continuous row method of sowing the mixture is 25:75% of the sowing rate in single-species crops, when the productivity of dry biomass is the greatest. Compared to the option without fertilizers, the most significant (1.3-2.0 times) increase in the productivity of all fodder agrocenoses under study is provided by the application of $N_{45}P_{30}K_{50}$, while the application of $P_{30}K_{50}$ or organic fertilizer humigran at a dose of 250 kg/ha – only by 1.2-1.3 times.

Cultivation of cereals in mixtures with white lupine in comparison with single-species crops of cereals in the version without fertilization increases the content of crude protein in dry fodder biomass by 5.6-8.0%. At the same time, the content of protein and crude fat increases and the content of crude fibre and nitrogen-free extractive substances (NFES) decreases, as well as the digestibility of the dry weight of the feed improves, which increased from 47-54% to 57-61% or by 7-10%.

Research into ways to increase the efficiency of using cheap symbiotic nitrogen in leguminous crops in fodder production by enriching cereal phytocenoses with them, involving a larger number of species of this family, has the prospect of continuing in different soil and climatic conditions of Ukraine. This will contribute not only to increasing the production of cheap grass fodder and improving its quality, but also to reducing energy and money costs, reducing environmental pollution with nitrogen fertilizers and improving soil fertility, and on this basis, strengthening the fodder base of Ukrainian livestock breeding.

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CONFLICT OF INTEREST

None.

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Кормова продуктивність сумісних посівів вівса посівного, кукурудзи і сорго суданського з люпином білим

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Анотація. Досліджень, спрямованих на накопичення та ефективне використання азоту симбіотичної його фіксації з повітря рослинами люпину білого, шляхом добору кращих злакових компонентів, оптимізації їх співвідношення та способів розміщення при вирощуванні у сумісних посівах з ним за різних систем удобрення в Лісостепу ще не проведено. Мета – встановити кращі злакові компоненти, їх співвідношення та способи розміщення з люпином білим при сівбі в сумісних посівах за різних систем удобрення для виробництва трав'яних кормів в Лісостепу України. Було використано наступні методи: польовий, лабораторний, математико-статистичний, розрахунково-порівняльний. Було встановлено, що найбільшу продуктивність на фоні без добрив (4,21-4,86 $t{\cdot}ha^{-1}$ сухої речовини) забезпечили одновидові посіви кукурудзи та люпину білого, а також їх сумісні посіви, які сформовано суцільним рядовим та смуговим способами, що на 2,60-3,17 $t{\cdot}ha^{-1}$ сухої речовини або в 1,8-2,6 рази більше порівняно з посівами вівса та його суміші з білим люпином і на 1,13-1,58 $t{\cdot}ha^{-1}$ або в 1,4-1,5 рази більше в порівнянні з посівами сорго суданського і його суміші з білим люпином. За рахунок накопичення та використання азоту симбіотичної фіксації продуктивність люпино-вівсяних сумішей збільшилася від 1,90 до 2,70-3,21 $t{\cdot}ha^{-1}$ сухої маси або в 1,4-1,7 рази, а люпино-соргових – від 3,17 до 3,43-3,47 або в 1,1 рази. Найбільш ефективним співвідношенням кожного злакового компонента до бобового в бінарних сумісних посівах було як 25:75 % від норми висіву в одновидових агроценозах, коли продуктивність сухої біомаси була найбільшою. Порівняно з варіантом без добрив найбільш суттєво (в 1,3-2,0 рази) збільшення продуктивності всіх досліджуваних кормових агроценозів забезпечило внесення $N_{45}P_{30}K_{50}$, тим часом як внесення $P_{30}K_{50}$ чи органічного добрива гумігран у дозі 250 $kg{\cdot}ha^{-1}$ – лише у 1,2-1,3 рази. Результати досліджень можуть бути використані при розробленні науково-методичних рекомендацій та навчальному процесі стосовно формування високопродуктивних агрофітоценозів з метою конвеєрного виробництва якісних трав'яних кормів для годівлі тварин

Ключові слова: агроценози суцільні та смугові; мінеральні та органічні добрива; однорічні злакові культури; сирий протеїн; сумісні та одновидові посіви; суха маса; трав'яні корми

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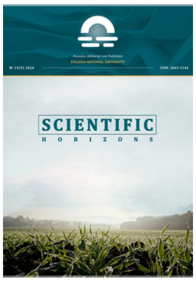

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Extension of the forming process in the selection of winter common wheat for productivity and quality by using the gene pool of related wheat species within the framework of food security

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Abstract. The formation process in the selection of winter common wheat for productivity and quality has been expanded by using the gene pool of related species. The purpose of this study was to expand the formative process in the selection of *Triticum aestivum* L. winter type of development with the further obtaining of genotypes with increased adaptability, plant productivity and grain quality through the use of winter common wheat with purple grain, whole grain wheat and Ethiopian wheat in

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hybridization. In the study, the methods of conducting the examination of plant varieties are used for carrying out phenological observations, morphological studies, evaluation of breeding material according to economic and valuable characteristics. In the creation of new forms, methods of hybridization and individual selection were used, and the TVEL method was used for pollination. The protein and gluten content were determined by infrared spectrometry. Parental components were studied and selected to expand the forming process to obtain productive grains from the main ear, thousand kernel weight, high grain quality, resistant to lodging, shedding of grain, drought-resistant and resistant to fungal pathogens, hybrid forms, specifically as a result of involvement of the source material *Triticum aestivum* L. and *Triticum sphaerococcum* Perc. in the hybridization. According to the results of the hybridization of winter common wheat and Ethiopian wheat, it was possible to obtain and breed in F_4 forms with a long ear (>10-11 cm), an increased amount of grain from the main ear (>55 pcs.) and a different colour of grain from dark brown to purple, as an indicator of increased anthocyanin content and high antioxidant capacity. The practical value of this study lies in the fact that the research results expand information on the use of winter common wheat in the selection of productivity and quality of other types of wheat: *Triticum sphaerococcum*, *T. aethiop.* var. *decoloratum*, and the developed proposals will allow considering the use of parental components of wheat in research, help improve methods of hybridization and selection of new forms with desirable traits in the system of interspecies crossings

Keywords: *Triticum aestivum* L.; *Triticum sphaerococcum* Perc.; *T. aethiopicum* var. *decoloratum* Jakubz.; selection for productivity and quality; interspecific hybridization; new hybrid forms

INTRODUCTION

Genetic variability is the key to successfully improving the quantitative and qualitative parameters of the harvest, which is important in the context of food security, which involves not only sufficient food, but also its high quality to ensure human health. Wheat is an important agricultural crop, the grain of which is the main food product for humankind, especially in developing countries.

As noted by Čurná & Lacko-Bartošová (2017), spelled grains produce groats for making high-tasting porridge, also suitable for dietary food. L.A. Vecherska *et al.* (2018) indicate that emmer wheat is widely used in breeding programs, especially for the improvement of durum and common wheat.

Scientists (Hospodarenko *et al.*, 2018; Diordieva, 2018) note the positive effect of crossing common wheat and spelled wheat, which results in the expansion of a new genetic diversity that combines the high protein and gluten content of spelled and the high productivity of wheat (Liubych *et al.*, 2019). The authors (Liubych, 2019) note that spelled wheat has a high content of protein, vitamins, macronutrients, carbohydrates and fats, which are easily and quickly absorbed by the human body.

Many scientists (Grausgruber *et al.*, 2018; Morgounov *et al.*, 2020; Garg *et al.*, 2022), based on many years of research, report that it is relevant to use the biopotential of wheat varieties with blue and purple grains – sources of anthocyanins, when consumed finished products from which their antioxidant properties are manifested, i.e., the absorption of free radicals, which is important for the prevention of many human diseases. According to studies (Lachman *et al.*, 2017; Hrivna *et al.*, 2018; Tian *et al.*, 2018), Ethiopian wheat grain is also characterized by high cereal and pasta properties.

H.H. Kassegn (2018) notes that in the 1960s and 1970s, commercial varieties of wheat with purple grains were created in China, Australia, New Zealand, and many European countries as part of a healthy diet. Saini (2021) and Gupta (2021) report that the Plant Genetic Resources Center of Canada has received constant requests from breeders for the Ethiopian Valgiorgio wheat genotype to be used in breeding for adaptability and quality. Since then, work on the creation of wheat with purple grain continues all over the world.

Specifically, in the Czech Republic, the scientific program of winter wheat breeding is aimed at creating productive genotypes in combination with high quality, including an increased content of anthocyanins, the latter is achieved by the "transfer" of purple colour to grain forms. Other scientists (Hong *et al.*, 2019) created five new mutations with purple grain colour using gamma irradiation of the hexaploid line of purple wheat K 4191 to improve its quality.

As noted by breeders (Leonov *et al.*, 2022), samples with blue and purple kernels were characterized by a lower yield compared to common wheat, but were characterized by a high content of phenols in the meal (over 800 µg/g of gallic acid equivalent), anthocyanins and increased antioxidant activity (over 500 µg/g of chlorogenic acid equivalent. Other scientists (Hong *et al.*, 2019), based on the results of the evaluation of wheat mutant lines with variable grain colour, also note that anthocyanins and phenolic compounds in wheat grain contribute to high antioxidant potential, and therefore, the purple colour of the grain is associated with a higher anthocyanin accumulation and antioxidant capacity.

According to the literature review of scientific studies (Morgounov *et al.*, 2020), anthocyanin pigmentation in wheat is controlled by dominant alleles of the genes Rc (coleoptile), Pc (culm), Plb (leaf plates), Pls (leaf sheaths), Pp (grain pericarp), Pan (anthers) and Ra (ear stigmas). Researchers (Ma *et al*., 2021; Moskalets *et al*., 2022) recommend using classical or modern methods of breeding and genetic engineering to increase the content of phenols, essential amino acids in wheat grains, which increase the nutritional value of cereals and bakery products, which is important in the context of healthy eating.

Triticum sphaerococcum Perc. is an endemic species for southern Pakistan and northwestern India, where it was one of the main crops, belonging to the group of hexaploid whole wheats, forming a hemispherical, with a shallow groove and high protein content and gluten in grain (Szczepanek *et al*., 2020). As noted by M. Skrajda-Brdak *et al*. (2019), *Triticum sphaerococcum* grain is a source of common low molecular weight phytochemicals, especially phenolic acids, ferulic acid (93-95%), which was accompanied by higher quantitative and qualitative variability of homologs in sterols. Therefore, the hexaploid wheat species *Triticum sphaerococcum*, known as a source of grain quality traits, is recommended for use in common wheat breeding. H.S. Kolyucha (2011) indicates that lines with genetic material from *Triticum sphaerococcum* have the highest rates of sedimentation and gluten content.

The purpose of this study was to create new forms of common winter wheat *in* breeding for productivity and quality by using the gene pool of related wheat species.

MATERIALS AND METHODS

The scientific research program provided for a comprehensive evaluation of the source material for productivity, resistance to lodging, resistance to diseases, as well as for the created new forms of studying the laws of inheritance and relationships of valuable economic traits in the plant, selection of samples based on a complex of economic and useful traits.

The total set of source material was formed due to own efforts, as well as samples provided by the National Centre of Plant Genetic Resources of Ukraine. Agrotechnics of wheat cultivation were carried out according to the generally accepted for the Forest-Steppe zone of Ukraine. The collection of source material was established at the Nosivka Breeding and Research Station of the V.M. Remeslo Myronivka Institute of Wheat the National Academy of Agrarian Sciences of Ukraine (NAAS of Ukraine) (southern part of Polissia of Ukraine) in 2016 and stationary of the Institute of Horticulture of NAAS of Ukraine (Northern Forest Steppe of Ukraine) in 2017.

Parental forms for crossings were sown manually in the crossbreeding nursery on plots of 2 m^2, with a row width of up to 20 cm. Parent pairs for paired (simple) crosses and hybridization were selected in 2018 (Tables 1, 2). The main methods of creating new forms were hybridization and individual selection. Pollination method – TVEL method. Seeds F_{1-3} were sown manually.

Table 1. *Parental forms of winter common wheat, involved in crossing with round-grained wheat of the Donor Kyivskyi variety*

No.	Name of parent forms	Origin of parent forms
1.	KS 22-04 (UA0108013*)	♀Zoryana Nosivska (UA) × ♂Myronivska 61 (UA)
2.	L 41-95 (UA0108030)	♀Myrleben (DE&UA) × ♂Poliska 92 (UA)
3.	KS 21	♀ Zoryana Nosivska (UA) × Poliska 29 (UA)
4.	Donzorna	♀Donska n/a × ♂Zoryana Nosivska (UA)
5.	KS 14-05 (UA0123342)	(♀Marishuntsman (GB) × ♂ (♀Kyianka (UA) × ♂Pony (USA))
6.	L59-95 (UA0108016)	♀Donska n/a × ♂[♀(♀MarisMadler(GB) × ♂Rona (USA)) × ♂Donska n/a]
7.	Zoriana Nosivska (UA 0110603)	♀ (♀Obrii (UA) × ♂MarisYuntsman (GB)) × ♂MarisYuntsman (GB)
8.	Ariivka (a. c. 171136**)	♀Donska n/a × ♂K-6477/91

Note: ** is the number of the national catalogue assigned by the National Centre of Plant Genetic Resources of Ukraine; a.c. is the author's certificate for a plant variety suitable for distribution in Ukraine*
Source: *compiled by the authors*

Table 2. *Combinations with participation in the crossing of Ethiopian wheat and winter common wheat of the Chornobrova variety*

No.	Combination name
1.	*Triticum aethiopicum var. decoloratum (Vavilov)* Filat. × Ariivka
2.	*Triticum aethiopicum var. decoloratum (Vavilov)* Filat. × PKBRodika (Romania)
3.	*Triticum aethiopicum var. decoloratum (Vavilov)* Filat. × L 41-95
4.	L 59-95 × *Triticum aethiopicum* var. *decoloratum* (Vavilov) Filat.

Table 2, Continued

No.	Combination name
5.	*Triticum aethiopicum var. decoloratum (Vavilov)* Filat. × Donor Kyivskyi
6.	Chornobrova × KS 22-04 (UA0108013)
7.	(L 59-95 ×*Triticum aethiopicum* var. *decoloratum* (Vavilov) Filat.) × Chornobrova
8.	(*Triticum aethiopicum var. decoloratum (Vavilov)* Filat.× L 41-95) × Chornobrova
9.	Chornobrova × *Triticum aethiopicum* var. *decoloratum* (Vavilov) Filat.× L 41-95)

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

Hybrids (F_{2-3}) were analysed for morphological and economic characteristics (plant height, ear length, ear density, weight of grain from the main ear, a thousand kernel weight, protein, and gluten content in grain). The density of the main spike was calculated as the number of developed spikes per 10 cm of spike length. In the fourth generation (F_5), considering the indicators of productivity and grain quality of previous years, the best samples were selected, which are the object of research.

Plants were previously selected to determine plant height in laboratory conditions.

During the research, the weather conditions of 2016-2022 were characterized by contrast both in terms of temperature and the level of moisture supply. Notably, the 2016-2022 years of conducting research on changes in meteorological factors during the growing season of wheat differed among themselves and substantially deviated from the multi-year average value in individual months. Specifically, 2016 was excessively humid, 2017 was abnormally dry, and 2018 was also hot. The analysis of weather conditions in 2017-2018 showed that the vegetation of wheat plants took place during a moderately warm autumn, a long winter period with a significant cooling at the beginning of spring (the average monthly air temperature in March was 1.8°C, which is 3.6°C lower above the norm), a short-lived spring and a hot summer (the average air temperature was 18.8°C, which is 2.3°C higher than the norm). Precipitation during wheat growth and development was uneven. In autumn (October 2017), precipitation fell 80 mm or 197% of the norm, in winter – 130 mm or 290% of the norm, in summer (July) – more than 160 mm or 150% of the norm. Dry conditions were observed from mid-spring to the second decade of June. The weather conditions of 2019-2022 were more or less favourable for the development of wheat plants. Specifically, the weather conditions in 2019 and 2022 at the beginning of the growing season were moderately favourable for the development of winter crops, but the second half of the growing season was hot and dry.

The above-mentioned weather conditions during 2016-2022 helped comprehensively evaluate the source material by a set of features and to single out the most valuable samples adapted to the conditions of the northern part of the Forest Steppe of Ukraine.

The studies used generally accepted methods and their modifications, which ensured high objectivity of the obtained results. Phenological observations, visual assessment of breeding material for disease resistance, and laying were carried out pursuant to the Methods of examination of plant varieties (Tkachyk *et al*., 2016). The content of protein and gluten was determined by infrared spectrometry (Chen *et al*., 2017). Harvesting was carried out manually during the full ripeness phase. The reliability of the research results and the degree of variation of the signs were evaluated using the MS Excel program.

RESULTS

The raw material of wheat was studied according to the productivity of the ear and its elements. On average, during the 2016-2017 research, the highest grain mass of the head ear, its grain size was determined in samples of winter common wheat KS 22-04, L 41-95, L 59-95, Zoryana Nosivska, Ariivka, KS 14 and KS 21, which were involved in hybridization. In 2018, hybrid grains were obtained, and in 2019 – the first generation, which was impressive with its morphological features and physiological features.

During the study of the source material, it was found out that the Donor Kyivskyi round-grained wheat has a number of positive economic characteristics: high heat resistance, vertical type of placement of the flag leaf, low stem, high resistance to lodging, high grain quality and baking quality. However, there are some negative signs, such as low grain mass from the main ear and a thousand kernel weight, high ear density, fine grain.

Crossing hexaploid common wheat with durum wheat, which also belongs to the group of hexaploid wheats, makes it possible to obtain fertile offspring, etc. Since this group of crosses (*Triticum aestivum* L. × *Triticum sphaerococcum* Perc. and *Triticum sphaerococcum* Perc. × *Triticum aestivum* L.) is characterized by normal seed setting by hybrid plants, as viable gametes are formed during normal chromosome conjugation in meiosis, the fusion of which produces a viable hybrid seed.

To obtain competitive forms with good grain and flour quality indicators based on the involvement of this species in crossbreeding, high-yielding common wheat samples with complex resistance to common pathogens were used as parental forms (Fig. 1).

***Figure 1**. Parental and hybrid forms (varieties, lines) of winter wheat involved in crossing: 1. Donor Kyivskyi; 2. Nosivochka (L 59-95); 3. F_1(♀Donor Kyivskyi x ♂KS 22); 4. F_1 (♀Donor Kyivskyi x ♂KS 21); 5. Zoriana Nosivska; 6. L 41-95; 7. KS 14-05; 8. Donzorna (KS 5); 9. KS 21; 10. KS 22-04; 11. Ariivka*

***Source**: photographed by the authors*

The Donor Kyivskyi round-grained wheat variety, as the mother form, was short (71.5-75.5 cm) and resistant to lodging (9 points), its ear is characterized as dense. Line KS 22-04, which is characterized by high strength of the stem near the second and upper internodes, increased weight of grain from the ear and a thousand kernel weight, high winter hardiness (9 points), high resistance to lodging (9 points), high resistance to pathogens of brown rust, root rot and powdery mildew (9 points) was used in the cross-breeding as both the maternal and paternal forms.

The analysis of the crop structure suggests that the hybrids of the first generation of common wheat from round-grained wheat were represented by a low and strong stem, a medium or short ear, a spherical ear scale and a rounded grain. In the second-third generations, plants were selected that were mostly close to common wheat in terms of morphotype (shape, density, and length of the ear, number and weight and size of grain, thousand kernel weight, etc.) and were endowed with the characteristics of round-grained wheat (strength of the stem, vertical placement of the flag leaf, etc.).

The most vivid examples of the selected forms are selection number 0271/18 (Donor Kyivskyi × Ariivka), which forms an ear 11.8 cm long, white, pyramidal, spiny, while the spiny spikes are lobed, their length is 4.3-8 cm; the number of spikelets – 20-21 pcs., 4-6 grains per spike and up to 80 grains from the main spike, weighing up to 3.6 g (Table 3).

***Table 3.** Indicators of comparative study of parental components and selected new breeding material*

Selection number	Name of the parent forms involved in crossing	Plant height, cm	Ear length, cm	Ear density***	Number of grains per ear, pcs.	Grain weight per ear, g	TKW, g
100/18	♀Donor Kyivskyi	71.5	6.5	26.5	41	1.63	38.7
101/18	♂KS 22-04*	88.5	9.3	17.5	52	2.37	51.2
0270/18	F_4 (♀Donor Kyivskyi × ♀KS 22)	90.3	8.4	14.8	45	1.85	46.8
0153/18/11	F_4(♀KS 22 × ♂Kyivskyi Donor)	80.2	9.8	16.6	57	2.28	49.4
0304/18	♂L 41-95*	83.5	7.6	18.5	65.7	2.17	50.6
0288/18	F_4(♀Donor Kyivskyi × ♂L 41-95)	69.7	6.7	20.3	58.5	1.76	48.5
0272/18/1	F_4(♀L 41-95 × ♂Donor Kyivskyi)	89.5	7.0	17.7	68.4	2.05	50.0
0272/18/2	F_4(♀L 41-95 × ♂Donor Kyivskyi)	77.5	7.5	18.0	60.5	2.31	52.6
103/18	♂L59-95*	85.8	7.9	18.4	45.6	2.11	50.5
0231/18	F_4(♀Donor Kyivskyi × ♂L 59-95)	80.2	8.3	16.5	47	2.30	51.1

Table 3, Continued

Selection number	Name of the parent forms involved in crossing	Plant height, cm	Ear length, cm	Ear density***	Number of grains per ear, pcs.	Grain weight per ear, g	TKW, g
104/18	♂Zoriana Nosivska	91.5	6.8	15.6	42	2.0	48.9
0230/18	F_4(♀Donor Kyivskyi × ♂Zoriana Nosivska)	78.5	6.4	19.6	39	1.89	44.8
0180/18	F_4(♀Zoriana Nosivska × ♂Donor Kyivskyi)	84.5	7.2	17.7	46	2.14	49.6
105/18	♂Ariivka* (a.c. 171136)	82.0	7.7	16.9	56	2.28	50.5
0271/18	F_4(♀Donor Kyivskyi × ♂Ariivka)	76.5	11.8	17.5	77	3.62	52.4
107/18	♂KS 14-05*	81.5	7.9	16.8	54	2.09	48.6
0227/18	F_4(♀Donor Kyivskyi × ♂KS 14)	76.3	7.5	18.5	44	1.88	46.4
0235/18/4	F_4(♀KS 14 × ♂Donor Kyivskyi)	85.7	8.6	15.9	56	2.45	53.5
109/18	♂KS 21	97.5	9.8	17.0	48	1.95	46.9
0233/18	F_4(♀Donor Kyivskyi × ♂KS 21)	86.5	8.2	19.4	53	2.22	48.2

Note: *the variety is erytrospermum; ** variety is spikatum; *** pieces of ears of corn/10 cm of spike rod length*
Source: *compiled by the authors*

Table 3 shows that individual selection numbers exceed the parental components in a number of features. Specifically, the numbers 0153/18/11, 0272/18/2, 0235/18/4 and 0233/18 exceed the number of grains from the main ear. Breeding numbers 0235/18/4, 0233/18 and others exceed the parents by the thousand kernel weight. Notably, the samples that substantially exceed the parental forms in terms of the length of the main ear were selected, namely, these are 0153/18/11, 0180/18, 0271/18, 0235/18/4, etc. Therewith, the combination of common wheat and round-grained wheat makes it possible to select samples with a lower ear density in the formation.

The degree of heterosis in the first generation helps predict the occurrence of transgressions in subsequent generations, which increases the efficiency of selecting samples with the desired traits in hybrid populations. In 2019, the degree of dominance and the degree of heterosis in the first generation were determined. The dominance and super-dominance of the mother component is established by the following characteristics: ear length, amount and mass of grain from the main ear. In terms of ear length, number and mass of grains in the ear, plants in the first generation exceeded one of the parent components. Therewith, the degree of phenotypic dominance was 1.14%, 1.63%, and 1.54%, respectively, which indicates positive over-dominance.

In the F_{2-3} generations, plants that were similar in phenotype to common wheat, but combined the characteristics of round-grained wheat, but also characterized by different stem heights (59.5-92.7 cm), as well as from spherical to the ovoid shape of the spikelet scale, rounded, oval, and ovoid grains, glabrous, semi-spinous, and spinous samples (Fig. 2).

Figure 2. *Formation in F_2 according to the ear of the hybrid combination Donor Kyivskyi × L 59-95: 1-3 – hybrids of the second generation*
Source: *photographed by the authors*

From one of the best combinations, it was possible to get hybrid forms, namely 0153/18/1, 0153/18/62, 0153/18/18, 0153/18/33, which inherited from the pollinator a strong stem of the semi-dwarf type, vertical placement of the flag leaf. The formation of common wheat and spherical wheat during hybridization helped select forms with gray and dark green colours of the ground part, with an increased number and mass of grains from the main ear, and different grain shapes (Table 4). Through interspecific hybridization, forms with increased productive bushiness were selected, namely, selection number 0153/18/11 (Fig. 3). Hybrid forms of the donor KS 22 combination are also characterized by a different ear morphotype (Fig.4). It is worth noting that the new forms of the above combination are characterized by increased resistance to fungal diseases, namely powdery mildew and fusarium head blight, as well as resistance to grain shedding and lodging (Table 5).

***Table 4**. Indicators of comparative study of parental components and selected new breeding material*

Variety/hybrid name	Plant height, cm	Ear length, cm	Ear density	Number of grains from the main ear, pcs.	Mass of grain from the main ear, g	Grain shape
♀Winter common wheat KS 22-04	88.5	9.3	17.5*	52	2.23	ovoid
♂Winter round-grained wheat Donor Kyivskyi	67.9	6.5	26.5	41	1.63	rounded
$F_4$0153/18/1	60.9	6.7	21.5	48	1.71	rounded
$F_4$0153/18/11	80.2	9.8	16.6	57	2.28	oval
$F_4$0153/18/62	62.6	8.8	16.2	54	2.42	ovoid
$F_4$0153/18/18	65.5	7.3	20.5	47	1.72	ovoid
$F_4$0153/18/7	89.5	8.2	18.7	44	1.85	oval
$F_4$0153/18/81	92.7	6.9	25.6	43	1.56	rounded
$F_4$0153/18/33	79.5	9.1	17.2	49	1.94	ovoid

***Note**: *17-22 – ear of medium density; 23-28 – dense ear*
***Source**: compiled by the authors*

***Figure 3**. Crossbreeding scheme: ♀KS 22-04 × ♂Donor Kyivskyi, selection in the first-third generations and the result of selection in the fourth generation ($F_4$0153/18/11)*
***Source**: photographed by the authors*

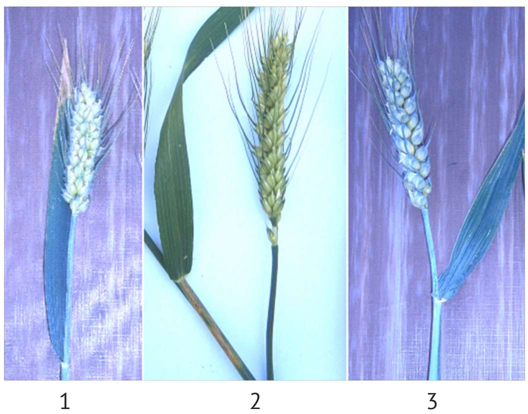

***Figure 4**. Comparison of the parent forms with the original hybrid form according to the characteristics of the main ear: 1 – round-grained wheat of the Donor Kyivskyi variety; 2 – common wheat of the KS 22 line; 3 – F_4 (Donor Kyivskyi × KS 22)*
***Source**: photographed by the authors*

***Table 5**. Results of field studies of indicators of economic suitability of new hybrid forms in comparison with parent components*

Variety/hybrid name	Resistance to adverse abiotic and biotic factors, score						
	lodging	abscission	droughts	powdery mildew	brown rust	fusariosis	winter hardiness
♀Winter common wheat KS 22-04 (UA0108013)	8	9	8	7	8	8	9
♂Winter round-grained wheat Donor Kyivskyi	8	9	7	8	8	9	8
F_4 0153/18/1	8	8	8	8	8	9	9
F_4 0153/18/11	8	9	8	8	8	9	9
$F_4$0153/18/62	8	9	8	8	8	8	9
$F_4$0153/18/18	8	9	8	8	8	9	9
$F_4$0153/18/7	8	9	8	8	8	9	9
$F_4$0153/18/81	8	9	7	8	8	8	8
$F_4$0153/18/33	8	9	7	8	8	8	8

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

It was found that through interspecies hybridization of winter common wheat and round-grained wheat, both through direct crossing and backcrossing, it is possible to increase the content of protein and gluten in new forms (Fig. 5) and to improve the properties of the dough, namely elasticity, extensibility, and gas retention ability of the dough, which positively affected the baking characteristics (Fig. 6).

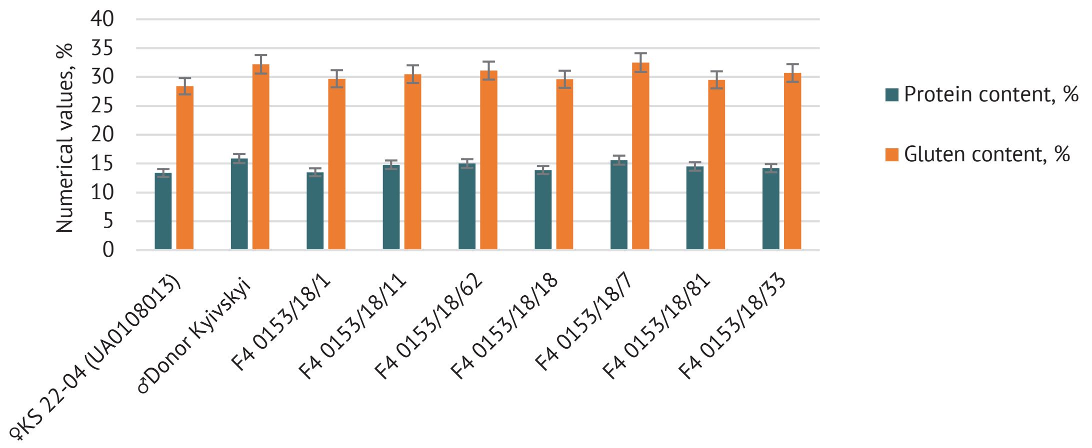

***Figure 5**. Protein and gluten content in new wheat samples compared to parental components*
***Source**: compiled by the authors*

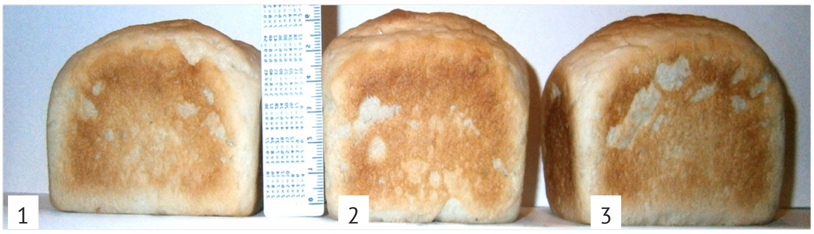

***Figure 6**. Comparison of loaves from the flour of the parent components and the hybrid form $F_4$0153/18/11: 1 – winter common wheat line KS 22-04; 2 – winter round-grained wheat of the Donor Kyivskyi variety; 3 – hybrid form $F_4$0153/18/11*

***Source**: photographed by the authors*

For the second group of crosses, species of the same genus, with a slightly different genomic composition, were selected: ♀*Triticum aestivum* L. (genomic formula AABBDD) and ♂*Triticum aethiopicum* Jakubz. var. *decoloratum* (Vavilov) Filat. (genomic formula AABB), but with the same A and B genomes, and therefore in hybrid populations, plants with an intermediate number of chromosomes will be gradually eliminated, and in the end, only two groups of plants will remain, approaching the original species in terms of phenotype.

The use of Ethiopian wheat as a pollinator had certain difficulties. Firstly, Ethiopian wheat is of a spring type of development, and to use it as a pollinator as best as possible, the mother form was subjected to vernalization and sown in the spring. This made it possible to obtain conditioned parent components for crossing. Second, Ethiopian wheat was sown in the fall at different times (midterm – September 30, late – October 15, and very late – November 10). The following growing year, the best ones were selected from the surviving Ethiopian wheat plants for further use in hybridization as pollinators. In such crossings, there is a significant part of homologous chromosomes. In F1 hybrids, during meiosis, many fertile gametes of parental species with 14 and 24 chromosomes are formed, which, during fusion, give rise to the formation of 28- and 42-chromosome parent species of wheat with stable heredity. Therewith, a fairly high percentage of seed set (⩾48%) and field similarity of 23=65% was noted, depending on the combination of crossing. In subsequent generations, among the main mass of plants, hybrid variability was already observed in the group of hexaploid and tetraploid wheat species, which increased with each generation. Part of the plants in F_2 and F_3 retained F_1 traits, which sharply decrease in subsequent hybrid generations. In this group of hybrids, recombinations were noted according to genetic morphological features and physiological and biochemical properties. For example, increasing the winter hardiness of plants morphologically similar to Ethiopian wheat, acquired from common winter wheat, a change towards decreasing grain mass from the main ear, the brown colour of the grain of common wheat to dark brown and purple through the expression of genes in Ethiopian wheat, etc.

Thus, the type of crossing of wheat species with different numbers of chromosomes is *T. aestivum* × *T. aethiopicum* var. *decoloratum* is accompanied by splitting and a relatively quick return of the hybrid offspring to the original parental species in terms of morphogenetic structure. For instance, in some hybrids of hexaploid wheat (*T. aestivum*) with tetraploid wheat (*T. aeth.* var. *decoloratum*), 42- and 28-chromosomal wheats with a stable species constitution of the parental species, but not the original varieties, were isolated already in F_2. In the F_3 and F_4 generations, the highest level of the shape-forming process was noted, while a significant range of variability was noted for several morphological signs and physiological properties: plant height; the length, shape, density, colour and grain size of the ear; the degree of manifestation of thorniness; the colour and placement of the flag leaf, the shape, mass and colour of the grains; the colour of spike scales, the duration of the growing season and winter hardiness of plants. Specifically, the forming process was dominated by samples with a loose, mostly spindle-shaped ear, oval in cross-section, while both spiny and semi-spiny forms, which had a light threshing, were selected. We also selected plants with a weak wax coating, a long ear (about 9 cm), spines with long and thin, almost parallel spikelets, with a clear sharp keel tooth on the spikelet scale, elongated-oval, purple, rarely dark brown grain, which was inherent in the paternal form, and with such features as a thickened stem, high grain size, average density of the ear, increased mass of grains from the main ear and plant, etc., which are more inherent in the maternal form.

Below are breeding samples that substantially exceed their parent forms in terms of economic characteristics. One of the interesting forms is selection number 0260/18 (*T. aethiopicum* var. *decoloratum* × Pekabe). The height of the plant exceeds 98 cm, the ear is white, spiny, 11.2 cm long, the lobes are 3.5-8 cm long, it contains 21 ears. Keel to the base, the shoulder is narrow or very narrow and bevelled, the tooth is straight up to 5 mm. The shape of the grain is oval or elongated-ovoid, the colour is dark brown with fragments of purple, the groove is of medium depth, the hair is short. The number of grains from an ear is 62 pcs., the weight of grains from an ear is 3.18 g, the thousand kernel weight is 52.0 g (Table 6).

***Table 6**. Indicators of comparative study of parental components and selected new breeding material*

Variety/hybrid name	Plant height, cm	Productive bushiness, pcs.	Ear length, cm	Number of grains from the main ear, pcs.	Mass of grain from the main ear, g	TKW, g	Grain colour	Winter hardiness, points
♀*T. aethiopicum*var. *decoloratum*	85.7	1.8	8.2	27.2	1.12	36.8	purple	3.1
♀Winter common wheat Pekabe variety	99.5	2.4	9.3	52.1	2.23	44.6	brown	8.8
0260/18	98.2	2.6	11.2	62.0	3.18	52.0	dark brown	6.5
0266/18 (T. aethiop. var. *decolor.* × Donor Kyivskyi)	86.5	2.1	7.1	54	2.19	40.8	brown	5.5
0262/18 (*T. aethiop.*var. *decolor.* × L 41-95)	88.3	3.5	10.8	61	2.48	50.4	brown	6.0
0143/18 (L 59-95 × *T. aethiop.* var. *decolor.*)	108.5	2.4	11.1	49	1.9	54.4	purple	6.3

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

Another selection number 0266/18 (*T. aethiopicum* var. *decoloratum* x Donor Kyivskyi), which in economic terms substantially (p>0.05) exceeds the parent forms. The specimen forms plants with a height of 86.5 cm, white, prismatic, 7.1 cm long, semi-spiny ear, and the length of the spikelets is 3-3.6 cm; scales are ovoid-rounded, the number of spikelets is about 19 pcs., the keel is clear, the tooth is bent, 1 mm long, the shoulder is short, narrow and bevelled. The seeds are brown, round-oval, the hair is medium, the groove is not deep. Number of seeds – 54 pcs., weight – 2.19 g, thousand kernel weight – 40.8 g. Sample 0262/18 (*T. aethiop.* var. *decolor.* × L 41-95) is 88.3 cm tall, has a white, spiny spike, 10.8 cm long spike, 5.3-7.7 cm long spikes, contains 22 ears. The keel of the spikelet scale is distinct, the shoulder is medium, straight with a hump, the tooth is straight up to 10 mm long. The seeds are dark brown with a purple tint, elongated-ovoid in shape, 7-9 mm long, the hair is medium, the groove is not deep. The number of grains from an ear is 61, the weight of grains from an ear is 3.48 g, the TKW is 60.4 g (Fig. 7).

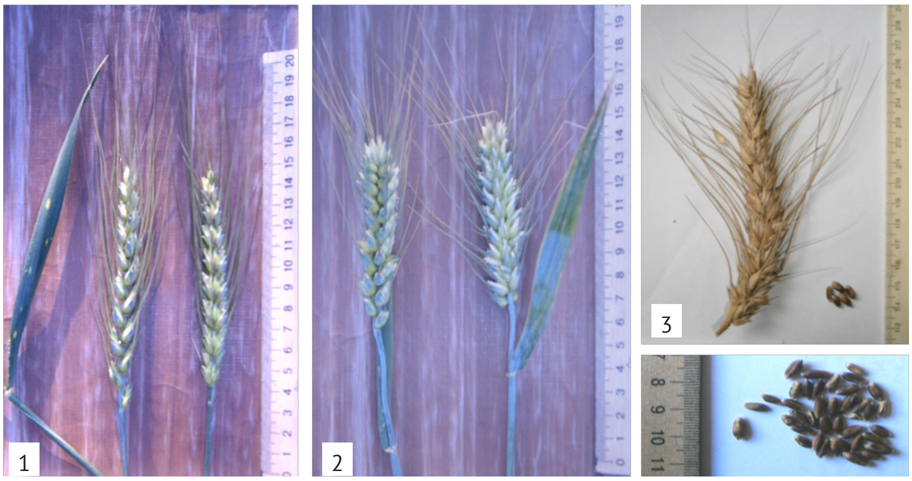

Figure 7*. Comparison of parental components and hybrid forms by ear: 1. ♀Triticum aethiopicum var. decoloratum (Vavilov) Filat.; 2. ♂ winter common wheat variety L 41-95; 3. F$_4$0262/18 (Triticum aethiopicum var. decoloratum (Vavilov) Filat. × L 41-95)*

Source*: photographed by the authors*

Sample 0143/18 (L 59-95 × *T. aethiopicum* var. *decoloratum*) forms productive plants 108 cm tall, while the spike length is over 11 cm. The spikelet is white, pyramidal, spiny, spikelets 3.7-9 cm long, contains 22 spikelets. The keel is clear, the tooth is straight, 4 mm long, the shoulder is narrow and straight. The sample is characterized by anthocyanin on the stem under the ear. The seeds are brown, elongated-ovoid, wrinkled. The number of grains from the main ear is 49 pcs., the mass from the main ear is 1.82 g, the TKW is 54.4 g. The length of the upper internode is 14 cm (Fig. 8).

Figure 8*. Comparison of parental components and hybrid forms by ear: 1.♀Triticum aethiopicum var. decoloratum (Vavilov) Filat.; 2. ♂ winter common wheat variety Nosivochka (L 59/95); 3. F$_1$0143/18; 4. F$_4$0143/18 (L 59-95 × T. aethiop.var. decolor.)*

Source*: photographed by the authors*

Notably, one of the disadvantages of the above-mentioned hybrids is low complex resistance to all adverse abiotic factors in the winter and early spring periods, such as sharp temperature drops, long thaws, i.e., the winter hardiness of winter-spring hybrids did not exceed 6 points, which is determined by the strong influence of the spring component, which was taken in simple crosses as a pollinator. This fact is confirmed by the research of scientists of the V.M. Remeslo Myronivka Institute of Wheat of the National Academy of Sciences of Ukraine (Vlasenko *et al.*, 2012).

In this regard, selection numbers 0260/18, 0266/18, 0262/18, 0143/18, which are superior in terms of economic characteristics, are involved in hybridization with common wheat samples characterized by increased winter and frost resistance. It was possible to expand the forming process of obtaining winter-resistant and samples with purple grain due to the involvement of the Chornobrova winter wheat variety in the crossbreeding.

DISCUSSION

According to the international organization IGC (2021), hexaploid bread wheat (*Triticum aestivum* L., 2 n=6 x=42, BBAuAuDD) accounts for about 90% of wheat production in the world. Researchers (Kopecky *et al.*, 2022) note that the genetic diversity of cultivated wheat is narrowing and increasingly becoming unsatisfactory in resistance to new pathogenic races and adverse environmental factors. Therefore, in the breeding of common wheat, the diversity of wheat species is a rich source of useful genes that can expand the shaping process and provide new forms with high nutritional quality and resistance to adverse abiotic and biotic factors. J. Zhou *et al.* (2022) note that such breeding approaches help introduce valuable genes from distant species into cultivated species, and are an important driving force for their improvement. In this context, the selection of wheat varieties with better resistance to biotic and abiotic stresses is crucial and, therefore, as J. Laugerotte *et al.* (2022) state, is a priority for agriculture.

The analysis of data on the quality of grain of round-grained wheat and common wheat hybrids indicates an increased content of protein and gluten, compared to the parental form. This is also noted by J.B. Alvarez *et al.* (2017) based on the results of an analogous research on interspecies hybridization regarding the improvement of grain quality in new forms of wheat. S. Michel *et al.* (2018) are convinced that in this way it is possible not only to influence the quality indicators of the grain, but also to improve the baking quality of bread wheat. This is also noted in the research. However, I.I. Motsnyi *et al.* (2019), based on the results of research, demonstrated that the increase in the protein content of the grain, which is observed in distant crossings, is not always associated with an improvement in the quality of flour.

Biologist, geneticist (Hughes, 2020) claims that the yield of flour from hemispherical grains was higher in hybrids obtained by crossing common wheat and round-grained wheat than in hybrids with more elongated grains. W. Hughes (2020) also notes that the localization of the *s* gene, which is considered responsible for the sphericity of the grains, was investigated in the hybrids created by interspecies hybridization, but this question is open. This is noted by Salina *et al.* (2000), who mapped the *S*1, *S*2, and *S*3 genes of an induced spherococcal mutation in common wheat (*Triticum aestivum*) using the resulting F_2 hybrid populations that were obtained with the participation of round-grained wheat. And considering this difference, W. Hughes (2020) identified the gene Tasg-D1, which is responsible for the round grain phenotype, and allows directing the future selection or genetic engineering of round-grained wheat varieties, with the purpose of obtaining high-yielding forms of wheat with increased flour yield. Scientists (Cheng *et al.*, 2020) isolated the Tasg D1 gene (Ta – *Triticum aestivum*; sg – hemispherical grain; D1 – the first sg gene identified in the D genome) in round-grained wheat, which is responsible for the spherical or spheroid shape of the grain. Previous studies by the above authors were also based on hybridization of *T. aestivum* with *T. sphaerococcum*, where they observed complete dominance of *T. aestivum* over *T. sphaerococcum*, indicating that the inheritance of *T. sphaerococcum* is controlled by a single pleiotropic gene. The scientists noted the expression of the discovered TaSG-D1 gene in various plant tissues, specifically, it was clearly expressed in the meristem of the shoot, roots, ear, grain, stem, and ovary tissue. Therefore, based on the above, the effect of Tasg-D1 on plant architecture associated with the *s* locus is pleiotropic. As noted by *Vlasenko et al.* (2012), the corresponding cleavage ratio corresponded to H. Mendel's model – 3:1 (plants with elongated grains/plants with hemispherical grains), indicating that the trait of hemispherical grains is controlled by a single nuclear gene, which is consistent with previous findings that the Tasg-D1 gene homologue in the A genome contributes to the development of hemispherical grain.

Most researchers (Osmachko *et al.*, 2020; Motsnyi *et al.*, 2021) note that as a result of introgressive hybridization, i.e., in genetics, it is the transfer of a gene from one species to the gene pool of another through repeated backcrossing of an interspecies hybrid with one of the parent species, it is possible to create valuable raw material for use in wheat improvement programs both in terms of quality and resistance to a complex of pathogens.

Breeding work with Ethiopian wheat made it possible to obtain valuable lines characterized by disease resistance, dark brown and purple grain colour, but with medium and weak winter hardiness. Interspecific hybridization between hexaploid and tetraploid wheat species leads to the development of pentaploid F1 hybrids with a unique chromosomal structure. But the hybrids obtained by crossing common wheat (*Triticum aestivum* L.) and Ethiopian wheat (*Triticum aethiopicum*) can improve the genetic origin of either parent through the transfer of interesting traits in further selection. Genetic variability derived from the two wheat species and transferred to pentaploid hybrids has the potential to improve disease resistance, abiotic tolerance and grain quality, as well as to improve agronomic traits. Therefore, as noted by S. Padmanaban *et al.* (2017), interploid hybridization can be a promising tool for the development of wheat genotypes that can have high productive and adaptive potential under changing climatic conditions. To obtain hybrids with increased winter resistance and purple and high-quality grain, the Chornobrova variety was used in the hybridization. According to Zhygunov *et al.* (2018), from the grain of common wheat of the Chornobrova variety, the yield of varietal flour exceeds 67%, which is 7% higher, and the yield of bran is 32.5%, which is 15% less than that of the best Kuialnyk variety. Therewith, the Chornobrova variety has even higher indicators of flour strength, indices of stretchability and elasticity of the dough, the yield of groats, compared to the above-mentioned variety. Other researchers (Homichak *et al.*, 2018) note that it is possible to obtain modified flour from the grain of the Chornobrova common wheat variety. As noted by G.M. Hospodarenko *et al.* (2021), winter common wheat wheat of the Chornobrova variety is promising for obtaining new types of modified wheat flour with changed technological parameters. Additionally, the grain of the common wheat variety Chornobrova has an increased content of essential amino acids. The following scientists, authors of the Chornobrova variety (Rybalka *et al.*, 2018) also claim that the Chornobrova variety is also gaining popularity in technologies for the production of nutritionally useful bread from sprouted grain (without flour and yeast) and healing juice from green 8-9-day sprouts. Therefore, the Chornobrova variety is also recommended to be used in breeding programs to create new varieties of winter common wheat, since modern breeding programs require constant enrichment with new genetic plasma and this is a condition without which progress in breeding is impossible.

Summarizing the above, as a result of interspecies hybridization, it is possible to obtain new forms of common wheat with desirable economic characteristics for further selection and crossings to obtain constant lines with increased productivity and quality for further breeding.

CONCLUSIONS

According to the results of interspecies hybridization, it was possible to expand the form-making process of obtaining hybrid populations and select the best forms of wheat with desired economic characteristics such as productivity and quality.

With the participation of selected types of wheat *T. aethiopicum* var. *decoloratum* and *Triticum sphaerococcum* Perc., new semi-dwarf (up to 85 cm tall) and short (over 85-105 cm tall) forms of winter wheat with purple grain, high resistance to lodging, and prominent protein content were created. The scientific provisions regarding the effectiveness of involving in the selection process of common wheat the related species of wheat – *T. aethiopicum* var. *decoloratum* and *Triticum sphaerococcum* Perc. – found further development.

The hybrid forms of the parent forms – common wheat x round-grained wheat are characterized mostly by a strong stem, short and semi-dwarf type, loose or medium-density ears, rounded spike scales and grains. Furthermore, the forms of the above combination are characterized by increased resistance to fungal diseases, in particular powdery mildew and fusarium head blight, as well as resistance to grain shedding and lodging.

Through the hybridization of winter common wheat and Ethiopian wheat, it was possible to form and select the best selection numbers 0260/18, 0266/18, 0262/18, 0143/18, which differ from the parental forms in the length of the ear, the number and mass of grains from the main ear, thousand kernel weight, increased drought resistance. Their lower winter hardiness compared to winter common wheat prompted to continue the selection work with them and involve them in hybridization with more winter- and frost-resistant varieties (lines). Specifically, this was achieved due to the involvement of the Chornobrova winter wheat variety in the crossbreeding, which helped obtain from combinations (L 59-95 × *Triticum aethiopicum* var. *decoloratum* (Vavilov) Filat.) × Chornobrova; *Triticum aethiopicum* var. *decoloratum* (Vavilov) Filat.× L 41-95) × Chornobrova; Chornobrova × (*Triticum aethiopicum* var. *decoloratum* (Vavilov) Filat.× L 41-95) winter-hardy hybrid forms with purple and dark brown grains. A promising direction of further research is the involvement of new forms of winter common wheat in the breeding process to create adaptive, high-yielding varieties with high grain quality.

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CONFLICT OF INTEREST

None.

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Розширення формотворчого процесу в селекції пшениці м'якої озимої на продуктивність і якість шляхом використання генофонду споріднених видів пшениць у рамках продовольчої безпеки

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Анотація. Розширено формотворчий процес у селекції пшениці м'якої озимої на продуктивність і якість шляхом використання генофонду споріднених видів. Метою досліджень було розширити формотворчий процес в селекції *Triticum aestivum* L. озимого типу розвитку з подальшим отриманням генотипів з підвищеною адаптивністю, продуктивністю рослин і якістю зерна за рахунок використання в гібридизації пшениці м'якої озимої з фіолетовим зерном, пшениці шарозерної і пшениці ефіопської. В роботі використані методики проведення експертизи сортів рослин з проведення фенологічних спостережень, морфологічних досліджень, оцінки селекційного матеріалу за господарсько-цінними ознаками. В створенні нових форм використані методи гібридизації і індивідуального добору, щодо запилення – твел-метод. Вміст білка, клейковини визначали методом інфрачервоної спектрометрії. Вивчено і підібрано батьківські компоненти, щоб розширити формотворчий процес з отримання продуктивних за кількістю і масою зерен з головного колосу, масою 1000 зерен, високою якістю зерна, стійких до вилягання, обсипання зерна, посухостійких і резистентних до збудників грибних хвороб гібридні форми, зокрема у результаті залучення до гібридизації вихідного матеріалу *Triticum aestivum* L. і *Triticum sphaerococcum* Perc. За результатами гібридизації пшениці м'якої озимої і пшениці ефіопської вдалося отримати і добрати в F_4 форми з довгим колосом (>10-11 см), підвищеною кількістю зерна з головного колоса (>55 шт.) і різним забарвленням зерна від темно-коричневого до фіолетового, як показника підвищеного вмісту антоціану та високої антиоксидантної здатності. Практична цінність роботи полягає в тому, що результати досліджень розширюють відомості про використання в селекції пшениці м'якої озимої на продуктивність і якість інших видів пшениць: *Triticum sphaerococcum*, T. aethiop. var. *decoloratum*, а розроблені пропозиції дозволять узяти до уваги використанні в дослідженнях батьківські компоненти пшениці, покращити способи проведення гібридизації та добору нових форм з бажаними ознаками в системі міжвидових схрещувань

Ключові слова: *Triticum aestivum* L.; *Triticum sphaerococcum* Perc.; T. aethiopicum var. *decoloratum* Jakubz.; селекція на продуктивність і якість; міжвидова гібридизація; нові гібридні форми

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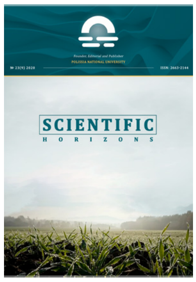

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Photosynthetic activity of sunflower hybrids under growth regulators in the Steppe of Ukraine

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Abstract. The climate of the southern steppe zone of Ukraine in recent years has been characterized by substantial warming, with a low, uneven amount of precipitation during the growing season of plants, which leads to a decrease in the reserves of productive moisture in the soil, and hydrothermal stress occurs in plants. Opportunities to increase the adaptation of plants to adverse factors are the use of plant growth regulators and the use of various methods of tillage aimed at preserving moisture. The purpose of this study was to investigate the influence of the plant growth regulator AKM+Ca on the operation of the photosynthetic apparatus of sunflower hybrids against the background of various methods of basic tillage in the conditions of the Southern Steppe of Ukraine. The following methods were used during the study: field, chemical (to determine qualitative indicators), and statistical (to assess the reliability of data). Field studies were conducted during 2017-2019 on southern heavy loamy chernozems. In the experiment, modified plant growth regulator AKM+Ca was used for pre-sowing

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seed treatment and foliar spraying of sunflower plants (beginning budding phase) of Talento and Colombi hybrids against the background of deep loosening or ploughing. It was found that the use of deep loosening, in contrast to ploughing, helps increase the dry matter content in sunflower plants and the net productivity of photosynthesis due to better preservation of moisture in the soil. The use of plant growth regulator AKM+Ca, regardless of the method of soil cultivation, contributes to the increase in the leaf surface area up to 31.2%, increases the photosynthetic potential of plants to 21.6% and the net productivity of photosynthesis to 15.9% during the growing season, and also increases the content of dry matter, compared to the control. The proportion of influence of the plant growth regulator AKM+Ca on the formation of the leaf surface area is 54.2%. The maximum positive effect was obtained with the combined use of AKM+Ca for pre-sowing treatment and spraying of sunflower plants during the growing season against the background of deep loosening of the soil. The research results can be used to adjust elements of agricultural technologies for growing sunflower seeds, increase crop productivity and conduct profitable agribusiness

Keywords: photosynthetic potential; net photosynthesis productivity; sunflower; plant growth regulator; ploughing; deep loosening

INTRODUCTION

Sunflower (*Helianthus appiis* L.) is the main oilseed crop in Ukraine. In the Steppe zone of the country under the cultivation of this crop, the main cultivated areas are concentrated. This is a drought-resistant crop that can withstand soil and atmospheric droughts for a long time. The oil from this crop is biologically and technically valuable. It has a prominent caloric content; it has good taste properties. According to the Ministry of Economic Development, Trade, and Agriculture of Ukraine, in 2021, the sown area of sunflower amounted to 6.5 million ha. The growth of acreage allocated for sunflower indicates a prominent level of its profitability. New varieties and hybrids of sunflower, which are more resistant to drought, broomrape, diseases, etc., are being intensively introduced into production in Ukraine. Therewith, the yield of sunflower seeds in Ukraine is significantly lower than in European countries (Germany, France, the Czech Republic, etc.). Therefore, studies of modern sunflower hybrids to improve the elements of cultivation technology through plant growth regulators and various methods of tillage are relevant and of practical interest.

Another reason for the need to reduce sunflower crops is the imbalance of scientifically based crop rotations and a rather sharp decrease in soil fertility. Non-observance of crop rotation is a consequence of violation of the phytosanitary condition, use of large reserves of water from the soil (Tsyliuryk *et al.*, 2021; Degani *et al.*, 2022). Against the background of the deterioration of the crop structure, the characteristic features of the Steppe zone of Ukraine are increased water and wind erosion. This limits the use of fertilizers (due to insufficient precipitation), leads to soil degradation and loss of organic substances on chernozems. Galliano *et al.* (2018) and Fedchyshyn *et al.* (2022) believe that such issues point to the need to normalize the action of anthropogenic factors by introducing certain elements of technologies aimed at minimizing soil cultivation and moisture conservation.

Chaika *et al.* (2019) and Kolesnikov *et al.* (2022) believed that the aggravation of the ecological situation in agriculture and the gradual loss of soil fertility led to a rethinking of the essence of the formation of the agricultural landscape. This was prompted by the consequences of the catastrophic scale of maximum loosening and turnover of the soil slice during conventional cultivation.

Yeremenko *et al.* (2018) pointed out that the reason for the low realization of the genetic potential of new sunflower hybrids is also the imperfection of technological measures for plant adaptation to unfavourable growing conditions. This is compounded by the high cost of energy resources (fuel, fertilizers, pesticides) and the need to further increase crop productivity. The solution to this issue is possible by using preparations to regulate growth and production processes. In their works, the authors (Khan *et al.*, 2020) described that plant growth regulators stimulate the germination process, protect seeds during their prolonged stay in adverse conditions, increase the field germination of seeds, contribute to the active development of the root system, and improve mineral nutrition.

Kohut *et al.* (2020) noted that the photosynthesis that occurs during the growing season of plants is one of the key biological processes. Thanks to photosynthesis, organic substances are formed from carbon dioxide and water under the influence of light. It is known that 80-90% of solar radiation is absorbed by the green leaf surface and only 1-2% of this energy is used for photosynthesis, the rest goes for transpiration (very rarely this indicator reaches 5-8%) (Aslam *et al.*, 2021; Shafiq *et al.*, 2021). The use of the latest elements of technologies, including growth regulators, allows for better formation of the photosynthetic apparatus of agricultural plants. They help regulate individual stages of plant ontogenesis to mobilize the potential capabilities of the plant, and their effectiveness has been proven in several studies (Jan *et al.,* 2019; Novytska *et al.,* 2020).

At the same time, research on the influence of growth regulators on plant growth and development in conditions of unstable moisture supply and high air temperatures against the background of various tillage is extremely insufficient, which determined the area of the present study. The purpose of this study was to establish the effect of the plant growth regulator AKM+Ca on the photosynthetic activity of sunflower hybrids using various methods of basic tillage in the Steppe zone of Ukraine.

MATERIALS AND METHODS

The experiment was conducted during 2017-2019 in the Melitopol District of Zaporizhzhia region. The Southern Steppe zone is substantially different from other zones of the country in terms of climatic and soil conditions and, accordingly, has its specific features for growing agricultural crops.

The weather conditions that developed during the experiment were marked by prominent amounts of active temperatures during the growing season (Table 1). Precipitation for the year falls about 480 mm, of which during the growing season – 253 mm (according to long-term data). In 2017 and 2019, humidification conditions were close to the long-term average values and are more favourable for growing oilseeds. The hydrothermal coefficient (HTC) over the years of research ranged within 0.46-0.85, which indicates that the area belongs to an arid zone. Notably, in 2018, against the background of high amounts of active temperatures, low precipitation (147 mm) was observed, and the hydrothermal coefficient was 70-85% lower than the other growing seasons under study.

Table 1. *Weather conditions of the experiment (2017-2019)*

Year of research	HTC	Precipitation during the growing season, mm	Sum of active temperatures, °C
2017	0.78	218	2,801
2018	0.46	147	3,223
2019	0.85	257	3,037

Source*: compiled by the author*

The soils of the experiment site are southern heavy loam chernozems with a humus content of 3.1%. Soils have a close to neutral reaction (water pH 7.1). The availability of easily hydrolyzable nitrogen in the arable layer is low (103 mg/kg according to Cornfield), mobile phosphorus is high (114 mg/kg according to Chirikov), exchangeable potassium is high (139 mg/kg according to Chirikov). However, uneven and insufficient precipitation during the growing season blocks the full use of nutrients by plants. In the experiment, mid-early high-oleic hybrids of Colombi and Talento sunflowers were studied under conditions of different main tillage and different methods of application of plant growth regulator AKM+Ca. The sunflower hybrids under study are recommended for growing in the Steppe zone of Ukraine. The scheme of the experiment is presented in Table 2.

Table 2. *Experiment scheme*

Tillage	Sunflower hybrid	Experiment variant	
Deep loosening	Talento	1	Control (pre-sowing treatment of seeds with water)
		2	Pre-sowing treatment of seeds with AKM+Ca
		3	Spraying plants with AKM+Ca in the budding phase
		4	Pre-sowing treatment of seeds with AKM+Ca + spraying of plants with AKM+Ca in the budding phase
	Colombi	1	Control (pre-sowing treatment of seeds with water)
		2	Pre-sowing treatment of seeds with AKM+Ca
		3	Spraying plants with AKM+Ca in the budding phase
		4	Pre-sowing treatment of seeds with AKM+Ca + spraying of plants with AKM+Ca in the budding phase
Ploughing	Talento	1	Control (pre-sowing treatment of seeds with water)
		2	Pre-sowing treatment of seeds with AKM+Ca
		3	Spraying plants with AKM+Ca in the budding phase
		4	Pre-sowing treatment of seeds with AKM+Ca + spraying of plants with AKM+Ca in the budding phase
	Colombi	1	Control (pre-sowing treatment of seeds with water)
		2	Pre-sowing treatment of seeds with AKM+Ca
		4	Spraying plants with AKM+Ca in the budding phase
		3	Pre-sowing treatment of seeds with AKM+Ca + spraying of plants with AKM+Ca in the budding phase

Source*: compiled by the author*

AKM is included in the list of pesticides and agrochemicals permitted for use in Ukraine as a plant growth regulator (Yashchuk *et al.*, 2016). It is a semisynthetic film-forming anti-stress preparation. The formulation includes distinol 0.015 g/l (dimethylsulfoxide + ionol), PEG – 1500 (440 g/l) and PEG – 400 (190 g/l), the rest – water (Kalytka *et al.*, 2011). According to laboratory studies, the plant growth regulator AKM was modified by adding Ca^{2+}ions (1.0 g/l). The resulting preparation seed material was inlaid a day before sowing (200 ml/t). The total volume of the working solution is 10 l/t of seeds. The plants were sprayed with AKM+Ca (500 ml/ha) in the phase of the inflorescence emergence (BBCH 50-51) based on the calculation of the consumption of the working solution of 200 l/ha.

The technology of growing sunflower seeds was generally accepted for this soil and climatic zone and was the same for all variants of the experiment, except for the factors under study. The seeds were sown at the beginning of the third decade of April, when the soil warmed up to 10-12°C. The seeding rate is 55 thous. pcs./ha with a row spacing of 70 cm. Predecessor – winter wheat.

The beginning of each phase of growth and development of sunflower was established after its onset in 10% of plants, complete – in 75% of plants, and the BBCH scale was used. During the studies, the leaf surface area was determined using the gravimetric method. The gravimetric method relates the weight of leaves from 10 plant samples to the weight of leaf cuttings (D=10 mm). Knowing the area of the leaf cuttings, the area of the leaf surface was calculated, and the area was given in thous. m^2 per 1 ha of the sown area (Hrytsaenko *et al.*, 2003).

The photosynthetic potential was defined as the total leaf surface that participated in photosynthesis from the beginning of vegetation to the end of photosynthesis (Hrytsaenko *et al.*, 2003) and was calculated according to the following formula (1):

$$PhSP = \frac{(S_1+S_2)\times n_1 + (S_2+S_3)\times n_2 + \cdots + (S_{n-1}+S_n)\times n_n}{2}, \quad (1)$$

where PhSP is the photosynthetic potential, thous. m^2/ha × days; $S_1, S_2, S_3 \ldots S_n$ is the area of leaves per 1 ha of sowing in the corresponding terms of determination, m^2/ha; $n, n_2 \ldots n_n$ is the number of days between the two corresponding definitions.

The net photosynthetic productivity (NPP) was calculated as the ratio of the growth of plant dry mass over a certain period of time to the half sum of the leaf surface areas at the beginning and at the end of the period. The NPP was calculated using the following formula (2):

$$NPP = \frac{B_2 - B_1}{0.5(S_1+S_2)n}, \quad (2)$$

where *NPP* is the net photosynthesis productivity, g/m^2·day; B_1 and B_2 are the dry matter mass of plants in the beginning and at the end of the accounting period, g; ($B_2 - B_1$) is the growth of the dry matter mass of plants in n days, g; S_1 and S_2 are the leaf areas in the beginning and at the end of the accounting period, m^2; $0.5(S_1 + S_2)$ is the average working leaf area during the experiment; *n* is the period between two observations, days.

The dry mass of the substance was determined gravimetrically according to generally accepted methods (Hrytsaenko *et al.*, 2003). Statistical assessment of the data was carried out according to the Yeshchenko (2005) method and the Agrostat program.

RESULTS AND DISCUSSION

The onset and duration of phenological phases primarily depends on the weather conditions of the year. In shaping the productivity of sunflower and other agricultural crops, it is important that plants undergo all phenological phases in full because this, first of all, affects the indicators of seed quality and the yield of this crop (Zimaroieva *et al.*, 2021).

During 2017-2019, it was found that the rate of development of sunflower plants was mainly influenced by ambient temperature, and in some interphase periods and humidification conditions, the general picture of the duration of interphase periods is presented in Table 3.

Table 3. *Duration of interphase periods of sunflower plant development, days*

Year	Hybrid	Sowing – germination (BBCH 00-12)	Development of 4-5 true leaves (BBCH 14-15)	Development of 6-7 true leaves (BBCH 16-17)	Development of 8-9 true leaves (BBCH 18-19)	Asterisk stage (BBCH 50-51)	Flowering-full ripeness (BBCH 63-99)	Duration of the growing season (BBCH 00-99)
2017	Talento	15	28	7	7	17	35	109
2018		12	25	7	7	23	32	106
2019		14	28	8	9	22	31	112
2017	Colombi	13	28	7	7	17	41	113
2018		12	26	7	7	20	38	110
2019		17	25	7	7	16	43	115

Source: *compiled by the author*

The growing season of 2018, unlike other years under study, was characterized by a low amount of precipitation and a higher sum of active temperatures, which somewhat affected the reduction in the duration of the growing season of sunflower hybrids Columbi and Talento. In general, the duration of the mid-early hybrids under study in the conditions of the Southern Steppe of Ukraine was 111±5 days. Thus, in the conditions of the Southern Steppe of Ukraine, when growing sunflower seeds, it is advisable to pay special attention to tillage technologies for better accumulation and preservation of moisture.

A fundamental element in plant productivity is photosynthetic activity, which is mainly determined by the area of the leaf surface, the number and mass of leaves, and the mesostructural composition of the leaf.

In the experiment on the investigation of the effect of tillage and methods of using the modified plant growth regulator AKM on the dynamics of the formation of the sunflower leaf surface area, the dependence of this indicator on the factors of the variety and the method of treatment with the plant growth regulator was observed (Table 4).

Table 4. *The dynamics of the formation of the leaf surface area of sunflower hybrids depending on the methods of soil cultivation and the use of plant growth regulators, thous. m²/ha (2017-2019)*

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase				
			12-14	18-20	39-41	50-51	63-65
Deep loosening	Colombi	1	12.0	16.7	19.8	27.8	45.2
		2	13.4	19.9	23.6	30.2	50.1
		3	-	-	-	-	48.7
		4	-	-	-	-	53.9
	Talento	1	11.9	17.0	20.0	27.3	40.0
		2	13.2	20.2	22.1	29.7	46.8
		3	-	-	-	-	43.2
		4	-	-	-	-	52.5
Ploughing	Colombi	1	12.6	16.7	21.6	27.4	47.7
		2	13.1	18.8	24.5	29.7	50.7
		3	-	-	-	-	49.1
		4	-	-	-	-	55.8
	Talento	1	11.9	16.6	20.9	25.4	39.1
		2	13.5	18.6	23.3	27.6	43.8
		3	-	-	-	-	41.7
		4	-	-	-	-	51.1
LSD_{05}	A		1.3	2.4	2.9	3.5	7.6
	B		1.3	1.4	2.8	2.2	4.6
	C		0.6	1.3	1.1	1.2	4.0

Source*: compiled by the author*

Already from the BBCH 12-14 development phase, an increase in the area of the leaf surface is observed. The gradual growth of this indicator reaches a maximum in the flowering stage (BBCH-63-65). Substantial changes occur in the variant with pre-sowing seed treatment with the PGR AKM+Ca for both hybrids under study, where the growth of this indicator was by 4-18%, compared to the control, regardless of the method of tillage.

Additional spraying of sunflower plants of Columbi and Talento hybrids with AKM+Ca in the inflorescence emergence phase (BBCH 50-51) contributes to the growth of the leaf surface area to the mass flowering phase (BBCH 63-65) by 18-31%, compared to the control. This is especially true for the Talento hybrid with the maximum increase in this indicator, where the influence of the variety factor is very well traced. Therefore, it should be expected that an increase in the leaf surface area will contribute to the growth of photosynthetic activity and increase the productivity of sunflower plants. In general, the formation of the leaf apparatus by plants directly depends on the amount of precipitation (BBCH 00-65). A close correlation is established here (r=0.87). The share of the effect of AKM+Ca on the formation of this indicator was 54.2% (Fig.1).

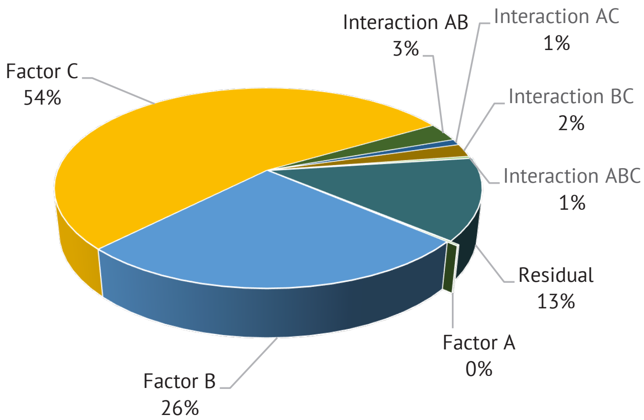

Figure 1. *The share of influence of the factors under study on the dynamics of the leaf surface area of sunflower, %*
Source*: compiled by the author*

The dry matter content of sunflower plants varies widely depending on the phase of hybrid development, hydrothermal conditions of the year and elements of cultivation technologies (Table 5).

Table 5. *Dynamics of dry matter accumulation by sunflower plants, g/ m²*

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase				
			12-14	18-20	39-41	50-51	63-65
Deep loosening	Colombi	1	26.9	45.3	154.7	245.6	752.3
		2	29.3	56.7	180.7	270.7	790.7
		3	-	-	-	-	763.8
		4	-	-	-	-	816.0
	Talento	1	26.5	51.1	143.8	244.1	707.6
		2	28.4	59.2	175.2	271.3	746.5
		3	-	-	-	-	725.6
		4	-	-	-	-	798.0
Ploughing	Colombi	1	27.8	45.8	167.2	243.9	712.6
		2	29.7	56.1	186.5	266.7	795.5
		3	-	-	-	-	775.0
		4	-	-	-	-	804.1
	Talento	1	25.0	46.8	153.6	207.0	695.0
		2	28.9	53.8	184.1	243.1	741.2
		3	-	-	-	-	721.8
		4	-	-	-	-	789.4
LSD_{05} B C		A	0.3	6.7	21.1	26.8	29.3
		0.3	3.5	13.5	17.0	15.7	
		1.3	3.5	16.4	9.9	57.5	

Source*: compiled by the author*

Already at the beginning of the development of sunflower plants (BBCH 12-14), a more intense accumulation of dry matter occurred in the variants of the experiment with the pre-sowing treatment of seeds with the PGR AKM+Ca, where this indicator was higher than the control by 6.8-15.6%, depending on the hybrid and the method of soil cultivation. In the subsequent growing season, this indicator gradually increased, and during the flowering phase, the dry matter content reached a maximum in all variants of the experiment.

The Columbi sunflower hybrid in the flowering phase had higher indicators of dry matter content with both methods of main tillage by 2.5-6.3%, compared to the Talento hybrid. Notably, with deep loosening as the main method of tillage, the Columbi hybrid has significantly higher values of dry matter content compared to ploughing, which can be explained by better preservation of moisture in the soil. Plants of this variant of the experiment were able to better use moisture and nutrients dissolved in it to form a more powerful phytomass.

Additional spraying of sunflower plants with the plant growth regulator AKM+Ca has the maximum positive effect on changes in the dry matter content. Thus, spraying plants with this preparation in the BBCH 50-51 phase significantly increases the dry matter content of the hybrids under study in both variants of tillage by 8.5-13.6% (BBCH 63-65). The general picture of the dependence of the dynamics of dry matter accumulation on the factors under study is presented in Fig. 2.

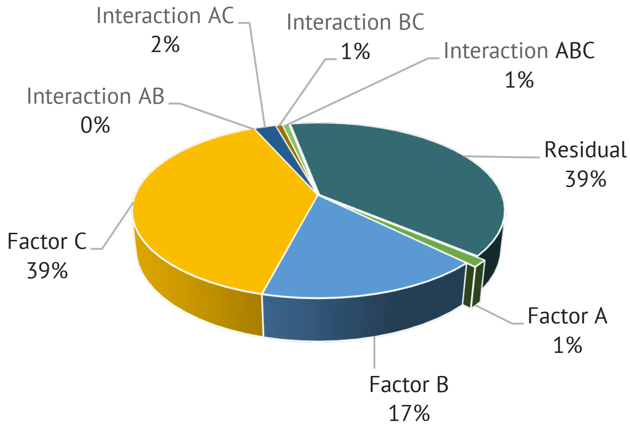

Figure 2. *The proportion of influence of the factors under study on the accumulation of dry matter by sunflower plants, %.*
Source*: compiled by the author.*

The process of photosynthesis is the main source of formation of plant biomass, provides energy to all growth processes, and energy is exchanged. It is the size and productivity of the photosynthetic apparatus that determines the yield of agricultural plants. The dynamics of photosynthetic potential of sunflower plants depending on the factors under study is presented in Table 6.

Table 6. *Photosynthetic potential of sunflower plants depending on the main tillage and the use of the PGR, million m*^{2}*·days/ha*

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase (for the period)			
			(BBCH 12-14)-(BBCH 18-20)	(BBCH 18-20)-(BBCH 39-41)	(BBCH 39-41)-(BBCH 50-51)	(BBCH 50-51)-(BBCH 63-65)
Deep loosening	Colombi	1	0.10	0.24	0.38	0.40
		2	0.12	0.28	0.43	0.44
		3	-	-	-	0.41
		4	-	-	-	0.46
	Talento	1	0.10	0.24	0.38	0.37
		2	0.11	0.28	0.41	0.42
		3	-	-	-	0.38
		4	-	-	-	0.45
Ploughing	Colombi	1	0.10	0.25	0.39	0.41
		2	0.11	0.27	0.43	0.44
		3	-	-	-	0.42
		4	-	-	-	0.47
	Talento	1	0.10	0.24	0.37	0.35
		2	0.11	0.27	0.41	0.39
		3	-	-	-	0.37
		4	-	-	-	0.41

Table 6, Continued

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase (for the period)			
			(BBCH 12-14)-(BBCH 18-20)	(BBCH 18-20)-(BBCH 39-41)	(BBCH 39-41)-(BBCH 50-51)	(BBCH 50-51)-(BBCH 63-65)
LSD$_{05}$		A	0.01	0.04	0.03	0.06
B		0.01	0.01	0.02	0.04	
C		0.01	0.02	0.02	0.02	

Source: *compiled by the author*

Thus, the pre-sowing treatment of the seeds of the sunflower hybrids under study contributes not only to the increase in dry matter in plants, the leaf surface, but also increases the photosynthetic potential of plants during the growing season. This is especially true for the BBCH 39-65 period, where there is a significant increase in this indicator. For the Columbi sunflower hybrid during the BBCH 39-51 period, the increase in photosynthetic potential under the action of the plant growth regulator was 10.3-13.1%, for the Talento hybrid – by 7.9-10.8%, compared to the control. In further development during the BBCH 50-65 period, this growth was, respectively, by 7.3-10.0% and 11.4-13.5%. Additional treatment of AKM+Ca plants at the inflorescence emergence contributed to an even greater increase in photosynthetic potential for the Colombi sunflower hybrid by 14.6-15.0%, and for the Talento hybrid – by 17.1-21.6%, compared to the control variant of the experiment. Therefore, the use of a modified plant growth regulator AKM+Ca contributes not only to the growth of plant biomass, but also to the activation of photosynthesis of sunflower plants, energy exchange for obtaining a high yield.

In the period of the inflorescence emergence-full flowering, varietal differences between hybrids can be traced on ploughing, where the Colombi sunflower hybrid had a higher photosynthetic activity by 17.1%, compared to the Talento hybrid. In general, the method of basic tillage did not substantially affect the photosynthetic potential.

During photosynthesis, approximately 95% of the total plant biomass is formed. Therefore, the indicator of the net productivity of photosynthesis is essential because when the dry mass of the plant changes, it characterizes the work of the leaf apparatus, reflects their assimilation activity and conditions the plant's potential for crop formation (Table 7).

Table 7. *Net photosynthetic productivity of sunflower plants under the conditions of the factors under study, g/m^2 per day*

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase			
			(BBCH 12-14)-(BBCH 18-20)	(BBCH 18-20)-(BBCH 39-41)	(BBCH 39-41)-(BBCH 50-51)	(BBCH 50-51)-(BBCH 63-65)
Deep loosening	Colombi	1	0.77	3.99	3.34	8.66
		2	0.90	4.19	3.82	9.16
		3	-	-	-	8.93
		4	-	-	-	10.04
	Talento	1	1.20	3.50	3.73	10.21
		2	1.29	3.83	4.24	10.92
		3	-	-	-	10.85
		4	-	-	-	10.82
Ploughing	Colombi	1	0.80	4.21	2.95	8.21
		2	0.85	4.44	3.13	8.34
		3	-	-	-	8.43
		4	-	-	-	8.50
	Talento	1	1.07	3.99	2.29	9.55
		2	1.09	4.36	2.28	9.68
		3	-	-	-	9.78
		4	-	-	-	9.91
LSD$_{05}$		A	0.05	0.24	0.53	1.48
B		0.04	0.27	0.23	0.78	
C		0.03	0.17	0.29	0.76	

Source: *compiled by the author*

Already at the beginning of leaf development (BBCH 12-20) in the experiment, the dependence of the NPP on the method of soil cultivation in the sunflower hybrid Talento was observed. The use of deep loosening, in contrast to ploughing, allows for better formation of phytomass and an increase in the NPP indicator by 12.1%. Such dynamics in this hybrid is observed during the BBCH 12-51 period, and the maximum growth of NPP is observed in the phase of the inflorescence emergence (62.9%).

Between the hybrids of sunflower Columbi and Talento, there are varietal features that are especially clearly traced in the variant of the experiment with deep loosening of the soil. Thus, during the BBCH 18-41 period, the Columbi hybrid had a higher NPP value than the Talento hybrid by 14.0%. However, in the next period (BBCH 39-65), the situation changes in the opposite direction and the Talento hybrid exceeds the Columbi hybrid in the indicator under study by 11.7-17.9%. In the version of the experiment using ploughing, the Talento hybrid also had advantages over the Colombi hybrid in the period of the inflorescence emergence–full flowering, where the indicator under study was higher by 16.3%.

When investigating the influence of the factor of using a plant growth regulator, certain features were also established, especially in the variant of the experiment using deep loosening of the soil. Thus, pre-sowing treatment of seeds with the PGR AKM+Ca significantly increases the NPP index during the entire study period by 5.0-26.9% in both hybrids under study.

Additional spraying of sunflower plants of the Columbi with the PGR AKM+Ca hybrid in the phase of the inflorescence emergence in the variant of the experiment with deep loosening of the soil contributed to the activation of the net photosynthesis productivity during the BBCH 50-65 period, where the NPP index was higher than the control by 15.9% and higher than the variant with pre-sowing treatment of seeds by 9.6%. The general picture of the dependence of changes in the indicators of net photosynthesis productivity on the factors under study is presented in Fig. 3.

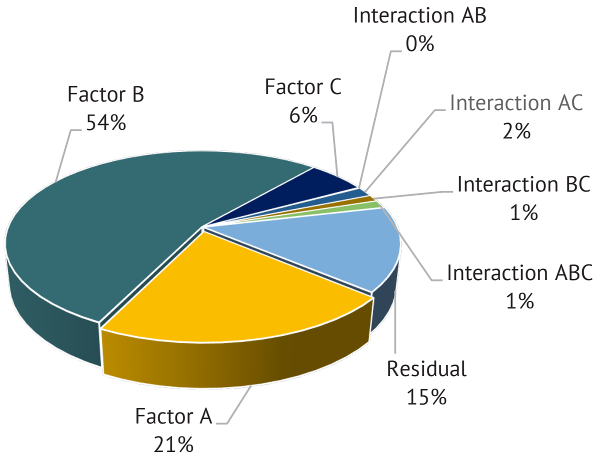

Figure 3. *The proportion of influence of the factors under study on the net photosynthesis productivity of sunflower plants, %*

Source*: developed by the authors*

The variety factor (54.0%) has a substantial influence on the net photosynthesis productivity from the factors under study. Therefore, with the observance of a high level of agriculture, the use of the latest elements of crop cultivation technology, namely, the use of plant growth regulators and methods of soil cultivation, it is possible to adjust the yield of sunflower well, because sunflower is still an economically attractive crop for growing in the Steppe of Ukraine.

During the growing season, weather conditions have a substantial impact on the formation of the sunflower crop: ambient temperature, the amount, and uniformity of precipitation (Hilwa *et al.*, 2019). In the arid zone of the Steppe, in the early stages of their development, sunflower plants use the moisture of the arable layer accumulated in the winter-spring period. Due to the further development of the root system and its penetration into the soil, sunflower plants use the moisture of groundwater (Vozhegova *et al.*, 2021). This contributes to the normal development and survival of plants during the period of harmful effects of air drought, which is most dangerous during the period of flowering of plants and seed ripening.

Turning the ploughed layer affects the redistribution of nutrients enriched with available nutrients of the entire ploughed layer at the expense of the upper part, as a result of which the overall productivity of the soil increases. However, this process can be harmful, especially in arid zones, because when the wet layer is turned over to the soil surface, it dries quickly. Research

(Liabah, 2022) found that when growing sunflowers on sod-podzolic soils with a light granulometric composition, the use of disc tillage tools to a depth of 10-12 cm is not substantially inferior to a deep loosener to a depth of 40-45 cm. Therefore, to solve the problem of reducing erosion processes, destroying the compacted subsoil, improving the infiltration properties of agricultural lands and preserving soil fertility, it is advisable to use deep loosening. Deep loosening of the soil involves loosening, crumbling, partial mixing, but without rotation of the layer, resulting in loosening of the soil aimed at preventing water erosion. When using a deep loosener, the stubble stays on the surface, which fixes the surface of the soil and does not allow it to be blown away by the wind (Yeremenko *et al*., 2020). The positive effect of deep loosening on the NPP indicator, compared to ploughing, is confirmed by the conducted studies.

One of the factors for obtaining stable yields is a well-developed photosynthetic apparatus, which has an optimal area and dynamics of functioning (Domaratskyi, 2021; Ma *et al.,* 2022). According to scientists, the optimal area of the leaf surface of agricultural crops, due to which the formation of maximum productivity is achieved, is 40 thous. m^2/ha. Other researchers (Gamayunova *et al*., 2019; Melnyk *et al*., 2020) found that for varieties and hybrids of the intensive type, which currently prevail in agricultural production, the optimal leaf area is within 50-60 thous. m^2/ha. The higher the coefficient of energy utilization for photosynthesis, the more completely dry phytomass is formed, and the smaller amount is spent on water transpiration.

For optimal formation of the photosynthetic apparatus of agricultural plants, regulation of individual stages of ontogenesis and mobilization of their potential, it is recommended to use growth regulators (Almashova *et al*., 2022; Kolesnikov *et al*., 2022; Bielashov *et al*., 2022). The published data are in good agreement with the conducted studies. Scientists also claim that plant growth regulators have a wide positive spectrum of action, which not only stimulates growth processes at various stages of ontogenesis, but also reduces the effect of the pesticide load on the plant, increases the yield of crops, improves the quality of grain and seeds, and strengthens the resistance of crops to adverse agroclimatic conditions, which is especially valuable in arid regions of the country (Karpenko *et al*., 2018). The use of Ca^{2+} with the AKM growth regulator contributed to the increase in the leaf surface area of sunflower, which is probably explained by the fact that calcium ions, as a structural component of photosystem II, improve the efficiency of photosynthesis, stimulate the links of plant antioxidant protection, which was proven when using exogenous calcium chloride (Sadak *et al*., 2023). Stimulation of the formation of the photoasimilation apparatus of sunflower plants under the action of calcium ions occurs through the effect on the pigment complex. Since, with calcium deficiency, a decrease in the rate of photosynthesis and transpiration, the productivity of photosystem II was shown (Sitko *et al*., 2019).

Thus, the research results confirm the data of other scientists on the influence of growth regulators on the formation of the photosynthetic surface of plants and its activity in arid conditions in the south of Ukraine.

CONCLUSIONS

The duration of sunflower interphase periods depends on environmental conditions: the sum of active temperatures and precipitation. The plants of sunflower hybrids under study, upon using deep loosening, have a high dry matter content and an indicator of net photosynthesis productivity, which is explained by the better preservation of moisture in the soil. The use of plant growth regulator AKM+Ca for pre-sowing seed treatment increases the leaf surface area by 4.0-18.0%, increases the indicators of the photosynthetic potential of plants during the growing season by 7.3-13.5% and the net photosynthesis productivity by 5.0-26.9%, compared to the control, regardless of the method of tillage.

The combined use of pre-sowing seed treatment and spraying of plants with AKM+Ca at the beginning of budding (BBCH 50-51) increases the area of the leaf surface by 18-31%, contributes to the growth of the dry matter content in both tillage options by 8.5-13.6% (BBCH 63-65) and photosynthetic potential by 14.6-21.6%, compared to the control. The combination of pre-sowing treatment and treatment of sunflower plants of the Colombi hybrid with the AKM+Ca against the background of deep loosening of the soil contributed to an increase in the net photosynthesis productivity (BBCH 50-65) by 15.9%, compared to the control, and by 9.6%, compared to the pre-sowing treatment seed.

In the period of the inflorescence emergence-full flowering, varietal differences between hybrids can be traced on ploughing, where the Colombi sunflower hybrid had a higher photosynthetic activity by 17.1%, compared to the Talento hybrid. The method of basic tillage did not substantially affect the photosynthetic potential. In addition, varietal features can be traced between hybrids according to the NPP indicator against the background of deep loosening of the soil. The influence of the variety factor is 54.0%. The obtained data confirm the prospects for further research into the crop structure, the biological yield of sunflower hybrids and the quality of products under plant growth regulators in the conditions of the Steppe zone of Ukraine, which will provide the population with high-quality food raw materials.

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None.

CONFLICT OF INTEREST

None.

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Фотосинтетична активність гібридів соняшнику за дії регуляторів росту в умовах Степу України

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Анотація. Клімат південної зони Степу України за останні роки характеризується суттєвим потеплінням, з низькою, нерівномірною кількістю опадів протягом вегетації рослин, що призводить до зниження запасів продуктивної вологи в ґрунті, у рослин виникає гідротермічний стрес. Можливостями підвищення адаптації рослин до несприятливих факторів є використання регуляторів росту рослин та застосування різних способів обробітку ґрунту, направлених на збереження вологи. Мета досліджень – дослідити вплив регулятору росту рослин АКМ+Са на роботу фотосинтетичного апарату гібридів соняшнику на фоні різних способів основного обробітку ґрунту в умовах південного Степу України. При виконанні досліджень використовували наступні методи: польовий, хімічний (для визначення якісних показників) та статистичний (для оцінки достовірності даних).Польові дослідження проводили впродовж 2017-2019 років на чорноземах південних важкосуглинкових. У досліді використовували модифікований регулятор росту рослин АКМ+Са для передпосівної обробки насіння та позакореневого обприскування рослин соняшнику (фаза початку бутонізації) гібридів Таленто і Коломбі на фоні глибокого рихлення або оранки. Встановлено, що застосування глибокого рихлення, на відміну від оранки, сприяє збільшенню показників вмісту сухої речовини в рослинах соняшнику і чистої продуктивності фотосинтезу за рахунок кращого збереження вологи у ґрунті. Використання регулятора росту рослин АКМ+Са, незалежно від способу обробітку ґрунту, сприяє наростанню площі листкової поверхні до 31,2 %, збільшує фотосинтетичний потенціал рослин до 21,6 % та чисту продуктивність фотосинтезу до 15,9 % протягом вегетації, а також підвищує вміст сухої речовини, порівняно з контролем. Частка впливу регулятора росту рослин АКМ+Са на формування площі листової поверхні становить 54,2 %. Максимальний позитивний ефект отримано при сумісному застосуванні препарату АКМ+Са для передпосівної обробки і обприскування рослин соняшнику по вегетації на фоні глибокого рихлення ґрунту. Результати досліджень можуть бути використані для корегування елементів агротехнологій вирощування соняшнику, підвищення продуктивності культури та ведення прибуткового агробізнесу

Ключові слова: фотосинтетичний потенціал; чиста продуктивність фотосинтезу; соняшник; регулятор росту рослин; оранка; глибоке рихлення

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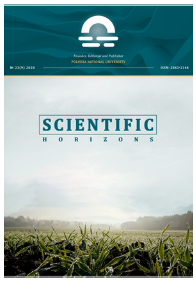

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Influence of nutrient media on the physiological parameters of grape microclones

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Abstract. Successful rooting of grape microclones in uncontrolled environmental conditions (*in vivo*) depends on the level of resistance, which is formed at the stage of their passage and growth *in vitro*. An important role in this case is played by indicators of the water regime of the vegetative mass. The purpose of this study was to get acquainted with the results of determining the water-holding capacity, the intensity of transpiration of grape microclones *in vitro* and to establish the share of their influence on the adaptation potential *in vivo*. Biotechnological, laboratory, vegetation, and mathematical and statistical research methods were used in this study. The obtained results showed that to optimize the physiological processes in the tissues of the leaves and shoots of grape microclones, to increase their viability under *in vivo* conditions, it is advisable to cultivate them *in vitro* on structured nutrient media (MS + agroperlite, MS + vermiculite, MS + agroperlite + vermiculite) with the content of phytohormones IAA – 0.2 mg/l, and 6-BAP – 0.3 mg/l. Structured nutrient media contributed to an increase in water retention capacity and a decrease in the intensity of transpiration of tissues of leaves and shoots of microclones of both technical and rootstock varieties. During 60 minutes of research, from 0.006 g to 0.034 g of water evaporated from microclones of technical varieties, from 0.003 g to 0.053 g from microclones of

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rootstock varieties, respectively. Transpiration intensity (after 10 min) decreased by 1.7-1.8 times. On the control Murashige and Skoog nutrient medium, plants evaporated a larger amount of water during the corresponding period of time: from 0.006 g to 0.079 g (technical varieties) and from 0.008 g to 0.086 g (rootstock varieties); the intensity of transpiration was higher. After cultivation of grape microclones on structured nutrient media, they were characterized by a higher content of dry matter in the tissues of leaves and shoots (14.6-15.0%) and better survival rates *in vivo* (76.3-98.5%, at 58.5-65.2% in control). The reliability of the results obtained is confirmed by the results of multivariate analysis of variance. The obtained results expand the understanding of dynamic changes in the indicators of the water regime of the vegetative mass of grape microclones *in vitro*, their influence on plant survival under *in vivo* conditions

Keywords: *in vitro*; water retention capacity; transpiration intensity; survival rate; phytohormones; biologically active preparations; mineral substrates

INTRODUCTION

Today, the method of tissue and organ culture *in vitro* is widely used in agricultural practice for accelerated reproduction of valuable genotypes. This method is based on the activation of organogenesis from various types of initial explants, on artificial nutrient media, under sterile conditions. This process of plant reproduction consists of several stages: the introduction of initial explants into *in vitro* culture; propagation of shoots in culture *in vitro*; obtaining plants with roots and their preliminary adaptation to open soil conditions; transfer of plants to *in vivo* conditions (Riabovol & Riabovol, 2019). The final stage in this process is the adaptation of test tube plants to non-sterile and uncontrolled environmental conditions. It was established that at this stage the largest number of microclones dies. This is because *in vitro* culture plants are in conditions that differ from natural ones in terms of physico-chemical parameters: water, light, temperature regimes, gas composition of air in culture containers, nutrient medium consistency, etc. Cultivation of plants *in vitro* in closed culture containers also requires compliance with the sterility regime, a certain gas environment, and ensures constant maintenance of the relative humidity of the air inside the containers. All this in a complex leads to a change in the course of many morphophysiological processes and functional changes of plants *in vitro*: they are characterized by an underdeveloped waxy cuticle of leaves, a damaged stomatal apparatus, weak photosynthetic activity, vitrification, a weak vascular connection between the root and the shoot, an unbranched root system and underdeveloped root hairs (Gritsak & Drobyk, 2020). Therefore, for the successful acclimatization of microclonal plants to *ex vitro* conditions, on the one hand, it is necessary to ensure a number of optimal physical factors (suitable substrate, air humidity, ventilation, acid-alkaline balance (pH), etc.), on the other hand, the plants must be in such a physiological biochemical state to gradually adapt to new, uncontrolled environmental conditions, i.e., it is necessary to optimize the conditions of plant growth and development at the stage of *in vitro* cultivation.

One of the determining factors that affects the physiological-biochemical, anatomical-morphological state of microclonal plants, specifically, general watering, water-holding capacity, transpiration intensity, the content of leaf pigments, dry matter in shoots and leaves is the composition and quality of the nutrient medium.

Studies by many authors have established that plants can react differently to the composition of the nutrient medium *in vitro*. Therefore, it must be selected considering the specific and varietal specifics. This was manifested in changes in anatomical indicators (Martins, 2018), growth and development indicators (Coelho *et al*., 2021), reproduction coefficient (Vujovic *et al*., 2020), the course of physiological and biochemical processes (Manocari *et al*., 2023). And this is understandable because the nutrient medium provides plants with the necessary macro- and microelements, vitamins, phytohormones and removal of metabolic products. Therefore, the issue of determining the influence of the nutrient environment on the course of physiological processes of grape microclones *in vitro*, their regulation to increase the adaptation potential is relevant and timely.

The purpose of this study was to determine the individual physiological indicators of grape microclones of rootstock and technical varieties under the conditions of cultivation on different nutrient media *in vitro*; to establish their influence on the viability of microclones *in vivo*.

To fulfil the purpose, the following tasks were set: to determine indicators of water-holding capacity, transpiration intensity, dry matter content in the tissues of leaves and shoots of grape microclones *in vitro* on different types of nutrient media and with different content of phytohormones; to determine the viability of grape microclones *in vivo*, after cultivation on different types of nutrient media; to determine the share of influence of factors – grape variety, content of phytohormones in the Murashige and Skoog nutrient medium (MS) and its structured base on the physiological indicators of grape microclones *in vitro*; to establish the dependence of the viability of grape microclones *in vivo* on the physiological state of plants *in vitro*.

LITERATURE REVIEW

Few scientific works have investigated the physiological and biochemical state of plants *in vitro* and *in vivo*. And all of them are considered mainly from the standpoint of modelling, impact of abiotic stress and screening of resistant genotypes. The most common abiotic stresses that affect plant growth and productivity are drought and salinity. They cause enormous economic losses as a result of reduced agricultural productivity. In such conditions, plants face a violation of osmotic potential, nutrient transport, and a decrease in photosynthesis. Conventional breeding methods do not always lead to the desired result in the selection and evaluation of stress-resistant plant forms and species. However, thanks to the application of *in vitro* methods of tissue and organ culture, in a short period of time and with a small amount of plant material, it is possible to investigate the mechanism and carry out screening of resistant forms and varieties of plants.

Martínez-Santos *et al*. (2021) evaluated the physiological and biochemical status of *Vanilla planifolia* Jacks. ex Andrews under conditions of *in vitro* water stress induced by polyethylene glycol (PEG). Microclonal plants of *Vanilla planifolia* Jacks. were cultivated on the semi-solid Murashige and Skoog nutrient medium (MS) with the addition of PEG-6000 (0%, 1%, 2% and 3% w/v). After 60 days, the height of the plants was determined, in the tissues of leaves and shoots – the content of dry matter, chlorophyll, soluble proteins, proline, glycine, stomatal index and the number of open stomata per unit area of the epidermis. The obtained results showed that with an increase in the concentration of PEG-6000 in the nutrient medium, plant height, the content of chlorophyll, soluble proteins, and the number of open stomata decreased, while the content of dry matter and amino acids, on the contrary, increased.

Hernández-Pérez *et al*. (2021) using similar concentrations of PEG-6000 in the MS nutritional medium based on the determination of biometric growth indicators, the content of dry matter in tissues, total protein, proline, glycine-betaine, performed *in vitro* screening of *Saccharum spp*. Hybrids, varieties Mex 69-290, Mex 79-431, CP 72-2086 and MOTZ Mex 92-207 resistant to water stress. Based on the results obtained, the water stress-tolerant Mex 69-290 variety was established. As the microclonal plants of this variety met the biometric parameters of development with an increase in the concentration of PEG in the nutrient medium, an increase in dry matter and amino acids was observed in the tissues.

Gao *et al*. (2020) investigated the effect of osmotic stress on tissue hyperhydration of microclones of *Dendrobium officinale* L. The latter were cultured on a solid MS nutrient medium supplemented with plant growth regulators, various concentrations of sucrose and agar. The level of hyperhydration was assessed by water regime indicators, relative electrical conductivity, and enzyme activity. The results indicated that high concentrations of sucrose, agar, PEG-6000 in the nutrient medium considerably increased the total water content, free water content, relative electrical conductivity, peroxidase activity, and reduced the content of bound water, proline, soluble protein, and sugars.

According to Khalid *et al*. (2021), who investigated changes in the physiological and biochemical state and biometric growth indicators of *Camelina sativa* L. under model drought MS+PEG-6000 (1-7%), it was shown that with an increase in the concentration of PEG to 2.0%, the ability of seeds to germinate, the content of water, chlorophylls, and carotenoids in the leaves increased significantly, and the processes of cotyledons unfolding and the appearance of true leaves accelerated. Subsequently, increasing the concentration of PEG led to a decrease in these indicators compared to the control. This is evidence that *Camelina sativa* L. can tolerate moderate water stress without any adverse impact on growth and physiological and biochemical parameters.

Bareera *et al*. (2019) conducted *in vitro* screening of drought-resistant varieties of *Brassica napus* L. For this, callus cultures of varieties B-56, B-18, ZMR-4, ZM-21, KM-256, ZMR-10, Punjab Sarsoon, Cyclon, Rainbow and UAF-11 were obtained on nutrient media with PEG-6000, the viability of which were evaluated by the content of dry matter, proline, glycine, betaine, total content of soluble sugar. The authors showed that when exposed to low concentrations of PEG-6000 in the tissues of callus cultures, all the above indicators increased. The exception was the mass index of wet callus, which, on the contrary, decreased.

Kovalikova *et al*. (2020) investigated the reaction of microclonal plants of five varieties of *Malus domestica* L. (“Malinové holovouské”, “Fragrance”, “Rubinstep”, “Idared”, “Car Alexander”), five varieties of *Prunus avium* L. (“Regina”, “Napolenova”, “Kaštánka”, “Sunburst”, “P-HL-C”) to osmotic stress simulated by increased concentrations of PEG-6000 in the medium. Stress, similar to drought, negatively affected the total water content, chlorophyll content, and leaf area of both plant species. Overall results indicate a wide range of water deficit tolerance among *Malus domestica* L. and *Prunus avium* L. cultures *in vitro*.

In separate scientific works, the salt tolerance of plants *in vitro* was evaluated based on physiological-biochemical, biometric indicators of microclonal plants. Thus, Putnik-Delić *et al*. (2019) investigated the effect of different concentrations of NaCl (0.2, 0.6, and 1.2 g/l) in the MS nutrient medium on the intensity of transpiration of microclones of *Brassica napus* L. of the Slavica cultivar. They proved that the intensity of transpiration decreased with increasing NaCl concentration in the nutrient medium. Al-Khateeb *et al*. (2020) investigated the effect of different NaCl salt content (from 0 to 300 mM) in the composition of the nutrient medium on photosynthesis, transpiration intensity and stomatal conductance of *Phoenix dactylifera* L. *in vitro*. The results showed that an increase in the salt concentration in the nutrient medium reduced the intensity of these processes.

Cioć *et al.* (2019) investigated the effect of red and blue spectrum light (in a ratio of 7:3), different concentrations of 6-benzyladenine (BA) (1, 2.5, and 5 μM) in growing microclones of *Gerbera jamesonii* Bolus. They proved that an increase in the concentration of BA contributed to an increase in the height of plants, the number of leaf blades, and a modification of lighting – the area of leaf blades. However, the authors noted that an increase in the concentration of BA was accompanied by a decrease in the content of dry substances in the vegetative mass, an increase in the intensity of lighting – an increase in the content of leaf pigments. Ki Young Choi *et al.* (2022) determined the effect of the intensity of white LED light on the growth of microclones of *Malus domestica* (M-9). Microclones were grown for 30 days under the influence of five white light-emitting diodes (LEDs) of different intensities: 100-500 (L1), 250-500 (L2), 500-500 (L3), 250-250 (L4) and 100-100 (L5). The authors stated that the number of leaves, stem diameter, wet mass of shoots, roots, and dry mass of shoots under white LED light 500-500 (L3) were significantly greater than those cultivated under other light intensities. Furthermore, a positive correlation was established between stomatal conductivity and transpiration rate. These results indicate that the light intensity of PPFD 500-500 was favourable for microclone growth *in vitro*.

Ergasheva *et al.* (2022) indicate the need to determine the physiological and biochemical state of microclonal plants when transferring them to uncontrolled environmental conditions. This will determine their survival rate and the yield of standard seedlings. Thus, scientists of Gulistan State University (Uzbekistan) determined the general watering of leaves and the intensity of transpiration of *Punica granatum* L. in the pre-adaptation period *in vitro* and when transplanting plants into non-sterile soil of local varieties – "Qora qayim", "Qizil anor", "Oq dona (Tuyatish)", "Achchiq dona". As a result, they proved that when microclonal plants were transferred to uncontrolled conditions, a high intensity of transpiration was observed, a substantial decrease in the water content in the leaves, i.e., a water deficit was observed. Therefore, the author recommends increasing the level of humidity to 90-95% at the stage of *in vitro* pre-adaptation, and then gradually reducing it to 50%, to ensure optimal mechanisms of plant adaptation to *in vivo* conditions.

The University of Bonn (Germany) investigated the influence of different growing conditions of *Populus canescens* L. – conditions *in vitro*, *ex vitro*, climate chamber, greenhouse on the development of the leaf apparatus, the composition of cuticular wax and transpiration of detached leaves. Studies have shown that when plants are transferred *in vitro* to other conditions, they quickly dehydrate, regardless of the amount of cuticular wax (Grünhofer *et al.*, 2021).

Thus, a brief review of the literature shows that there are very few scientific studies providing the results of research on the determination of the main physiological indicators of plants in the culture of tissues and organs *in vitro*, depending on the modification of the mineral and phytohormonal basis of the MS nutrient medium. And for grapes, such studies were generally not conducted.

MATERIALS AND METHODS

The study was conducted in the Department of Grape Seeding, Propagation and Biotechnology of the National Scientific Centre "V.E. Tairov Institute of Viticulture and Winemaking" (NSC V.E. Tairov IVW) during 2018-2022.

The object of research was microclones of grapes – Yarylo, Zagrei (technical varieties), Dobrynia, Harant (rootstock varieties). Physical parameters of cultivation: air temperature – 24-25°C, air humidity 60-70%, photoperiod – 16 hours, lighting 2500-3000 lux. All works were carried out under sterile conditions of laminar flow and culture boxes equipped with ultraviolet irradiators.

To cultivate grape microclones in the culture of tissues and organs *in vitro*, a modified Murashige and Skoog nutrient medium (MS) was used. The modification of the environment consisted in changing the amount of phytohormones (indolylacetic acid (IAA), 6-benzylaminopurine (6-BAP), adding biologically active preparations (Radifarm, Klonex gel) and mineral substrates (agroperlite, vermiculite) (Table 1).

Table 1. *Research scheme*

Experiment variants	Composition of the nutrient medium			
	basis	phytohormone content, mg/l		additional components
		IAA	6-BAP	
Control 1	MS	0.3	0.2	-
Control 2	MS	0.6	0.5	-
Variant 1	MS	0.3	0.2	Radifarm (2.5 ml/l)

Table 1, Continued

Experiment variants	Composition of the nutrient medium			
	basis	phytohormone content, mg/l		additional components
		IAA	6-BAP	
Variant 2	MS	0.6	0.5	Radifarm (2.5 ml/l)
Variant 3	MS	0.3	0.2	Clonex gel
Variant 4	MS	0.6	0.5	Clonex gel
Variant 5	MS	0.3	0.2	agroperlite
Variant 6	MS	0.6	0.5	agroperlite
Variant 7	MS	0.3	0.2	vermiculite
Variant 8	MS	0.6	0.5	vermiculite
Variant 9	MS	0.3	0.2	agroperlite + vermiculite (1:1)
Variant 10	MS	0.6	0.5	agroperlite + vermiculite (1:1)

Source: *compiled by the authors*

The MS medium was prepared as prescribed, after which other components were added, except for Clonex gel. It was applied by immersing the basal part of micropropagules before planting on a nutrient medium. Agar-agar was used for gelation of modified nutrient media. In nutrient media for the first-fourth variants of the experiment, it was used in the amount of 7.0 g/l, for the fifth–tenth variants of the experiment – 6 g/l.

Nutrient media were autoclaved under a pressure of 1 atm. for 15 min. After autoclaving and solidification of modified nutrient media with mineral substrates, two-layer (structured) nutrient media were formed in glass culture containers. The nutrient medium: mineral substrates ratio was 1.0:0.5. The *Radifarm preparation* is an extract of plant origin, which contains amino acids, steroids, glycosides, polysaccharides, betaine, vitamins, and trace elements. It promotes rapid rooting of plants, uniform growth, development of vegetative mass, root system, reduces the stress caused by transplanting plants.

The *Clonex gel preparation* is a complex of substances: indolylbutyric acid, vitamins, hormones, trace elements, nutrients necessary for the development and growth of the root system of plants. *Mineral substrates agroperlite, vermiculite* are minerals of the hydromica group, the use of which helps increase the aeration properties of nutrient substrates (nutrient media).

After 90 days of cultivation, the following were determined in the vegetative mass of grape microclones: water-holding capacity (%), transpiration intensity (g×(m^2×h)), dry matter content (%) (Sherer, 2011); plant viability was determined 30 days after planting in the greenhouse.

RESULTS AND DISCUSSION

In cells and tissues, there are two forms of water – free and bound. Free water is characterized by sufficient mobility, is a solvent that ensures the course of all physiological and biochemical reactions. The action of the stress factor, first of all, leads to evaporation and reduction in the cells of this particular form of water. Bound water is divided into osmotically bound and colloidal bound, it is located either in the middle of the colloidal system or on the surface of the colloids, between them.

The ability of plants to retain a certain part of water due to osmotic forces and increased hydrophilicity of biocoloids is a universal reaction of the body to the deterioration of environmental conditions. Therefore, under any stressor, a decrease in water loss occurs due to an increase in the water retention capacity of tissues.

Water-holding capacity is an indicator that characterizes the loss of water by the vegetative organs of plants over a certain period of time. In the technology of *in vitro* reproduction of grapes, it is important from the standpoint of transferring plants to uncontrolled conditions *in vivo* and their survival.

Analysis of the dynamics of water loss by leaves and shoots of grape microclones *in vitro* (pre-adaptation stage) of rootstock and technical varieties cultivated on modified nutrient media with agroperlite, vermiculite and their mixture (fifth-tenth variants) showed that they decreased in relation to the control values (control 1, control 2).

Thus, grape microclones of rootstock varieties lost 0.003 g after 5 min, 0.008 g after 10 min, 0.011 g after 15 min, 0.022 g after 20 min, 0.032 g after 30 min and 0.053 g after 60 min of water, which is 50.0% (after 5 min), 36.3% (after 10 min), 33.3% (after 15 min), 26.6% (after 20 min), 32.0% (after 30 min) and at 37.2% (after 60 min) less than control values (Fig. 1).

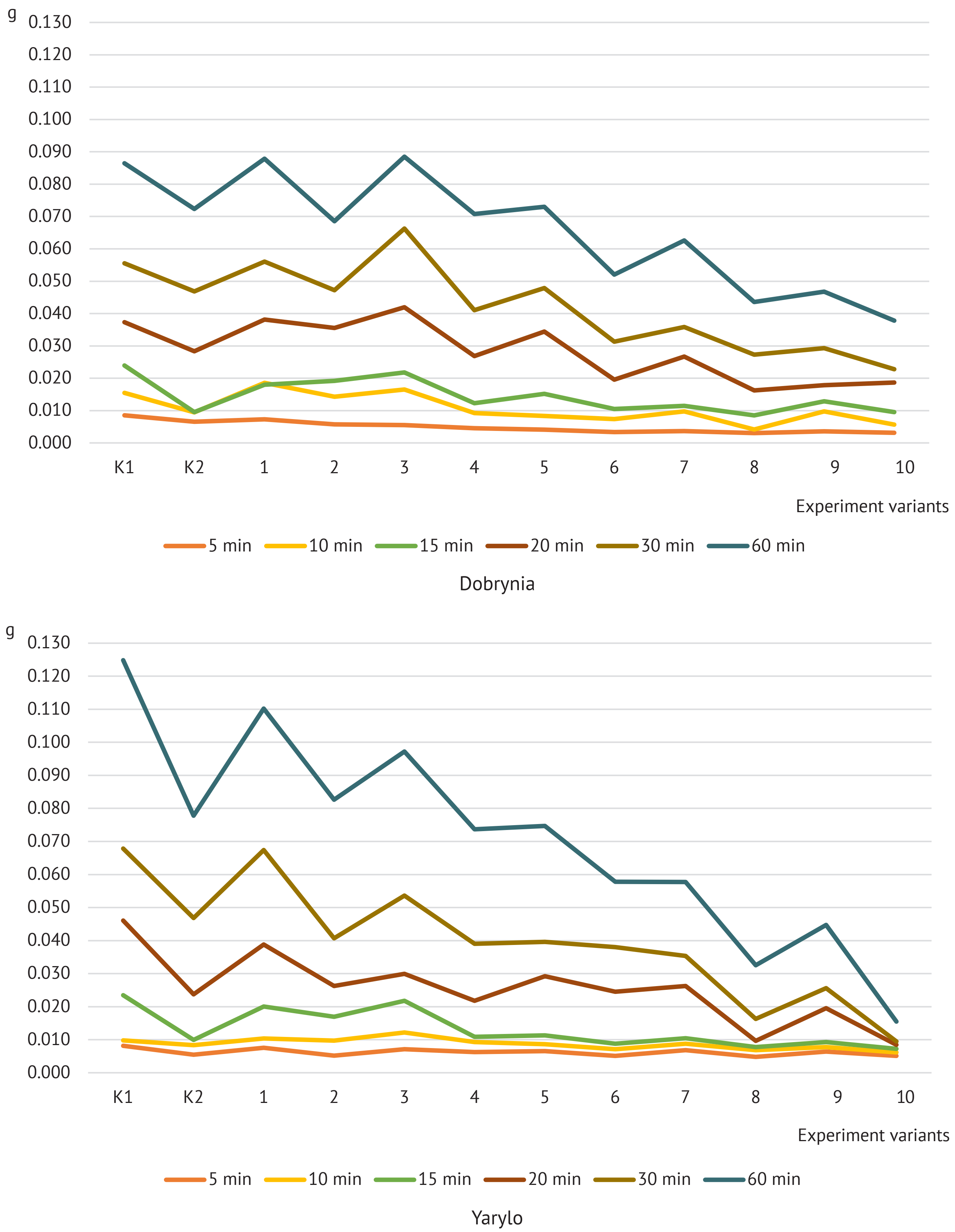


Figure 1. *Dynamics of water loss by grape microclones of rootstock and technical varieties on different types of nutrient media (average for 2018-2022)*
Source: *compiled by the authors*

Microclones of technical varieties lost 0.006 g, 0.007 g, 0.009 g, 0.014 g, 0.020 g, 0.034 g of water after the indicated time intervals, which was also less than the control values by 16.6%, 22.2%, 46.6%, 44.0%, 56.8%, 58.2%.

In grape microclones on nutrient mediums with Clonex gel and Radifarm (first-fourth variants), the water loss rate was at the control level. On average, plants of these variants lost from 0.007 g to 0.082 g of water (rootstock varieties) and from 0.006 g to 0.088 g of water (technical varieties) after 5-60 minutes.

Therefore, the results of the determinations indicate that the water-holding capacity of the tissues of grape microclones on structured nutrient media was the greatest, which indicates a potentially greater stability of these microclones in changing conditions. Furthermore, the indicator of water-holding capacity was generally higher in the experimental and control variants, where the content of phytohormones in the composition of the MS was equal to 0.2 mg/l 6-BAP, 0.3 mg/l IAA (first, third, fifth, seventh, ninth variants).

After analysing the experimental material, multiple analysis of variance was performed. The main influencing factors were the grape variety (factor 1), the content of phytohormones in the MS nutrient medium (0.2 mg/l 6-BAP, 0.3 mg/l IAA) (factor 2) and the structured base of the MS (addition of BAP or mineral substrates) (factor 3). According to the results obtained, the revealed differences in the results of the experiment are reliable, since the factual values of the Fischer criterion (for all the main factors of influence) at the significance level of P – 0.05 were greater than their tabular values (Table 1-2).

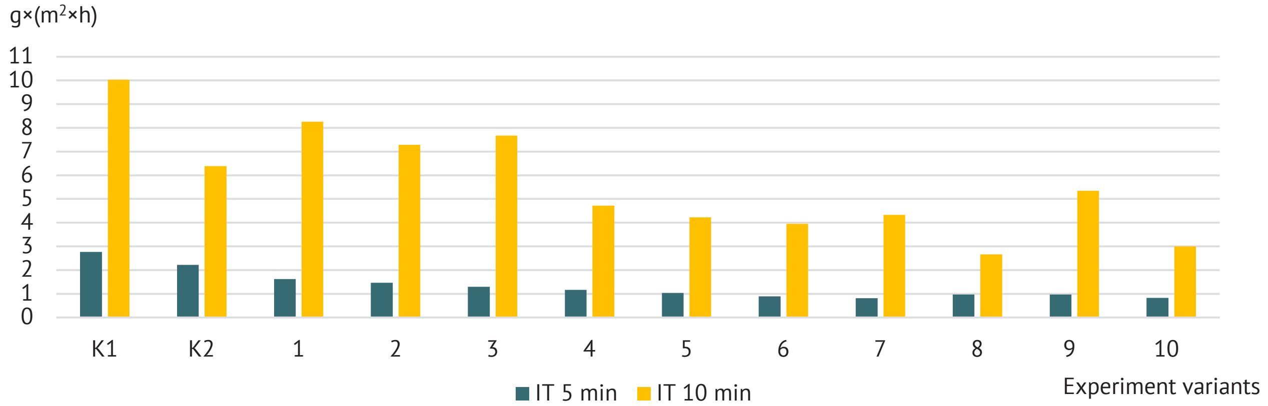
***Table 2**. Results of dispersion analysis on the effect of the type of nutrient medium on the water-retaining ability of grape microclones*

Factors of influence	$F_{fact.} / F_{theor.}$ Share of influence of factors, %				
	Water evaporation				
	5 min	10 min	20 min	30 min	60 min
Factor 1	314.23/2.69 20.14	591.66/2.69 24.72	523.34/2.69 27.11	476.35/2.69 31.84	439.83/2.69 26.22
Factor 2	887.63/3.94 18.96	960.05/3.94 13.37	887.02/3.94 17.58	681.06/3.94 15.17	769.04/3.94 15.28
Factor 3	356.00/2.30 38.03	557.59/2.30 38.83	278.83/2.30 31.63	338.37/2.30 37.70	465.00/2.30 46.20
Factor 1 × Factor 2	30.40/2.69 1.94	130.24/2.69 5.44	20.00/2.69 1.18	19.13/2.69 1.27	24.53/2.69 1.46
Factor 1 × Factor 3	14.76/1.77 4.73	52.37/1.77 10.94	32.35/1.77 9.61	17.46/1.77 5.83	20.62/1.77 6.14
Factor 2 × Factor 3	98.05/2.30 10.47	34.64/2.30 2.41	42.77/2,30 4.23	14.42/2.30 1.60	8.87/2.30 0.88
Factor 1 × Factor 2 × Factor 3	11.35/1.77 3.63	14.04/1.77 2.93	22.59/1.77 6.71	13.19/1.77 4.40	6.33/1.77 1.88
Error	2.10	1.36	1.95	2.59	1.94

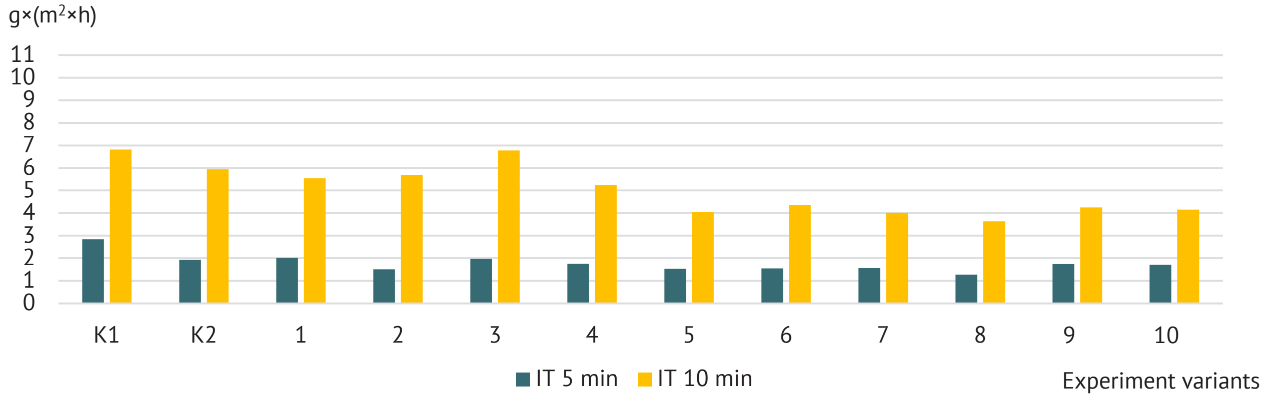
***Source**: compiled by the authors*

This method of research helped establish the share of the influence of each factor on the water-holding capacity of the vegetative mass of grape microclones from their total population. Thus, Factors 3 (structured basis of MS) and 1 (grape variety) had the most significant share of influence. Depending on the variants, they were within 31.63-46.20% (factor 3) and 20.14-31.84% (factor 1) of the total 100% of the population. The influence of Factor 2 (the content of phytohormones in the nutritional medium of MS) slightly decreased and was within 13.37-18.96%, the interaction of these factors was within 1.18-10.94%. The share of unaccounted factors was small and amounted to 1.36-2.59%.

Transpiration is the process of evaporation of water from the surface of plants over a certain period of time. The amount of transpiration depends on many factors, including temperature, lighting, water supply, etc. Determining the intensity of transpiration of grape microclones *in vitro* showed that it depended on the structured basis of the nutrient medium and the content of phytohormones in it. It was the largest in control plants (C1) and after the use of biologically active preparations (first, second, third variants) (Fig. 2).



Dobrynia



Yarylo

Figure 2. *The intensity of transpiration of grape microclones of grafted and technical varieties on different types of nutrient media (average for 2018-2022)*

Source: *compiled by the authors*

Thus, for microclones of grape rootstocks, the intensity of transpiration in the first variant (MS + Radifarm + IAA 0.3 mg/l; 6-BAP 0.2 mg/l) was the highest among the experimental variants and was equal to 1.6 g×(m^2×h) after 5 min, 8.3 g×(m^2×h.) after 10 min. Compared to the control values, a decrease of 1.1% (after 5 min) and 1.6% (after 10 min) was noted. In the second variant (MS + Radifarm + IAA 0.6 mg/l; 6-BAP 0.5 mg/l) the intensity of transpiration was equal to 1.5 g×(m^2×h) after 5 min, 7.3 g×(m^2×h) – after 10 min, which was more than the control (C2) by 1.3%, 2.7%. In the third variant, where Clonex gel was used (IAA 0.3 mg/l; 6-BAP 0.2 mg/l), the transpiration intensity was less than the control values by 1.5%, 2.7%. For grape microclones of technical varieties, according to the indicated experimental options, a similar pattern was noted, although the level of transpiration intensity was lower, and was within 5.5-6.8 g×(m^2×h), while for microclones of rootstock varieties – within 7.3-8.3 g×(m^2×h).

After cultivation of grape microclones on structured nutrient media (the fifth-tenth variants), the intensity of transpiration of the vegetative mass was lower, compared to both the first-fourth variants (MS+BAP) and the controls (C1, C2). In microclones of rootstock varieties, this difference with controls was equal to 1.5 (after 5 min) – 3.4 (after 10 min) g×(m^2×h), with variants where BAP was applied – 0.4 (after 5 min) – 1.9 (after 10 min) g×(m^2×h), in microclones of technical varieties – 0.8-2.5 g×(m^2×h) and 0.3-1.3 g×(m^2×h) according to variants.

The results of the variance analysis indicated that the difference between the experimental and control variants was reliable only after determining the intensity of transpiration of the vegetative mass of plants after 10 min ($F_{act.}$>$F_{theor.}$); after determining this indicator, after 5 minutes, the value of $F_{fact.}$ was smaller than $F_{theor.}$ Data were also obtained that helped determine the proportion of influence of each factor on the intensity of transpiration. The substantial influence of Factor 3 (structured basis of MS (adding BAP or mineral substrates)) was proved – 52.7% and Factor 1 (grape variety) – 21.5%; the influence of Factor 2 (the content of phytohormones in the MS nutritional medium), albeit substantial, was estimated at 5.4%.

During preparation and transfer of microclonal grape plants from *in vitro* conditions to *in vivo* conditions, the tissue structure of leaves and shoots plays an important role. It is usually evaluated by dry matter content or total hydration. The determination of the mass of wet and dry growth of grape microclones followed by the determination of the content of dry substances showed that most of them were synthesized in the leaves and shoots of plants that were cultivated on structured nutrient media (Fig. 3).

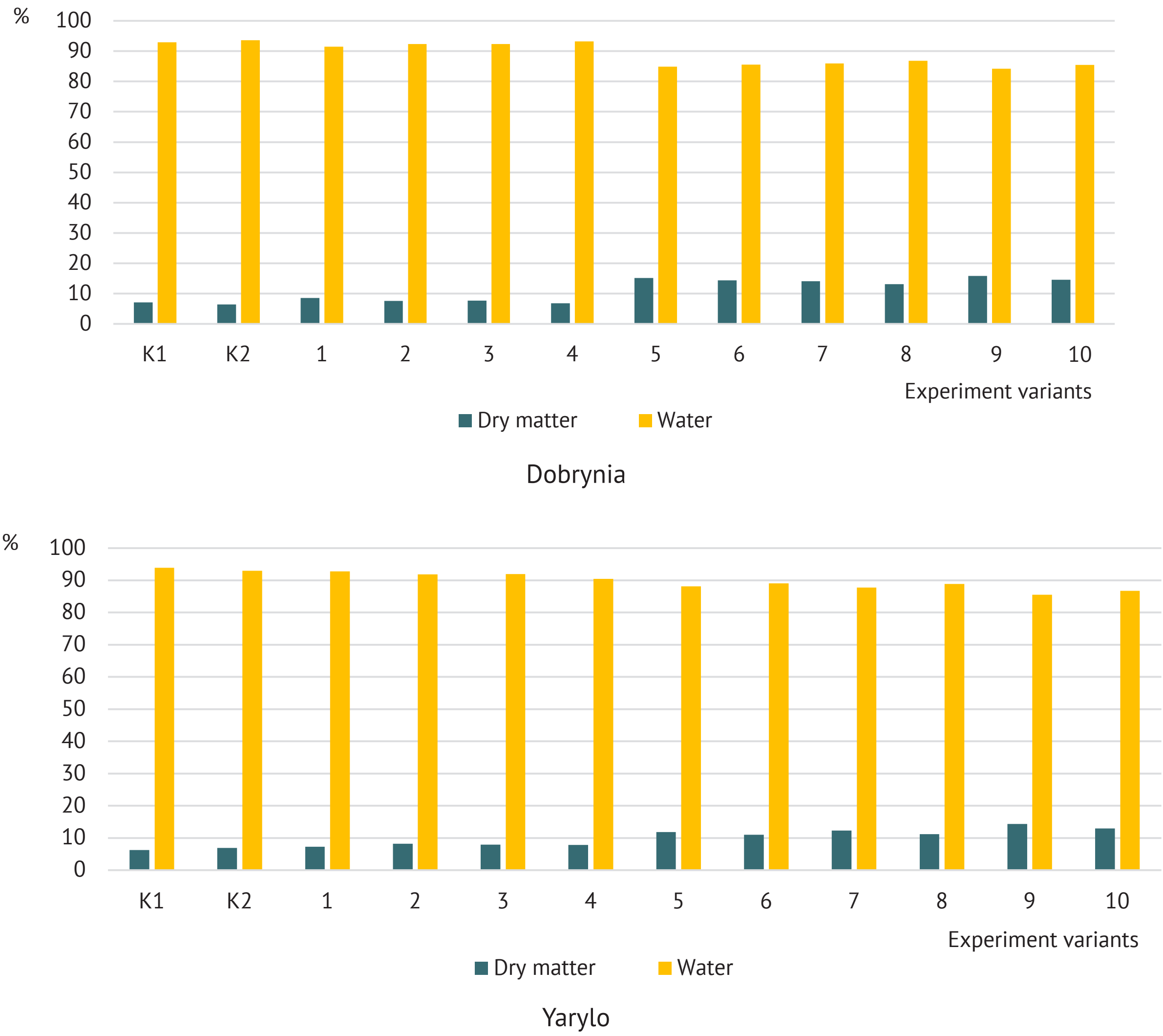


Figure 3. *The content of dry matter and water in the tissues of leaves and shoots of grape microclones of grafted and technical varieties on different types of nutrient media (average for 2018-2022)*
Source: *compiled by the authors*

Thus, in the indicated versions of the experiment, the dry matter content was equal to 12.0-15.2% (rootstock varieties), 11.0-14.9% (technical varieties). On nutrient media with the use of biologically active preparations Radifarm and Clonex gel, this indicator was equal to, on average, 6.8-8.7% (rootstock varieties) and 7.3-9.1% (technical varieties). In plants of control variants, the dry matter content in the tissues of the vegetative mass was 6.7-7.5% and 6.6-7.8%, respectively, in rootstock and technical grape varieties. Thus, in microclones of the first and fourth variants, the dry matter content was 0.8-1.2% higher than the control values, and in microclones of the fifth and tenth variants – by 5.6-7.8%.

The analysis of the results of the multiple variance analysis indicated that the identified differences in the results of the experiment are reliable ($F_{fact.}>F_{theor.}$) at the significance level P – 0.05. The factor structured MS basis had the greatest influence on the accumulation of dry matter in the vegetative mass of grape microclones during *in vitro* cultivation – 90.5%. Other main factors of influence (grape variety, hormonal basis of MS), albeit significant, were estimated at 2.2%.

Engraftment of grape microclones in vivo. The results of the study proved that the largest number of such plants were after cultivation of grape microclones *in vitro* on nutrient media with mineral substrates, but mainly on those where the content of phytohormones in the composition of the MS was equal to 0.3 mg/l IAA, 0.2 mg/l BAP (fifth, seventh, ninth, and tenth variants). The viability of microclones of grape rootstock varieties was at 85.5% (Dobrynya) – 92.5% (Garant), microclones of technical varieties – at 82.4% (Zagrei) and 85.5% (Yarylo) (Fig. 4).

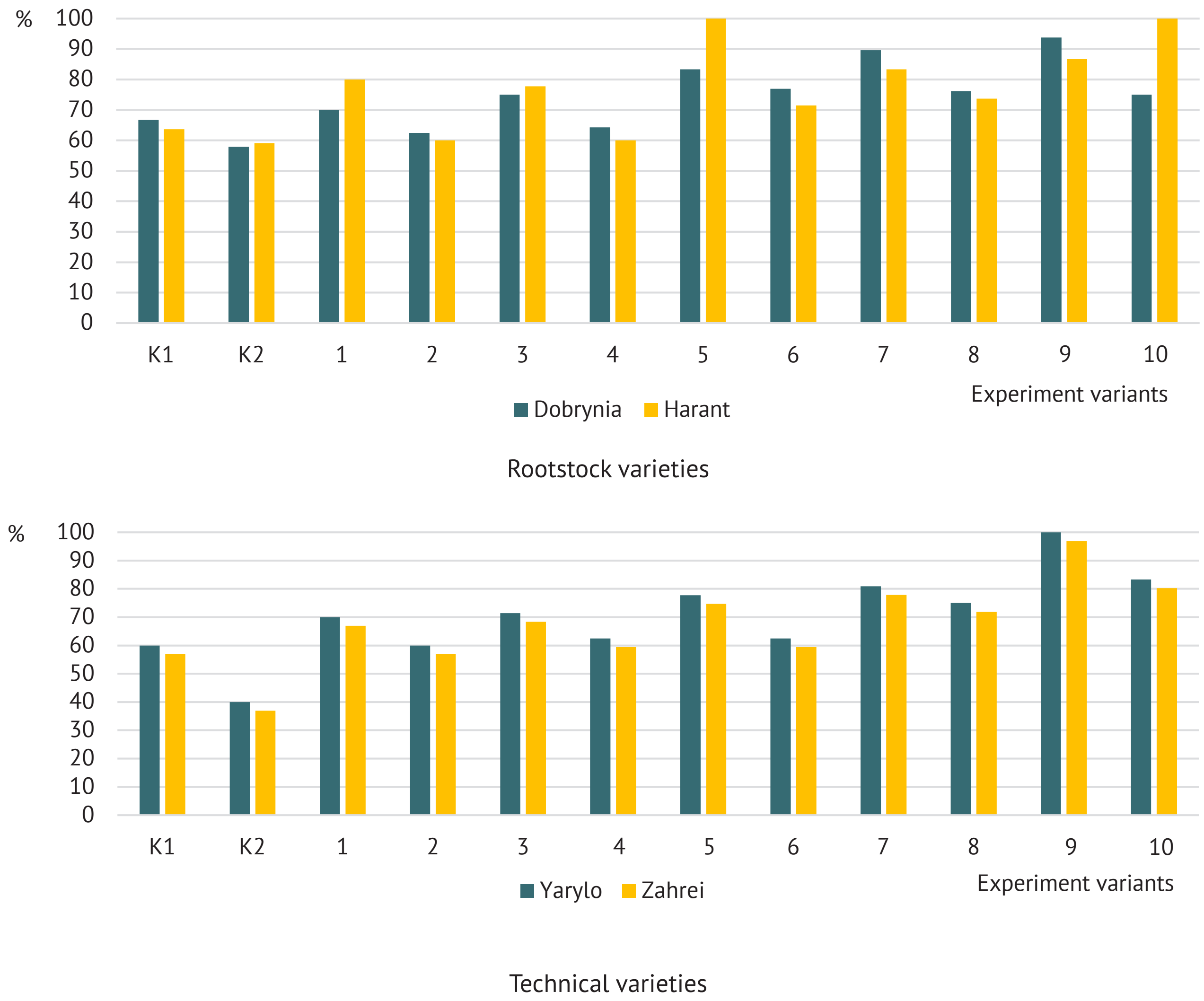


Figure 4. *Viability of grape microclones of grafted and technical varieties in vivo (average for 2018-2022)*
Source: *compiled by the authors*

Compared to Control 1, the difference was between 12.0% and 40.0%. After the use of biologically active preparations, the survival rate of grape microclones was at the level of control values. In similar variants, but with a higher content of phytohormones – 0.6 mg/l IAA, 0.5 mg/l BAP (second, fourth, sixth, eighth variants), the survival rate of microclones decreased and was at the level of Control 2.

A multiple correlation-regression analysis was conducted to establish the dependence of the viability of grape microclones *in vivo* on their physiological state formed *in vitro* (water regime, transpiration intensity, dry matter content). The results indicated that the multiple correlation coefficient between the independent variables water-holding capacity, transpiration intensity, dry matter content and the dependent variable microclonal survival *in vivo* was equal to 0.82, which indicates a high multiple correlation, according to the Chaddock scale. According to the coefficient of multiple determination R^2, the viability of grape microclones depended on the indicated independent variables by 70.0%. Determination of the standardized regression coefficient β helped compare the relative contribution of each independent variable to the prediction of the dependent variable. As evidenced by the received predictors, dry matter content and water-holding capacity are statistically significant and important – β(dry matter) = 1.04, β(water-holding capacity) = 0.36.

For *in vitro* plants to successfully take root in non-sterile conditions, they must be ready to overcome the stresses to which they are exposed during the adaptation process. According to the data of the authors

(Bag, 2019; Leite, 2021), to increase the percentage of survival of plants *in vivo*, it is necessary to start preparing them for new conditions *in vitro*, including a decrease in air humidity. In this regard, the quality and physical properties of the nutrient medium are of paramount importance. Research by many authors has established that different agricultural plants, their varieties, and forms react and manifest themselves differently in *in vitro* culture on different types of nutrient media, and therefore, the quantitative and qualitative composition of the nutrient medium should be selected considering varietal specificity. For the reproduction of grapes with the use of *in vitro* tissue and organ culture, modified nutrient media based on Murashige and Skoog medium are used. Its composition includes macro- and microsalts, calcium chloride, iron chelate, vitamins, indoleacetic acid, 6-benzylaminopurine, sucrose, agar (Zelenianska, 2022). According to the results of the research in this paper, for better growth and development of grape microclones of rootstock and technical varieties, the course of physiological processes in the tissues of leaves and shoots, optimal is the Murashige and Skoog nutrient medium with a minimum content of phytohormones in the composition: 0.3 mg/l IAA, 0.2 mg/l BAP. Analogous results were obtained (Sota, 2019; Okello, 2021) on the culture of *Aspilia africana* (Pers.) C.D. Adams and *Rosmarinus officinalis* L.).

At the moment of transfer of *in vitro* plants to *in vivo* conditions, they are exposed to a strong influence of water stress. As a result, this leads to dehydration of tissues, destruction of membranes. Plants are especially sensitive to dehydration immediately after their removal from culture containers, which is associated with non-functioning stomata, reduced water absorption, and high transpiration. The main water loss occurs in the first 10-14 days due to non-functional stomata. Therefore, it is important that before transferring the plants to *in vivo* conditions, they have functioning leaves. It is known that stomatal closure occurs at an air humidity of 65%, but at such humidity, rapid wilting and death of plants occur. Therefore, (Grytsak, 2020; Hannachi, 2021) recommend initially maintaining (*in vivo*) humidity within 99-95%, then reducing it to 50-60%. But without expensive temperature and humidity control systems, this is very difficult to achieve (Chen, 2021).

To obtain functional leaves from microclonal plants, it is necessary to achieve a balance of water exchange (optimize water exchange and transpiration) even *in vitro*. This can be done by reducing the temperature at the base of the culture containers, applying a thin layer of lanolin paste, vegetable oil, paraffin, polyethylene glycol, on a nutrient medium. However, experimental plants under such influences were characterized by weak growth and development. Based on this information, the authors suggested that adding agroperlite and/or vermiculite to the MS nutrient medium (creating structured nutrient media) would also help reduce humidity in the culture tanks and promote additional aeration of the nutrient medium. The obtained experimental results on indicators of the water regime, including the intensity of transpiration, confirmed our assumption. It was established that on structured nutrient media (MS + agroperlite, MS + vermiculite, MS + agroperlite+vermiculite) grape microclones were characterized (compared to the control, MS by prescription) by higher water-holding capacity and lower intensity of transpiration of leaf and shoot tissues. It is known that the greater the water retention capacity of plant leaves, the better they will tolerate the adverse impact of abiotic environmental factors (Gupta, 2020). In our case, the greater the water-holding capacity of grape microclones, the better they will take root in uncontrolled conditions. The obtained results proved that on structured nutrient media, which the authors of this paper determined to be the most effective (MS + agroperlite, MS + vermiculite, MS + agroperlite+vermiculite), the tissues of leaves and shoots of grape microclones had a higher water-holding capacity, a lower intensity of transpiration, and their viability *in vivo* was at 76.3-98.5%. For comparison; in the control, the viability of grape microclones *in vivo* was at 58.5-65.2%. This is explained by the fact that on the indicated nutrient media, grape microclones, already *in vitro*, used water more economically. Such savings are associated with structuring, adding mineral substrates to the nutrient medium. This, on the one hand, improved the aeration of the substrate, on the other hand – modelled more natural cultivation conditions. Comparable results were obtained (Hoang, 2020) upon cultivating *Eutrema japonicum*, on a nutrient medium with agroperlite.

Before planting grape microclones *in vivo*, the authors also determined the content of dry matter in leaves and shoots. According to our results, their largest number was synthesized on structured nutrient media. According to the data (Grytsak, 2020), it was established that at the maximum values of the indicators of wet and dry mass growth, plants form new leaves much faster *in vivo*.

As a result of the conducted multiple dispersion and correlation-regression analysis, the authors noted a prominent dependence of the formation of indicators of the water regime of grape leaves and shoots, the content of dry substances on the composition of the nutrient medium, and a high correlation between the indicators of the water regime of microclones and their viability *in vivo*.

CONCLUSIONS

To increase the adaptation potential of grape microclones *in vitro*, it is advisable to cultivate them on structured nutrient media with mineral substrates – MS (IAA 0.3 mg/l + 6-BAP 0.2 mg/l) with the addition of agroperlite or vermiculite (MS + agroperlite, MS + vermiculite, MS + agroperlite + vermiculite).

On structured nutrient media, grape microclones were characterized (compared to the control) by higher water-holding capacity and lower transpiration intensity of leaf and shoot tissues. Drying the plants and determining the amount of moisture that evaporated after short intervals of time (after 5, 10, 15, 20, 30, and 60 min) showed that the water-holding capacity increased (on average for the variants) by 0.5-8.1% (technical varieties) and by 0.6-3.0% (rootstock varieties).

On the contrary, the intensity of transpiration (after 10 min) of grape microclones decreased, which was typical for both technical and rootstock varieties. Compared to the control, this indicator decreased by 1.8 times in plants on MS + agroperlite, MS + vermiculite nutrient media and by 1.6 times in plants on MS + agroperlite + vermiculite nutrient media. In the tissues of leaves and shoots of microclones of grapes, a larger amount of dry substances was synthesized. Compared to the control, microclones of technical varieties accumulated 6.0% (MS + agroperlite), 5.9% (MS + vermiculite), 7.4% (MS + agroperlite + vermiculite) more dry matter; in microclones of rootstock varieties – by 6.9%, 6.6%, and 8.1%, respectively.

The largest number of plants that took root *in vivo* and were further characterized by active growth and development was after *in vitro* cultivation on structured nutrient media. Compared to the control, this indicator increased by 19.8-26.5% in the MS + agroperlite variants, by 21.0-21.3% in the MS+vermiculite variants, and by 25.1-40.0% in the MS + agroperlite + vermiculite variants.

The reliability of the obtained results was confirmed by the results of multiple variance and correlation-regression analysis. It has been proved that factors such as the structured basis of MS (27-52%) and grape variety (20-30%) had the greatest influence on indicators of water-holding capacity, intensity of transpiration of the vegetative mass of grape microclones *in vitro*, only factor of the structured base of MS substantially influenced the indicator of dry matter content (90%). A positive correlative dependence of the viability of grape microclones *in vivo* on the physiological state formed *in vitro* (R=0.82) was established.

The perspective of further research is to determine the anatomical structure of the stomatal apparatus of the lower epidermis of leaves of microclones of grafted and technical varieties of grapes under the conditions of cultivation *in vitro* and *in vivo*, establishing its influence on the water regime and adaptation potential of plants.

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CONFLICT OF INTEREST

None.

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Вплив поживних середовищ на фізіологічні показники мікроклонів винограду

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Анотація. Успішне приживання мікроклонів винограду в неконтрольованих умовах довкілля (*in vivo*) залежить від рівня стійкості, який формується ще на етапі їх пасажування і росту *in vitro*. Важливу роль при цьому відіграють показники водного режиму вегетативної маси. Метою роботи було ознайомлення з результатами визначення водозатримуючої здатності, інтенсивності транспірації мікроклонів винограду *in vitro* та встановлення частки їх впливу на адаптаційний потенціал *in vivo*. У роботі використовували біотехнологічні, лабораторні, вегетаційні та математично-статистичні методи досліджень. Отримані результати показали, що для оптимізації фізіологічних процесів у тканинах листків та пагонів мікроклонів винограду, підвищення їх приживлюваності в умовах *in vivo* доцільним є їх культивування *in vitro* на структурованих поживних середовищах (МС + агроперліт, МС + вермікуліт, МС + агроперліт + вермікуліт) із вмістом фітогормонів ІОК – 0,2 мг/л, і 6-БАП – 0,3 мг/л. Структуровані поживні середовища сприяли підвищенню водозатримуючої здатності та зниженню інтенсивності транспірації тканин листків і пагонів мікроклонів як технічних, так і підщепних сортів. Протягом 60 хв. досліджень у мікроклонів технічних сортів випаровувалось від 0,006 г до 0,034 г води, у мікроклонів підщепних сортів – відповідно від 0,003 г до 0,053 г. Інтенсивність транспірації (через 10 хв.) зменшувалась в 1,7-1,8 рази. На контрольному поживному середовищі Мурасіге-Скуга за відповідний проміжок часу рослини випаровували більшу кількість води: від 0,006 г до 0,079 г (технічні сорти) та від 0,008 г до 0,086 г (підщепні сорти); інтенсивність транспірації була вищою. Після культивування мікроклонів винограду на структурованих поживних середовищах вони характеризувалися більшим вмістом сухих речовин у тканинах листків і пагонів (14,6-15,0 %) та кращими показниками приживлюваності в умовах *in vivo* (76,3-98,5 %, при 58,5-65,2 % у контролі). Достовірність отриманих результатів підтверджено результатами багатофакторного дисперсійного аналізу. Отримані результати розширюють уявлення про динамічні зміни показників водного режиму вегетативної маси мікроклонів винограду *in vitro,* їх вплив на приживлюваність рослин в умовах *in vivo*

Ключові слова: *in vitro*; водозатримуюча здатність; інтенсивність транспірації; приживлюваність; фітогормони; біологічно активні препарати; мінеральні субстрати

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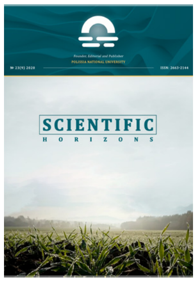

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Varietal features of elements of soybean cultivation technology during irrigation

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Abstract. An important advantage of soybean (*Glycine max* (L.) Merr.) over other crops is a prominent protein content and a balanced amino acid composition, in connection with which the creation of a wide range of varieties becomes relevant, as their cultivation could meet the needs of processing industries, as well as the development of optimal varietal cultivation technologies, which allow unleashing the genotypic potential of productivity. The purpose of this study was to substantiate the specific features of the formation of productivity of modern soybean varieties depending on the elements of cultivation technology in irrigation conditions. Research methods: field, morphometric,

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laboratory, statistical (correlation and regression analysis). Field studies were conducted during 2019-2021 in the agroecological zone of the Southern Steppe within the Kakhovka Irrigation System. Features of the growth and development of soybean varieties of different maturity groups were established: fast crops – Monarkh, Arnika, early crops – Pysanka, Sofia, mid-early – Sviatohor, Evridika. The yield of soybean varieties varied depending on the timing of sowing, plant density, and varietal characteristics. The maximum productivity of crops of early varieties Arnika and Monarkh at 2.81-3.39 t/ha was formed during the sowing period of May 1 and the optimal sowing density of 700 thous. plants/ha. In the group of early crops, Sofiia and Pysanka varieties showed the maximum yield of 3.17-3.22 t/ha during the sowing period of May 1 and plant density of 700 thous. plants/ha. Varieties of the mid-early crops Sviatohor, Evridika gave the maximum yield of 3.76-4.28 t/ha for sowing on May 1 and a density of 500 thous. plants/ha. To obtain the maximum yield of soybeans under irrigation conditions, there is an optimal sowing period and an optimal density of coenosis for each maturity group of varieties: fast crops showed the maximum yield when sowing on May 1 and with a density of 700 thous. plants/ha, early and mid-early crops – when sowing on May 1 and with a plant density of 500 thous. plants/ha. The results of this study can be used in production conditions to adjust the elements of agricultural technology of soybean seed production and obtain high yields with a prominent level of profitability

Keywords: sowing period; plant density; yield; dry matter weight; thousand kernel weight

INTRODUCTION

Soybeans have the potential to increase the sustainability of agricultural production systems, and therefore more attention is needed to spread this crop, specifically in the EU. A more profound understanding of the key determinants that affect soybean germination and rooting is the first step to facilitate its implementation in agricultural systems.

The yield of soybean grain is determined by the interaction of the plant, the external environment and the growing technology. In agrotechnical activities, research focuses on crop density and row spacing. Hlupak (2020) found that increasing the density of coenosis to certain parameters of plant density leads to an increase in yield, but a further increase in the density of coenosis causes shading of plants and a decrease in the yield of individual varieties of different genotypic origin.

Furman *et al.* (2022) established that in thinned crops, plants branch intensively, form an excessive number of leaves, beans, and seeds, under the weight of which and under the influence of wind gusts, the branches often break off. Beans in such crops are attached low on the stem and ripen unevenly, which leads to a decrease in the overall yield, despite the usually high individual productivity of the crops.

Research conducted in Sichuan Province (China) established that it is possible to achieve the maximum accumulation of biomass and its redistribution in favour of beans and grain during the soybean sowing period, specifically, the early periods contribute to a greater development of biomass and productivity (Ahmed *et al.*, 2018). In the climatic conditions of Korea, it was found that the density of soybean crops can regulate the morphometric characteristics of plants and promote more efficient use of light energy, which can improve the photosynthesis and increase yield (Lee *et al.,* 2019).

Jańczak-Pieniążek *et al.* (2021) noted that the corresponding variety of soybean crop density is the main intangible and environmental factor of agricultural technology. Studies in Poland proved that the yield was more affected by weather conditions. Strong plant density reduced the parameters of the productivity structure, increased the height of plants.

Lamichhane *et al.* (2020) carried out field studies for three sowing periods from mid-March to mid-April in the northern climatic zone of France to estimate the possibility of expanding soybean areas in the northern part of the country in the future due to climate changes. Their study indicated that the main reasons for the decrease in field germination included soil crust, low-temperature soil, drying of the upper soil layer. These results necessitate the creation of soybean varieties with increased cold resistance for early sowing periods.

Markovska *et al.* (2023) found that a large amount of precipitation, a cold, prolonged spring, high humidity and low soil temperature lead to the lengthening of individual phenological phases of soybean plant development, the occurrence of stressful conditions and, as a result, a general weakening of soybean plants and pathogen damage.

Didora *et al.* (2022) in the conditions of Polissia and Milenko *et al.* (2022) in the conditions of the Poltava region, established the response of fast-growing soybean varieties to improved elements of cultivation technology under conditions of natural moisture availability. Varietal responses were established for each region, the best genotypes and improved technology elements were recommended, which indicates the need to improve varietal technology in each agroecological zone. The early sowing period (at 10-15°C) led to a delay in germination and seedling. Early sowing resulted in more nodes, but shorter internodes. The delay in sowing after May 1 led to a significant linear decrease in seed yield, which indicates the importance of early sowing for unleashing the yield potential of the variety and efficient use of moisture.

Rybalchenko (2018) proved that one of the crucial elements of soybean plant productivity that affects the formation of real yield is the thousand kernel weight. The parameters of this indicator are controlled by the genotype of the variety, as well as technological methods of cultivation.

Fellahi *et al.* (2020) indicate that grain size is an important feature that determines the yield of a variety for grain crops. Therewith, selections based on a set of attributes calculated using index ratios provide a more reliable assessment. Bizari *et al.* (2017) found that index scores for multiple traits when evaluating the productivity of soybean varieties were more informative than estimates for individual traits and yields. For the genotypic characteristics of grain varieties, it is proposed to use several indices, among which one of the most informative and widespread is the grain yield index, which is determined by the ratio of useful products to total biomass. Batashova *et al.* (2020) proved that the index characterizes the level of attraction of useful nutrients from the leaf-stem mass to the reproductive organs and can be an indicator of the intensity of the variety and the effectiveness of cultivation technology under various agroecological conditions. According to Morgun *et al.* (2019) a prominent positive correlation of plant biomass with yield can occur at certain stages of organogenesis, which can be an additional index indicator for determining the productivity of promising varieties.

Mazur (2019) studies have found that the assessment of soybean varieties based on indices and correlations of relationships provides an opportunity to assess the productivity potential for plant biomass, yield index, and the thousand kernel weight in greater detail. The use of indices to search for valuable genotypes is widely discussed in scientific circles. Céron-Rojas & Crossa (2018) proved that the use of correlation-regression analysis of several quantitative traits helps more effectively determine the selection value of genotypes, compared to the assessment of individual indicators.

The purpose of this study was to establish the influence of sowing time and coenosis density on the correlation and regression dependences of seed yield of modern soybean varieties of different ripeness groups with yield index, biomass, and seed size in the conditions of irrigation of the Southern Steppe, to establish the optimal type of variety for unlocking the potential of productivity with unlimited cultivation technologies.

MATERIALS AND METHODS

The study was conducted according to the thematic research plan of the State Higher Educational Institution "Kherson State Agrarian and Economic University" under the task "Modern aspects of informatization of agricultural production based on modelling and forecasting of production processes in agroecosystems" (state registration number 0120U100997). Field experiments were conducted during 2019-2021 at the base of the university on the territory of the "VYKO" Farm in the Novotroitsk District of the Kherson Region in the agro-ecological zone of the Southern Steppe (HTC_{V-IX}=0.50-0.60) of the Kakhovka Irrigation System.

The soil of the experimental plot is medium loamy, dark chestnut. Agricultural techniques for growing soybean varieties in experiments were generally accepted for the southern zone of Ukraine. Predecessor – corn. The study was carried out pursuant to the methods of research on irrigated land described in the studies of Vozhehova *et al.* (2014), Ushkarenko *et al.* (2008). Statistical processing of research results was performed using the Agrostat computer software package.

In a three-factor experiment, the following were studied: sowing dates (factor A) – April 15, May 1, May 15; soybean varieties (factor B); plant density (factor C) – 500, 700, 900 thous. plants/ha. The material for the study was modern soybean varieties of Ukrainian selection of different maturity groups: fast crops – Monarkh (originator – Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences, Kherson), ArniKa (originator – NSC "Institute of Agriculture of the National Academy of Agrarian Sciences", Kyiv); early crops – Pysanka (originator V.Ya. Yuryev Institute of Plant Breeding of the National Academy of Agrarian Sciences, Kharkiv), Sofiia (originator – Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences, Kherson); mid-early crops – Sviatohor (originator – Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences, Kherson), Evridika (originator – Breeding and Genetics Institute – National Center for Seed Science and Varietal Research).

Repetition was fourfold, the sowing area of the sub-subplot – 200 m^2, the accounting area – 150 m^2. Irrigation was carried out by a VALLEY sprinkler with a pre-irrigation soil moisture level in the soil layer of 0-50 cm – 75% field capacity.

RESULTS AND DISCUSSION

A review of literature sources and studies conducted during 2019-2021 indicates that the yield value depends on the factors under study: the sowing period, the genotype of the variety, the density of coenosis. One of the indicators that depends on the genotype of the variety and the elements of the technology is the thousand kernel weight (TKW).

Over the years of research, the TKW of soybean seeds on the variants for studying the influence of the first ultra-early sowing period on April 15 averaged 156.0 g, the second sowing period on May 1 – 158.8 g, the third sowing period on May 15 – 156.4 g (Table 1).

Table 1. *TKW of soybean seeds depending on the technology elements, g (average for 2019-2021)*

Sowing period for soybean varieties *(factor A)*	Soy variety *(factor B)*	Soybean plant density, thous. plants/ha *(factor C)*			Average by factor A	Average by factor B
		500	**700**	**900**		
April 15	Monarkh	149.9	147.7	145.3	156.0	147.6
	Arnika	145.6	143.9	140.9		143.5
	Pysanka	158.7	155.7	153.7		156.0
	Sofiia	161.6	158.7	156.7		159.0
	Svyatohor	168.7	165.7	161.3		165.4
	Evridika	167.7	164.5	160.4		164.2
Average by factor		**158.7**	**156.0**	**153.1**		
May 01	Monarkh	153.8	150.7	148.8	158.8	151.1
	Arnika	151.8	148.7	145.8		148.8
	Pysanka	162.3	159.8	155.7		159.3
	Sofiia	163.9	160.8	157.8		160.8
	Svyatohor	171.8	166.8	162.7		167.1
	Evridika	170.4	165.8	161.4		165.9
Average by factor		**162.3**	**158.8**	**155.4**		
May 15	Monarkh	148.9	146.1	144.2	156.4	146.4
	Arnika	147.7	144.9	143.8		145.5
	Pysanka	156.7	155.5	153.4		155.4
	Sofiia	159.8	157.7	155.6		157.7
	Svyatohor	170.8	169.7	161.9		167.4
	Evridika	169.8	167.5	160.8		166.0
Average by factor		**159.0**	**156.9**	**153.3**		
LSD_{05}, g		Factor A – 1.31; factor B – 2.16; factor C – 2.45				

Source: *compiled by the authors*

Therewith, the genotype of the soybean variety had the maximum effect on the TKW trait. For all sowing periods and density options, fast-growing varieties Arnika and Monarkh showed a TKW from 140.9 to 148.8 g, early crops Pysanka and Sofia – 153.4-155.6 g, mid-early crops Evridika and Sviatohor – 160.4-161.3 g, i.e., the difference between fast and mid-early crops was 12.5-19.5 g. The density of the coenosis also had a substantial impact on the TKW. In varieties of all ripeness groups, the maximum TKW was observed at a density of 500 thous. plants/ha, with an increase in density to 900 thous. plants/ha, the trait under study tended to decrease for all sowing periods.

One of the main tasks of the study was to determine the level of influence of individual elements of soybean plant productivity on the formation of real yield. There is a positive correlation of moderate strength between the TKW sign and yield (Fig. 1).

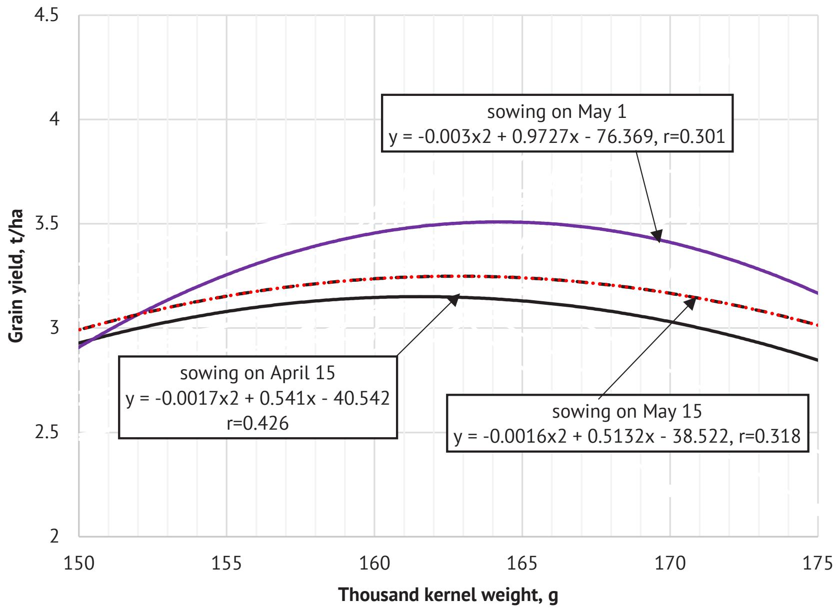

Figure 1. *Correlation and regression models of the dependence of seed yield of soybean varieties and the TKW at different sowing dates*

Source: *compiled by the authors*

Between TKW and grain yield of soybean varieties for the sowing period on April 15, the correlation coefficient was 0.426, the optimum TKW was within 161-163 g; for the sowing period of May 1, the correlation coefficient was 0.301, the optimum TKW was within 163-167 g; for the sowing period of May 15, the correlation coefficient was 0.318, the optimum TKW was within 160-165 g.

The capacity and duration of dry matter accumulation depend to an important extent on the genetic characteristics of the variety, the intensity of plant growth and the intensity of photosynthetic potential. With the intensity of growth processes, the formation of the assimilation surface of leaves accelerates, the photosynthetic activity of plants increases, and their real yield increases. The conducted studies have indicated that the formation of aboveground dry matter of modern soybean varieties largely depends on both the time of sowing and the density of plants (Table 2).

Table 2. *The mass of dry matter of soybean plants of different genotypes in the phase of bean ripening depending on the elements of agrotechnology, t/ha (average for 2019-2021)*

Sowing period for soybean varieties *(factor A)*	**Soy variety *(factor B)***	**Plant density, thous. plants/ha *(factor C)***			**Average by factor A**	**Average by factor B**
		500	**700**	**900**		
April 15	Monarkh	7.13	7.21	7.21	6.58	7.19
	Arnika	6.05	6.10	6.17		6.11
	Pysanka	6.52	6.56	6.62		6.57
	Sofiia	6.77	6.48	6.35		6.53
	Svyatohor	6.80	7.00	6.87		6.89
	Evridika	6.22	6.13	6.20		6.18
Average by factor C		**6.58**	**6.58**	**6.57**		
May 01	Monarkh	7.22	7.21	7.20	6.86	7.21
	Arnika	6.34	6.11	6.09		6.18
	Pysanka	6.60	6.30	6.42		6.44
	Sofiia	6.57	6.48	7.02		6.69
	Svyatohor	7.78	7.77	7.60		7.72
	Evridika	6.96	6.83	6.98		6.92
Average by factor C		**6.91**	**6.78**	**6.89**		

Table 2, Continued

Sowing period for soybean varieties *(factor A)*	Soy variety *(factor B)*	Plant density, thous. plants/ha *(factor C)*			Average by factor A	Average by factor B
		500	700	900		
May 15	Monarkh	7.07	7.07	7.11	6.75	7.08
	Arnika	6.02	6.17	5.87		6.02
	Pysanka	6.79	6.61	6.77		6.72
	Sofiia	6.93	6.79	6.93		6.88
	Svyatohor	7.49	7.20	7.27		7.32
	Evridika	6.56	6.45	6.38		6.46
Average by factor C		**6.81**	**6.72**	**6.72**		
LSD_{05}, t/ha		Factor A – 0.20; factor B – 0.31; factor C – 0.16				

Source: *calculated by the authors*

It was established that the dry matter mass of fast crops Arnika and Monarkh reached their maximum values when sowing on May 1 and a density of 500 thous. plants/ha, early crops Pysanka and Sofiia – on May 15 at a density of 500 thous. plants/ha, mid-early crops Evridika and Sviatohor – on May 1 at a density of 500 thous. plants/ha.

A positive correlation of moderate strength was observed between the dry matter mass and the yield of soybean grain (Fig. 2).

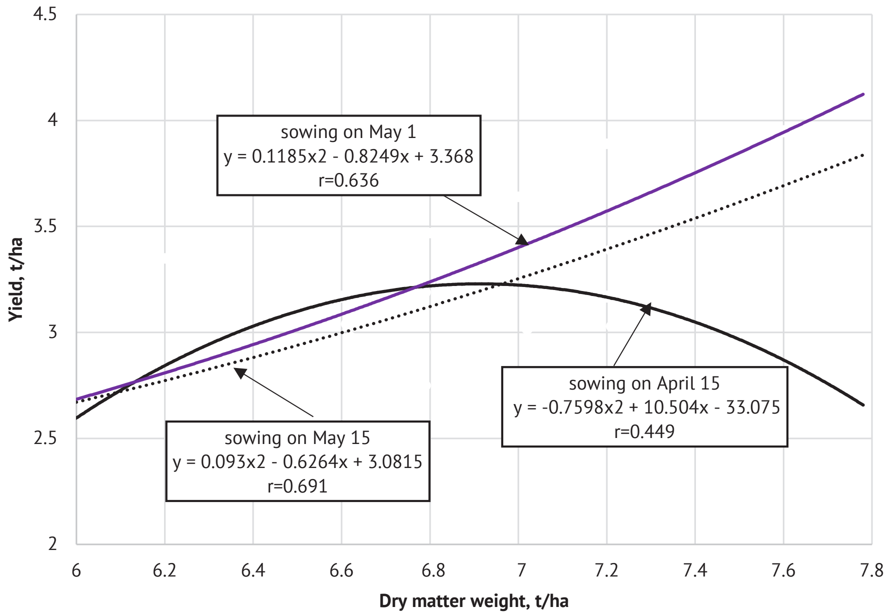

Figure 2. *Correlation and regression models of the dependence of soybean seed yield and dry matter biomass on different sowing dates*

Source: *compiled by the authors*

During the sowing period of May 01 and May 15, the correlation coefficients were of moderate strength. During the sowing period of April 15, the relationship was positive, but it had a clear curvature, which indicates a certain limited seed yield by excessive biomass.

The productivity index determines the ratio of grain mass to the total mass of the aerial part of the plant and characterizes the targeted use of assimilation products for the formation of the grain part of the crop. The indicator "yield index" of the soybean varieties under study ranged from 0.39 to 0.55 on average. This indicator of the yield index shows the physiological efficiency of the plant and its ability to convert the resulting dry matter into an economic crop (Table 3).

Table 3. *The "yield index" indicator of soybean plants of different genotypes in the bulk phase depending on the elements of agrotechnology (average for 2019-2021)*

Sowing period for soybean varieties *(factor A)*	Soy variety *(factor B)*	Plant density, thous. plants/ha *(factor C)*			Average by factor A	Average by factor B
		500	700	900		
April 15	Monarkh	0.40	0.42	0.43	0.46	0.42

Table 3, Continued

Sowing period for soybean varieties *(factor A)*	Soy variety *(factor B)*	Plant density, thous. plants/ha *(factor C)*			Average by factor A	Average by factor B
		500	700	900		
April 15	Arnika	0.39	0.40	0.42	0.46	0.40
	Pysanka	0.42	0.43	0.45		0.43
	Sofiia	0.43	0.46	0.48		0.46
	Svyatohor	0.51	0.52	0.55		0.53
	Evridika	0.50	0.53	0.54		0.52
Average by factor C		**0.44**	**0.46**	**0.48**		
May 01	Monarkh	0.45	0.47	0.44	0.48	0.45
	Arnika	0.44	0.46	0.43		0.44
	Pysanka	0.48	0.47	0.45		0.47
	Sofiia	0.49	0.48	0.44		0.47
	Svyatohor	0.55	0.53	0.52		0.53
	Evridika	0.54	0.53	0.51		0.53
Average by factor C		**0.49**	**0.49**	**0.47**		
May 15	Monarkh	0.43	0.44	0.46	0.46	0.44
	Arnika	0.41	0.42	0.45		0.43
	Pysanka	0.42	0.46	0.43		0.44
	Sofiia	0.43	0.47	0.44		0.45
	Svyatohor	0.49	0.54	0.51		0.51
	Evridika	0.50	0.53	0.52		0.52
Average by factor C		**0.45**	**0.48**	**0.47**		

Source: *calculated by the authors*

To find a relationship between the productivity indicators of soybean plants, correlation coefficients were calculated between the grain yield of soybean varieties of different origins and the yield index. The highest yield of soybeans was observed with a productivity index of 0.49 to 0.53. There is a direct dependence between these indicators of significant strength – the correlation coefficient was 0.882-0.894 (Fig. 3).

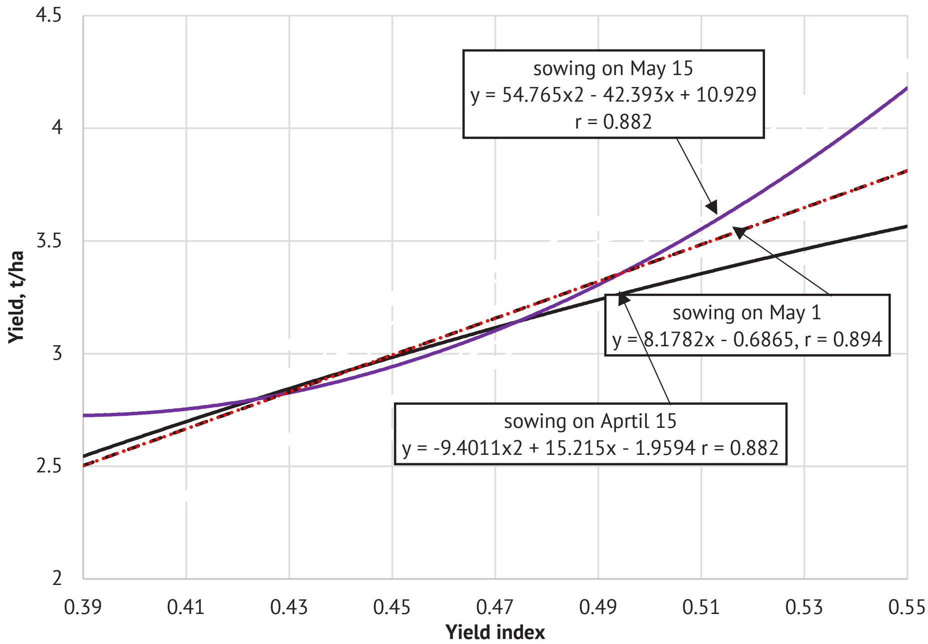

Figure 3. *Correlation and regression models of the dependence of grain yield of soybean varieties and the yield index at different sowing dates*

Source: *compiled by the authors*

The grain yield of soybean varieties of different maturation groups is the main indicator of the effectiveness of the developed elements of cultivation technology. The formation of grain yield of soybean varieties is substantially influenced by the genotype of the variety, the sowing period, and the density of plants (Table 4).

Table 4. *Yield of soybean seeds depending on the technology elements, t/ha (average for 2019-2021)*

Sowing period for soybean varieties *(factor A)*	Soy variety *(factor B)*	Plant density, thous. plants/ha *(factor C)*			Average by factor A	Average by factor B
		500	700	900		
April 15	Monarkh	2.85	3.03	3.11	3.03	3.00
	Arnika	2.36	2.44	2.59		2.46
	Pysanka	2.74	2.82	2.98		2.85
	Sofiia	2.91	2.98	3.05		2.98
	Svyatohor	3.47	3.64	3.78		3.63
	Evridika	3.11	3.25	3.35		3.24
Average by factor C		**2.91**	**3.03**	**3.14**		
May 01	Monarkh	3.25	3.39	3.17	3.30	3.27
	Arnika	2.69	2.81	2.62		2.71
	Pysanka	3.17	2.96	2.79		2.97
	Sofiia	3.22	3.11	3.02		3.12
	Svyatohor	4.28	4.12	3.95		4.12
	Evridika	3.76	3.62	3.46		3.61
Average by factor C		**3.40**	**3.34**	**3.17**		3.30
May 15	Monarkh	3.04	3.11	3.27	3.11	3.14
	Arnika	2.37	2.59	2.64		2.53
	Pysanka	2.75	3.04	2.91		2.90
	Sofiia	2.88	3.19	3.05		3.04
	Svyatohor	3.57	3.89	3.71		3.72
	Evridika	3.18	3.42	3.32		3.31
Average by factor C		**2.97**	**3.21**	**3.15**		
LSD_{05}, cm over the years of research		Factor A – 0.11; factor B – 0.15; factor C – 0.12				

Source: *calculated by the authors using the program Agrostat*

It was established that the highest grain yield was formed in the mid-early crop variety Sviatohor during the sowing period of May 01 and the density of 700 thous. plants/ha – 4.28 t/ha. Fast crop varieties Arnika and Monarkh gave the highest grain yield at 2.59-3.11 t/ha with a sowing period of April 15 and a sowing density of 900 thous. plants/ha. During the sowing period on May 15, they also showed a maximum yield of 2.64-3.27 t/ha with a density of 900 thous. plants/ha. The maximum yield at 2.81-3.39 t/ha was obtained during the sowing period on May 01, the optimal sowing density was 700 thous. plants/ha.

The increase in grain yield was substantially affected by both the sowing period and the density of plants. The increase in productivity at the optimal sowing date of May 1 and a density of 700 thous. plants/ha and in comparison with the minimum productivity shown by Arnika and Monarkh varieties for sowing on May 15 and a density of 500 thous. plants/ha was 11.5-13.7%.

Sofiia and Pysanka varieties in the early crops group showed an average soybean grain yield of 2.85-3.14 t/ha over the years of research. The maximum yield of varieties of this group was shown during the sowing period on May 1 and the plant density of 700 thous. plants/ha – 3.17-3.22 t/ha. During the sowing period of April 15, the maximum yield was observed with a density of 500 thous. plants/ha – 2.98-3.05 t/ha, for sowing on May 15 and a density of 700 thous. plants/ha – 3.04-3.19 t/ha.

The increase in yield for the sowing period of May 1 and the density of 700 thous. plants/ha compared to the minimum yield for the sowing period of April 15 and the density of 500 thous. plants/ha was 10.6-15.6%. The maximum yield in the experiment was shown by varieties of the mid-early Sviatohor and Evridika groups sown on May 01 and a density of 500 thousand plants/ha – 3.76-4.28 t/ha. Upon sowing on April 15, the maximum yield was observed at a density of 900 thous. plants/ha – 3,353.78 t/ha, upon sowing on May 15, the maximum yield of these varieties was observed at a density of 700 thous. plants/ha – 3.42-3.89 t/ha.

The yield increment during the optimal sowing period of May 1 and plant density of 500 thous. plants/ha compared to the minimum yield during the sowing period of April 15 and the density of 500 thous. plants/ha was 17.1-19.8%.

For each group of maturation of soybean varieties, the optimal sowing time and optimal plant density were determined to obtain the maximum yield under irrigation conditions. Fast varieties of crops showed the maximum yield upon sowing on May 01 and with a plant density of 700 thous. plants/ha, early and medium-early varieties of crops sown on May 01 and with a density of 500 thous. plants/ha.

Notably, the established patterns of influence of the timing and density of coenosis on the yield of innovative soybean varieties under irrigation conditions are not sufficient, and this issue requires further scientific research. According to the results of the conducted studies, a substantial increase in soybean grain yield depends on the maturation group, sowing time, and plant density. This is consistent with the data of other researchers, namely, Ivaniv & Hanzha (2021) observed that the maturity group of soybean varieties has the greatest influence on the trait "TKW", while the difference between fast and mid-early crops is 18-19 g. Plant density and TKW had a substantial impact on soybean yield under irrigation conditions. Rybalchenko (2018) established the relationship between the TKW and soybean yield at the genotypic level. The study conducted by Naydenova & Georgieva (2019) on non-irrigated lands in Bulgaria, on the contrary, shown that soybean genotypes with a shorter growing season have a higher seed yield, which may be explained by better seed filling.

In laboratory and field experiments to determine the characteristics of seed germination and growth as a function of temperature, moisture, and soil structure, Lamichhane *et al.* (2020) observed that upon sowing in mid-April, seedling death due to drought was higher, compared to earlier sowing dates. This is also confirmed by our study, when we observed certain risks of early sowing to unlock the productivity potential of varieties. Grabovsky's *et al.* (2023) showed that sowing in unheated soil can affect a decrease in field germination due to damage to seeds by fungal pathogens, which is quite consistent with our study results. Early sowing dates can also lead to changes in the habitus of soybean plants. This is confirmed by Carciochi *et al.* (2019), who found changes in morphological parameters, an increase in the number of nodes and shorter internodes. Vozhehova *et al.* (2020) observed the effect of increasing the thickening of crops from 600 to 800 thous. plants/ha on improving the photosynthetic potential, but already 900 thous. plants/ha led to a decrease in this indicator. Our research has confirmed this, but only in certain varieties. Thus, soybean varieties in the early sowing period had a sufficiently high dry matter mass at a density of 500 thous. plants/ha, but the yield was considerably higher at a density of 900 thous. plants/ha, which indicates excessive branching in the early periods and a decrease in the attraction of assimilation products to reproductive organs from lateral branches. This response to sowing dates and coenosis density is specific for individual genotypes, which should be established by field studies.

In the studies of Fellahi *et al.* (2020) superior breeding lines showed higher yield compared to control varieties due to TKW, biomass and yield index. Naydenova & Georgieva (2019) claim that among the important utilitarian characteristics of soybean varieties, the TKW is the main one that determines the productivity of the variety. This trait changes little under different growing conditions and is caused by 75-80% by the genotype of the variety and the cultivation technology, the size of seeds indirectly determines the yield. Our experiments partially confirm this, but the dependence of the yield of soybean varieties on the TKW was not linear. For each variety and sowing period, there is an optimum seed size, and this indicator is mainly regulated by plant density and varietal characteristics. In general, the present study confirms the findings of previous studies by Didora *et al.* (2022) regarding the need to improve varietal technologies to reveal the genotypic potential of soybean productivity.

Analysing the results obtained, it can be argued that the authors do not have a common opinion on the optimal timing of sowing and density of plants, so the research conducted on Ukrainian modern varieties in the conditions of the agroclimatic zone of the south of Ukraine is relevant and quite suitable for further implementation in production.

CONCLUSIONS

Based on the results of studies of the influence of technology elements on the productivity of modern soybean varieties of different maturation groups, it was found that each group of soybean maturation varieties under irrigation conditions has its own optimal sowing time and optimal cenosis density to obtain the maximum yield.

It was established that the dry matter mass depends on the density of the coenosis and the timing of sowing: fast crops Arnika and Monarkh reached their maximum values when sowing on May 1 and a density of 500 thous. plants/ha, early crops Pysanka and

Sofiia – on May 15 at a density of 500 thous. plants/ha, mid-early crops Evridika and Sviatohor – on May 1 at a density of 500 thous. plants/ha.

The maturity group of soybean varieties showed the maximum influence on the "thousand kernel weight" trait, and the mid-early crops Evridika and Sviatogor varieties showed the maximum values of the indicator – 160.4-161.3 g. In soybean varieties of all maturity groups, the maximum TKW was observed at a density of 500 thous. plants/ha, with an increase in density to 900 thous. plants/ha, the TKW decreased during all sowing periods.

Fast varieties of crops showed the maximum yield upon sowing on May 01 and with a plant density of 700 thous. plants/ha, early and medium-early varieties of crops – sown on May 01 and with a density of 500 thous. plants/ha. The maximum yield of soybean crops was observed with a yield index of 0.49 to 0.53. A significant linear relationship was established between yield indicators and the yield index (correlation coefficient was 0.882-0.894). In the experiment, the mid-early variety Sviatohor showed the highest grain yield of 4.28 t/ha for the sowing date of May 1 and a density of 700 thous. plants/ha, which is related to the genotype of the variety and optimized technology under irrigation conditions.

Therewith, additional studies are needed to determine the influence of sowing dates and plant density on the quality indicators of soybean grain, especially on protein content.

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CONFLICT OF INTEREST

None

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Сортові особливості елементів технології вирощування сої при зрошенні

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Анотація. Важливою перевагою сої (*Glycine max* (L.) Merr.) над іншими культурами є високий вміст білка та збалансованість амінокислотного складу, у зв'язку з чим актуальності набуває створення широкого набору сортів, вирощування яких змогло б забезпечити потреби переробних виробництв, а також розробка оптимальних сортових технологій вирощування, що дозволяють розкрити генотиповий потенціал продуктивності. Метою дослідження було обґрунтування особливостей формування продуктивності сучасних сортів сої залежно від елементів технології вирощування в умовах зрошення. Методи дослідження: польові, морфометричні, лабораторні, статистичні (кореляційно-регресійний аналіз). Польові дослідження проведено протягом 2019-2021 рр. в агроекологічній зоні Південного Степу в межах дії Каховської зрошувальної системи. Встановлено особливості росту і розвитку сортів сої різних груп стиглості: скоростиглих – Монарх, Арніка, ранньостиглих – Писанка, Софія, середньоранніх – Святогор, Еврідіка. Урожайність сортів сої змінювалася залежно від строків сівби, густоти рослин та сортових особливостей. Максимальна продуктивність рослин скоростиглих сортів Арніка та Монарх на рівні 2,81-3,39 т/га сформувалась за строку сівби 01 травня й оптимальної щільності посіву 700 тис. рослин/га. В ранньостиглій групі сорти Софія і Писанка максимальну урожайність 3,17-3,22 т/га показали за строку сівби 01 травня та густоти рослин 700 тис. рослин/га. Максимальну урожайність 3,76-4,28 т/га сорти середньоранньої групи Святогор, Еврідіка дали за сівби 01 травня та густоти 500 тис. рослин/га. Для отримання максимального врожаю зерна сої в умовах зрошення для кожної групи стиглості сортів існує оптимальний строк сівби й оптимальна щільність ценозу: скоростиглі сорти максимальну урожайність показали за строку сівби 01 травня та густоти 700 тис. рослин/га, ранньостиглі та середньоранні сорти – за сівби 01 травня та густоти рослин 500 тис. рослин/га. Результати дослідження можуть бути використані у виробничих умовах для коригування елементів агротехніки насінництва сої й отримання високих врожаїв з високим рівнем рентабельності

Ключові слова: строк сівби; густота рослин; урожайність; маса сухої речовини; маса 1000 насінин

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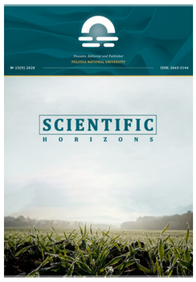

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The impact of greenhouse gases on climate change

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Abstract. Climate change has become a threatening problem for all countries of the world. For Kazakhstan, one of the world's largest grain exporters, with its previously predominantly arid climate, developed mining industry, metallurgy and mainly coal-fired heat and electricity generation, slowing down warming is becoming an urgent task. The purpose of this study is to summarise various aspects of the impact of greenhouse gas emissions on climate change in the Republic of Kazakhstan and the possibilities of reducing greenhouse gas emissions through Kazakhstan's transition to a new economic model based on the use of renewable energy sources. During the study, various methods of analysis were used – analytical selection based on a given or identified feature, comparative analysis of similar characteristics of various objects, statistical analysis of dynamic series, synthesis, representing the primary theoretical generalisation of empirical data. As a result of the study, a noticeable dependence of changes in average annual temperature and precipitation on total greenhouse gas emissions was identified. Moreover, the identified similarity of the dynamics of the main climatic indicators with the dynamics of individual greenhouse gases in Kazakhstan requires further research. It is also concluded that individual innovations in the form of individual renewable energy power plants or a Quota trading system determined by the highest values will not lead to a noticeable reduction in greenhouse gas emissions. Only the transition to

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a green economy, which should become a state priority, and its principles and main characteristics should be the reference when making any government decisions. This study can become a starting point for many theoretical and practical studies and show the need to reduce greenhouse gas emissions not as a purely mechanical process, but in conjunction with other phenomena, which can be useful in making managerial decisions

Keywords: air temperature change; precipitation and the threat of desertification; emissions monitoring; green economy; alternative energy

INTRODUCTION

Climate change has become one of the most acute problems of humankind. The anthropogenic factor with the development of industrial production and the growth of emissions into the atmosphere has caused global warming. Back in the 70s, the UN drew attention to the potential threat of climate change and in 1992 adopted The Rumour Convention of the United Nations on Climate Change (1992), and subsequently The Kyoto Protocol to the United Nations Frame Convention on Climate Change (1997) to it, The Paris Agreement (2016) as documents containing mechanisms for reducing emissions and preventing the irreversibility of climate change. Solving problems related to climate change has become one of the global Sustainable Development Goals up to 2030 (2015).

The development and adoption of these documents have intensified the efforts of countries to reduce emissions in a coordinated manner. Greenhouse gases such as carbon dioxide CO_2, methane CH4, nitrous oxide N_2O, hydrofluorocarbon compounds, perfluorocarbon compounds, sulphur hexafluoride SF_6 should be noted among the emissions most affecting climate change (The Kyoto Protocol..., 1997). Most countries of the world, including the Republic of Kazakhstan, have joined these documents, committing themselves to reduce greenhouse gas emissions, which most affect the process of global warming. Pursuant to the Paris Agreement, the Republic of Kazakhstan has committed to reducing greenhouse gas emissions by 15-25% by 2030 compared to 1991, and to achieve carbon neutrality by 2060 (Luomi *et al.,* 2020).

Numerous studies conducted in the Republic of Kazakhstan due to the increased attention to the problem of climate change, as a rule, pay attention to certain aspects of the problem or solving problems of reducing greenhouse gas emissions in a particular industry. Thus, for example, A. Maldynova *et al.* (2022), M. Bekturganova *et al.* (2019), and a number of other researchers consider and justify possible transformations of the energy sector of Kazakhstan on the way to decarbonisation, based on industry positions. S.B. Kenenbayev and G.L. Yesenbayeva (2020), associate the success of the development of agriculture in Kazakhstan with adaptation to climate change through new technologies. K. Kaimuldinova *et al.* (2022) devoted their study to the inclusion of climate change and sustainable development issues in the educational programmes of the Republic of Kazakhstan.

This allows for accumulating a database, doing their primary analysis, and providing a basis for generalisations and further consideration of a specific problem in a complex. For example, the EU countries have gone through the evolution of approaches from environmental protection and reducing polluting emissions to linking these emissions with the problem of climate change, and seeing the main way to eliminate or stop the problem by reducing greenhouse gas emissions with a dominant carbon group, they came to the need to recognise the inevitability of replacing carbon energy sources with renewable sources. This has led to the fact that a whole revolution is taking place in the world in the field of energy and transport, supported by the course of transition to a new economic model – a model of sustainable economic development (other names, less capacious, but popular, are circular economy, green economy).

The main purpose of this study was to show the problem of the impact of greenhouse gas emissions on climate change in the Republic of Kazakhstan with its possible solution by changing the approach to the problem itself and moving to a new economic model that would maximally stimulate the reduction of emissions and eliminate the substantial detrimental effect of anthropogenic factors on the climate. In it, based on the analysis of international documents, legislation of the Republic of Kazakhstan, scientific publications and statistical materials of RSP “Kazhydromet”, the Bureau of National Statistics of the Republic of Kazakhstan, the tasks were set to show the relationship of the problem of climate change in the Republic with the global problem of climate change; to indicate natural and economic factors of climate change at the level of primary generalisation; identify unresolved problems, show the connection between the desire of the Republic of Kazakhstan to decarbonise the economy and the development of alternative energy as the material basis for the transition of the economy to a new model.

Since 2013, the Republic of Kazakhstan has set a course for the transition to a green economy, adopting The concept of the transition of the Republic of Kazakhstan to the “Green Economy” (2013). However, the lack of a systematic approach is causing the transition to be slow and inconsistent. The attempt at primary generalisation and the application of an integrated approach to the problem undertaken in this study can serve as a basis for further theoretical research, and the identified unresolved problems – become the subject of practical management decisions.

MATERIALS AND METHODS

In the course of this study, the initial international documents were analysed, such as "Agenda 21", (1992), The Framework Convention of the United Nations on Climate Change (1992), The Kyoto Protocol to the United Nations Frame Convention on Climate Change (1997), The Paris Agreement (2016), Sustainable Development Goals up to 2030 (2015), reports of the UN working groups preparing analytical information and conclusions for subsequent decision-making. These documents show and record the existing relationship between the changes that occur with the climate and greenhouse gas emissions. The Environmental Code of the Republic of Kazakhstan (2021), The concept of the transition of the Republic of Kazakhstan to the "Green Economy" (2013), Strategy "Kazakhstan-2050" (2019-2022) adopted by the Republic of Kazakhstan were also analysed as documents showing what actions the Republic of Kazakhstan assumes to implement The Kyoto Protocol to the United Nations Frame Convention on Climate Change (1997) and The Paris Agreement (2016).

After establishing a proven relationship between greenhouse gas emissions and climate change, documents containing quantitative data on climate change parameters such as atmospheric temperature, precipitation, extreme weather events and their frequency, greenhouse gas emissions according to the list defined by the Kyoto Protocol and in terms of carbon dioxide emissions (CO_2) were analysed. This is the National Report on the state of the Environment and on the use of Natural Resources of the Republic of Kazakhstan for 2021 (2022), The annual bulletin of monitoring the state and climate change Kazakhstan/RSP Kazhydromet. (2008-2021), which allowed making their statistical analysis. Based on these quantitative indicators, dynamic series of fluctuations in the average annual temperature and the average annual precipitation level by year were compiled, showed in Figures 1 and 2. Each of these figures shows the norm calculated by RSP "Kazhydromet" based on long-term data. This allows seeing both the trend in temperature and precipitation fluctuations and all deviations from the norm over the years simultaneously. Figure 3 shows the dynamic series of greenhouse gas emissions (in terms of CO_2) and greenhouse gas emissions from energy industry to trace their similarity/dissimilarity.

Based on the data of RSP "Kazhydromet", the dynamics of emissions of all greenhouse gases according to the list of the Kyoto Protocol for two-year periods and in general for 12 years (2010-2022) is calculated so that it is possible to compare the dynamics for each of the greenhouse gases with the dynamics of fluctuations in average annual temperatures. The analysis of such comparisons and a factor-by-factor analysis of the effect of each of the gases on the average annual temperature can be the subject of further research. The analysis of study materials by various authors containing a primary analysis of greenhouse gas emissions in certain industries based on the collection of arrays of primary empirical information gave the author the opportunity to identify common features of processes occurring in various industries.

That is, the use of various methods of analysis from an analytical selection of characteristics for sampling, statistical methods of analysis to the method of comparative analysis of process parameters in previously selected periods and regions became a preparatory stage for the initial theoretical generalisation of empirical materials selected by the author using analytical methods. The selected characteristics of the impact of greenhouse gas emissions on climate change were compared with the characteristics of new economic models of the economy, in particular, the green economy, which the Republic of Kazakhstan plans to transition to. Ultimately, the similarity and differences between the model of a sustainable economy, a green economy, a low-carbon, and a circular economy can also be an impetus for a new study.

RESULTS

For the Republic of Kazakhstan, about ninety per cent of the territory of which is located in the desert, semi-desert, and arid steppe zone with a predominance of flat terrain, the problem of climate change is very acute. In the last seventy-five years, an increase in surface air temperature has been recorded, and the deviation of the average annual air temperature in some years from the norm has increased to 2°C. (Seventh national communication…, 2017). Moreover, out of the ten warmest years in the period from 1936 to 2020, seven fall at the beginning of the 21st century. The average annual values for the period of 1961-1990, which are 5.4°C in air temperature and 317.7 mm in precipitation, are used as normative climatic indicators in the Republic of Kazakhstan.

According to the RSP "Kazhydromet", there has been a persistent warming trend since the 1960s. During the estimated period of 1976-2021, the average annual temperature increased by 0.32°C every ten years. The highest rate of warming was observed in the western and south-western regions (from 0.44°C/10 years to 0.54°C/10 years), the lowest – in the central, northern, and eastern regions (from 0.23°C/10 years to 0.29°C/10 years). Over the last decade of 2012-2021, the average annual air temperature was +6.61°C, exceeding the norm by 1.19°C, whereas, in the previous decade of 2001-2010, the average annual excess of the norm was 1.09°C. The warmest was the five-year period of 2017-2021 with an average annual air temperature of +6.69°C, exceeding the norm by 1.27°C. (The national report on the state…, 2022).

After the accession of Kazakhstan to the Kyoto Protocol, climate change and greenhouse gas emissions (primarily CO_2) began to be monitored in the republic, which is important for investigating their impact on climate change. The reasons for the reduction to the norm of average annual temperatures and their sharp increase in some years should be the subject of separate research. Moreover, it can be a combination of the influence of global climatic fluctuations and the anthropogenic factors on the territory of the republic itself. Figure 1 shows the changes in the average annual temperature for the period of 1990-2021, with the first two decades shown as single periods, and since 2010 annual values are given.

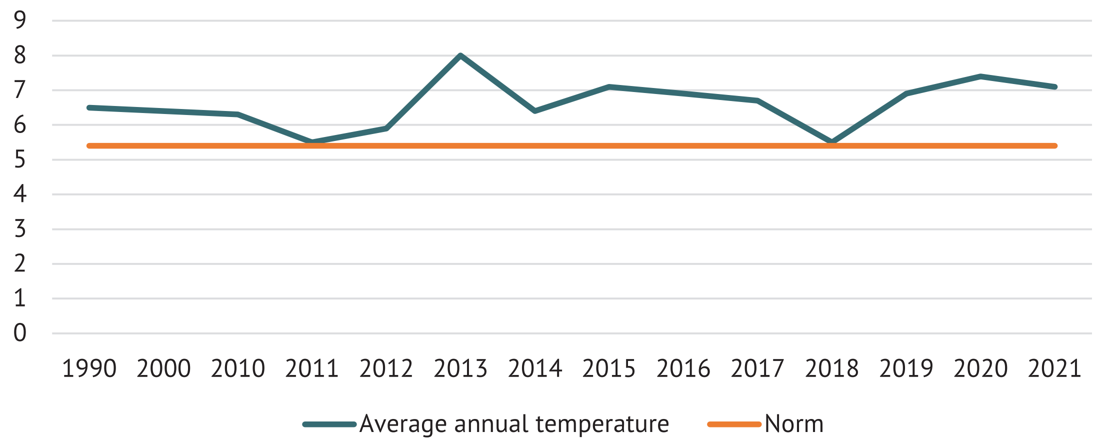

Figure 1. *Average annual temperature for 1990-2021 in the Republic of Kazakhstan, °C*
Note: *Norm – 5.4°C*
Source: *The annual bulletin of monitoring the state and climate change Kazakhstan/RSP Kazhydromet (2008-2021)*

In 2021, the average annual precipitation in Kazakhstan amounted to 85.5% of the norm or 272 mm. Thus, the greatest shortage of precipitation was observed in the Mangystau and Kyzylorda regions, where an average of 29.9% and 64.1% of the norm fell, respectively. A 20-40% precipitation deficit of the norm was observed in Atyrau, Kostanay, North Kazakhstan, Akmola, Karaganda, Turkestan, Zhambyl, and Almaty regions. In the last two decades, there has been a tendency to increase the monthly precipitation deficit in April-May and August-October, and to exceed the norm in February and March. An increase in the proportion of liquid precipitation creates problems with snow accumulation and the creation of a moisture charge for the soil for the growing season, which is important for the development of agriculture (Annual Bulletin of monitoring the state and climate change of Kazakhstan: 2021, 2022). In the period 2011-2021, six out of ten years were marked by a deficit of the average annual precipitation in relation to the climatic norm, as shown in Figure 2.

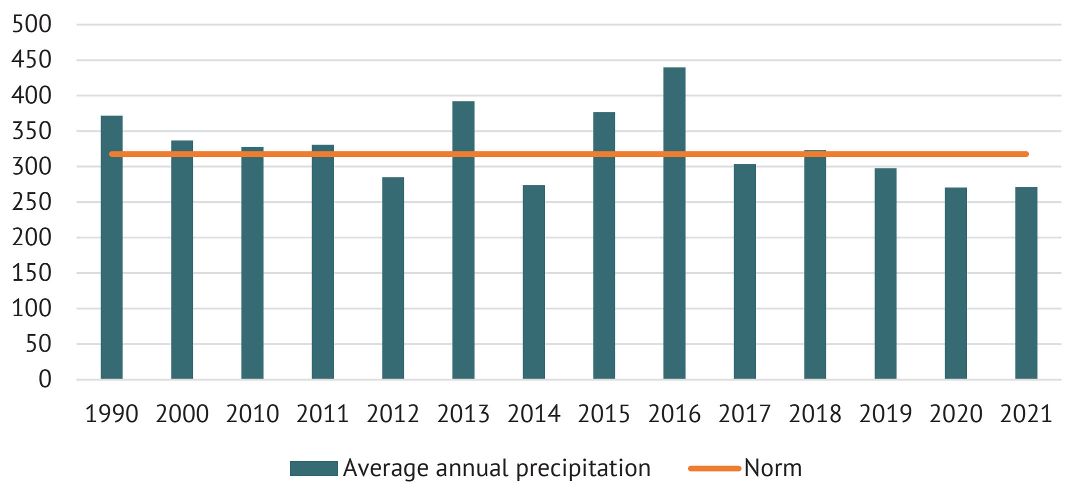

Figure 2. *Average annual precipitation for 1990-2021 in the Republic of Kazakhstan, mm*
Note*: Norm – 317.7 mm*
Source: *The annual bulletin of monitoring the state and climate change Kazakhstan/RSP Kazhydromet (2008-2021)*

In addition, precipitation has increasingly become extreme. The number and frequency of extreme weather events have also increased, which was highlighted by The national report on the state of the environment and the use of natural resources of the Republic of Kazakhstan for 2021 (2022). Moreover, Almaty and the Almaty region account for 38.7% of all registered cases, Zhambyl region – 7%. The most frequent natural hydrometeorological phenomena in Kazakhstan are heavy rainfall, strong wind, heavy blizzard and heavy snow, floods, abnormal cold, abnormal heat, drought, ice, hail, and dust storms. There were 46 more cases of such phenomena in 2021 than in 2020. The abundance of heavy rainfall, the rapid melting of glaciers due to the increase in average annual temperatures pose a threat of mudslides and landslides. Thus, over the past five years, the number of landslide-prone areas amounted to 390 and increased by 43%, and the number of mudslide-prone areas increased by 80% and amounted to 729 in 2021 (Almaty region – 243, Almaty – 195, Zhambyl region – 140, Turkestan region – 100, East Kazakhstan region – 23, Shymkent – 28).
An increase in average daily temperatures and a shortage of precipitation in early spring are also one of the main causes of forest and steppe fires that cause substantial material damage. In 2021, it amounted to KZT 6.138 million, which is almost three times more than in 2020. The same reasons create conditions for the occurrence of spring and autumn droughts. A precipitation deficit of 80-100% with an air temperature exceeding 1.6-3.7°C compared to the norm caused an autumn drought in Almaty, Zhambyl, Turkestan regions in 2021 (The national report on the state..., 2022; Kaimuldinova *et al.,* 2022). All these phenomena and the increase in their intensity indicate the existence of a persistent trend towards climate change in Kazakhstan.

Since climate change is a global problem, researchers from many countries have been investigating its causes. The results of the work of specially created intergovernmental working groups showed that the intensity of climate change is a consequence of anthropogenic activity, pointing to one of the main factors – greenhouse gas emissions. The physical mechanisms of impact and models of possible scenarios are presented in the Reports of these working groups. The same issues of the impact of greenhouse gases on atmospheric air circulation in global and regional aspects are also considered in the long-term studies of S. Manabe (2019), in which, based on modelling, a direct link between greenhouse gas emissions and climate change is proved.

Documents adopted within the framework of the UN, such as The Rumor Convention of the United Nations on Climate Change (1992), The Kyoto Protocol to the United Nations Frame Convention on Climate Change (1997), Strategy "Kazakhstan-2050" (2016) have become binding documents on reducing greenhouse gas emissions for countries that they were joined. The Republic of Kazakhstan is one of them. Kazakhstan is one of the thirty countries – the largest sources of greenhouse gas emissions in the world, ranks eleventh in the world in terms of the carbon intensity of GDP and is one of the 15 countries with the highest CO_2 emissions per capita. The main sources of greenhouse gases in the Republic of Kazakhstan are energy, industry, and transport. 82% of all greenhouse gas emissions in Kazakhstan are related to energy production, of which 31% is the result of fuel combustion directly in the energy sector, 9% in manufacturing and construction, 7% in transport (Barlybaeva *et al.,* 2021). In addition, specific sources of influence on the climate are deserts, as a source of dust storms, and the Aral Sea, from where millions of tonnes of aeolian dust, consisting of fine particles of sand and salt, rise in strong winds. The direct relationship between the total amount of greenhouse gas emissions without land use, land use change, and forestry (LULUCF) in Kazakhstan and the amount of emissions from energy industry is shown in Figure 3.

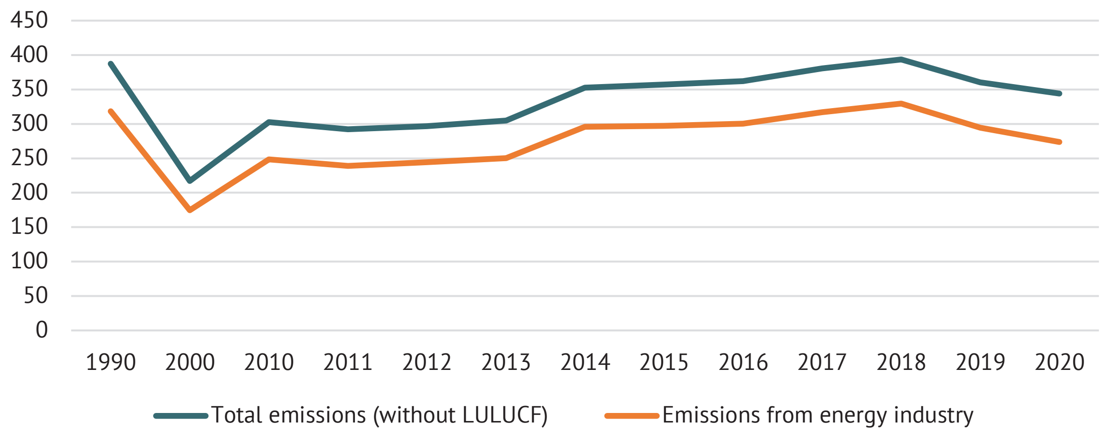

Figure 3. *Total greenhouse gas emissions (without LULUCF) and emissions from energy industry for 1990-2020 by sector in the Republic of Kazakhstan, thousand tonnes CO_2-eq*
Source: *The national report on the state of the environment and the use of natural resources of the Republic of Kazakhstan for 2021 (2022)*

For example, the lack of monitoring associated with global databases makes it impossible to include most cities of Kazakhstan in global air quality ratings. The differences between WHO air quality standards and standards in the Republic of Kazakhstan make existing national indicators incomparable with international ones, which makes it difficult to really assess the situation with atmospheric air, and in general with the trends of anthropogenic impact on climate change in the country. Kazakhstan uses only one-time maximum values for PM 10 (PM is a term for a mixture of solid particles and liquid droplets in the air), PM 2.5, and NO_2 to assess air quality and does not use the average annual MPC, whereas WHO uses average daily and annual limit values, which implies constant monitoring of the entire spectrum of emissions in the atmosphere. For example, the standard of the maximum one-time value for PM 2.5 applied in Kazakhstan is sixteen times higher than the average annual WHO standard (Assanov *et al.,* 2021).

The monitoring system needs to be expanded, especially in cities and at facilities that are major sources of emissions. The lack of the necessary amount of information distorts the real picture. Examples of the shortcomings of the existing monitoring system are given by D. Assanov *et al.* (2021). They note that all coal-fired power plants in Kazakhstan (except one) do not use installed emission control equipment. Monitoring stations are located 3 and 30 km from the largest power plants in Aksu and Ekibastuz, respectively, and record relatively low levels of atmospheric air pollution there, and the Pavlodar aluminium plant with CHP-1 is not included in the monitoring network. In addition, reports of the Republic of Kazakhstan on the implementation of international commitments to reduce greenhouse gas emissions are given according to one universal indicator – emissions recalculated by CO_2 equivalent, whereas The Kyoto Protocol to the United Nations Frame Convention on Climate Change (1997) assumes monitoring and reduction of emissions for the entire list of greenhouse gases defined in it. The importance of such detail is demonstrated in Table 1.

Table 1. *Dynamics of greenhouse gas emissions 1990-2020 by period*

	2000 in % to 1990	2010 in % to 2000	2012 in % to 2010	2014 as % of 2012	2016 as % of 2014	2018 as % of 2016	2020 in % to 2018	2020 in % to 2010	2020 in % to 1990
Carbon dioxide (CO_2)	52.9	167	98.76	122.02	102.42	108.85	83.9	112.72	99.86
Nitrous oxide (N_2O)	81.61	109.1	92.71	101.59	106.12	108.12	105.5	114.0	101.52
Methane (CH_4)	60.32	67.33	97.31	105.05	103.13	109.27	106.12	122.23	49.64
HFC	-	410.64	108.54	113.77	106.69	97.76	100.43	129.34	531.1 (by 2000)
PFU	-	-	109.52	84.16	112.43	109.7	102.59	116.63	249.55 (by 2008)
Sulphur hexafluoride (SF_6)	-	-	105.78	109.84	102.49	104.37	107.44	133.53	140 (by 2007)
Total emissions (in CO_2 equivalent) excluding LULUCF	56.07	139.15	98.29	118.87	102.68	108.82	87.3	113.97	88.92

Source: *The annual bulletin of monitoring the state and climate change Kazakhstan/RSP Kazhydromet (2008-2021)*

The key year is 2010, as from this year emissions of certain greenhouse gases are monitored by The Kyoto Protocol to the United Nations Frame Convention on Climate Change (1997). The table shows that the emissions of hydrofluorocarbon (HFC), perfluorocarbon (PFC) compounds, and sulphur hexafluoride SF_6 for the period 2010-2020 have greater dynamics compared to carbon dioxide, whose emissions were monitored in previous periods. It was this decade that was recognised as the warmest in the history of observation.

The relationship between the increase in the number of emissions of these compounds and their impact on climate change in Kazakhstan (Figures 1 and 2, reflecting the main climate parameters – air temperature and precipitation), and identification of their main sources require further special studies. The need for detailed monitoring of emissions in all regions of the Republic of Kazakhstan can be shown by comparing the emission situation for 2021 in two neighbouring regions — Almaty and Zhambyl. Notably, despite the proximity, their very geographical location has an impact on the features of climate change. A substantial part of the territory of the Zhambyl region is occupied by the Betpak-Dala and Moyinkum deserts, therefore, the already arid region undergoes rapid desertification with climate warming. More protected by the Alatau mountains, the Almaty region, due to intensive economic activity, is more susceptible to extreme weather events. Thus, Almaty and Almaty region account for 38.7% of all registered cases, Zhambyl region – 7%.

The main sources of atmospheric air pollution in Zhambyl region are stationary sources – power plants and industrial enterprises. There are 5,380 of them in the region, with total emissions of 30.8 thousand tonnes per year. The structure of emissions in the cities of Taraz, Zhanatas, Karatau, Shu and the village of Kordai consists mainly of suspended particles of PM5 and PM10, sulphur dioxide, gaseous compounds not included in the list of greenhouse gases under the Kyoto Protocol, and particles of heavy metals. This indicates that the main sources of atmospheric air pollution are industrial enterprises of the region and power plants. The transport factor is present but does not play such a substantial role as the two above-mentioned sources of pollution. The emission monitoring system in the Zhambyl region does not cover all sources of pollution. It has only ten units, of which there are five observation posts in Taraz, including one automatic station, one automatic station in Zhanatas, one automatic station in Karatau, one automatic station in Shu, and one automatic station in Kordai (Newsletter of the state of the environment of the Zhambyl region 2021). With existing emission standards focused on the highest possible level and insufficient monitoring, the emission data provided in the bulletin cannot be called such that they record all emissions produced even by stationary sources. Thus, unlike the Almaty region, the Zhambyl region does not fall under the effect of heat supply emissions. Exceeding the maximum permissible concentrations of pollutants in five positions were recorded in Taraz, assumably, due to the larger number of monitoring stations than in other cities of the region. However, this issue requires additional research. Greenhouse gas emissions in the Zhambyl region are not monitored by monitoring stations.

The Almaty region is home to the metropolis of Almaty, which affects the structure and volume of emissions of pollutants into the atmosphere. The main sources of emissions are stationary sources – power plants and industrial enterprises. Motor transport provides a substantial part of emissions. Thus, there are 25,380 stationary sources of emissions in the Almaty region, of which 10,359 are in Almaty. The total emissions of enterprises in Almaty amounted to 46,060 tonnes. In Almaty, 151 sources of heat supply are among stationary sources of emissions. Such information is not recorded for the region. Kazhydromet calls the thermal power plants, road transport, and agricultural and construction facilities the main sources of air pollution in the Almaty region. The total emissions of pollutants in the Almaty region amounted to 2,800 tonnes in 2021. Motor transport in Almaty amounted to 517,500 units in 2021, and annually its number increases by more than 1,700 units. Motor transport in the Almaty region amounted to 119 thousand units in 2021. Monitoring of atmospheric air pollution in Almaty is conducted at 16 observation stations, 11 of which are automatic. In addition, there is a mobile environmental laboratory that occasionally monitors the state of the air at ten points. There are four observation stations in the Almaty region in Taldykorgan, Talgar, and Zharkent (Information Bulletin of the State of the Environment of the Almaty region 2021). The monitoring is conducted according to the list of substances, among which there are no greenhouse gases, named in the Kyoto Protocol.

The analysis of the list of indicators that are regularly monitored by the observation stations of the RSP “Kazhydromet” showed that greenhouse gas emissions from these observation stations are not included in the area of their constant attention. Greenhouse gas emissions are also not included in the nomenclature of environmental statistics indicators and even green economy indicators, which are regularly monitored and submitted in their bulletins by the Bureau of National Statistics of the Republic of Kazakhstan. Information on greenhouse gas emissions appears only in the section on the implementation of the Sustainable Development Goals up to 2030 (2015) of the Bureau of National Statistics, and regular information on primary observations in the data of Kazhydromet and the Bureau of National Statistics is not identified.

The Strategy “Kazakhstan-2050” (2019-2022) and The concept of the transition of the Republic of Kazakhstan to the “Green Economy” (2013), adopted in the Republic of Kazakhstan, involve the development of energy-saving technologies, carbon capture and storage, and the transfer of the electric power industry to renewable energy sources. In the context of decarbonisation, they aim to increase the share of renewable energy sources in the Republic of Kazakhstan to 10% by 2030 and to 50% by 2050 of the total electricity production. Therewith, these documents suggest a reduction in greenhouse gas emissions in Kazakhstan by 2030 by 31% below the level of 1990, by 2060 – by 97%. However, in fact, these documents are more of a tribute to involvement in international processes, and not strategic documents for the development of the Republic of Kazakhstan, on the implementation of which all government activities would be based. Apparently, there is still inertia in the attitude towards the environment as something secondary, to which attention is paid according to the residual principle. Therewith, climate change has become an acute problem for the whole world and for Kazakhstan itself. Fixing the parameters of climate change and the factors influencing this process, and the adoption of legislative and regulatory documents in the Republic of Kazakhstan in the context of fulfilling international obligations are certainly positive phenomena. However, in practice, there is a lack of actions to implement them. Some positive examples only emphasise this trend.

As such small examples, the work on decarbonisation and reduction of greenhouse gas emissions in the Zhambyl region in 2019 can be noted. Kazphosphate LLP, disposing of 21-22 thousand tonnes/ “boiler” dust per year. The processing of “boiler” dust yields

1-1.5 thousand tonnes/year of phosphorus-potash fertilisers. There is also the introduction of a GHG emissions accounting system, thanks to which emissions are reduced by 18-21 thousand tonnes of carbon dioxide per year by reducing the consumption of natural gas during the production of phosphorite agglomerate (Abdildin *et al.,* 2021). The general trend, with the exception of some positive examples, is generally opposite to the objectives set in the Strategy and other documents, which does not contribute to reducing greenhouse gas emissions. Thus, D. Assanov *et al.* (2021) note that investments in atmospheric air protection decreased 2.6 times in 2018 compared to 2013. The main reason for the lack of systematic work to reduce greenhouse gas emissions is the low degree of interest of enterprises in implementing green technologies. Thus, for enterprises in Kazakhstan, the MPC (maximum permissible concentrations) of emissions are set based on the highest level of emissions measured during the maximum production volume. This allows enterprises not to reduce the amount of emissions, and to preserve outdated technological processes without violating legislation. The Republic of Kazakhstan was the first in Central Asia to introduce an emissions trading system (ETS) and suggests its improvement to stimulate the transition to a low-carbon economy (decarbonisation) or green economy (which is similar, but not identical). The introduction of a carbon tax is currently being discussed.

Thus, relying on the research of other authors concerning certain issues of climate change, reduction of greenhouse gas emissions, transition to the green economy and its parameters, and transition tools, the author in this study made an attempt to show a holistic picture consisting of the relationship of physical and meteorological processes with the state and structure of the economy of Kazakhstan today and the transition to new models of the economy of the future (sustainable, green, low-carbon). This paper can become the basis for higher-level generalisations in further investigations. Conventional models of economic development are focused mainly on the consumption of natural resources and do not have built-in mechanisms to stimulate the reduction of greenhouse gas emissions, which is noted in some fragments of this study. At this stage, it is of utmost importance to develop a step-by-step plan for the transition from the existing technologically and economically outdated model of the economy to the model of sustainable development of the Republic of Kazakhstan, based on the analysis of the experience of the European Union and individual European countries, its adaptation to the conditions of the republic.

DISCUSSION

The link between greenhouse gas emissions and climate change towards its warming is considered scientifically proven by the work of Intergovernmental Groups under the auspices of the United Nations and numerous independent researchers. This resulted in a number of international documents obliging the signatory countries to reduce greenhouse gas emissions, mainly of carbon origin. The reduction of emissions has inevitably led to the emergence of new technologies and concepts for the development of energy based on renewable energy sources.

Greenhouse gas emissions are the result of human economic activity. Recognising this indisputable fact and the need to reduce greenhouse gas emissions, a number of researchers raise the question of the need for further investigation of greenhouse gas emissions and suspended particles of natural origin, for example, as a result of volcanic activity, and natural cycles of climate change. This will allow for the further evaluation of the ratio of all factors and correctly choosing methods to mitigate the consequences of their negative impact on human life (Hegerl *et al.,* 2019). They also highlight the fact that the issue of other products of anthropogenic impact, for example, aerosols, remains poorly investigated.

Chinese researchers Y. Sun *et al.* (2022), analysing the anthropogenic impact on climate change, note that so far it is possible to talk about a clear relationship between the impact of greenhouse gas emissions and urbanisation on the increase in air temperature. However, a clear correlation between human activity and the total amount of precipitation has not yet been established, although the results of numerous experiments indicate the connection of extreme precipitation with human activity. The question of the impact of the anthropogenic factor on the extreme wind remains poorly investigated. There is also no comprehensive vision of the human impact on the various manifestations of climate change, which makes it difficult for governments to make the right policy choices regarding the mitigation of the consequences of such changes. Each country solves these issues based on the current situation and the degree of understanding of the problems related to climate change.

In the Republic of Kazakhstan, the main sources of greenhouse gas emissions are energy, industry, and transport. The basis of the energy of the Republic of Kazakhstan consists of thermal power plants operating on local coal and generating 60.5% of electricity. The burning of coal as the main fuel for the production of electric and thermal energy is the main source of greenhouse gas emissions and a factor of climate change in Kazakhstan. Naturally, it is impossible to solve this problem without radical reform of the entire energy sector. Despite the fact that the production of electricity at gas turbine power plants is growing, and the share of its production at hydroelectric power plants, wind, solar, and biogas power plants increased from 9.1% in 2011 to 10.4% in 2019, coal-fired power remains the backbone of the industry. Moreover, the capacity of power plants commissioned more than 30 years ago is 54.3% of the total installed capacity (Maldynova *et al.,* 2022).

Outdated equipment for burning high-ash coal gives the bulk of greenhouse gas emissions, and the system of standards and regulations that currently exists in the Republic of Kazakhstan, inherited from the USSR, gives little incentive to economic entities to reduce emissions and use new technologies in the electric power industry and metallurgical industry (Assanov *et al.,* 2021). The need for a more stringent approach to the establishment of MPC and the provision of emission quotas to enterprises is also indicated by M. Bekturganova *et al.* (2019), A. Barlybaeva *et al.* (2021). The application of strict emission standards for coal-fired power plants has been successful in China, which has largely similar climate change trends (Sun *et al.,* 2022). After the introduction of ultra-low emission standards for coal-fired power plants in China in 2014, almost all coal-fired power plants in 2017 were equipped with emission management equipment, primarily CO_2. In the period from 2014 to 2017, annual emissions by Chinese power plants of all types of pollutants, including particulate matter, decreased by 60-72%, depending on the type of emissions.

Quite rightly, the above-mentioned researchers talk about the need for an inventory of emissions, analysis of their sources, expansion and optimisation of the monitoring system, harmonisation of all indicators and standards with international analogues. The transport sector is one of the largest sources of direct greenhouse gas emissions, accounting for about a quarter of global greenhouse gas emissions, which are still rising. In Kazakhstan, greenhouse gas emissions in the transport sector account for 7% of the total. With the current trend towards an increase in the number of motor vehicles, this share may increase, especially in large cities. In such densely populated cities as Almaty and Astana, the largest number of cars are registered, respectively, more than 500 and 300 thousand. The increase in the number of motor transport in Kazakhstan is largely caused by the inefficiency of public transport and the lack of alternatives for the population (Assanov *et al.,* 2021).

The spread of electric vehicles covers all countries of the world. Many states aim to gradually replace cars with internal combustion engines with electric cars. For example, there is no federal policy in the United States to encourage the introduction of electric vehicles, but some states have set a goal of reducing greenhouse gas emissions from vehicles to zero by 2050. Japan intends to sell only electric vehicles by 2050. India has pledged to stop selling fossil fuel-powered cars by 2030. China is developing a plan to stop the production and sale of vehicles with internal combustion engines. Noting this global trend as mitigating the intensity of climate change, researchers R. Zhang and S. Fujimori (2022) argue that the development of electric transport without the transition of the electric power industry to renewable sources does not solve the problem of the total amount of greenhouse gas emissions affecting global climate change. The combination of electrification of transport with an energy policy to reduce carbon emissions can contribute to the transition to a low-carbon future.

Even though the Republic of Kazakhstan is located mainly in arid climatic zones, it is one of the largest producers and exporters of grain in the world. Climate change is seriously affecting agriculture. The main grain-producing regions of Kazakhstan are increasingly covered by severe droughts, leading to a decrease in grain yields by more than 50%. They are especially often repeated in the Aktobe, West Kazakhstan, Karaganda, and Kostanay regions (Kaimuldinova *et al.,* 2022). The increase in average annual temperatures, droughts, increased winds and dust storms creates conditions for land desertification and undermines the functioning of one of the most important sectors of the economy of the republic, threatening not only the food security of Kazakhstan but also the whole world. The main problem of crop production in Kazakhstan has always been the lack of moisture in the soil, which has worsened due to climate warming. The availability of water will become a serious limiting factor in the development of the economy of Kazakhstan in the future, so it is necessary to make every effort to adapt crop production to the changed conditions. This can be achieved by resource-saving technologies with the most rational use of moisture, soil, and energy. The main direction should be the transition to the development and implementation of adaptive landscape farming systems (ALFS) in agricultural production (Kenenbayev & Yesenbayeva, 2020).

The waste management sector is in fourth place in the list of global greenhouse gas emissions sources since solid household waste accounts for 5% of such emissions. Mainly this is about such greenhouse gases as CH_4 and N_2O, formed at landfills without gas utilisation and open landfills, where the final disposal of solid household waste takes place. This is currently the main waste management practice in Kazakhstan. As a positive example, in 2017, the amount of greenhouse gas emissions (in CO_2 equivalent) generated daily in Tehran as a result of incineration became almost 17 times less compared to the practice of waste disposal. The EU example also shows that efficient waste management can reduce greenhouse gas emissions (Temireyeva *et al.,* 2022).

Having joined international documents such as Agenda 21, The Rumor Convention of the United Nations on Climate Change (1992), The Kyoto Protocol to the United Nations Frame Convention on Climate Change (1997), and The Paris Agreement (2016) since 1992, the Republic of Kazakhstan has adopted a number of laws and programmes for implementation of commitments, such as Environmental Code of the Republic of Kazakhstan (2021), Strategy "Kazakhstan-2050" (2019-2022), and The concept of the transition of the Republic of Kazakhstan to the "Green Economy" (2013). Kazakhstan became the first country in Central Asia and Asia to introduce a system of trading quotas for greenhouse gas emissions (Bekturganova *et al.,* 2019). Decarbonisation implies a reduction in carbon dioxide (CO_2) emissions per unit of GDP (tonnes/USD/capita) for the economy in general and reduction of CO_2 emissions per unit of energy produced (kg/barrel) for the economy of the energy system. Such decarbonisation directions as electrification, decarbonisation, electricity production, and energy efficiency were identified to achieve progress on these targets in the Republic of Kazakhstan (Maldynova *et al.,* 2022).

Currently, Kazakhstan exceeds the level of carbon intensity of the gross domestic product of the Organisation for Economic Cooperation and Development by 3-5 times (Bekturganova *et al.,* 2019). In 2018, the production of environmentally friendly products in Kazakhstan decreased by 4.4% compared to 2014. A. Kazhmuratova *et al.* (2020) indicate the low efficiency of investments in environmental innovations, despite the actualisation of this problem in Kazakhstan. Therewith, the share of environmental innovations from 2014 to 2018 decreased from 12.7% to 7.8% in the total number of innovations. A study on the introduction of green technologies by enterprises of Kazakhstan in the context of industries and regions conducted by Abdildin *et al.* (2021) showed that the main sources of emissions (mining, metallurgical, oil, and gas industries) reduced the number of green technologies used.

Freshwater sources, food security, ecosystems, human habitat and infrastructure are most affected by the climate risks of global warming, according to S. Fawzy *et al.* (2020). This can cause an increase in poverty and changes in the social structure of society. Ultimately, climate change affects the physical and psychological health of a person, which in the future will require not only work on reducing emissions but also preparing the entire healthcare sector for new conditions and needs (Ebi *et al.,* 2021). The risks are primarily associated with extreme weather events, which are becoming more frequent, and the consequence of which is a tendency to increase the number of victims.

Reducing emissions and decarbonising the economy are necessary, but not the only measures to mitigate climate change. The second promising method is the method of capturing and binding CO_2. The third method that can be applied without reducing the concentration of greenhouse gases is the use of geoengineering technologies to stabilise or reduce air temperature (Fawzy *et al.,* 2020). The latter method is applicable for a short period since it does not eliminate the causes of temperature rise inherent in the first two methods. Governments should prepare appropriate tools for the possibility of their application and promotion of their application to apply various measures to mitigate the effects of climate change.

In addition to the efforts of governments, various non-state subjects are also involved in reducing emissions and mitigating the effects of climate change – cities, regions, entrepreneurs, and public organisations, the actions of which should complement national policy. A study by T. Kuramochi *et al.* (2020), conducted in ten countries, showed that the actions of non-state actors can reduce emissions by 3.8-5.5% more compared to the envisaged irrational programmes by 2030. However, the effectiveness of their actions, especially in cities and regions, depends on the accuracy of information on emissions (Gurney *et al.,* 2021). This is especially important for cities where the main sources of emissions are concentrated. Therewith, it should be considered that the established technological and managerial order of things can slow down the necessary changes.

CONCLUSIONS

The Republic of Kazakhstan is one of the largest producers of grain crops, has a developed mining and metallurgical industry, and is among the countries with the highest greenhouse gas emissions in absolute terms (CO_2-equivalent) and in terms of emissions per capita and per unit of GDP. Provoked by emissions from large enterprises, climate changes occur towards warming, snow cover decrease in winter, and extreme droughts, winds, and rains become more frequent. Frequent sandstorms together with desert sands carry small salt particles. All these phenomena pose a threat to the agriculture of Kazakhstan and cause great damage.

The fixation of greenhouse gas emissions is poorly organised. The most well-established is the system for monitoring CO_2 emissions. But this system also does not cover many large sources of emissions (power plants, large enterprises). Emissions of other greenhouse gases are even more insufficiently monitored. Accordingly, in the reports of the Republic of Kazakhstan to international organisations, greenhouse gas emissions are represented by the only calculated indicator of CO_2. The dynamics of emissions of other greenhouse gases and their impact on climate change remain little-known, incomplete, and poorly investigated. The main source of greenhouse gas emissions in Kazakhstan is thermal power plants powered by local coal, equipped mainly with physically and morally obsolete equipment installed more than thirty years ago. Technical re-equipment of these facilities with just more modern equipment is impractical. There is a need for a complete technical reform of the energy industry and its transfer to renewable energy sources. This will also be a conceptually novel approach to the construction of energy networks.

Since 1992, the Republic of Kazakhstan has signed a number of international documents on climate change and environmental protection, adopted documents, such as Strategy "Kazakhstan-2050". The concept of the transition of the Republic of Kazakhstan to the "Green Economy", indicates intentions to join the global processes of changing the economic model from one based on the consumption (burning) of non-renewable resources to a model based on its energy and industry on renewable resources, a model of waste-free production when it returns to the natural environment a minimum of substances that do not pose threats to people and the environment. Naturally, this represents a change in all sectors of the economy, management systems, and social life. This process will take place gradually, and its speed depends not only on the objective need for changes but also on the degree of awareness of the importance of the transition to a new economic model for the survival of humanity in general, each nation, and each locality.

In the meantime, the accepted documents are poorly executed. According to the old Soviet approach, environmental issues, and other issues of the environment and human living conditions, were considered something secondary, optional, and even frivolous, which can be ignored. Inertia has persisted, and the introduction of green technologies is slow, especially in polluting industries. Even a promising emissions trading system suffers from this approach. Quotas are set at the highest level of emissions, not at the lowest, which creates little incentive to change anything in production technologies. Until the subject of sustainable development (green economy, decarbonisation, circular economy as its sides) becomes the main one for the government of the country, through the prism of which all processes will be considered – not a single issue of a seemingly technical nature can be solved, including the issue of reducing the emission of greenhouse gases, which most provoke climate warming in arid Kazakhstan.

This study is an attempt to summarise the materials of various researchers concerning various aspects of the problems of climate change, reducing greenhouse gas emissions, and stimulating economic entities to reduce emissions, into a more holistic picture on the example of the Republic of Kazakhstan. It may become the subject of other studies concerning the development of elements of a new model of the economy or a higher level of generalisation. In addition, this study may be of interest to people making managerial decisions, as it shows the relationship of many processes that are not apparent at first glance.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Вплив парникових газів на зміну клімату

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Анотація. Зміна клімату стала загрозливою проблемою для всіх країн світу. Для Казахстану, одного з найбільших світових експортерів зерна, з його раніше переважно посушливим кліматом, розвиненою гірничодобувною промисловістю, металургією і переважно вугільною генерацією теплової та електричної енергії, уповільнення потепління стає нагальним завданням. Метою цього дослідження є узагальнення різних аспектів впливу викидів парникових газів на зміну клімату в Республіці Казахстан і можливостей скорочення викидів парникових газів шляхом переходу Казахстану до нової економічної моделі, заснованої на використанні відновлюваних джерел енергії. Під час дослідження були використані різні методи аналізу – аналітичний відбір на основі заданої або ідентифікованої ознаки, порівняльний аналіз схожих характеристик різних об'єктів, статистичний аналіз динамічних рядів, синтез, що представляє собою первинне теоретичне узагальнення емпіричних даних. В результаті дослідження було виявлено помітну залежність змін середньорічної температури та кількості опадів від загальних викидів парникових газів. Крім того, виявлена схожість динаміки основних кліматичних показників з динамікою окремих парникових газів в Казахстані вимагає подальших досліджень. Також зроблено висновок, що окремі інновації у вигляді окремих електростанцій на відновлюваних джерелах енергії або системи торгівлі квотами, що визначаються за найбільшими значеннями, не призведуть до помітного скорочення викидів парникових газів. Лише перехід до зеленої економіки, який має стати державним пріоритетом, а його принципи та основні характеристики – орієнтиром при прийнятті будь-яких державних рішень. Це дослідження може стати відправною точкою для багатьох теоретичних і практичних досліджень і показати необхідність скорочення викидів парникових газів не як суто механічного процесу, а в комплексі з іншими явищами, що може бути корисним при прийнятті управлінських рішень

Ключові слова: зміна температури повітря; опади та загроза опустелювання; моніторинг викидів; зелена економіка; альтернативна енергетика

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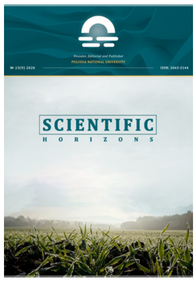

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Analysis of the economic efficiency of growing pigs for meat and its improvement

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Abstract. Agriculture has always played a vital role in Ukraine, which is primarily due to the geographical features of the location. Currently, the agricultural sector is the basis of the country's international specialisation. Thus, finding opportunities to improve this sector efficiency is still relevant. Therefore, the purpose of the study was to find ways to increase efficiency during activities in one of the agriculture branches, namely livestock breeding, within the framework of raising pigs. The main methods during work were analysis, deduction, modelling, forecasting, etc. During the study, a detailed review of the

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considering possibilities of the efficiency improvement of raising pigs was conducted. They were conventionally divided into two categories: connected with management processes and directly caring for animals. Thus, the author concludes that by using some methods of raising animals, a better quality of meat can be achieved, and therefore receive higher profits from its sale. During the study, possibilities connected with diet regulation, animals living conditions (temperature, enclosures, etc.), genetics and some others were directly considered. As for management tips, they are also analysed and provided by the authors: in particular, it was determined that cost reduction plays a huge role in such enterprises. In addition, the work considers the features of these enterprises work in terms of environmental safety and mentions the state role in the industry development

Keywords: agriculture; Ukraine economy; entrepreneurship; management; livestock breeding

INTRODUCTION

Agriculture plays a key role in the development of any country (Praburaj, 2018; Till, 2022). This opinion is now held by most researchers in the world (Mundlak *et al.,* 2004), but it was not always so. Thus, in the 20th century, it was believed that the agricultural sector had a passive role, the essence of which was the redistribution of labour and part of investments (Lewis, 1954). This led to a certain neglect of the industry, which could cause huge losses in the long-term. The main reason for the agriculture importance is that it plays an important role for the economy and in terms of strategic security: being able to grow its own resources at least to meet most of the domestic population needs, the country can be protected from external price fluctuations of agricultural products, supply restrictions, etc. (Steven & Wiebe, 2021). This is very important, especially in the realities of ongoing globalisation (Nugroho *et al.,* 2021; Assaoui & Fabian, 2021).

Now, the agricultural sector is one of the principal areas of activity in Ukraine (Dmytriieva & Sviatets, 2021). There are many reasons for this: a significant role in the country's international trade in agricultural products (Kholoshyn *et al.,* 2021), a large share of the sector in the country's GDP (Kaminskyi *et al.,* 2021), a significant role in job creation etc. Therefore, creating the most favourable conditions for enterprises in this industry stays relevant. Crop production is widespread in Ukraine, considering the placement of chernozem soils on its territory (Pozniak, 2019). Nevertheless, livestock breeding also stays a critical component of development within the framework of Ukrainian agriculture. In addition, it is currently becoming even more relevant, considering the crisis phenomena that began to appear in the pig farming in Ukraine after the full-scale invasion of russia (reduction of livestock, decrease in the competitiveness of local enterprises, increase in pork imports, etc.) (Maksym *et al.,* 2022). Thus, it is still important to assess the economic efficiency of raising different types of animals. In this work, the assessment was conducted for pigs.

A substantial number of scientists were engaged in the study of the productivity improving of livestock breeding. S. Millet *et al.* (2018) assessed the efficiency of raising pigs (namely, their protein absorption), considering the managing features by some processes connected with animal care. In the work, the authors mention the role of proper fattening, selection, and castration. However, attention is not paid to other essential elements that are also present during the management of a pig-raising farm. V. Maksym *et al.* (2022) conducted a study on the assessment of the current state of pig farming in Ukraine (sharp changes in which occurred primarily due to the beginning of the full-scale invasion of russia) and the possibility of increasing the efficiency of pig farming. Attention should be also paid to the works that evaluated the cultivation industries in different countries. Thus, G. Wang *et al.* (2021) conducted a study within China. Scientists clearly indicated the main threats facing meat producers and provided advice for minimising them in the future. In addition, the work of A.K. Ruckli *et al.* (2021) should be noted, who assessed the features of pig farms in terms of their negative impact on the environment.

Thus, the purpose of the work was to assess the possibilities for increasing the efficiency of pig raising. This can make it possible to increase the incomes of farmers all over the world (including in Ukraine), and therefore to increase the strength of the country in the face of external crises and create more added value.

MATERIALS AND METHODS

During the study of the economic efficiency increasing analysis of pigs raising for meat, the author assessed the general industry state in Ukraine. For this, some data were used on the number of pigs in the country by year, slaughtered animals, and pork exports in general. To assess the possibilities and methods of the efficiency increasing of pig raising, data from various scientific sources were used. The existing methodology was assessed for its efficiency, after which the conclusions were made of which of them is the most effective, how they can be used in a single system, and how it will help in terms of pigs raising for meat.

As part of the study, the author used some statistical data sources. Among them, the official website of the State Statistics Service of Ukraine should be noted, the data of which made it possible to consider in more detail some inbuilt tendencies connected with the pig farming development in the country (the number of raised and slaughtered animal units, etc.) (Ukrstat Agriculture, 2023), as well as statistical data from International Trade Centre, namely the TradeMap platform (2023). These data made it possible to assess the situation in terms of international trade in pig meat by the country. In addition, the author used some data from the Ukrainian legal and regulatory framework, namely the Law of Ukraine "On State Support of Agriculture of Ukraine" (2004).

During the study, the author used an analytical approach. It made it possible to conduct an analysis of a substantial number of various sources and to identify patterns in pig farming, as well as to find opportunities to improve the efficiency of this process. A quantitative approach was also used, because the statistical data describing the functioning features of the pig farming in Ukraine were also used during the work. In addition, the author used a considerable number of scientific study methods. The main among them can be considered the analysis considering the information volumes that had to be processed during the work. In addition, the historical study method was used, which made it possible to assess the functioning features of pig farming in Ukraine and some other countries (China, Nigeria, etc.), their features of conducting business. Statistical study methods were also used in the work, which were used to process quantitative data; at the same time, the graphical method made it possible to depict all of them in an understandable form. The deduction method was used to assess the general state of pig farming in Ukraine, considering the known data on individual indicators that characterise it. Modelling also became important, which was used in assessing the impact of the advice provided in the work to increase the economic efficiency of pig farming. For more qualitative conclusions about the future state of such farms, forecasting was used. The comparison made it possible to assess various methods of assessing the efficiency improvement of pig raising and to make conclusions about which of them should really be used.

RESULTS

To begin with, authors will consider some data about the pig farming development in Ukraine. Thus, Figure 1 below shows information about the number of pigs in the country from 1990 to 2022.

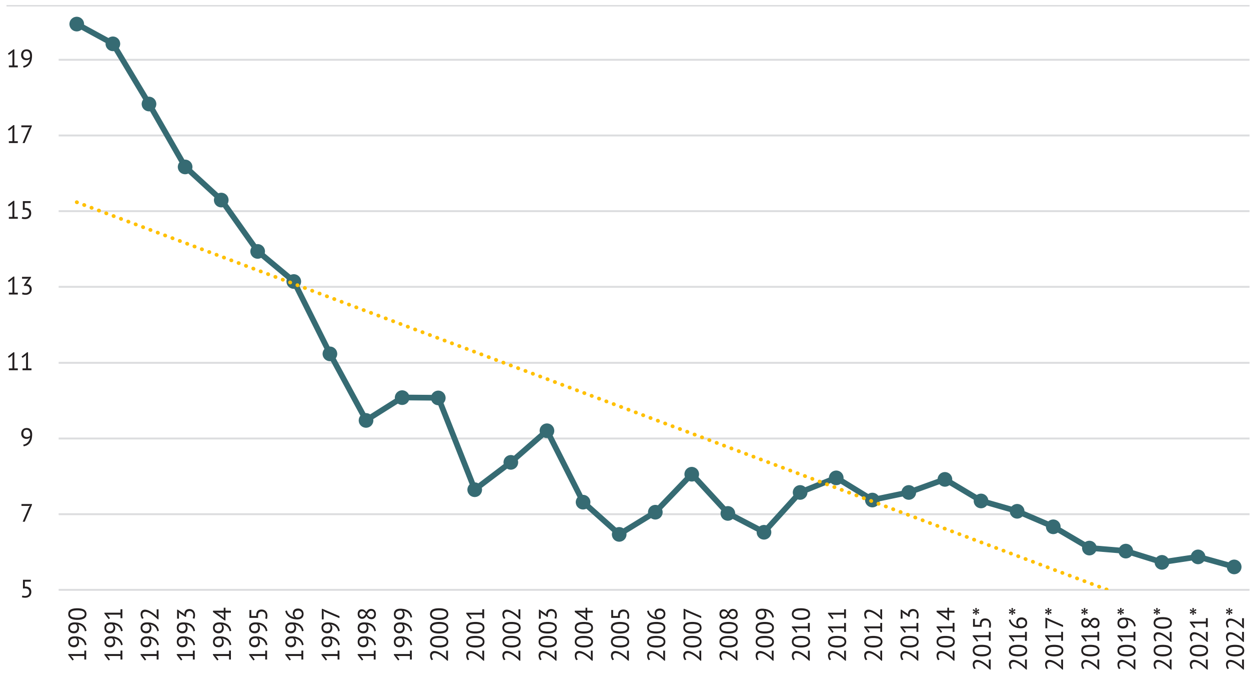

Figure 1. *Number of pigs in Ukraine from 1990 to 2022, million animal units*

Note: *The data are provided without considering the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of the temporarily occupied territories in the Donetsk and Luhansk regions.*

Source: *created by the author based on data from the State Statistics Service of Ukraine (Ukrstat Agriculture, 2023)*

As it can be seen from Figure 1, the number of pigs in Ukraine has a gradual downward tendency: the decline was most active until 2000, after which it slowed down; however, it accelerated again after 2014. All this indicates on the existing problems in the industry. However, it is interesting to note that the pig slaughter data, shown in Figure 2 below, provides evidence of something different.

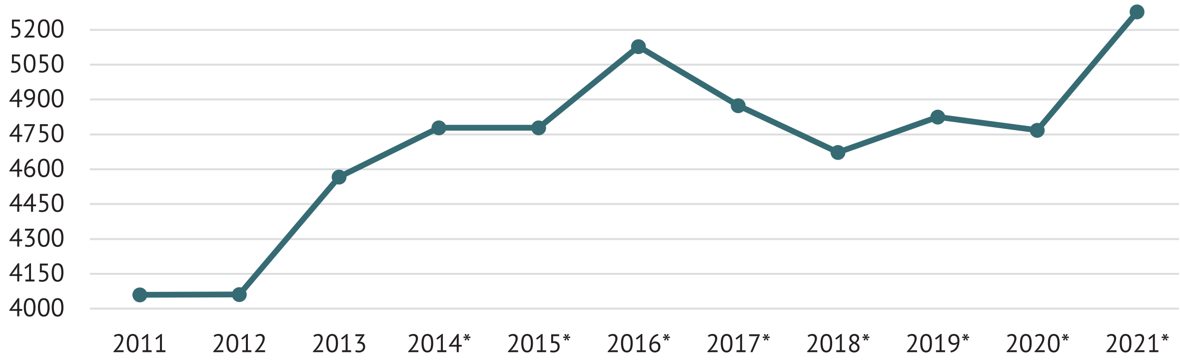

Figure 2. *The number of pigs slaughtered in Ukraine in 2011-2021, thousand animal units*
Note: *The data are provided without considering the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of the temporarily occupied territories in the Donetsk and Luhansk regions*
Source: *created by the author based on data from the State Statistics Service of Ukraine (Ukrstat Agriculture, 2023)*

As Figure 2 shows, the number of animal units for slaughter in Ukraine is increasing every year on average, while the number of pigs being raised is decreasing. It is possible to calculate the difference between the data on the number of pigs in the country in general and the number of animals slaughtered in 2011-2021: this figure drops sharply from 3.9 thousand to only 0.6 thousand animal units. This may indicate a gradual increase in the agriculture efficiency. Figure 3 shows data on this product export.

Figure 3. *Pig meat export by Ukraine in 2002-2021, million dollars*
Source: *created by the author based on data from the State Statistics Service of Ukraine (Ukrstat Agriculture, 2023)*

As it can be seen from Figure 3, the pig meat trade in Ukraine is quite unstable and can vary greatly from year to year. Thus, the average values for all this time reached the level of up to 10 million dollars, however, in some years they reached 20-95 million dollars. As of 2021, Ukraine's meat exports have been gradually increasing since 2018. Data for 2022 is not currently available, but it can be assumed that it will be significantly lower than in 2021 due to the full-scale invasion of russia and the significant export capacity of Ukraine. Thus, it can be concluded that pig farming in the country is gradually declining, which can relate to Ukraine's greater direction towards trade in plant sector products. There are quite a few indicators that can be used to assess the economic efficiency of pig farming. In general, they can be described as shown in Table 1.

Table 1. *The list of indicators of economic efficiency of an enterprise*

Seq. No.	Factor class	Factor name
1	Costs	Fodder
2		Fuel and lubricant oil
3		The rest of the material costs
4		For labour payment

Table 1, Continued

Seq. No.	Factor class	Factor name
5	Costs	Social contributions
6		Amortisation
7		Services payment to third-party organisation
8		Other general production costs
9	Other	Fodder conversion
10		Sale price
11		Production of products per 1 average annual animal unit
12		Fodder cost
13		Marketability level
14		Maturity level
15		Average annual livestock at an enterprise

Source: *created by the author based on data from the work of V. Maksym et al. (2022)*

As Table 1 shows, 15 indicators of the economic efficiency of pig farming can be identified. Over 50% of them (8/15) are in a certain way connected with the expenditure side of the enterprise organisation, while others can be of the most diverse nature: price, livestock volumes, production efficiency, etc. Thus, a particularly vital component of increasing the economic efficiency of pig farming is the costs minimisation.

It should be noted that the efficiency of pig raising can vary depending on the company size that wants to start a business. Thus, in most countries of the world, producers of agricultural products can be divided into two groups: small (small farmers and SMEs) and large (certainly, medium-sized enterprises can be distinguished, but they will have characteristics of both small and large, therefore, it is more important to consider these two groups) (Havlicek *et al.,* 2020). They have unique features within the production processes, which affect the price and market relations. Thus, production processes in large pig farms resemble those typical of industry: they are precise, efficient, and narrowly focused. Thus, animals raised by such producers have a competitive advantage in the market. In turn, small farmers have less favourable conditions, they often do not specialise in one production and are forced to subsidise their own production with the help of external resources (although some modern studies come to the opinion that small farms can show a better result than large ones, in developing countries, but this statement needs a separate discussion (Delvaux *et al.,* 2020; Aragon *et al.,* 2022). Thus, given their competitive advantages and large production volumes, large producers have the opportunity to influence the price, which reduces the number of small enterprises and leads to the actual agriculture monopolisation, which negatively affects its further development. However, it should be noted that how efficient production on the farm will be depends also on a farmer's capabilities. Thus, education and level of a manager's knowledge (especially in the agricultural industry) strongly affects the efficiency of raising of any species plants or animal species. Thus, especially in developing countries, it is farmers fault for existing inefficiencies in their enterprises and could increase their income level by an average of 3% without involving innovative technologies (Umeh *et al.,* 2015).

The diet chosen by a farmer plays a special role in raising pigs, which is already a part of increasing efficiency by optimising animal care. If possible, feeding should be adapted for each animal individually (Soleimani & Gilbert, 2021). In other words, the diet choice should be determined based on the genetic line features of certain breeds of pigs; this makes it impossible to offer a universal option of diets. It is also important how much food the animals will consume during the raising and in the last development stages. Thus, reducing the food amount from the ad libitum level (that is, when animals can eat as much as they want) by 25% leads to a decrease in weight gain by 27-35% (Lebret, 2008). Sometimes, this feature can be used skilfully. For example, to regulate the amount of fat and meat in a pig after slaughter (because fat begins to be actively deposited at an older age).

Some manipulation of the future pigs' weight can be done using the compensatory growth response, that is, a physiological phenomenon that accelerates the final growth rate, which is achieved by initial food restriction and subsequent ad libitum feeding (Campbell, 1983; Menegat *et al.,* 2020). The animal's response to such feeding strategy can vary depending on when it is introduced and the feeding restriction duration: for example, if restriction begins between 28 and 90 days of age, a response can be expected at slaughter after approximately 140 days (Therkidsen *et al.,* 2002). In addition, this feeding strategy can improve muscle protein absorption, which will improve pig tenderness, especially in females (Kristensen *et al.,* 2004); this strategy leads to an increase in adipose tissue in pigs and the growth of internal organs. It is possible to change some meats quality and in the case of pigs feeding ad libitum. This is made by changing animals' diet. Thus, in the case of decreasing the amount of proteins or lysine in the diet, but with the provision of a sufficient energy amount, the softness and juiciness of the meat in pigs improves, but in this case the growth rate decreases (Lebret, 2008). At the same time, if pigs are limited in terms of obtaining amino acids for some time before slaughter, then the volume of adipose tissue can be increased.

It is also important to consider how housing conditions (amounts of free space, temperature, etc.) can affect the carcass quality after slaughter. Thus, air temperature affects the energy requirements and growth performance of pigs: they grow if pigs are kept in colder conditions and vice versa. Thus, the best temperature (thermoneutral zone) was established, which is determined within the framework of 22-28 degrees Celsius (Renaudeau *et al.,* 2008; Gourdine *et al.,* 2021). Decreasing the temperature to 17-22°C can lead to an increase in the growth rate of pigs due to greater voluntary feed consumption (Lebret, 2008; Schmitt *et al.,* 2021). Even the amount of free space provided to animals has a certain influence. Thus, if 0.76 m^2 was allocated per pig, the growth rates of pigs were comparatively lower than in the case when the area increased to 3.5 m^2 (Beattie *et al.,* 2000).

It is interesting to compare the pigs raising under the conditions of organic farming, that is, under active enclosure and receiving their established organic diet (which consists of at least 90% organic feed ingredients per the European Union (EU) Directive) (Lebret, 2008). In addition, the use of synthetic amino acids, antibiotics, growth stimulants and products with GMO (genetically modified organisms) is prohibited in organic raising. In fact, the study results in this case can vary. As it was shown in the works of some scientists (Hansen *et al.,* 2006), pigs raised in organic conditions had a lower daily gain and an increased content of lean meat in the carcass compared to other studied groups. At the same time, other scientists conclude that it is not too important whether the animals are fed organic or chemical food: the conditions of their keeping play a much greater role (Millet *et al.,* 2005).

Another key component that should be monitored is the conversion of plant protein to animal protein, which decreases under conditions of active nitrogen release with pus (Millet *et al.,* 2018). In general, there are three strategies connected with increasing nitrogen efficiency: genetic selection, castration, and selection of optimal animal weight. Nevertheless, the fact that selecting genes (through gradual selection) that would increase the efficiency of proteins absorption is rather questionable. Even in the 20th century, J. Hammond (1947) assumed that any selection of such genes would only lead to an increase in the protein energy efficiency. However, more modern studies show that such an effect can still be achieved (Moehn *et al.,* 2004; Sarri *et al.,* 2021). The next way to improve the efficiency of plant protein conversion is castration (Tomasevic *et al.,* 2020; Weiler *et al.,* 2021). Studies show that for males, castration does lead to better protein absorption (Moehn *et al.,* 2004). Regarding the last point, that is, the weight loss efficiency for better protein absorption is not clear. Thus, for a long time, scientists could not conclude about whether such an effect is present at all: some studies indicate its presence (Shirali *et al.,* 2012), while others did not notice it at all (Aymerich *et al.,* 2020). In general, scientists concluded that the animal weight at the end of the feeding process should be within certain limits, which are about 115.2 kg for fat breeds, and 96.6 kg for lean breeds (Morel & Wood, 2005). Thus, the use of all the abovementioned methods will be able to significantly increase the efficiency of meat production on pig farms. Nevertheless, it should be remembered that some indicators can be individually distinguished for individual breeds or differ due to external conditions. Therefore, it is important to check all these methods in practice.

DISCUSSION

Within the framework of their study, V. Maksym *et al.* (2022) assessed the efficiency of pig production at agricultural enterprises in Ukraine. In general, scientists come to the conclusion that there are only a few effective directions for increasing the profitability of meat production, these are: costs optimisation and sales policy improvement (reduction of all costs types due to the use and involvement of material and technical, and labour resources), finding new high-quality sales markets, the development of a full-cycle vertically diversified form of production organisation (with the help of the use of self-grown fodder of the grain group for animal feeding and the use of own capacities for their further processing). Optimising products should become especially important in the realities of high electricity prices caused by russia's invasion of Ukraine. It is also should be mentioned that the scientists built a rather complex model for assessing the economic efficiency of pig raising, which used 15 indicators. This made it possible to assess the possibilities and efficiency of growing this animal type in different regions of Ukraine. Note that some of these methods were also mentioned by the author in the abovementioned work. They are really efficient in terms of increasing the efficiency of the economic and management component of the process.

An interesting study on pig raising in Nigeria was conducted by J.C. Umeh *et al.* (2015). This country as a whole is quite special in terms of the economy management, taking into account the geographical conditions of its location. Scientists note that in Nigeria there are inefficiencies in the way farmers manage at enterprises. Therefore, they describe the following tips for improving the efficiency of pig farmers (primarily in terms of state regulation): optimising the use of available resources; encouraging farmers to join together to share knowledge, technology and practices; the policy of improving credit opportunities for entrepreneurs; encouraging studies in the agriculture industry and creating consultation services for such enterprises. Notably, as mentioned above in the author's study, similar methods of influence should be relevant in Ukraine as well, as one of the most promising opportunities for increasing the activities efficiency in the agricultural sector, including pig raising, is the improvement of scientific potential. Studies on the state of this industry in China was conducted by G. Wang *et al.* (2021). Scientists write that there is certain inefficiency in the country connected with the low return on costs of most enterprises in the country's agrarian sector. G. Wang *et al.* (2021) note that production at the capacity limit could reduce the production cost for different farmers from 21% to 47%, which is a large amount. The second thing the authors pay attention to is the use of the latest technologies, which will, among other things, be aimed at reducing farm waste. According to them, it can also improve production efficiency. The main advice provided by G. Wang *et al.* (2021) are the following: firstly, farmers should actively adapt to the rapid changes in the environment and quickly switch to organic fuels, waste-free production, etc.; secondly, entrepreneurs should pay more attention to the existing territorial advantages they have to improve the competitive situation in the market; thirdly, to more actively study modern world trends within the framework of technological development, quickly involve the latest technologies in production; fourth, to use financial instruments to protect oneself from external shocks (pandemics, world crises, etc.). It should be noted that these approaches are also quite applicable in the realities of Ukraine, however, their use will be more relevant in the future, when enterprises will find an opportunity to overcome more urgent problems connected with insufficient funding, insufficient efficiency of growing technologies, etc.

B. Lebret (2008) in his study sufficiently shows a large number of components that affect the business efficiency and are primarily connected with the features of animal raising. He describes feeding systems, raising, pig care features, etc. In general, the main conclusion from their study is that optimisation and quality use of animal care processes (which was also described by the abovementioned authors in the work) can significantly increase the efficiency of pig raising and will allow entrepreneurs to receive significantly higher incomes in the future. Unfortunately, they are often available primarily to large enterprises, while the possibilities of small farms, whose role in the economy is also high, are extremely limited. In the framework of the abovementioned study, the author notes that large companies do have comparative advantages in conducting activities in agriculture; nevertheless, the increase in the SMEs number should remain a vital component of national policy due to certain benefits they bring (higher mobility, adaptation possibility, job creation, etc.).

Recently, the problems of sustainable development are becoming more and more relevant, which is why ensuring compliance with its principles and purposes is important for any company, including farms (Kalinowska *et al.,* 2022; Herger, 2020), because it is one of the most important components for achieving the country's sustainable development purposes (Laurett *et al.,* 2021). As noted by T. Soleimani & H. Gilbert (2021), the main methods for reducing the influence of pig farms on the external environment are the preparation of appropriate rations in accordance with the genetic line requirements, as well as ensuring their ecological optimisation. In turn, G. Samarin *et al.* (2021) study the features of the EU countries attitude to this problem. They write that the European Union already has an active program of ecologically clean agriculture, which includes several strategic areas, namely: protection of livestock and people from harmful microorganisms; development of ecological production of products; development and improvement of equipment for waste disposal and cleaning of livestock breeding emissions; development of regulatory documents on environmental protection and reduction of product losses during transportation. According to scientists, the spread of such principles is particularly important for the future agriculture development as a whole. A.K. Ruckli *et al.* (2021) in turn assessed how successful modern pig farms have been in terms of ensuring sustainable development in terms of "green" energy production. Based on their study, it can be concluded that on most farms (even in highly developed countries) there are still needs to improve the performance of environmental sustainability. Moreover, they show that improving farm and field management is crucial to simultaneously reduce the environmental influence and promote biodiversity of pig farming, at least in European realities.

Thus, it can be concluded that pig farming in Ukraine is currently in a long-term stagnation, which only worsened with the beginning of a full-scale invasion. However, to solve the existing problems, there are many tools that can be used both by the entrepreneurs themselves and by the state. From a farmer's point of view, a lot of advice has been given above on efficiency improving of managing such an enterprise: from improving some management components to making some changes in animals' diet. Nevertheless, it should be noted that the state also has certain influence levers. They can be found in the Law of Ukraine "On State Support of Agriculture of Ukraine" (2004), which clearly describes the possibilities of state support for the country's agriculture. Among them, the following can be distinguished: providing financial support, reducing the loans price, compensating leasing payments, opening access to all the necessary information for conducting business, etc. As it was shown above in the study, because the most critical component of the efficiency of pig farming business management is the reduction of the expenditure part, therefore, it can be assumed that the financial support methods are the most effective for this industry. Thus, ensuring their more active implementation could also have a positive impact on Ukrainian pig farming in the long-term.

CONCLUSIONS

Thus, within the framework of this work, an analysis of the economic efficiency of pig farming was conducted, as well as ways to increase it. All methods described in the study were divided into two types: those connected with the change of the management features of the enterprise, and those connected with the approach change to animal care. It was shown that the most vital role in efficiency increasing of the company's management is played by the reduction of the expendable part, as it makes it possible to significantly increase the competitiveness of products compared to other manufacturers. In addition, the attention should be paid to pricing, conducting a marketing campaign, production rates, etc. In addition, a key role is often played by the of education level of managers at enterprises, which indicates the need for their constant self-improvement need.

If we consider the possibilities of increasing efficiency in terms of animal care, special attention should be paid to the feeding features. By providing a competent diet, the final animals weight can be increased. In addition, dietary restrictions can be applied. It allows manipulating the final volumes of meat and fat that will be in the pig carcass. In turn, the use of compensatory growth reaction (feeding reduction for a certain number of days before slaughter and subsequent diet according to the ad libitum method) makes it possible to increase the final weight of the carcass. The attention should be also paid to the conditions in which animals live: the amount of free space, enclosures, temperature, etc. In addition, the authors recommend adhering to such conditions of enterprises operation, within the framework of which they will fit into the framework of sustainable development, primarily by minimising the negative impact on the environment.

It is promising for further studies to conduct similar studies (on the efficiency assessment of raising a particular breed or species) in the realities of Ukraine. In addition, it is important to regularly conduct a general assessment of the agriculture state in Ukraine and to look for existing inefficiencies.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Аналіз економічної ефективності м'ясного свинарства та шляхи її підвищення

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Анотація. Сільське господарство завжди відігравало важливу роль в Україні, що зумовлено насамперед географічними особливостями розташування. Нині аграрний сектор є основою міжнародної спеціалізації країни. Таким чином, пошук можливостей підвищення ефективності цього сектору залишається актуальним. Тому метою дослідження було знайти шляхи підвищення ефективності діяльності однієї з галузей сільського господарства, а саме тваринництва, в рамках вирощування свиней. Основними методами під час роботи були аналіз, дедукція, моделювання, прогнозування тощо. Під час дослідження було проведено досить детальний розгляд можливостей підвищення ефективності вирощування свиней. Їх умовно розділили на дві категорії: пов'язані з процесами управління та безпосередньо доглядають за тваринами. Таким чином, автор приходить до висновку, що за допомогою деяких способів вирощування тварин можна досягти кращої якості м'яса, а отже, отримати більший прибуток від його реалізації. Під час дослідження безпосередньо розглядалися можливості, пов'язані з регулюванням раціону, умовами утримання тварин (температура, вольєри тощо), генетикою та ін. Що стосується управлінських порад, то вони також проаналізовані та надані авторами: зокрема, визначено, що зниження витрат відіграє величезну роль на таких підприємствах. Крім того, в роботі розглянуто особливості роботи цих підприємств з точки зору екологічної безпеки та зазначено роль держави в розвитку галузі

Ключові слова: сільське господарство; економіка України; підприємництво; управління; тваринництво

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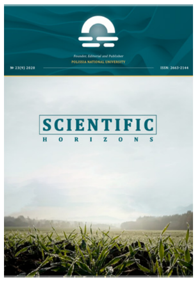

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Development of a competitive strategy of an organic production enterprise based on discriminant analysis

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Abstract. This study offers an additional toolkit that will allow substantiating the formation of a strategy for future development considering the potential growth or reduction of activity, which is relevant for producers of organic products, since considering the potential trajectory of development will provide an opportunity to protect the enterprise from unfounded decisions in the event of a reduction in activity and will help activate existing reserves in case of future growth, which is relevant and quite in demand. The purpose of this study was to prove or refute

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the hypothesis about the influence of several factors on the development of organic products, as well as to determine the further strategy of the enterprise. For this, data from 75 Ukrainian enterprises that grew organic products were analysed. The division of enterprises into groups depending on the volume and growth rate and identification of factors affecting the future development of organic producers was carried out using cluster and discriminant analysis. The factors that substantially affect the future development and allowed dividing the enterprises under study into groups were the diversification of production, the replacement of crops, changes in the volume of organic production, and changes in production efficiency. Whereas the factors "percentage of new (or withdrawn from production or not certified) crops in the new year to the total volume of production last year" and "change in the area of organic soil" did not show sufficient influence on the distributive capacity of the model, and were excluded from further analysis. It is proposed to develop a strategy for enterprises producing organic products based on a differentiated approach for three different groups of enterprises, namely: those that potentially have high potential, speed of development and expansion of activities; those that are potentially expected to reduce and decrease the production of organic products; those that develop at moderate rates. The obtained equations can be used in practical activities for additional justification of the development strategy of organic producers

Keywords: competitive advantages; sustainable development; competitiveness; success factors; organic products

INTRODUCTION

The world market of organic products has grown substantially over the past decades and continues to grow, and therefore the formation of strategies for entering such markets and functioning on them is becoming increasingly relevant for Ukrainian enterprises. As a result, the identification of competitiveness factors and the development of winning strategies for agricultural producers become a promising area of scientific research. The trends that cause the need to research the competitiveness of enterprises of all sectors of the economy in modern realities are as follows: digital transformation of relations between the consumer and the producer (Kryshtal *et al.*, 2022), between the producer and the supplier and the restructuring of business processes of enterprises and supply chains as a result. One of the relevant studies is the work of Garcia *et al.* (2023), who examines the sustainability of the agri-food supply chain from small producer to consumer and proposes its improvement, through a modelling approach for the farmer and a digital counterpart.

The orientation of the world economy towards the processes of resource conservation, green economy, circular economy is highlighted by Yaremova *et al.* (2021), where approaches to the possible development of society in the production of goods based on renewable biological resources are considered. The paper proves that with the development of the circular economy, the society will be able to overcome the modern challenges and will help produce consumer products not only by neutralizing the harmful effects of management and minimizing industrial waste, but also ensure the restoration of bioresources. Ostapchuk *et al.* (2020) suggests that Ukrainian agricultural producers combine the concept of lean production and "green logistics", which can rationally use the available resources of the enterprise and environmental protection during both the production and sale of food products.

The transition of agricultural enterprises to the principles of sustainable development is a reason for scientific discussions. Thus, Shkuratov *et al.* (2021) proposed a methodology for assessing the ecological efficiency of the spatial organization of rural areas. This method will help use rural areas to increase the efficiency of agricultural production and minimize adverse consequences for the ecosystem.

A current trend is the investigation of the social responsibility of producers (Skydan *et al.*, 2023) and the formation and development of production, social, and market infrastructure (Kravchuk *et al.*, 2021). However, as noted by Yatsiv & Yatsiv (2018), a considerable part of agricultural enterprises in Ukraine do not consider their own resource capabilities and their place in the competitive environment. This is conditioned upon the lack of consistency in the development of corporate strategies.

Peng (2019) and Sahota (2020) investigated the development of organic production and consumption markets at the level of the global economy, individual countries, or regions. A study by Hou *et al.* (2022) proved that the market for organic products in the USA is developing rapidly, and demand considerably exceeds supply, which indicates the need to find ways to develop organic agriculture. According to scientists, supporting scientific research in the field of organic production, increasing the number of workers in the industry and a strong consumer base are crucial for the development of the organic production sector in the United States and around the world.

Analysis of factors that can influence the purchase of organic products showed that the key in this case is the concern of the population for their health and future generations. Mishra (2022) recommends raising public awareness about the impact of organic food on human health and on the planet, which will be an incentive to buy more healthy foods. The study (Wang *et al.*,

2017) emphasized that the greater the investment in organic production, the greater the competitiveness of the producer. While the authors (Marasteanu & Jaenicke, 2018), on the contrary, considered the impact of the development of organic farming on the economy and the qualitative transformation of the economy based on the principles of sustainable development through the development of organic farming and organic production.

The state of development of the organic market in Ukraine is analysed in the study (Bogomolova, 2021), which states that organic agriculture is one of the most promising areas of the country's agricultural economy. The transition to organic production will increase the level of environmental awareness of the population and improve the balance between environmental and economic factors of society. The institutional environment of the production of organic products was investigated by Kotsenko (2022) and the current state of institutions supporting the activities of producers of organic products in Ukraine was analysed, and it was noted that the further development of organic agriculture requires the development of regulatory documents, national support using the practices of the countries of the European Union.

Despite a significant amount of research on the issue of environmentalization of agriculture, the development of organic production and its competitiveness, it is necessary to investigate the issue of forming a competitive strategy for the production of organic products and their competitive advantages, which determined the purpose of this paper.

MATERIALS AND METHODS

To solve the tasks set, general scientific and special methods of cognition were used during the study. The synthesis and comparison method was used to develop recommendations on enterprise development strategies, the generalization method was used to form conclusions and recommendations, while tabular and graphical methods were used to visualize the results obtained. The study of the results of efforts of agricultural producers to achieve certain competitive advantages allows assessing the prospects of existing vectors of development of the Ukrainian agricultural sector. To determine the impact of several factors on the competitiveness of organic production enterprises, it is proposed to use cluster analysis. The data of 75 agricultural enterprises of Ukraine, which entered the European markets of organic products, according to the data of the Ukrainian certification body "Organic Standard" (n.d.), were studied. All the above-mentioned enterprises are certified for organic production, which means that the objects of observation have authorized technical documentation that meets the established norms and standards for products, production environment, materials and resources, environmental management, quality management system, waste disposal, etc. Factors used to evaluate the company's performance:

Diversification of production (X_1) is a criterion that is successfully used to determine the competitiveness of enterprises in many sectors of the economy (Belenkova, 2020; Raj, 2022). This factor is quite informative, regulated by the company's managers, and it is also effortless to assess. The study evaluates the diversification of production by the number of organic crops that are grown. Among the enterprises under study, the number of crops varies from one to thirteen.

Expansion (reduction) of certain types of production (X_2) is the percentage of new (or withdrawn from production or not certified) crops in the new year to the total volume of production last year. This factor shows the dynamism of production, the ability to adapt the enterprise to changes in market conditions. It differs from the previous one in that it estimates the proportion of organic crops that have been replaced by others, introduced a new one, or reduced one, estimating the depth of transformations. For the enterprises under study, the factor varies from -1.37 to 10.16.

The turnover of crops (X_3) is an indicator according to which the replacement of crops with new ones was evaluated (in the analysis, it is marked as "1"), stability and absence of replacements (marked as "0"), the reduction of the production nomenclature – (marked as "-1"), the increase in the number of new cultures (mark "2").

Change in the volume of organic products (X_4) is an indicator that characterizes the increase or decrease in the volume of production of organic products in relation to the volume of the previous year.

Change in the area of organic soil (X_5) (Aceleanu, 2016) is an indicator that characterizes the increase or decrease in the area of land that meets the requirements for organic farming and is certified to the area used by the enterprise last year.

Changes in production efficiency (X_6) (Zeru, 2018) is an indicator that is calculated as an increase or decrease in the yield per 1 ha of certified land compared to the previous year. Since the producers of various crops, which carry out economic activities in different regions of the country, are evaluated, it does not make sense to evaluate the yield of each crop or the average for each producer. However, the proposed relative indicator characterizes how much more or less efficiently the enterprise conducts business activities in comparison with its results in the previous period. This relative assessment can be applied upon determining competitiveness. If additional data are available on the performance of producers of homogeneous products, this indicator can be updated or replaced with yield.

Cluster and discriminant analysis was performed using the TIBCO Statistica statistical analysis software package (Statistica 10). Since different measurements use completely different types of scales (thousand square meters, percentages, units, fractions of a unit, etc.), the data needs to be standardized (normalized). Standardization is performed according to Eq. (1) for the mean square deviation σ (Marets & Vilchynska, 2016):

$$z_i = \frac{x_{ij}-\bar{x}}{\sigma_{xj}}, \quad (1)$$

where z_i is the normalized value; x_{ij} is the initial value of the indicator; x is the average value of the indicator; σ is the mean square deviation. Ward's method was used for tree clustering.

RESULTS AND DISCUSSION

There were several stages in this research. At the first stage, tree clustering was performed to find out whether enterprises form groups and select the previous number of clusters, for which we use the Ward's method. This method is based on the results of variance analysis to estimate distances between clusters. Based on the minimum sum of squares (SS), groups of enterprises are formed at each stage of the clustering process. As a measure of the distance between enterprises, the Euclidian distance was chosen, which is the geometric distance between objects in a multidimensional space (Belenkova, 2019):

$$L = \sqrt{\sum_i^n (x_i - y_i)^2}. \quad (2)$$

The results of this stage indicate that there are at least two groups of enterprises that differ in size, business strategy, and efficiency. The next result obtained from a hierarchical clustering is a vertical dendrogram (Fig. 1), the analysis of which helps visually identify the division of enterprises into three groups (highlighted by a red line).

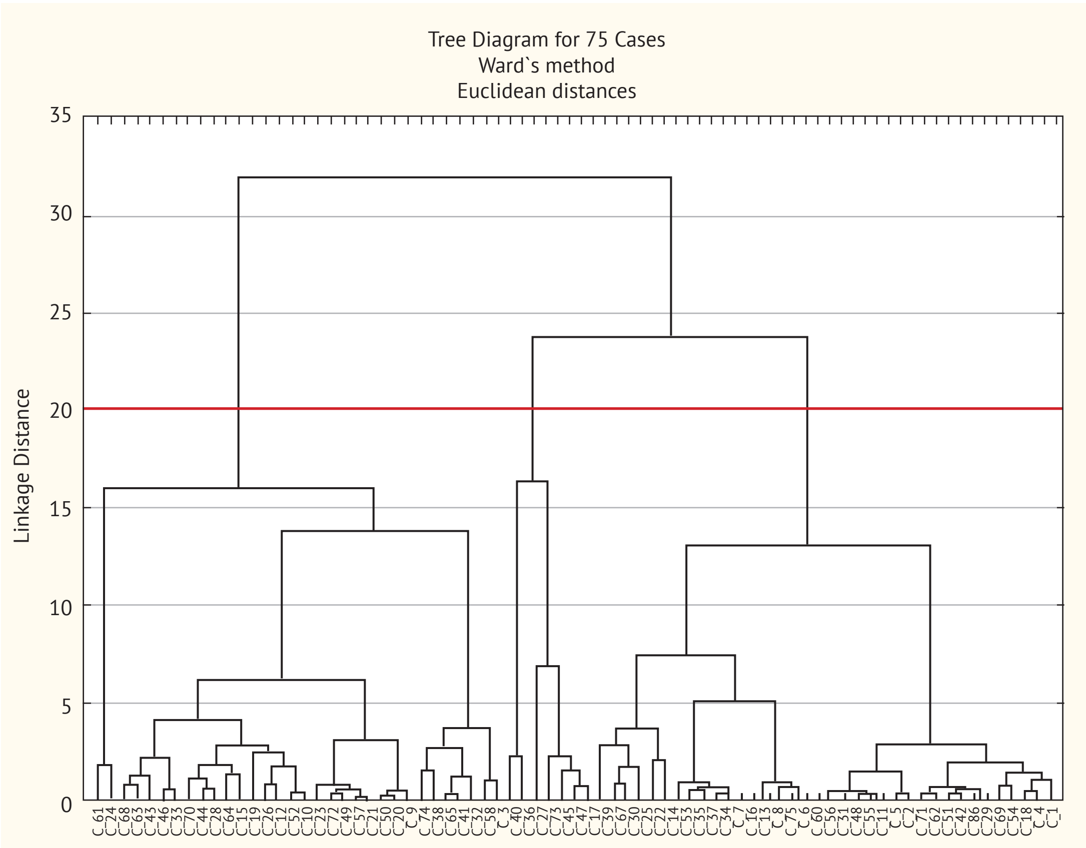

Figure 1. *Dendrogram of hierarchical classification of the enterprises of Ukraine under study – producers of organic products (Euclidean distance, Ward's method)*

Source*: compiled by the authors*

Determination of intersection points in Figure 1 revealed that according to the selected factors: diversification of production (X_1); expansion (reduction) of certain types of production (X_2); turnover of crops (X_3); change in volumes of organic products (X_4); change in organic soil area (X_5); change in production efficiency (X_6), appropriate division of agricultural enterprises from organic production into three or five clusters. As a result, it was assumed that the analysed enterprises form three clusters (highlighted by a red line in Fig. 2). Considering the results of visual analysis, further evaluation according to the k-mean method was based on the distribution of data into 3 clusters (Table 1).

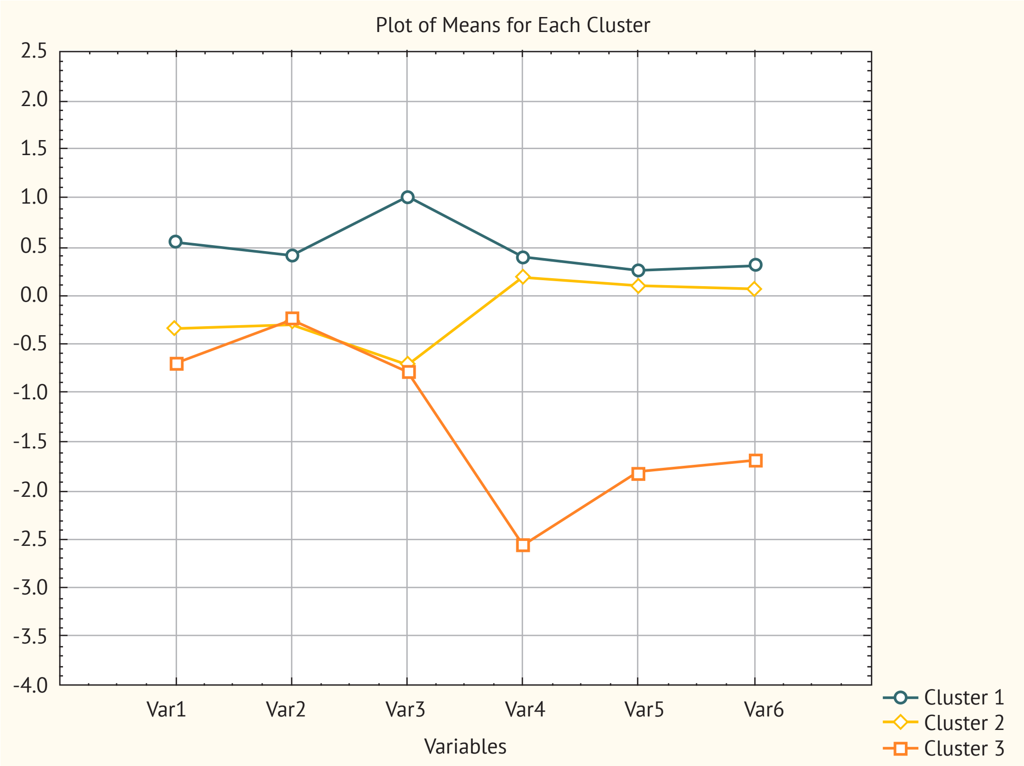

Figure 2. *Graphical representation of the ratios of standardized parameters in clusters 1-3*
Source: *calculated by the authors*

Table 1.*Characteristics of clusters of agricultural enterprises of organic crop production in Ukraine obtained by the k-mean method*

Parameter	Cluster 1 n=31	Cluster 2 n=7	Cluster 3 n=37
X_1	0.550099	-0.70018	-0.328427
X_2	0.411856	-0.26930	-0.294119
X_3	1.021662	-0.76076	-0.712060
X_4	0.372646	-2.54692	0.169632
X_5	0.276719	-1.80607	0.109843
X_6	0.300952	-1.68319	0.066292

Source: *calculated by the authors*

Enterprises of the first cluster are characterized by the highest values of all analysed parameters. They mostly expand the sown areas for organic crop production, increase the volume of production of organic products, mostly increase the efficiency of operational activities, and also implement a policy of diversification – although the number of cultivated plant species of the enterprises of this cluster starts with two, but the average value for the entire group is 5.06≈5. This is much more than in other groups. The volume of production of certified organic products is 1.2-1.6 times less than that of enterprises of the third group, and the size of certified land plots is 1.2-2 times.

Therewith, the efficiency of enterprises in this cluster increased the most among the analysed groups. The increase in efficiency is the result of the fact that enterprises of this cluster are actively experimenting with new plant species, actively introducing new ones (61% of enterprises), or replacing already grown types of products (32%), choosing the optimal product structure of the product range to ensure competitiveness (Fig. 3). Therewith, only 7% of the analysed enterprises reduced the types of organic crops grown. In general, the strategy of enterprises of this cluster can be described as active, innovative, aimed at finding new more promising areas of activity, as well as at developing and certifying new plant species.

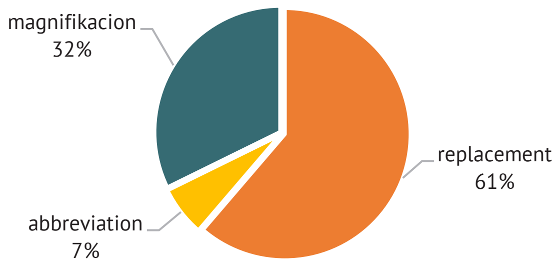

Figure 3. *Distribution of organic production enterprises of the first cluster aimed at growth or reformatting the strategy's activities, %*
Source: *calculated by the authors*

As a result of the analysis, enterprises with the lowest X_1-X_6 indicators were assigned to the second cluster. Although there are only seven such enterprises, they differ essentially from others in that they reduce the area of organically certified land, reduce the volume of organic products, and the efficiency of all firms in this group substantially decreased in the analysed period. In addition, the analysed enterprises pursue a fairly conservative development policy, since during the analysed period they either did not change the plants grown, or even reduced their number (Fig. 4). Therewith, the reduction in the types of plants grown did not help optimize production, as evidenced by a decrease in the efficiency and market share of each of the group's enterprises. A sharp reduction in the volume of organic products of the enterprises under study can be caused by several reasons. Firstly, the growing conditions or the product itself may not meet the requirements for obtaining a certificate of conformity, which is determined by current compliance control. Or the management of enterprises decided to implement a cost-saving strategy by increasing the volume of growing non-organic products.

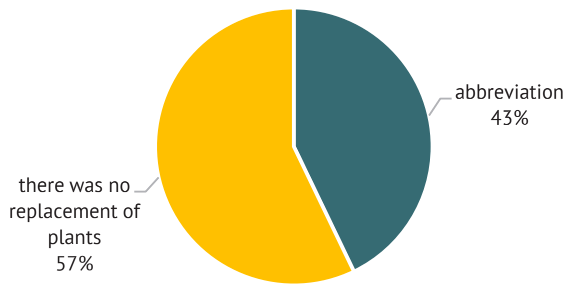

Figure 4*. Distribution of organic production enterprises in the second cluster survival or reduction strategies, %*
Source: *calculated by the authors*

Enterprises of the third cluster pursue a fairly moderate strategy, without sharply increasing the area of certified land and the volume of organic production. The average number of organic products grown per enterprise is 2.8≈3. Therewith, the group has a conservative approach to the implementation of activities, since 57% of enterprises did not change the plant species they cultivated, did not try to expand their activities, and 38% of enterprises generally reduced the number of types of products subject to certification. In contrast, only 25% increased the number of certified types of products, and no company of the group made changes in types of products (Fig. 5).

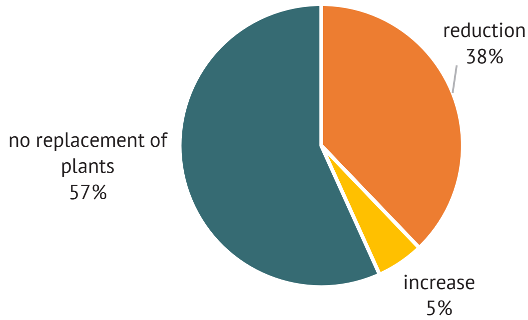

Figure 5. *Distribution of organic production enterprises of the third cluster, strategies to preserve or reduce the enterprises of the cluster, %*
Source: *calculated by the authors*

For the possibility of classification of new enterprises engaged in the production of organic products, we will create classification functions using discriminant analysis. The criteria for evaluating the quality of the created models should be the following indicators: Wilks' Lambda (λ); Partial Lambda λΛ; Fisher's F test; significance level of the F-criterion/p-level; tolerance (toler), and the multiple correlation coefficient 1-Toler (R-Sqr.) (Boedeker & Kearns, 2019; Tian *et al.*, 2022; Kei *et al.*, 2023).

Wilks's lambda (λ) is a measure that suggests the degree of distribution of a data set on a population. The indicator is measured on a scale from 0 to 1. The more λ approaches the maximum value, the worse the relationship of the resulting equation distributes data across populations. The lower the value of λ, the better the separation capacity of the obtained equation (Boedeker & Kearns, 2019). Partial lambda shows how much a single variable contributes to general discrimination. By analogy with Wilks' Lambda, the partial lambda has a greater effect on the distribution of data into separate independent groups if its value approaches zero, and if this measure is close to one, then the discriminating power of an individual factor is small.

The value of the indicator "tolerance" (Toler.) indicates a strongly separate variable affecting the separation power of the model. The larger the given meter, the smaller the contribution to the overall function of the individual factor. As a result, the four most influential and significant factors in terms of separation ability were selected to create discriminative functions (Table 2).

Table 2. *Result of step-by-step discriminant analysis of organic production enterprises*							
Seq. No.	**N=75**	**Wilks' Lambda**	**Partial Lambda**	**F-criterion (2.51)**	**p-level**	**Toler.**	**1-Toler.(R-Sqr.)**
1	X_4	0.112050	0.855867	5.64161	0.005440	0.539107	0.460893
2	X_3	0.165672	0.578852	24.37312	0.000000	0.836891	0.163109
3	X_1	0.139216	0.688859	15.13117	0.000004	0.829553	0.170447
4	X_6	0.118393	0.810013	7.85737	0.000860	0.475375	0.524625

Source: *calculated by the authors*

The number of model steps is 4, the number of observations is 75, F(12,134)=24,102 p<.0000. The analysis of tabular data helped determine that the cumulative value of Wilks' lambda (λ) is 0.118, which indicates a sufficiently strong separating power of the model, since the value of the indicator is closer to zero than to one. Notably, the level of discrimination will improve if λ is closer to 0. The review of the indicators presented in Table 2 and the statistical characteristics of these indicators showed that the presence of the variable X_4 "increase in the production of organic products" in the discrimination procedure has the greatest impact on the discriminating power of the model (has the smallest value of partial lambda = 0.112 among all the factors analysed, which shows the unit contribution of the factor to the separating power of the model). Apart from X_4, variables X_3 (product strategy – increase, reduction, replacement or long-term cultivation of selected types of organic plants), X_1 (diversification of activity – number of species certified as organic plants grown by one producer), X_6 (change in activity efficiency) contribute to general discrimination. Using these variables, it is possible to divide new enterprises into groups and determine the most successful strategy for each group. During discrimination, two indicators were discarded, since the level of statistical significance of factor exclusion from the p-level analysis exceeds 0.05 (Table 3).

Table 3. *Factors that were discarded as a result of the analysis*							
Seq. No.	**N=75**	**Wilks' Lambda**	**Partial Lambda**	**F-criterion (2.51)**	**p-level**	**Toler.**	**1-Toler.(R-Sqr.)**
1	X_5	0.104699	0.915955	3.07386	0.052818	0.352064	0.647936
2	X_2	0.104163	0.920672	2.88646	0.062736	0.858213	0.141787

Source: *calculated by the authors*

To estimate how accurately four factors were selected for dividing different enterprises into separate populations, 2 discriminant functions were calculated. The number of functions is selected according to the rule of the number of variables (75) or the number of aggregates (3) minus one, depending on which of the numbers is smaller.

Table 4 shows which of the roots are statistically significant by consistently applying the significance criterion.

Table 4. *Results of canonical analysis with stepwise criterion for canonical roots*						
Removed roots	**Chi-square is a criterion for the sequence of removing roots**	**Canonical correlation r**	**Wilks' Lambda**	**Chi-square**	**Number of degrees of freedom**	**Significance level (P)**
0	3.393191	0.878849	0.095900	162.9393	12	0.000000
1	1.373569	0.760719	0.421306	60.0754	5	0.000000

Source: *calculated by the authors*

According to Table 4, it can be argued that one or more roots are statistically significant, since the probability obtained in the first row of the table (before excluding canonical roots) is lower than the generally accepted criterion of statistical significance (0.001-0.05). The same situation is observed after the removal of the first root – the significance level p is many times lower than generally accepted criteria, and therefore we can conclude that both roots are statistically significant and can be used to divide organic production enterprises into groups based on the potential for future development as a basis of the future strategy.

Comparing the two functions with other meters, we see that for the first one, the canonical correlation coefficient is 0.8789. This value is close to unity, which is the maximum value, which means that when using the first function, 87.89% of the variance of the dependent variable is explained by the proposed model, and the second function explains only 7.607%. According to the Wilks' lambda metric, it can be concluded that the first function has a higher resolution, and therefore will be able to more accurately classify new enterprises into one of the groups (leaders, conservatives, unstable enterprises). Individual equations intended for the classification of enterprises are presented in Table 5.

Table 5. *Classification functions for different groups of organic production enterprises*

Variable	G_1:1	G_2:2	G_3:3
X_4	0.68791	-7.8781	0.91410
X_3	1.84499	-0.5061	-1.45006
X_1	1.25661	-1.7060	-0.73007
X_6	0.64416	-2.3878	-0.08795
Constant	-2.19780	-15.1871	-1.29520

Source: *calculated by the authors*

Figure 6 presents the distribution of enterprises by group. It can be seen that the enterprises of the 2nd group are clearly distinguished from the enterprises included in the 1st and 3rd groups, while the aggregates of enterprises of the 1st and 3rd groups may overlap. This is quite logical, since it is often difficult to distinguish between enterprises that will have high growth rates in the future and enterprises that expect a moderate rate of development. Perhaps, to improve the separation ability, it is advisable to search for additional parameters or estimated indicators. However, the resulting equations have sufficient discrimination capabilities and can be applied in practice.

As a result, the equations for each of the groups are obtained as follows:

Group 1 (leadership, success, development)

$$y_1 = 0.6879 \cdot x_4 + 1.845 \cdot x_3 + 1.257 \cdot x_1 + 0.644 \cdot x_6 - 2.198 \quad (3)$$

Group 2 (reduction of activity)

$$y_2 = -7.878 \cdot x_4 - 0.5061 \cdot x_3 - 1.706 \cdot x_1 - 2.388 \cdot x_6 - 15.187 \quad (4)$$

Group 3 (conservative policy, moderate development)

$$y_1 = 0.9141 \cdot x_4 - 1.45 \cdot x_3 - 0.73 \cdot x_1 - 0.088 \cdot x_6 - 1.295 \quad (5)$$

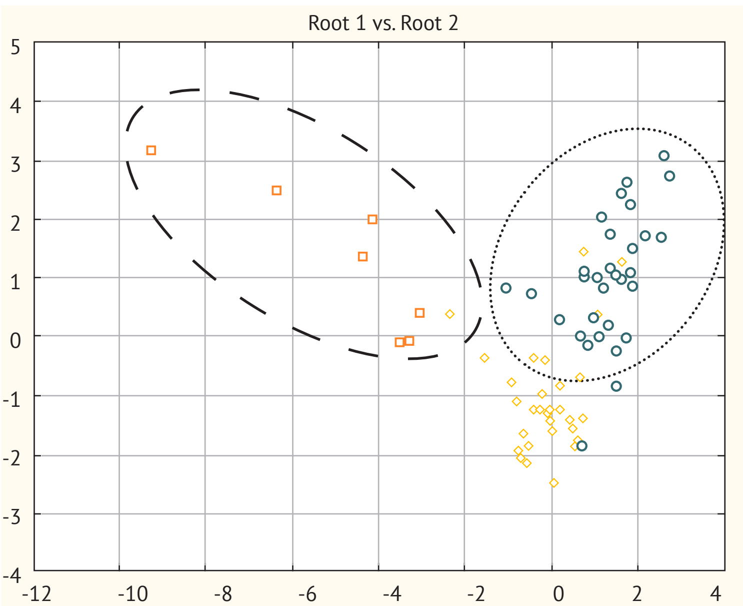

Figure 6. *Scatter diagram of canonical values for organic production enterprises of groups 1-3*

Source: *calculated by the authors*

Using the created equations, it will be possible to classify new cases in the future. The enterprise will be assigned to that group, according to the equation of which the obtained value will have the maximum indicator. To check the accuracy of the created functions, we will use the classification matrix. The data in Table 6 indicate that the variables for constructing the functions were chosen successfully, and the results have a sufficient level of adequacy.

Table 6. *Classification matrix*

	Percent	G_1:1	G_2:2	G_3:3
G_1:1	83.8710	26	0	5
G_2:2	100.0000	0	7	0
G_3:3	91.8919	3	0	34
Total	89.3333	29	7	39

Source: *calculated by the authors*

From the matrix, we can conclude that among the enterprises of the 2nd group, 100% are assigned to the group correctly. This means that those businesses that are not functioning well enough and have insufficient efficiency can be easily identified using the proposed features. As for the enterprises of the third and first groups, the classification functions showed themselves quite well when grouping them (83.87% of the enterprises that are developing well and working efficiently were correctly classified, and among the enterprises that showed a moderate trend towards the development of organic production, there were 91.89% of correctly classified cases). These data are visually confirmed in Figures 3, 5, which clearly shows that the enterprises of the second group are at some distance from the enterprises of the first and third groups, which made it quite easy to classify the second group. While the set of points that mark the enterprises of the first and third groups, although they do not completely overlap, they are quite close, which makes classification difficult. The equations have sufficient accuracy, so they can be used to classify new cases, namely, to identify enterprises that can potentially achieve prominent growth rates, or, conversely, those that are likely to reduce their activities.

Organic production is developing at an active pace all over the world, it can help in solving many issues, including food transformation, ensuring sustainable development of territories and preserving the Earth. The motives of consumers for buying organic products in the world are quite different, it is concern for their health, to be in the trend of the movement for a healthy lifestyle, reasonable consumption, care for the environment and restoration of the Earth's resources. The study (Tandon *et al.*, 2021) is based on the determination of favourable and inhibitory intentions to purchase organic products, in which three different theories were used to investigate the behaviour of consumers of organic products. It is established that the consciousness of buyers is associated with facilitators and inhibitors, which may mean that conscious consumers will choose organic products, since they understand that the choice of organic products will benefit not only for their own health, but also for nature. The next step is environmental well-being, which also has a positive impact on the purchase of organic products. An interesting factor that can affect purchasing power is the gender factor, which is manifested in the fact that housewives are more inclined to buy organic products, since they are aware of the usefulness of such products for their health and the health of their family. This study is quite significant for scientists because it determines the main areas in the work of the policy of advertising and distribution of organic products.

Based on the research materials, according to the EFA model, four key factors that can positively influence the level of consumption of organic products were determined, namely the naturalness of food products, their quality, trust in the producer and marketing. The developed model will allow manufacturers to develop a specific strategy to increase market share and profitability of the enterprise by satisfying consumers (Sobhanifard, 2018).

Somewhat different research results regarding the factors affecting organic production were obtained in (Hou *et al.*, 2022). They suggest identifying such factors as macroeconomic, demographic, political, and agricultural production factors. The macroeconomic factor affects organic production directly through average household income and average per capita income, i.e., the higher the average household income, the higher the development of organic production in a certain area. The political factor affects through the provision of national support to organic producers, non-monetary and monetary assets that can be provided by the state, which can affect organic production directly and indirectly. The next factors are demographic factors, the scientists single out such factors as the percentage of Hispanics, whites, the percentage of non-citizens, the total population, the number of male farmers and their average age. Equally important is the factor of agricultural production, i.e., the size and number of farms, the number of labour resources. Notably, the size of the farm does not always affect the amount of organic goods produced, since productivity is more important.

Of great importance for the development of organic production are programs aimed at the regional development of the industry. By studying the practices of European countries, scientists (Ihnatenko & Novak, 2018) managed to identify the main areas of national support, ways of their implementation and ways of improving them. They also allocated resources that can influence the development of organic production in the future. The program of implementation of national support for organic production at the regional level proposed by scientists can be proposed for implementation at organic enterprises, in rural communities, and in government bodies. Such national programs for the development of organic production are very relevant, since they are based on strengthening regional, informational and advisory components and are aimed at preserving and restoring resources and will be able to implement employment of the rural population.

The search for ways to develop organic agriculture, specifically, the determination of the best development strategies for producers, is relevant. Thus, the study (Aghasafari *et al.*, 2020) determined the strategies for the development of organic agriculture in Iran based on SWOT analysis data. The study revealed 9 possible strategies for the development of organic agriculture, and scientists singled out the three most successful strategies: the first is the development of a program that would inform consumers about the benefits of organic products, the second is the creation of a competitive market for organic products, while the third is the implementation of organic education and teaching the basic principles of organic farming.

The development of the market for organic products and the interest in organic products on the European market of the Ukrainian producer prove that Ukraine has all the prerequisites for entering the world market and meeting the needs of growing consumer demand for environmentally friendly products around the world (Bogomolova *et al.*, 2021). The competitive environment of the market of organic products is one of the areas of research of scientists, since the determination of methods of ensuring competitiveness, specifically, the determination of the competitive advantages of organic products will help develop organic production in the correct vector. That is why it is advisable to research and develop strategies for the competitiveness of producers of organic products.

Mechanisms for ensuring the competitiveness of the domestic organic agricultural sector should be considered using evidence from the countries of the European Union, since Ukraine, entering the world economic arena, must consider the specifics of the European organic market. Therefore, the study (Hranovska, 2017) is quite informative, specifically, the proposed mechanism for stimulating organic production by agricultural enterprises and enterprises producing organic products is important. The basis of the mechanism includes tools for stimulating organic production, which are divided into four groups: subsidy (tax concessions, loan concessions, certain compensations and subsidies); infrastructure (development of rural areas, development of laboratories, marketing research); informational; and legal.

In the study (Bilotkach, 2022), great importance for the formation of a competitive strategy of organic production is given to the institutional component, which makes provision for the introduction of certain changes to the legislative acts governing the production and circulation of organic products of Ukraine. The main areas of national support should be as follows: allocation of subsidies from the state budget for producers of agricultural organic products; reimbursement to producers of part of the cost of seeds and certification costs. Such steps, according to the scientist, can not only strengthen the internal market of organic products, but also increase the competitiveness of Ukrainian organic products on international markets. The results of this study prove that the main strategies for the development of organic producers are three areas: the strategy of re-profiling or expanding activities, diversification of production, increasing the volume of organic production and increasing the number of certified land.

CONCLUSIONS

Analysis of the activities of producers of organic products of Ukraine by dividing them into groups, depending on numerous factors, allows attracting additional tools for the formation of a competitive strategy of an organic agricultural enterprise. The factors that led to the division of enterprises into groups were diversification of production, turnover of crops, expansion or reduction of certain types of production, changes in the volume of organic products, changes in the area of organic soil, and changes in production efficiency. Using the Ward's method, it was possible to visually identify the division of enterprises into three groups, resulting in three clusters, respectively. The first cluster includes enterprises that characterize the highest value from the parallel used in the evaluation. The second cluster includes enterprises characterized by increased efficiency of enterprises. Enterprises included in the third cluster are characterized by a moderate strategy, while they do not dramatically increase either the number of organically certified lands or the number of products.

The paper suggests a strategy for the competitiveness of organic products, considering the factors of the company's own activity. The proposed classification and the created system of equations can serve as a basis for developing strategies to ensure the competitiveness of organic production enterprises.

A potential area for enterprises of the first and third groups is to ensure competitive advantages through differentiation, product expansion by varieties, types, assortment, which, unlike other markets of agricultural products that are focused mainly on the strategy of reducing costs, should become the basis of progressive development for enterprises that operate specifically on the markets of organic products. Such a strategy is quite logical, since organic products by their very nature should stand out from other similar products on the market due to higher quality, compliance with the principles of sustainable development and green economy, healthy lifestyle, environmental friendliness and satisfaction of consumer needs for healthy food. The strategy of development of the unique value of the product is recommended to be used by producers who are focused on the retail market of EU countries.

Prospects for further research are the search for new success factors of the strategy of organic production enterprises, the creation of new discrimination equations based on them, as well as the development of a number of economic and mathematical models for enterprises of different sizes, types of activity, and regional affiliation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Формування конкурентної стратегії підприємства з органічного виробництва на основі дискримінантного аналізу

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Анотація. У статті запропоновано додатковий інструментарій, який дозволить обґрунтовувати формування стратегії майбутнього розвитку з урахуванням потенційного зростання або скорочення діяльності, що є актуальним для виробників органічної продукції, оскільки врахування потенційної траєкторії розвитку дасть можливість убезпечити підприємство від необґрунтованих рішень у разі скорочення діяльності і дозволить задіяти існуючі резерви у разі майбутнього зростання, що є актуальним і досить затребуваним. Метою роботи було довести чи спростувати гіпотезу про вплив на розвиток органічної продукції ряду чинників, а також визначення подальшої стратегії діяльності підприємства. Для цього проаналізовано дані 75 українських підприємств, що здійснювали вирощування органічної продукції. Розподіл підприємств на групи в залежності від обсягів та темпів зростання і виявлення чинників, що впливають на майбутній розвиток виробників органічної продукції здійснено за допомогою кластерного та дискримінантного аналізу. Чинниками, які суттєво впливають на майбутній розвиток та дозволили розподілити досліджувані підприємства на групи, стали диверсифікація виробництва, заміна культур, зміна обсягів виробництва органічної продукції, зміна ефективності виробництва. Тоді як чинники «відсоток нових (або виведених із виробництва або не сертифікованих) у новому році культур до загального обсягу виробництва минулого року» та «зміна площі органічного ґрунту» не показали достатнього впливу на розподільчу здатність моделі, та були виключені з подальшого аналізу. Запропоновано формувати стратегію підприємств-виробників органічної продукції на основі диференційованого підходу для трьох різних груп підприємств, а саме: тих, що потенційно мають високий потенціал, швидкість розвитку і розширення діяльності; тих, що потенційно чекає скорочення та зменшення випуску органічної продукції; тих, які розвиваються помірними темпами. Отримані рівняння можна використовувати у практичній діяльності для додаткового обґрунтування стратегії розвитку виробників органічної продукції

Ключові слова: конкурентні переваги; сталий розвиток; конкурентоспроможність; чинники успіху; органічна продукція

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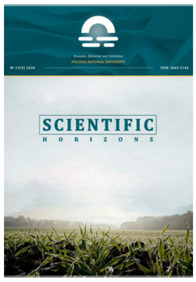

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The state of the agricultural sector in Ukraine during wartime: The case of farmers

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Abstract. The military aggression of russia against Ukraine has a significant negative impact on the agricultural sector of the economy, which is one of the key industries for Ukraine. Among the consequences of this aggression are a decrease in production levels, an increase in costs for security and infrastructure restoration, an increased risk of losing personnel and crops, as well as complications in the export of products. The purpose of this study is to assess the state of the agricultural sector under the conditions of war and to investigate the peculiarities of the activities and adaptation to war of individual agricultural producers, using farmers as an example. To achieve this goal, the dialectical method of cognition of economic processes, the basic principles of modern economic theory, and scientific works of domestic and foreign scientists studying the impact of war on the development of the agricultural sector of the economy were used. A sociological research method, in particular interviews, was used to achieve the research goal. The article examines the role of the agricultural sector in the Ukrainian economy and global food security, analyzes the impact of the war on the agricultural sector, and characterizes the current state of agricultural activity under the conditions of war using farmers as

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an example. According to the obtained data, the impact of war on the agricultural sector is significant and has various economic, social, and environmental consequences. The study shows that some commodity producers, using farmers as an example, have adapted to the war and have been able to maintain their market positions, while others have suffered significant losses and could not function properly. This research can be an important source of information for the development of state policy on support for agricultural commodity producers, specifically farmers, under the conditions of war and post-war recovery. It is necessary to consider the possibility of attracting investments in the agricultural sector, supporting farmers through a credit system, and cooperating between farmers

Keywords: agriculture; farms; war; food security; efficiency; global challenges; European integration

INTRODUCTION

The russian invasion of Ukraine on February 24, 2022 poses a significant threat to food security and the agricultural sector in Ukraine and around the world. The invasion has caused severe damage to the agricultural sector, disrupted supply chains of Ukrainian agricultural products, led to food shortages and increased prices. The current state of the agricultural sector, the impact of the war on it, and the adaptation of producers to wartime conditions can be vividly seen in the example of Ukrainian agricultural producers, specifically farmers.

The relevance of studying the current state of Ukraine's agricultural sector in wartime lies in its importance for Ukraine, as 17% of the population works in this sector, it generates 53% of foreign exchange earnings and accounts for 20% of GDP (Data from the Ministry of Agrarian Policy and Food of Ukraine, 2023). It is also important for balancing global food security, as Ukraine has the potential to provide food for over 1 billion people.

In a considerable number of studies, scientists have identified the consequences of war on the agricultural sector of Ukraine's economy, particularly on the production and export of agri-food products (Adekoya, 2022; Câmpeanu, 2022). Researchers (Skydan *et al.,* 2022) argue that the state of the agricultural sector in wartime is complex and requires state support for balanced functioning. Military actions and export restrictions have necessitated ensuring the stability of agriculture in Ukraine.

Fiott (2022) confirms that the deliberate destruction of agricultural infrastructure and the blocking of logistical routes for food exports by russia have become noticeable trends of the war. The analysis of russia's military aggression against Ukraine indicates significant damage to the agricultural sector, the recovery of which will require years and investments. According to data from the Center for Food and Land Use Research of the KSE Institute and the Ministry of Agrarian Policy and Food of Ukraine (2022), indirect losses in the agricultural sector because of russia's aggression amount to 34.25 billion US dollars, and direct losses – 6.6 billion dollars.

Mamonova (2023) emphasizes that the agricultural sector is actively adapting to the conditions of military operations, especially in the context of small farms, which have managed to adapt to the new management realities. Scientists highlights the need to analyze farmers' adaptation to war, their activities during this period, and development prospects, particularly for small farmers who ensure economic, social, and environmental security in rural areas. In the conditions of military operations, it is essential to provide access to resources and funding for the development of small agricultural enterprises. This can include support from the state and international organizations, including through financial loans, training programs, and other support measures. Authors (Nykoluk, 2021; Vasylkovska, 2019) claim that it is necessary to develop a comprehensive strategy to support farmers in Ukraine, which would take into account current challenges and trends in the global agricultural sector, as well as contribute to the recovery and stabilization of the Ukrainian agrarian economy after military events.

Scientist (Béné, 2020) argues that the situation in the agricultural sector of the economy has changed due to global challenges, such as the COVID-19 pandemic and russian aggression against Ukraine, which have affected international logistics chains. The COVID-19 pandemic slowed down international logistics and demonstrated the advantages of small producers focused on the domestic market and less dependent on external shocks (Gutierrez, 2022). Borodina (2022) emphasizes the need to support farming households, which are the basis for rural development.

At the moment, it is essential to assess the state of development of the agrarian sector of the economy in the conditions of war and to investigate specific aspects of farmers' adaptation to modern global challenges, the key of which is russian aggression against Ukraine, in order to develop further proposals for the post-war reconstruction of the agrarian sector of the Ukrainian economy and to identify management forms and production structures of agricultural products that should be prioritized in post-war Ukraine, taking into account socio-economic and environmental criteria.

The purpose of this study is to assess the current state of the agrarian sector of the economy in the conditions of war on the example of farmers, to explore the specific features of organizing agricultural activities in wartime conditions, and the specifics of farmers' adaptation to new challenges.

MATERIALS AND METHODS

This study used data obtained from Ukrainian statistical sources (State statistics of Ukraine, 2021, Agricultural export portfolio of Ukraine, 2023), including indicators of land cultivation ease, agricultural and animal husbandry production efficiency, as well as information on farms and agricultural holdings. The study compared data from different commodity producers to analyze sown areas of agricultural crops and the number of farm animals for the period spanning from 2000 to 2021. By using these data sources, the study was able to gain insights into the relative performance of different agricultural producers, as well as identify trends and changes in production efficiency over the years studied. This study is based on both data of Ukrainian statistics and primary qualitative interview data collected in Ukraine from October-November 2022.

The interview data were collected in the context of the completion of the harvest and a partial summary of the results of the 2022 agricultural year, in preparation for 2023. The purpose of the interviews was to gather information from farmers who have directly or indirectly suffered from russian aggression and to determine the features of adaptation of farmers to production activities in the conditions of war. When conducting the research, ethical and methodological guidelines for conducting "remote research" in conflict conditions were used. A total of 15 semi-structured in-depth interviews (approximately one hour each) were conducted with farmers ("Kavetskoho", "Yuran M", "Veselivske", "Agrotorg", "Vladar" "Polish Geese" and others).

Selection of individuals for in-depth interviews involved defining the research question, determining the sample size, identifying the target population, developing a sampling strategy, screening potential participants, and recruiting and scheduling participants. The sample size was based on the research question and available resources. The target population was selected based on the research question, and a sampling strategy was developed based on the characteristics of the target population. Potential participants were screened based on selection criteria, and the recruitment process was transparent. Overall, a systematic approach was used to ensure a representative sample that provided valuable insights into the research question. Authors used these steps in our research to select participants for in-depth interviews. These interviews were supplemented by numerous chats, calls, and e-mails with representatives of agrarian businesses and agrarian economists.

The interview was administered to farm managers who were actively involved in livestock and crop production in the Korosten district of Zhytomyr region, despite the ongoing war.

The selection of respondents for the conversation was carried out by the "snowball" method (each subsequent person informs the researchers with whom among his acquaintances he can talk on the same topic) with elements of the "maximum variation" method (respondents are selected in such a way that each case, if possible, differed as much as possible from the previous one). As such the results of such a study cannot be considered as representative of the farming population in the region. Instead, the purpose was to understand the general context of the phenomenon and trace the diversity of events and people's views. This method is most suitable for recording the subjective individual experience of socio-historical processes and events that have occurred. The field stage of the work was carried out ten months after the beginning of the russian aggression, in the conditions of the continued hostilities on the territory of Ukraine. Before each interview, the respondent's consent was obtained verbally.

Authors used an in-depth interview method. The semi-structured in-depth interview method was guided by a small set of questions and a general conversation plan. The sequence of questions and their wording were not fixed and could change for each subsequent respondent in accordance with the course of the conversation and the course of the respondent's thoughts, to which the interviewer adapted.

During the course of the scientific research, which included surveys of farmers, the focus was on the following aspects: activity of agrarians in the first days of the war, conducting the sowing campaign in conditions of military conflict, compliance with technological standards of production, storage of agricultural products, formation of farmers' cooperatives, functioning of dairy farms, analysis of price disparity, the problem of providing labor resources, and changes in the structure of sown areas.

RESULTS AND DISCUSSION

The impact of the war on the agricultural sector and global food security. The agricultural sector of the economy has always played one of the most important roles in Ukraine. Before the full-scale invasion of russia, for many years, Ukrainian agricultural producers held leading positions in the world among product exporters. Today, the damage caused to the agricultural sector of Ukraine as a result of active hostilities is estimated at billions of dollars, and it will take several years and significant investments to restore the agricultural infrastructure. It will take tens of years to overcome environmental consequences and demining the territory.

The invasion of russian invaders into the territory of Ukraine caused the destruction of well-established agricultural processes and logistics chains. Many cultivated areas are now mined or unusable due to the consequences of massive bombings, there is no access to part of the land, and the enemy is deliberately destroying warehouses and agricultural machinery. All these factors will fully influence the development of the agricultural complex in the near future.

In connection with the fact that the agricultural sector has been among the front-runners of advanced news for the past five to seven years, at the beginning of hostilities, most experts mistakenly believed that farmers would suffer little from the criminal actions of the invaders. However, very quickly, already in March 2022, it became clear that this was a false assessment. When exports from Ukraine by sea stopped, it became clear that there are huge volumes of grain that cannot be exported and sold. This problem was eliminated by opening the sea corridor. However, farmers currently have several related problems, such as mined fields, disrupted logistics, high prices for diesel fuel, etc. (According to the Ministry of Agrarian Policy and Food of Ukraine, 2023).

The complexity of these processes lies in the impossibility of planning because there is no understanding of how many areas will be sown and in what amounts. But already today, having some data on the amount of grain sown, authors can say that it is extremely insignificant compared to last year's indicators. In addition, the situation with the weather conditions is disappointing. All this collectively allows us to draw conclusions that the situation that has developed in the agricultural sector is quite difficult both for the internal social and economic security of Ukraine and for the global food market. The grain agreement signed in July in Istanbul by representatives of Ukraine, russia, Turkey, and the UN has become a lifeline for Ukrainian farmers. However, not all problems of the agricultural sector could be solved by exporting the grain blocked by the occupiers.

The russian invasion of Ukraine shocked the world, causing terrible suffering and destruction, and the dire consequences are already being felt beyond the conflict zone. The war disrupted global food security, causing food prices for consumers and fertilizer prices for producers to skyrocket. It is already clear that this crisis requires immediate global action to provide relief in the short term, as well as policy changes to diversify global food markets in the long term to increase resilience and avoid future crises.

According to FAO (2023) estimates, if the export of wheat, fertilizers, and other goods from Ukraine and russia is stopped for a long time, the number of malnourished people worldwide may increase from 8 to 13 million in 2023. Food insecurity is most pronounced in the Asia-Pacific region, followed by sub-Saharan Africa and the Middle East. Commodity food prices have been rising steadily even before russia's invasion of Ukraine, according to the FAO's food price index, which reached a record high back in early February. Grain and vegetable oil prices reach levels exceeding the global food price crisis of 2008-2009.

Russia's invasion of Ukraine has slowed, and in some cases stopped, the production and trade of russian and Ukrainian grain and vegetable oils, which account for a significant share of the global market – for example, about 30% of global wheat and barley exports. Fertilizer exports from russia and Belarus, which together account for the main share of world production, have also been suspended.

Examining the price dynamics of key agricultural crops, specifically corn, soy, and wheat, from 2019 through mid-2020, a stabilization of prices for these commodities is observed. Minimal price variability was observed, indicating the absence of significant influencing factors on the price or the effectiveness of the market regulatory mechanism. The transformation of price dynamics began in late 2020. Notable price fluctuations, especially their growth, could be triggered by several factors. Primarily, these could have been factors related to the COVID-19 pandemic, which affected global agriculture and logistics. Another significant factor could have been unfavorable weather conditions, which negatively affect crop yields. The price peak was reached in mid-2021, which could indicate an increase in demand for these products on a global level or problems with supplies (Fig. 1). In 2022, prices for the main agricultural crops continued to be at a prominent level.

Prices for most grain and oil crops have risen sharply since the beginning of the war. This is because russia and Ukraine together supply about 12% of the world's export of agricultural products in caloric terms and more than 30% of the world's export of wheat (Gafarov, 2022). The two countries hold significant shares in the wheat-dependent economies of the Middle East and North Africa, where wheat prices have risen by more than 30% from pre-war levels. Fertilizer and energy markets also saw price increases and supply disruptions.

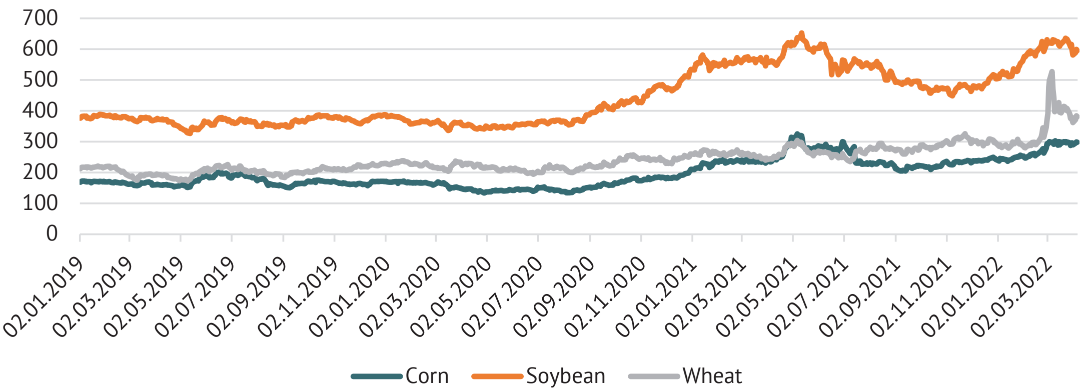

Figure 1. *Food prices in US dollars. per metric ton, 2022*

Source: *IFPRI*

The National Bank forecasts a decrease in the production of cereals and legumes in 2023 by 15.2% to 45.6 million tons compared to 53.8 million tons in 2022. Prices in global markets will show a decline. According to the regulator's data, grain production in 2022 decreased by 40%, although these figures are mainly due to a significant reduction in harvested areas due to the occupation and mining of some territories, as well as in the context of record harvests in the previous year.

At the same time, thanks to the partial reorientation of spring crops in favor of rapeseed and soybeans (which replaced part of the corn), their production even exceeded last year's indicators. The production results of oilseeds turned out to be better than expected. Prices for wheat in global markets in 2023 will decrease by 13.9% to $310.3 per ton, for corn – by 18.4% to $259.9 per ton. Notably, as a result of military operations or due to the temporary occupation of territories, farmers do not have access to 25% of the sown area. Global food prices have been declining for the tenth consecutive month. The FAO Food Price Index in January 2023 stood at 131.2 points, which is 0.8% less than in December and 17.9% lower than its peak reached in March 2022 (Data from National Bank forecasts, 2023).

The war in Ukraine affects not only food security, but also has economic consequences for all countries. Today, it is a question of environmental security and a common future. Russia's war in Ukraine is the first international conflict in the last 20 years with such significant and irreparable damage to the environment. Authors can already account for more than 250 cases of ecocide. These are also detonations of fuel and lubricant warehouses, and oil product storages with corresponding consequences for the environment. (Data from the Ministry of Environmental Protection and Natural Resources of Ukraine).

Military actions destroy the forests of Ukraine, which will also affect the world's food security as forests perform protective functions. Their destruction and damage will affect the climate of these regions and may lead to significant erosion processes. In the south of Ukraine, the consequences may result in wind erosion and desertification. This, of course, will affect agriculture and agricultural producers.

Researchers are convinced that the longer the war lasts, the greater and more persistent its negative consequences will be for global food security. At the same time, there is currently little research that, using the example of a specific type of commodity producer, such as farmers, explores the current state of the war and the adaptation of agrarians to modern challenges.

Today, many farmers find it difficult to purchase fuel, which has become more expensive since the beginning of the war. If we talk about spring field work, then the situation is critical. Today, issues of logistics and technology development are acute, because we are entering a completely new level of competition with our partners. It makes sense in this period to rethink the agrarian and economic policy of the state with the aim of maximum adaptation of domestic commodity producers to modern global challenges, the key of which is russian aggression.

Farmers' interviews. Conducting interviews with farmers from the Korosten district of Zhytomyr region allowed for a more detailed understanding of the current state of agriculture, evaluating farmers' adaptation strategies to the current realities of the industry, identifying key challenges, and determining potential paths for development in the context of post-conflict recovery of the Ukrainian agrarian economy. The obtained results were systematized in several directions: the beginning of military operations, the sowing campaign, production strategies, storage of products, cooperation, problems of dairy farms, price disparity, etc.

Farmers who were interviewed recall the uncertainty and insecurity in the first days of the war when it was unclear whether to prepare for sowing and whether the threat of occupation of their lands was real. On the third week after the start of military operations, most farmers who were on the territory controlled by Ukraine resumed work and started sowing but faced several difficulties with logistics and the possibility of timely organization of the sowing campaign. As a result, only 70% of the planned volume of work was completed, technological operations were not fully performed, and the cost of resources increased 2-3 times.

Farmers took various measures to ensure production under conditions of resource shortages, such as sowing without prior processing, using alternative sources of seed material, and cooperation. Some equipment (tractors) was handed over by farmers to the Armed Forces for the construction of military facilities, resulting in a shortage of agricultural machinery.

Significant difficulties arose in connection with the storage of agricultural products. The products are stored in warehouses that were previously used by collective farms. In doing so, the method of storage on the floor without the use of dryers was applied. Even though grain is best stored in elevators, this opportunity was absent. This problem was widespread among farmers in the region. Buyers refused to visit the Korosten district due to its proximity to Belarus, which led to lower prices for products compared to the all-Ukrainian indicators.

Small dairy farms faced a lack of a sales market for their products during the first two months of the war, leading to a loss of income and exhaustion of financial resources. Farmers had to process milk into cheese, but sales of this product also proved difficult. The availability of funds for the spring sowing and harvesting period was limited. The main challenges were and remain the preservation of animal populations and providing them with feed. The restoration of land for agricultural needs is also complicated due to the mining of territories.

Farmers are concerned about the significant decrease in prices for agricultural products (by 30-40%), while the costs of fertilizers, fuel, and plant protection products, which are mainly imported, have increased. As a result, an imbalance has arisen between the value of products and the cost of their production. The increase in product prices does not solve the problem, as the purchasing power of the population still is low. Small farms, dependent on the earned funds, are particularly sensitive to this issue, unlike large agricultural holdings, which have certain internal reserves.

Farmers noted that during the year of war, the structure of agricultural crops underwent minor changes in favor of technical crops that are subject to processing in the domestic market, such as soybeans and sunflowers. This year there will be a decrease in the area sown with wheat but an increase in peas and buckwheat. Production of cereals and legumes may be reduced, as well as the likely decrease in the production of wheat, barley, and corn. The main reason is the complication of exports. Currently, exports have been partially restored, but numerous problems exist, including more expensive logistics.

Farmers face problems in providing workers. For family farms, the situation is ambiguous, as most of them do not have legal status, independently cultivate their land, and as a result, have no legal basis for reserving their workers. Moreover, a considerable number of farm managers are now serving in the Armed Forces. Therefore, the question of the future of agriculture becomes extremely relevant, as for most farms it depends on one person.

Farmers pointed out that in the situation of war, survival is only possible due to state support, but state resources are limited. Cooperatives have proven to be the answer to the needs of small farmers. The 2022 planting season highlighted the complexity of independent management in difficult conditions, characterized by constant threats and uncertainty. To ensure a successful harvest, farmers need to implement new technologies, adhere to crop rotation, and increase the amount of fertilizers. This is only possible with the availability of appropriate resources. The war has intensified the need for farmers to unite and consolidate their resources.

Respondents noted that one of the key advantages of small farmers is their flexibility and rapid adaptation to challenges. While large agricultural enterprises (agroholdings) were forced to partially suspend operations in the area, small farmers continued their activities. Most stayed and tried to work, adapting to the difficult conditions. However, there are numerous problems, especially for farmers working in frontline areas. In some cases, the harvest was left in the field, and there are also areas with landmine warnings. As a result, the harvest was not collected in such places. Moreover, there is a threat from the Belarusian border, as a result of which a significant part of the land is mined or cannot be used due to potential dangers of attacks from Belarus.

Despite limited financial potential, farmers have demonstrated high activity since the beginning of the military conflict, providing significant assistance to military personnel and internally displaced persons. They provide support in the form of food products, including vegetables, purchasing vehicles, and actively cooperating with volunteers and charitable organizations. Small farms are still the axis of economic and social activity in rural areas, surviving through their own efforts and supporting the livelihood of the village. However, their resource potential has its limits. Most resources are already close to exhaustion.

Systematized results of interviews with farmers are presented in Table 1.

Table 1. *Results of farmers' interviews*

Activity during the first days of the war (all 15 farmer respondents remained in their area)
• no one could predict how the events would unfold. • the farmers didn't know if the Russian troops would march here. • the farmers decided not to remain under occupation. • the move was difficult as they had to leave behind everything that had been earned over decades. • everything was unfolding very quickly, and there was occasional panic.
Sowing campaign under wartime conditions (only 6 out of 15 respondents were able to fully carry out the sowing campaign)
• three weeks after the war, the farmers began preparing for the planting season; • 60-70% of the planned volumes of work for the planting campaign have been completed; • prices for fuel, fertilizers, chemicals, and seeds have doubled or even tripled; • the biggest problem for farmers was logistics; • there remains a significant amount of land that is either already mined or potentially unusable due to the possible threat of invasion from Belarus.
Compliance with production technology (12 surveyed respondents noted that they saved on production technologies)
• farmers economized and minimized all technological operations;

Table 1, Continued

Compliance with production technology (12 surveyed respondents noted that they saved on production technologies)
• some of the farming equipment was handed over to the armed forces for the construction of checkpoints and defensive platforms on the roads; • farmers did not fully adhere to technological operations, they applied less fertilizer and were behind the planting campaign schedule; • the biggest problem for farmers is working capital, they have spent all their savings.
Storage of agricultural products (7 respondents had problems with storing products)
• farmers are having significant problems with product storage; • farmers store products in warehouses where a collective farm used to be; • farmers use floor storage without installed dryers, products spoil, but there is no other option; • it is understood that grain is better stored in elevators, but such possibilities are not available now; • buyers do not want to travel to the korosten district for grain due to its proximity to the belarusian border.
Creating a farmer's cooperative (4 respondents mentioned uniting for the sowing campaign)
• it's hard to survive in wartime conditions alone, especially to continue working on the farm; • the war has further exacerbated the need for farmers to unite; • for a good harvest, a modern farmer needs to: implement new technologies; adhere to crop rotation; increase the amount of fertilizers. All of this can only be realized with the availability of the appropriate resources; • certain field work was carried out by farmers using a single tractor, taking turns with neighboring farmers.
Dairy farm activities (4 farmers who produced milk lost the ability to sell their products for two months)
• farmers had nowhere to sell their produce. Dairy factories stopped, logistics stopped; • farmers tried to process products, to make cheese. But there were difficulties with logistics; • farmers were giving out milk, cream, and cheese to local people; • the main question for farmers in times of war – how to save the animals; • the problem of farmers – the issue of providing feed for the animals.
Price disparity (all 15 surveyed farmers confirmed the problem of price disparity)
• the key problem for farmers, as for everyone else, is that the price of agricultural products has effectively decreased by 30-40%; • prices for plant protection means, mineral fertilizers, seeds, and fuel have increased; • there was a period when farmers physically could not purchase fuel at any price; • currently, farmers also need to increase the cost of the goods they sell, but who will buy them when people still have no money.
The problem with labor resources (6 surveyed farmers had problems with workers in wartime conditions)
• large agricultural enterprises managed to "reserve" machine operators; • farmers are having problems with workers; • sometimes for a farmer, the loss of a single worker means the cessation of the farm's operation; • a significant number of farm managers are currently defending the country as part of the Armed Forces, the activity of the farms is suspended; • many machine operators from the farms have voluntarily joined the Armed Forces.
Change in the structure of sown areas (9 of the surveyed farmers changed the structure of sown areas)
• due to the proximity of the border and the mining of a significant territory, the sowing area has decreased; • the volumes of technical crops cultivation, which are processed on the domestic market, have increased. These are soy and sunflower; • farmers sowed less wheat and more peas and buckwheat; • the production of wheat, barley, and corn will decrease.

Source: *conducted interviews with local farmers*

Despite the enormous difficulties and danger to life, the farmers have managed to cultivate their land and then harvest. Admittedly, the harvest was different from last year. They work themselves and give work to many people in the village. Farmers had many problems. Most of them did not have fuel (small owners did not have a license to store fuel in reserve, and what they had was donated to the needs of the Ukrainian army), so they used cart transport and manual labor. Small farmers began to cooperate, they shared seeds and equipment and replaced chemical fertilizers with organic ones. Given that they have small areas of agricultural land, they were able to adapt to the market, namely the domestic market, producing, for example, buckwheat instead of corn.

Farmers began to unite. On the initiative of agricultural producers in Ukraine, the public union "Agroproducers of Occupied Territories" was created, one of the main tasks of which is to speed up work on demining agricultural lands. Today, 130,000 km^2 are mined or damaged and the part of the production areas in the agricultural sector are lost. Currently, it is needed to find funding for demining the territories that were under occupation.

Ten months of war showed that smaller holders could better adapt and survive in extreme conditions by relying on short food chains, alternative resources of production, mutual aid, and reciprocity. If there was still proper support from the state, they would be able to be quite competitive. War and uncertainty drove people back to the land. It is a resource that can feed. The advantages and problems of farmers' activities in wartime conditions highlighted in the research are presented in Table 2.

Table 2. *Benefits and issues with farmers during wartime*

Benefits	Issues
• flexibility and quick adaptation to challenges; • if large farms and agricultural holdings partially stopped working in the district, small farmers did not; • farmers work on their land and this is their only income; • now the advantage of the farmer is to be physically present on his land; • farmers also focus on the domestic market. They ensure the food security of a specific area and support the Armed Forces	• mining of large areas, including agricultural land; • proximity to the border with Belarus, constant danger of attack; • problems with logistics and sale of agricultural products; • significant problems with working capital; • lack of workers, especially machine operators; • lack of opportunity to harvest (a significant portion of the corn crop remained in the fields)

Source: *conducted interviews with local farmers*

Preparations for the 2023 planting year continue in conditions of low financial capital for farmers. Prices in the middle of the country for agricultural products are below the market, while other services have become more expensive, in particular, supply chains sometimes take up to 80% of the value of exported products. Agribusiness also operates against the background of problems with energy carriers.

The war forced farmers to adapt to modern realities, change the structure of cultivated areas, and reorient to new logistics routes and new product sales markets. Before the war, most of the harvest was wheat, sunflower, and corn, as a significant part of it was intended for export. The blockade of ports showed the disadvantages of exporting a large volume of these goods, therefore the demand for niche high-margin crops (peas, berries, mustard, etc.) is growing, the transportation of which is more variable. There are reasons to believe that such trends will continue to develop in the coming years. In rural areas, the trend towards food self-sufficiency can be expanded by keeping birds and animals.

According to preliminary estimates by scientists, the potential damage caused only to the agricultural infrastructure in Ukraine is about 6 billion US dollars, but if we take into account the damage and loss of potential benefits associated with the disruption of work, disruption of supply chains, reduction of export opportunities, etc., then the losses reach about 22-23 billion US dollars according to various estimates (KSE Agrocenter, 2022). Although the exact value cannot be established due to the complexity of calculations and the continuation of hostilities.

Currently, it is necessary to review the state policy in the direction of greater support for farms, which have proven to be more adapted to modern global challenges and ensure the economic, social, and environmental sustainability of the rural areas where they carry out economic activities. Small and medium-sized farms have more opportunities to implement greener practices and support local communities and economies. In modern economic conditions, farmers face many risks and challenges. In the course of the conducted research, it was found that farmers face difficulties in privatizing land that is temporarily used, there are difficulties in developing rural infrastructure, insufficient state support for livestock development, they need an advisory system and scientific-innovative support. In wartime conditions, key issues became the necessity of surveying and demining fields and preferential lending for production activities. Based on an interview with farmers of the Zhytomyr region, directions for supporting farms in the conditions of the post-war reconstruction of the agrarian sector of the Ukrainian economy are outlined (Fig. 2).

Support for farms should be carried out at the expense of accelerating the privatization of land that is in temporary use, state support for the development of animal husbandry, reducing taxation, loaning the fund to farmers for the purchase of equipment, assistance in surveying and demining fields, scientific and innovative support for their activities and the introduction of innovations.

To minimize the negative consequences of russia's military invasion of Ukraine and to restore the agricultural sector of the Ukrainian economy after the war, it is necessary to introduce innovations and modernize agricultural production. In the long term, provided the war ends and Ukraine wins, the agricultural sector will need investments for recovery. If they include a modernization component, Ukraine will have a chance to reach a higher level of productivity and use new technologies in the production, storage, processing, and logistics of agricultural products with added value.

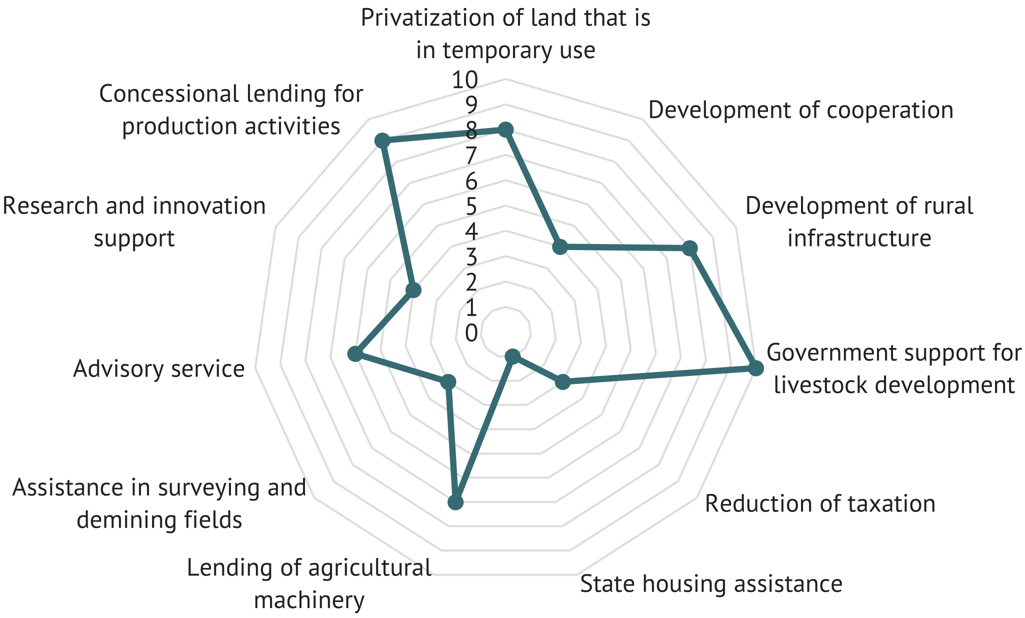

Figure 2. *Areas of support for farms in the conditions of the post-war reconstruction of the agrarian sector of the Ukrainian economy*

Source: *conducted interviews with local farmers*

There are currently debates among scientists regarding the further consequences of the war on the agricultural sector and the country's economy as a whole. M. Banse (2022) in his scientific works notes that the war will cause economic damage worldwide, leading to an asymmetric shock, the consequences of which must be dealt with over 15 years. G. Celi *et al.* (2022) consider the asymmetric impact of war: resilience, vulnerability, and implications for EU policy. Scientists equate russia's military invasion of Ukraine with the financial crisis of 2009 and the COVID-19 pandemic, as there is an increase in uncertainty, which negatively affects consumption and investment, and has a depressive effect on GDP and employment.

The agrarian sector in Ukraine is characterized by considerable complexity and multi-aspectuality, within which the efficient use of land resources and their potential plays a significant role. Research by L. Kurbatska *et al.* (2023) emphasizes many factors influencing this process, with which authors fully agree. However, a critical challenge that confronted Ukraine's agrarian sector in 2022-2023 was the invasion by russia, which caused targeted damage to this sector of the economy. The impact of this situation on the global context is also important to consider. According to A. Nimani and D. Spahija (2023) the invasion provoked an intense rise in prices on the global market, affecting the prices of food products, which surged rapidly. In their research, Y. Wang *et al.* (2023) also draw attention to significant fluctuations in agrarian markets following the onset of russia's invasion in Ukraine.

The topic of restoring Ukraine's economic potential in the post-war period and the role of different goods manufacturers in this process is in the focus of research by T. Borko *et al.* (2022). In this work, authors also focus on this aspect and emphasize the importance of further support specifically for farms.

Scientists V. Brown (2022) and co-authors highlight the significant potential of farms in the context of modern global challenges. This demonstrates the need for intensifying efforts to stimulate the development of farms and maintain their competitiveness at the global level. As evident from our findings, farms not only play a key role in the development of Ukraine's agrarian sector but also have a great potential to withstand modern challenges. Given this, their role and contribution to restoring Ukraine's economic potential in the post-war period cannot be underestimated.

It is important to provide adequate support for farms, as they are capable of making a significant contribution to the restoration and strengthening of the country's agrarian sector, stimulating rural development, improving food security, and affecting price stabilization on the global market. Strengthening farms in Ukraine will contribute to increasing productivity and stabilizing market fluctuations caused by political and military challenges.

CONCLUSIONS

The conducted research allows us to conclude that the war had a significant impact on the agricultural sector of the Ukrainian economy. At the regional scale authors found that the russian invasion of Ukraine has caused the destruction of well-established agricultural processes and logistics chains, including warehouses and agricultural machinery. Many cultivated areas are now mined or unusable from the bombings and there is no access to part of the land. Disrupted logistics have increased the prices for diesel fuel and other inputs. The harvesting period occurred late, and a much smaller area of grain was sown relative to the previous year.

The agricultural sector in Ukraine faces a challenging environment due to the impact of military actions and export restrictions. In this context, it is essential to achieve a balance between agricultural production, diversification, and the development of both large and small commodity producers to ensure sustainable growth. This balance must consider both foreign and domestic markets, as well as the environmental and social impact of agricultural activities. Achieving this balance will be crucial to ensuring the long-term success of the agricultural sector in Ukraine.

Among the farmers interviewed, authors found that the war has had a clear negative impact on their farm. The interviews conducted with farmers from the Zhytomyr region allowed an assessment of the state of agriculture and adaptation of farmers to the conditions of war. In the first days of the war, all 15 surveyed farmers continued their activities in place. However, only 6 of them were able to fully carry out the sowing campaign in the conditions of war. Most respondents (12) noted that they economized on production technologies. Storing products became a problem for 7 farmers. Four respondents joined a cooperative to carry out the sowing campaign. Four dairy farmers lost the ability to sell their products for two months. All surveyed farmers faced the problem of price disparity. Six of them pointed out issues with labor resources in wartime conditions. Nine farmers changed the structure of sown areas.

During the research, it was established that diverse agricultural production of farmers contributes to reducing the negative consequences of war, providing for self-consumption and ensuring food security in rural areas. Currently, supporting small farms is especially important for the socio-economic security of rural areas and creating conditions for internally displaced persons. To achieve this goal, the following measures are proposed: increasing state support for the development of animal husbandry, preferential lending for production activities, simplification of land privatization procedures, development of rural infrastructure, consulting services, and scientific and innovative support for farm enterprises. The mentioned changes will promote the modernization of small farming enterprises in the agricultural sector, allowing Ukrainian farmers to cope with the negative consequences of war, contemporary challenges, and continue to support food security more effectively at both the national and global levels.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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Стан аграрного сектору в Україні у воєнний час: приклад фермерів

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Анотація. Військова агресія росії проти України має значний негативний вплив на аграрний сектор економіки, який є однією з ключових галузей для України. Серед наслідків цієї агресії – зниження обсягів виробництва, збільшення витрат на безпеку та відновлення інфраструктури, зростання ризиків втрати персоналу та врожаю, а також ускладнення експорту продукції. Мета цього дослідження – оцінити стан аграрного сектору в умовах війни та дослідити особливості діяльності та адаптації до війни окремих агровиробників на прикладі фермерських господарств. Для досягнення поставленої мети використано діалектичний метод пізнання економічних процесів, основні положення сучасної економічної теорії, наукові праці вітчизняних і зарубіжних вчених, які досліджують вплив війни на розвиток аграрного сектору економіки. Для досягнення мети дослідження використано соціологічний метод дослідження, зокрема інтерв'ю. У статті досліджено роль аграрного сектору в економіці України та глобальній продовольчій безпеці, проаналізовано вплив війни на аграрний сектор, охарактеризовано сучасний стан сільськогосподарської діяльності в умовах війни на прикладі фермерів. Згідно з отриманими даними, вплив війни на аграрний сектор є значним і має різні економічні, соціальні та екологічні наслідки. Дослідження показує, що деякі товаровиробники, на прикладі фермерів, адаптувалися до війни і змогли зберегти свої ринкові позиції, тоді як інші зазнали значних втрат і не змогли функціонувати належним чином. Це дослідження може стати важливим джерелом інформації для розробки державної політики підтримки сільськогосподарських товаровиробників, зокрема фермерів, в умовах війни та післявоєнної відбудови. Необхідно розглянути можливість залучення інвестицій в аграрний сектор, підтримки фермерів через систему кредитування, кооперації між фермерами

Ключові слова: сільське господарство; фермерські господарства; війна; продовольча безпека; ефективність; глобальні виклики; європейська інтеграція

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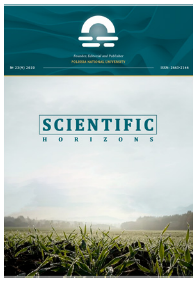

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The role of personnel management in increasing productivity at agricultural enterprises in Mongolia

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Abstract. The relevance of improving the efficiency of agriculture in Mongolia and, accordingly, the role of personnel management in the implementation of this task has grown especially in recent years when the number of pastures and arable land has substantially decreased due to an increase in the area of mineral extraction. The purpose of the study is to determine the most effective motivation and planning system for them, considering the national characteristics and mentality of agricultural workers, mainly nomadic shepherds, and to form recommendations on the most acceptable management style for this group. The Holfstede typology of cultural dimensions was used as a key method to identify the cultural and behavioural characteristics of the target audience. During the survey conducted among 1514 staff representatives and processing of its results, the average indicators for six cultural dimensions were calculated, and estimates of these indicators were given. According to the obtained data on the typology of cultural

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dimensions, it was determined that values in the examined social group are largely determined by traditions and customs, which means that a managerial model is in demand that will not impose existing Western management principles but uses its own tools based on relatively democratic principles. Based on the obtained characteristics, recommendations were formed on such key management tools as the principles of subordination, the system of setting tasks and monitoring their implementation, and on the effective motivation of personnel. The practical importance of the study lies in the development of recommendations for improving personnel management and, as a result, increasing efficiency at agricultural enterprises in Mongolia

Keywords: management, cattle breeding, agro-complex, agriculture, Hofstede method

INTRODUCTION

Historically, the basis of the economy of Mongolia was agriculture – geographical features and a large area of pastures stimulated the development of cattle breeding. Shepherds roaming with herds of horses, flocks of sheep, herds of goats and cows have been forming their unique mentality for centuries and passing on knowledge and skills to their children from generation to generation. According to a study by the International Fund for Agricultural Development (Mongolia Country Strategy, 2021), agriculture accounts for about 11% of the gross domestic product (GDP) of Mongolia, 83% of which is the livestock sector, which directly or indirectly provides jobs for more than a third of the able-bodied population of the country.

Nevertheless, at the end of the 20th century, after the transition of the economy of the state to market relations and the intensive development of mining technologies, the vector of the main economic area changed from the agro-industrial complex (AIC) towards the mining of deposits of copper, gold, coal, uranium, etc. I. Batmunkh (2021), who examined environmental problems in the mining sector, calculated that more than 8 thousand hectares of land were damaged by gold mining alone throughout the country. In addition to mining, agricultural machinery also had a technogenic impact on pastures and arable land. Thus, in particular, the problem of land pollution with diesel fuel and engine oil was examined by U. Tserendorj (2022), who reflected on the main risks of such pollution and formed recommendations for optimal cleaning and operation of large agricultural machines.

Thus, the explosive growth of technologies has substantially affected the agriculture of the country – territories that were recently occupied by pastures and acreage are intensively turning into mines and storage sites for waste soils, and these changes are irreversible. Forced land cuts had a negative impact on the routes of nomadic shepherds, the volume of fodder, livestock, and crops. The solution for the current situation is to increase the efficiency of agriculture, minimising the consequences of technogenic processes. A number of studies have been conducted in the search for ways to increase the productivity of AIC of Mongolia.

For example, L. Bayasgalankhuu *et al.* (2022) conducted an energy analysis of wheat yield and concluded the need to substantially limit the use of nitrogen fertilisers, since the energy costs of their use are unreasonably high. A. Batmunkh *et al.* (2022), in the process of investigating economic globalisation and environmental sustainability in Central Asia, confirm the hypothesis that the region is at the stage of an industrial economy and propose a roadmap for expanding interstate relations, including joint reclamation of the lands of Southern Mongolia, which will lead to an increase in the yield from steppe lands.

Regarding the efficiency of agriculture and productivity, such a negative natural phenomenon as drought should be considered. L. Nanzad *et al.* (2021) assessed the impact of droughts on the productivity of terrestrial ecosystems, identified signs of their approach at early stages and identified crops most susceptible to water scarcity. The results of their work are aimed to increase the readiness of staff and authorities for droughts, and, as a result, minimise negative consequences.

Therewith, one of the key factors in increasing the effectiveness of almost any process is the systematisation and improvement of its management. Regarding the situation under study, this refers to better management of personnel who are accustomed to existing in the traditional paradigm and avoid substantial changes – both in everyday life and in labour relations. The question of the behaviour of Mongolian farmers in the context of sustainable agricultural development has already been examined by B. Puntsagdorj *et al.* (2021). Having considered behavioural models through the prism of agricultural subsidies, they determined the readiness of farm employees to introduce new farming methods but ignored the management problem.

Filling the gap in the studies of new management solutions in agriculture in Mongolia, in this paper, the task was set to examine the specific features of the target audience and to identify the psychological and cultural characteristics of its representatives.

LITERATURE REVIEW

The subject of agriculture in Mongolia, as a leading branch of the economy with a huge production potential, attracts the attention of many researchers, especially in the context of the global fight against hunger, which has been exacerbated in recent years.

Y. Takahashi *et al.* (2019) examined the possibilities of increasing agricultural productivity in Mongolia using information-communication technologies. As a result of the calculations he received, it was identified that investments in lightweight drones and automated crop control systems are economically justified even for small farms. Such innovations are impossible without the proper technical training of personnel, which means that the role of management in increasing productivity is especially high in that area.

J. Yuan *et al.* (2022), analysing the cyclical transformation of land cover between pastures and arable lands on the example of the aimags of Archangel, Tuve, and Dornod, noted that the spatial distribution of the intensity of land use indicates that its principles are largely influenced by short-sighted management decisions. Moreover, improper management and lack of high-quality information work with personnel lead to uncontrolled migration in rural areas of Mongolia (Amartuvshin *et al.,* 2021).

M.L. Markowitz (2013) warned about the risks of the raw material model of the Mongolian economy in her work. According to the author, long-term mining hinders the sustainable development of the economy, because the funds received "at the moment" from coal or gold mining are spent over time, while crop and cattle breeding without proper support is declining. Consequently, according to the conclusions obtained in her study, a qualitatively different approach in the management of agro-industrial complex personnel is necessary for the formation of the food security potential of the country. B. Zandaria (2022), based on his own calculations, concluded that the total funds needed for the rehabilitation of the existing territories of Mongolia affected by mining are up to 51.1% of the budgets of local authorities. Therewith, without fundamentally novel approaches in the management and implementation of planned measures for the reclamation of territories and the achievement of sustainable development goals, there is a risk of repeating the same mistakes that led to the current situation.

An important contribution to the examination of the psychology of farmers and their management approach was made by Y. Shang and T. Xiong (2021), who surveyed representatives of 469 farms to determine their readiness to ensure future crops and crop prices. As a result of that, it was identified that farmers have a low estimate of their own ability to predict crop prices, but, nevertheless, they do not trust such an assessment from specialists and, in most cases, refuse to issue insurance. This contradiction leads to the conclusion that to get the trust of the farmers, it is necessary to convey to them the essence of innovations (in this case, insurance products) in an accessible form.

L. Janz (2007) noted a major difference in the mentality of nomadic pastoralists and sedentary shrews. Moreover, this contradiction was considered by her in the context of the psychological confrontation between representatives of two Asian subcultures – nomadic and sedentary. Taking this hypothesis as a basis, considering national, cultural, and behavioural traditions when evaluating the methods of personnel management becomes even more important in the agro-industrial complex of Mongolia.

Notably, almost all authors, researching ways of introducing innovations in the agro-industrial complex of Mongolia did so in the context of the existing Western management paradigm. Therewith, as can be seen from a number of studies mentioned above, the specific features of the personnel of Mongolian farms are such that any management system should be adapted to the existing mentality and traditions of generations of nomads and pastoralists. Considering the above, the purpose of this study is to identify key cultural codes and social characteristics of personnel and form a specialised set of recommendations for their management.

MATERIALS AND METHODS

First, it was necessary to identify the psychological characteristics of such a unique target audience as Mongolian nomads-shepherds and farmers to fully assess the management role of farms and enterprises of the agro-industrial complex. Due to the evident specific features – geographical remoteness from settlements, closed communities, constant challenges of wildlife, regular movements, and the absence of a stationary home in its conventional sense – this social group has been formed for many generations in a relative cultural and social vacuum.

Therefore, when it comes to managing such personnel, the existing experience of Western management is not applicable. It was decided to conduct a study according to the typology of cultural dimensions developed by Geert Hofstede to form an original approach and understand the logic, motivation, and values of Mongolian agricultural workers. Within the framework of these measurements, the attitude of a person to work, the service hierarchy, life orientation, and ethnic and cultural characteristics are determined.

The survey was conducted in six key categories listed below. The Power Distance Index (PDI) is the degree to which people who do not have power or have little power agree that power is distributed unevenly in society, i.e., the higher this indicator, the more society agrees that the leader has indisputable authority.

Individualism (IDV) – assessment of the dominance of individual interests. The higher this indicator, the less collective goals and collective responsibility are inherent in such a society. Masculinity (MAS) is a focus on achieving results at any cost. The lower this indicator, the higher the value of intangible benefits, relationships in the team, and quality of life. Avoiding uncertainty (UAI) index is the need to have specific plans and understand how to achieve them. Consequently, the lower this indicator, the higher the willingness of this society to take risks (Zandariya, 2022).

The long-term orientation (LTO) is a kind of persistence coefficient, a willingness to endure hardships and failures here and now in the expectation of future well-being. The IVR assumption is the degree of satisfaction with life, and readiness to fulfil one's own desires independently. During the study, 1514 employees of agricultural facilities in Mongolia were interviewed, representing different groups – by age, gender, and labour specialisation. The studies were conducted in the field on the territory of Eastern Mongolia in the provinces of Dornod and Sukhbaatar, and in Central Mongolia in the aimag of Tuva. Respondents were asked to assess the degree of their agreement with the statements in six categories on a scale from "completely disagree" to "completely agree". The survey was conducted under the legend of a general sociological study to avoid distrust of the interviewer group.

For the convenience of respondents, the response scale assumed a five-point system, which was already translated into an accepted one-hundred-point system by the formula (1) at the analysis stage:

$$X_{100} = (X_5 - 3) \times 25 + 50, \tag{1}$$

where, X_{100} – evaluation of the indicator according to the hundred-point system, and X_5 is an assessment of the indicator on a five-point system.

The assessments of each respondent were recorded, after which average indicators were formed for each of the six categories of culture measurement, which, in turn, formed the basis of recommendations on personnel management.

RESULTS

A survey of 1514 representatives of this social group was conducted to identify the cultural characteristics of employees of the agro-industrial complex of Mongolia. The respondents were randomly selected from three aimags in the centre and east of the country. Their structure in the context of the main social characteristics is presented in Table 1.

Table 1. *Structure of the respondent group*

Groups	Indicator	Number, persons	Specific weight in the group, %
Gender	Male	1105	73
	Female	409	27
Age	Under 20	91	6
	20-40	954	63
	40-60	424	28
	Over 60	45	3
Specialisation	Cattle breeding	1019	67
	Agriculture	495	33

Source: *compiled by the authors based on the survey data*

Since the sample was random, these proportions of indicators in social groups can be considered representative. All cultural features measured using the Hofstede methodology were formed under the influence of society throughout the respondents' lives – "cultural programming" was created by people around them, first by family, and then by work colleagues. The uniqueness of the target audience of this study, that is, employees of small family farms, lies in the fact that often in relatively isolated sums, family members, neighbours, and colleagues are practically the same team, which means that in the absence of outside opinions, the "cultural programming" of the environment produces the maximum effect.

For better contact with the respondents and the formation of confidence in the questionnaire, the interviewers voiced the legend of the global social survey, because in this case, those taking part in the survey became the "majority" in their own eyes and reduced the number of psychological barriers. First of all, it was necessary to identify the power distance index. The answers of all respondents were collected, the average score of the indicator was calculated and the index was determined according to the one-hundred-point system according to the formula (1). As a result, the PDI was 15 points out of a hundred. This means a low degree of power distance, characteristic of countries and communities where equality is valued, and the leader is perceived as a colleague and a reliable friend. This indicator also indicates the cultural traditions of decentralised management, which is evidently characteristic of nomadic life and scattered isolated farms.

The next indicator to be calculated is the individualism index. According to the results of the survey of the target audience, the average IDV was calculated – at 18 points. A low indicator of this index indicates the presence of collective goals in society. Unlike individualistic cultures and companies, where employees overprotect their own personal space and rely only on themselves, the staff of Mongolian agro-industrial enterprises embraces working in groups and the absence of pronounced internal competition. Historically, this is explained by the tradition of group nomadism and clan gatherings for making important decisions. Therefore, the leader should avoid accepting authoritarian expressions of will without consulting the team.

The so-called MAS masculinity index demonstrates which of the two value models the collective tends to – work (conditionally male role) or take care (conditionally female). Named according to conventional family stereotypes, the roles identify the true need of team members – to receive maximum income no matter what, or to maintain human and trusting relationships among employees. This index, according to surveys conducted in selected collectives, amounted to 42 points. This means that, despite a certain balance of interests, there is a certain bias towards the "female" team, when it is necessary to concentrate efforts on taking care of the staff. It is characteristic that this index in other Asian cultures is much higher and definitely dominates the "male" indicator. The peculiarity of the Mongolian nomadic culture in the value of the MAS index can easily be explained by the substantial isolation of nomads – in the wild and depending on natural disasters, good relations within the collective can be lifesaving.

An important cultural feature is also the readiness for uncertainty. Harsh natural conditions and difficult life are already quite unpredictable factors, which means that the target audience of the study is trying to minimise at least those risks that they can affect. Thus, the UAI score was a substantial 83 points out of 100. From the standpoint of management and personnel management, this refers to people's need for clear algorithms, formalised rules, conditions, and instructions. In addition, such a pattern of behaviour presupposes the willingness of employees to regularly interfere with management in the process as a momentary "pointing finger".

The next indicator of cultural dimensions – long-term orientation – was also examined using surveys. The resulting LTO index of 50 points indicates a predominantly neutral attitude to the idea of high goals pushed back in time. On the one hand, farmers are used to the fact that the result of their work is not immediately evident, and it takes months and, sometimes, years to make sure of the successful implementation of the project. On the other hand, long demanding work without visible confirmation of the correctness of the chosen path is also not for them. Evidently, in matters of long-term planning, a similar balance should be observed, and when forming global plans, intermediate control points and rewards should not be disregarded.

The final parameter is the assumption. The summed and analysed responses of the respondents eventually gave an indicator of this index of 35 points. Since communities with high IVR assumption rates are characterised as declaring relatively free satisfaction of desires, it should be stated that the target audience of this study does not perceive personal happiness as an unambiguous value. Difficult working conditions and limited resources have formed in generations of Mongolian farmers the need to control the satisfaction of momentary desires and needs and introduced regulation of these impulses through a system of social prohibitions and norms.

In general, the indicators of cultural dimensions of the examined community are as follows in Table 2.

Table 2. *Average indicators of respondents' cultural measurements*

PDI	IDV	MAS	UAI	LTO	IVR
15	18	42	83	50	35

Source: *compiled by the authors based on the survey data*

Summarising the results of surveys on all indicators, it can be stated that from the standpoint of management, the audience does not tolerate an authoritarian style and is used to taking part in decision-making. Such decisions should be made together, while the absence of conflicts and mutual trust is important in the team. The staff should understand the purpose of management changes and have the tools for intermediate control of achieving this goal. In the process of management, it is necessary to remember the presence of certain self-restrictions and taboos among employees, which should not conflict with management decisions.

Based on the generalised portrait of the employee obtained, democratic principles of leadership should be adopted to improve the efficiency and productivity of labour in agricultural enterprises in Mongolia. With a democratic approach to management, the manager makes all decisions together with the team that is involved in the planning process. Therewith, it is important to keep a balance and avoid unnecessary initiatives of the staff, since their lack of the necessary managerial qualifications can neutralise the whole essence of managerial reforms.

Among the positive aspects of the democratic style is the prevalence of a high degree of satisfaction with their work among team members and, consequently, increased productivity. Therewith, such an approach may be ineffective in case of critical and time-pressure situations when a decision is needed immediately. Considering such specific features of AIC personnel as remoteness, isolation, lack of constant monitoring, and operational feedback, some aspects of socially oriented management should also be adopted. Despite the inevitable loss of efficiency, in some cases it is the approach in which human relations in the team and a friendly environment come first, that can provide results in the long term.

Setting tasks to staff in the context of the results of cultural measurements can be initially visionary – i.e., it is quite possible that employees can clearly and in detail describe the goal set, provide tools, and they will be able to choose the methods of achieving the result themselves based on their own experience. It is proposed to conduct such an experiment on a separate focus group under conditions of increased control, and if it is successful, introduce such an innovation in other areas.

In any case, the recommended democratic leadership style is also good because it allows using the knowledge and skills of individual team members in the common interests. The life experience, practical skills, and actual qualifications of experienced shepherds and farmers are valuable resources, and the task of the manager is to direct these qualities in the right area, eliminate unnecessary prejudices and thereby increase the overall efficiency of the project.

The issue of productivity growth is key in this context. The economy of Mongolia, which has experienced explosive growth in mining, is still in a vulnerable state, and the level of poverty of citizens is one of the highest in the region. Consequently, the growth of labour productivity in the agro-industrial complex can be an impetus to the withdrawal from the economic crisis. Conversely, low labour productivity is a key element of a self-sustaining negative feedback system known as the poverty trap or development trap. Under this system, low productivity leads to a decrease in economic indicators; a budget suffering from a deficit is forced to limit investments in education; as a consequence, the decline of the vocational training system leads to a decrease in the number of qualified personnel, which ultimately leads to an even more critical decrease in labour productivity. Therewith, it is important to understand that this refers not to the abstract productivity of some administrative or economic enterprise, but to specific people, individual labour indicators, whose effective work should form the basis of the economic revival of the country.

A qualitative growth of management in the agricultural sector is necessary to break this vicious circle. The management principles proposed above, formed considering the special mentality of Mongolian farmers, are designed to normalise productivity indicators in the medium term. In addition, it is necessary to move away from the legacy of the period of a rigidly planned economy in Mongolia and introduce into the study such value concepts demanded by respondents as friendly patronage from the head, decentralisation of management sources, regular industry khurals for consultations and exchange of experience, and an effective motivation system.

The motivation here can be values that are also unique and unusual for other economies and societies. In particular, most respondents noted that the best reward for effective work for them would not be money or premium household items, but young cattle, the value of which grows as they grow older. In addition, such "alive bonuses" do not require a separate transport resource, especially valuable for a nomadic lifestyle. Within the framework of increasing overall efficiency, the recommendation of mutual rotation of employees of the agricultural sector deserves special attention – mentally being part of the nomadic culture, employees of settled agricultural farms demonstrate greater efficiency after a temporary change of situation and work in other fields. In addition, such rotations also contribute to the exchange of experience between farms.

It is important to emphasise that the growth of labour productivity as such is not an end goal in itself – even with a certain increase in indicators, the focus on primary production with a low added value substantially limits the development of farms, making them dependent on circumstances. Consequently, the increased resources obtained as a result of increasing the productivity of enterprises, yields, and livestock, it is necessary to invest in agro-processing – even the simplest points of processing of raw materials substantially increase the income of both pastoralists and farmers.

It is the adapted control system that will help to make this qualitative leap in the near future. Farmers who have established primary processing points on the territory of their farms will be able to increase income by supplying higher-grade products to the market.

DISCUSSION

The problems of personnel management have been examined quite extensively before, but there has not been a narrow focus on the Mongolian-specific features. Nevertheless, a number of issues and solutions examined in this study resonate with the conclusions of other authors.

N. Berber and A. Slavić (2022) investigated the nature and specific features of human resource management in the agro-industrial field and described the practice of the main and most important personnel management measures in the example of 12 operating enterprises in the agricultural sector. In investigating motivational mechanisms in the personnel management structure of specific enterprises, the authors analysed the main management models that showed practical positive experience and proposed the most effective scheme. Such a motivational model includes in its structure a number of constituent elements – goals, objectives, principles, methods, and tools – and priority areas that allow the management of the company to increase the effectiveness of employees' work.

A. Adeel (2017) also examined the problem of systematisation of human resource management in agriculture. The author calculated that human capital is a more important and valuable resource than technological developments and financial sources since the time to train a qualified specialist is measured in years. In addition, he suggested that finding a person in the hierarchical structure of the company is in itself a satisfaction of internal ambitions and needs for socialisation, which serves as a certain motivation for productive work.

Z. Zhai *et al.* (2020) examined the agricultural sector of the economy in the context of the global challenges of the growing world population and the fourth evolution of technology, reviewed thirteen different representative decision support systems and concluded that the importance of systematic development of skills and technological savvy of agro-enterprise personnel is critically high.

Since the northern regions of China have similar geographical problems to the Mongolian ones, the experience of researchers of this country in the integration of agriculture and tourism is interesting. Y. Liu *et al.* (2023) examined the development of remote territories in the context of green tourism gaining popularity around the world. The results of their study show that attracting tourists who want to personally experience the exoticism of remote pastures and nomadic life has a substantial positive impact on the development of rural areas. In the context of the national and cultural characteristics of the Mongolian peasants identified in the course of the study, it can be concluded that this innovation will take root in their environment, which means that it is necessary to promptly develop appropriate personnel management systems and logistics processes.

Regarding the uneven development of regions within one country, the experience of the Kyrgyz Republic should also be mentioned. Its mountainous regions, due to objective geographical reasons, have a relatively low economic potential, which leads their inhabitants to lag behind in the social field. Despite the general increase in prosperity, which began with the independence of Kyrgyzstan in 1991, the transition to a market economy has increased the property stratification of residents of different regions of the country. Insufficiently developed regional policy has led to such negative consequences as unemployment, increased social tension, an increase in the volume of the shadow economy, and, as a result, the state budget deficit. The heterogeneity of indicators for the economic and social development of the population requires intervention. Consequently, a precise regional policy with clear algorithms for the individual development of separate districts should be the basis for the updated management concept at all levels.

S. Guliyeva *et al.* (2021), investigating a similar subject of the effectiveness of a personality-oriented approach in working with agricultural workers, identified that the development of employee value is directly proportional to labour productivity in the agro-industrial sector. According to the results of the analysis of the econometric model, the most stimulating factors influencing labour productivity in the agro-industrial complex were such values as the moral qualities of employees, a democratic approach in relations with subordinates, self-development, aid in self-fulfilment, tolerance, and dedication to the common cause. In other words, the desire for improvement and development, the achievement of goals (both personal and corporate), freedom of expression, and the absence of total control by management with a prominent level of development of moral values, and tolerance in the team, leads to a substantial increase in labour productivity. All this, in a certain sense, echoes the above-mentioned results of the study and the recommendations for a democratic style in management.

Evidently, a long-term increase in labour productivity is impossible without the personal positivity experienced by employees from the work done. D. Bodescu *et al.* (2022) examined the relationship between productivity and satisfaction of food industry workers by conducting surveys of 254 employees and 17 managers from 60 companies. As a result, it was determined that a low level of staff satisfaction requires higher remuneration for their work. All other things being equal, it is more financially costly for employers than the services of employees with a prominent level of satisfaction.

J. Cock *et al.* (2022) analysed labour productivity in global agriculture through the prism of a choice between two concepts – nominal quantitative yield growth and efficiency of return from a conditional unit of labour expended. The authors of the study recommend further development of labour productivity according to the second concept, which assumes an increase in farm income from the transition to higher-value agricultural crops to avoid impoverishment of small farms and relocation of their employees to cities in search of more profitable work.

P. Colnago and S. Dogliotti (2020) also conducted their study on labour productivity in agriculture. As a result of their work, it was confirmed that labour productivity is a key factor in increasing the sustainability of family farm systems, income, and quality of life. The main factors shaping labour productivity were the difference in crop yields, the distribution of the labour force across diverse types of production activities, and their efficiency and profitability.

The essence of the study by C. Hogan *et al.* (2022) on the subject of efficiency growth in the field of agriculture was to identify productive techniques and technologies of work when performing specific tasks, and an assessment of the time savings that could be obtained by performing them during the peak labour intensity on dairy farms of spring calving. Labour savings were assessed for 12 substantial individual work methods and technologies, of which 5 were related to milking, 4 to calf care, 2 to cow care, and one to pasture management.

Another aspect of the problem of personnel management in agriculture is the age of employees.

H. Urbancová and P. Vrabcová (2020), using the example of agricultural enterprises in the Czech Republic, examined demographic trends and the resulting problems of workforce shortage. Based on a quantitative study of 136 companies operating in the raw materials sector, the authors identified organisational advantages and effective human resource management strategies designed to ensure a generational change in farms. The surveyed respondents see the main advantages in keeping key employees, increasing motivation and productivity, and improving the organisational climate. Drawing parallels with the survey data obtained as a result of the current study, the absence of an age problem and, accordingly, the need to manage demographics can be stated.

In investigating the role of personnel management, it is important to consider the information received in the context of sustainable human resource management (HRM), a trend that has been dynamically developing over the past 15 years. R. Kramar (2022) notes that HRM strategies are designed to define goals, methods, and types of management that personnel management specialists will be able to apply in the medium term in the context of the global sustainable development movement, involving concern for the environment and the well-being of present and future generations. The author formulates the six defining characteristics of HRM as readiness for contradictions, concern for the development of abilities, the need to recognise negative results, attention to the practical implementation of knowledge, a clear statement of values, and the development of a system of unified measurable indicators.

Thus, the results of the work done and its comparison with the experience of other studies indicate that the approach to assessing labour productivity indicators was correct. The role of management in increasing these indicators is also confirmed by the experience of a number of authors. Therewith, the unique situation that has developed in remote pastures and isolated agricultural enterprises in Mongolia requires substantial amendments when trying to transfer this experience to local realities.

CONCLUSIONS

The data obtained as a result of the study confirm the initial hypothesis that quality management has a positive effect on labour productivity growth in agricultural enterprises in Mongolia. Therewith, any innovations in management should be evaluated in advance from the standpoint of cultural characteristics and national traditions of the farm and of remote pastures staff.

The results of a survey conducted in the field among the target audience of interest showed that according to Hofstede's typology of cultural change, the most effective management style is democratic when leadership takes place in a relatively mild manner and the boss is an understanding friend and attentive supervisor, not a soulless commander. Therewith, it is important to maintain good relations within the team and to involve the collective council in making key decisions.

Thus, the goal of forming recommendations for effective management, which was originally set, was successfully completed. In subsequent studies, it will be necessary to analyse the results of the factual implementation of the proposed management style.

In addition, among the innovations recommended by the results of the study are: state control over the exploitation of mining areas, and the reclamation of those arable lands that were polluted by mining operations; introduction of the simplest relatively inexpensive technical means in farms on the level of a reconnaissance drone, sensors of humidity, acidity, temperature, lighting, etc.; the unification of the remote control system by technical means by developing an Android programme for remote monitoring of sensors in the national language; the creation of local places for the primary processing of raw materials; development of conditions for the launch of the so-called green tourism programme, which should include the development of routes, the preparation of a cultural programme, the regulation of medical insurance, and the development of logistics infrastructure.

From a practical standpoint, following these recommendations will improve the quality of management and labour productivity in the agro-industrial complex of Mongolia, which will provide an important impetus for the development of the economy.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Роль управління персоналом у процесі підвищення продуктивності праці на сільськогосподарських підприємствах Монголії

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Анотація. Актуальність підвищення ефективності сільського господарства Монголії і, відповідно, роль управління персоналом у реалізації цього завдання особливо зросла в останні роки, коли кількість пасовищ і ріллі істотно скоротилася за рахунок збільшення площі видобуток корисних копалин. Мета дослідження – визначити для них найбільш ефективну систему мотивації та планування з урахуванням національних особливостей і менталітету працівників сільського господарства, переважно кочових пастухів, і сформувати рекомендації щодо найбільш прийнятного стилю управління для цієї групи. Типологія культурних вимірів Холфстеда була використана як ключовий метод для визначення культурних і поведінкових характеристик цільової аудиторії. У ході опитування 1514 представників персоналу та обробки його результатів розраховано середні показники за шістьма культурними вимірами та надано оцінки цих показників. Згідно з отриманими даними щодо типології культурних вимірів було визначено, що цінності в досліджуваній соціальній групі значною мірою визначаються традиціями та звичаями, а це означає, що затребувана управлінська модель, яка не нав'язуватиме існуючі західні принципи управління, а використовує його власні інструменти, засновані на відносно демократичних засадах. На основі отриманих характеристик сформовано рекомендації щодо таких ключових інструментів управління, як принципи субординації, системи постановки завдань і контролю за їх виконанням, ефективної мотивації персоналу. Практичне значення дослідження полягає в розробці рекомендацій щодо вдосконалення управління персоналом і, як наслідок, підвищення ефективності роботи сільськогосподарських підприємств Монголії

Ключові слова: господарювання; скотарство; агрокомплекс; землеробство; метод Гофстеде

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