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Optimisation of the density of chufa (*Cyperus esculentus* L.) plants in the Kyiv region

Abstract. To achieve the optimal compromise between yield and soil fertility that will help balance two important aspects of agricultural production – high crop yields and long-term soil fertility – it is necessary to understand the impact of changing row spacing on vegetable crop growth and the soil environment. The research aims to determine the adaptive properties of the "Pharaoh" variety by studying the feeding area and plant density to obtain high-quality chufa nodules in the Kyiv region. The main research methods were field studies and analysis of the variance of morphological traits and economically valuable indicators of chufa. It was found that different plant densities had an impact on the development of vegetative organs of chufa due to competition for resources during the growing season. The variety "Pharaoh" showed a high intensity of aboveground mass formation in sparse crops with a plant density in the range of 28-33 thousand plants per hectare, with the number

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of leaf bundles reaching 145.2-147.4 pieces, and their average height is 50.4-52.3 centimetres. At the same time, the size of the nodules increased with a lower plant density, since with a larger feeding area, plants formed more powerful ones with thicker leaf bundles. Plants arranged in a 60×60 cm spacing (28 thousand plants/ha) formed larger nodules with the largest dimensions: 3.1 cm in length, 1.0 cm in width, and 1.2 cm in thickness. It has been substantiated that chufa of the "Pharaoh" variety was characterised by higher economic and valuable indicators under the schemes of planting 60×50 and 60×60 cm nodules. The high marketable yield of freshly harvested nodules was formed at a plant density of 28-33 thousand units/ha and amounted to 4.2-4.6 t/ha. The highest average yield of nodules after drying was obtained under the plant spacing of 60×60 and 60×50 cm, which was 3.35 and 2.99 t/ha, which was 20.9 and 7.8% higher than the control, respectively. Chufa is a promising crop in terms of food security and income generation, and precise management of plant placement will help to balance yield and soil fertility

Keywords: nodules; arrangement; bush, leaf bundles; rhizome; productivity; yield

INTRODUCTION

Chufa or earth almonds (*Cyperus esculentus* L.) are one of the less common crops that are valued for their high dietary and medicinal properties. The sweetish and nutty-flavoured nodules are used raw, boiled, and fried. They can replace peanuts, almonds, and soybeans in the confectionery industry. Flour made from chufa is used to make cakes, biscuits, and pastries. In cooking, it is used to make high-quality halva and sweets. In the processing industry, chufa is used to produce sugar, starch, and oil, which is as good as olive oil in terms of quality. Chufa products are a source of important physiologically active substances that are not available in other foods. Chufa oil is also valued in cosmetics and perfumery (Guo *et al.*, 2021; Oyedara *et al.*, 2022).

Chufa first became known in Ukraine in the 1930s. At that time, more than 100 hectares of chufa were grown in the Kherson region for the Odesa Confectionery Factory (Zavadska *et al.*, 2021). The crop remains promising for the southern regions of Ukraine. *C. esculentus* is the only species of the cultivated genus *Cyperus*. No wild forms of the species have been recorded in Ukraine. The National Botanical Garden named after M. Hryshko of the National Academy of Sciences of Ukraine has been introducing chufa since its foundation in 1945-1946. The first to start researching the culture in the scientific institution was a prominent Ukrainian breeder, Professor D. Lykhvar. The research results showed that growing the crop was also promising in the Forest-Steppe region of Ukraine. The selection of chufa was started, the varieties of which were included in the State Variety Testing and planting material was propagated (Marchyshyn *et al.*, 2021).

M. Druzhynina in the 1950s and V. Hryn in the 1970s studied the elements of the technology of growing and using chufa. On the fields of the Glevakha research farm, the National Academy of Sciences, together with scientists from the Institute of Mechanisation and Electrification of Agriculture of the National Academy of Agrarian Sciences, researched the technological processes of mechanised cultivation and harvesting of chufa. To date, the varieties "Pharaoh" and "Novinka" are known for the Forest-Steppe and "Ingulskyi" and "Snihurivskyi" for the Steppe of Ukraine (Ivasiuk *et al.*, 2019; Marchyshyn *et al.*, 2020).

Before the war with Russia, chufa production in Ukraine was gradually reviving. Increasing the yield of the crop is possible by improving its cultivation technology. One of the most important technological elements that result in higher yields of high-quality nodules is the optimal density of chufa plants. Different plant densities create different conditions for the growth and development of tuberous crops, including chufa. Previous studies have shown that with an increase in plant density, the productivity of each plant decreases (Bobos *et al.*, 2019).

The increase in the number of plants in a row contributed to a smaller growth of the chufa plant bush, which is reflected in the change in this indicator. Plant height is an important indicator that reflects the characteristics of crop growth and development and can change under the influence of environmental factors and elements of cultivation technology (Asare *et al.*, 2020).

The plasticity and stability of chufa influence its high economic value, along with the diverse use of fresh and processed nodules and deserves to be introduced in Ukraine. The soil and climatic conditions of the Forest-Steppe of Ukraine are favourable for growing high-quality chufa products. However, irrigation is required to ensure high yields. Moisture deficit is a limiting factor in obtaining a high and high-quality nodule yield (Abano *et al.*, 2021; Pascual-Seva & Pascual, 2021). Under unfavourable growing conditions, the right variety and density of chufa plants are important. These facts prompted us to conduct a study on the selection of the optimal feeding area for chufa plants for the conditions of the Kyiv region for cultivation in non-irrigated conditions.

The research aims to determine the adaptive properties of plants of the "Pharaoh" variety based on the study of the feeding area and plant density to obtain high-quality chufa nodules in the Kyiv region. The study of economically valuable traits of the crop will improve the technology of chufa cultivation, which will make it possible to provide the population with valuable and high-quality nodules for fresh consumption and the processing industry.

MATERIALS AND METHODS

The study was conducted in the educational laboratory (EL) "Fruit and Vegetable Garden" of the National University of Life and Environmental Sciences of Ukraine for three years – from 2019 to 2021. The training laboratory is located in the northern part of the Forest-Steppe and has soddy-medium podzolic soils (Zavadska *et al.*, 2021).

The research object was the chufa of the "Pharaoh" variety, which was created in the M.M. Gryshko National Botanical Garden (2009). Different schemes of nodule placement on the vegetable field of the Department of Vegetable Growing and Indoor Ground were studied. These schemes were as follows: 60×30, 60×40 (control), 60×50, 60×60 cm. The plant density, depending on the arrangement scheme, ranged from 28 to 56 thousand plants/ha.

The area of the experimental plot was 5 m^2. In all variants, row spacing was the same (60 cm). The feeding area in the experiment was regulated by the number of plants in a row. During the experiment, the phenological phases of plant growth were determined, the yield was recorded and the resistance of plants to diseases and pests was studied according to the methodology developed by G.L. Bondarenko & K.I. Yakovenko (2001).

During the growing season, which lasted from 05 June to 05 August 2019-2021, biometric measurements of plants were carried out. In particular, the height of the shoots was determined by measuring the length of the largest leaf using a ruler. The number of leaves on each plant was also counted. The surveys were carried out three times during the growing season – every month during the growth of vegetative mass. The dynamics of vegetative mass growth of plants of different chufa variants were determined. During the growing season, no diseases or pests were found on the chufa crops. The technology of chufa cultivation was used, which is generally accepted in production conditions without irrigation. Bulbs were planted to a depth of 5-6 cm on 10 May 2019-2021. 3 bulbs were sown in each hole.

After harvesting, which was carried out on 28-30 September after the leaves had turned yellow, the plants were dug up and the nodules were shaken off. They were then separated from the rhizomes and the remaining soil was sieved through a sieve and washed in running water. Then the nodules were cleaned, dried, and weighed to determine their average weight and weight of 1000 pcs. The size of the nodules was also analysed by measuring their length, width, and thickness. To analyse the data, we performed an analysis of variance using the XLSTAT add-in in MS Excel. The study was conducted following the requirements of the Convention on Biological Diversity (1992). The technology of chufa cultivation was used, which is generally accepted in production conditions and was carried out without irrigation. The bulbs were planted on 10 May during 2019-2021 to a depth of 5-6 cm, with 3 bulbs sown in each hole.

RESULTS AND DISCUSSION

It was found that the density of plants in chufa influenced the formation of aboveground mass.

During the entire growing season, the plants were characterised by different intensities of vegetative mass formation. The results of the research show that the lowest bush height was at a plant density of 56 thousand plants/ha, and with a decrease in density it increased. Chufa plants were very sensitive to changes in the feeding area. The thickened crops of chufa of the "Pharaoh" variety were characterised by lower dynamics of vegetative mass formation (Fig. 1, 2).

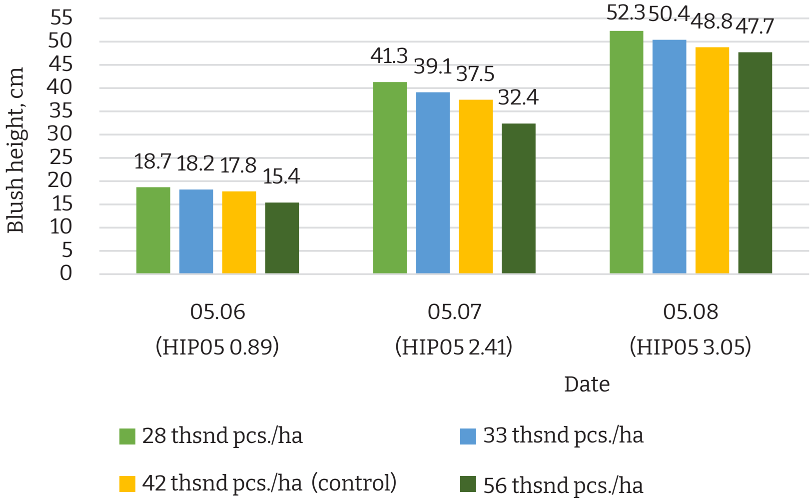

Figure 1. Influence of plant density on the height of the chufa bush of the "Pharaoh" variety (average for 2019-2021), cm

Source: compiled by the authors

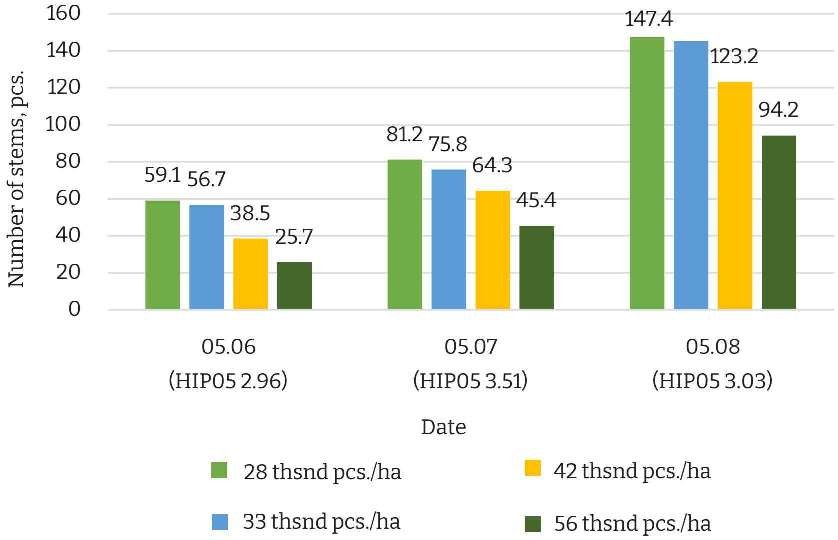

Figure 2. Influence of plant density on the number of stems of chufa variety "Pharaoh" (average for 2019-2021), pcs.

Source: compiled by the authors

After analysing the biometric parameters of chufa plants under different sowing schemes, it is possible to note that plants with the lowest plant density (28 thousand units/ha) had a more developed vegetative mass. This tendency was observed for all the dates of accounting, which were conducted in the research.

The chufa variety "Pharaoh" was characterised by a lower bush height at the highest density of 56 thousand plants/ha. At the same time, the density of plants also affected the number of stems, which was higher in plants with a lower density of 28 thousand units/ha, where thicker leaf bunches were formed. In thickened crops, shorter leaves of the bush were formed with a length of 47.7 cm, which is 1.1 cm more than in the control. However, the height of the bush and the number of leaves in sparse sowings (60×60 cm) increased to 52.3 and 147.4 pcs, respectively, which is 4.6 cm and 53.2 pcs less than in the control.

Thus, the study results indicate that different plant densities had an impact on the development of chufa vegetative organs. This is explained by the fact that during the growing season, plants competed with each other for access to light, moisture, and nutrients. A greater accumulation of leaf mass was found in chufa in sparse crops with a plant density of 28-33 thousand plants/ha, where the number of leaf bundles was 145.2-147.4 pcs. with a bush height of 50.4-52.3 cm.

Valuable economic indicators of chufa are the result of complex physiological transformations of organic and mineral substances in plants through their photosynthetic activity. The main factors that determine the intensity of photosynthesis and crop productivity are the degree of plant density in the area. It is the combination of plant density and placement in the cultivation technology that creates favourable optimal growing conditions and ensures that plants have uniform access to light, water, nutrients, and carbon dioxide in the topsoil.

The economic organ of chufa is the formation of nodules on the rhizome. The plant develops 150-200 nodules (up to 1000 pcs.) under one plant. The size of the nodules ultimately determines the productivity and yield of the plants.

The size of chufa nodules was found to be influenced by the placement of plants in the area (Fig. 3).

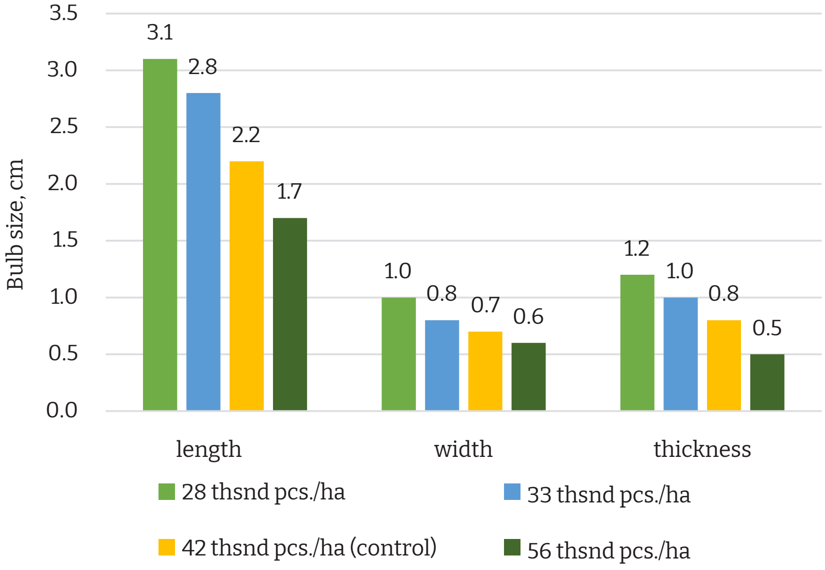

Figure 3. Effect of plant density on chufa nodule size (average for 2019-2021)

Source: compiled by the authors

The size of the nodules affected the productivity of the chufa and depended on their width, length and thickness. On average, over three years, the length of the nodules was 1.7-3.1 cm. Moreover, on crops with a lower plant density (28 thousand plants/ha), the length increased to 3.1 cm. This trend was also observed for other biometric parameters, namely the width of the nodules was 0.6-1.0 cm. At the same time, a larger width (1.0 cm) was found in the 60×60 cm planting scheme, which is 0.3 cm higher than the control.

With a decrease in the density of chufa plants, an increase in the size of their nodules was observed. This is due to the larger feeding area of the plants, which formed a better-developed rosette of leaves consisting of thicker leaf bundles (Fig. 4).

The thickness of the chufa nodules also depended on the plant density and ranged from 0.5-1.2 cm. At the same time, the lowest value of 0.5 cm was found on crops with a plant density of 56 thousand plants/ha under the 60×30 cm spacing scheme. A greater nodule thickness of 1.2 cm was observed on sparse crops (60×60 cm), which is 0.4 cm higher than the control.

Thus, reducing the density of chufa plants increased the size of the nodules. The largest size of nodules developed on the plant in the 60×60 cm spacing (28 thousand units/ha) with the largest length (3.1 cm), width (1.0 cm) and thickness (1.2 cm).

Figure 4. Formation of the vegetative mass and root system of chufa depending on the area of plant placement

Note: 1 – 60×30 cm; 2 – 60×40 cm; 3 – 60×50 cm; 4 – 60×60 cm

Following the research results, the density of chufa plants influenced the yield of nodules, which depended on their average number and plant productivity (Table 1). Significantly higher average plant productivity was also found at a plant density of 33 thousand plants/ha, which was 127 g, which is 32 g more than the control. The lower productivity of 72 g is characterised by plants with a spacing of 60×30 cm and a plant density of 56 thousand plants/ha.

Table 1. Influence of the timing and depth of planting of nodules on the economically valuable indicators of chufa (2019-2021)

Plant layout, cm	Plant density, thousand plants/ha	Average number of nodules, pcs.				Average productivity per bush, g				Weight of 1000 pieces of raw bulbs, g			
		years			Average	years			Average	years			Average
		2019	2020	2021		2019	2020	2021		2019	2020	2021	
60×30	56	168	170	175	171	70	71	74	72	415	420	425	420
60×40 (c)*	42	180	185	187	184	92	97	97	95	510	525	520	518
60×50	33	211	215	218	215	123	128	129	127	584	595	590	590
60×60	28	262	280	278	273	157	172	170	166	598	614	610	607
HIP$_{05}$					9.86				8.02				11.44

Note: (c)* – control

Source: compiled by the authors

The variety "Pharaoh" is characterised by a large mass of 1000 pcs. 420-607 g of nodules under all plant placement schemes. However, at a plant density of 28-33 thousand units/ha, bulbs were formed of a larger size with a weight of 1000 units 590-607 g, which is 72-89 g more than the control. A higher mass of nodules influenced higher plant productivity and yield. A greater weight of 1000 bulbs of 607 g were characterised by plants with a 60×60 cm arrangement, which influenced their high yield. Lower economically valuable indicators were found in thickened crops. The bulbs under the 60×30 and 60×40 cm arrangement schemes were formed of smaller sizes with the lowest weight of 1000 seeds, which was 420-518 g.

The productivity of nodules from one bush and their number and size influenced the marketable yield of chufa. At a higher density of 42-56 thousand units/ha, chufa of the **"**Pharaoh" variety had the lowest marketable yield of freshly harvested nodules of 4.0 t/ha (Fig. 5). At the same time, the highest yield increase was obtained in the variety with a lower plant density of 28 thousand plants/ha, where the marketable yield was 4.6 t/ha, which is 0.6 t/ha more than in the control. This is due to the formation of a larger bush, where a larger number of bulbs were found.

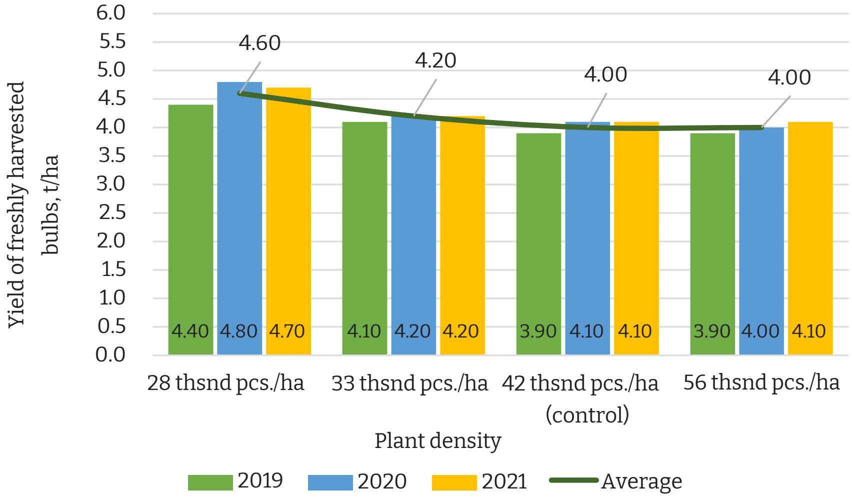

Figure 5. The yield of freshly harvested bulbs (2019-2021) (HIP$_{05}$ 0.15), t/ha

Source: compiled by the authors

Thus, chufa of the "Pharaoh" variety is characterized by high economic and valuable indicators under the schemes of 60×50 and 60×60 cm with a plant density of 28-33 thousand units/ha, where the highest marketable yield of freshly harvested bulbs was formed at 4.2-4.6 t/ha with a weight of 1000 units of 590-607 g.

X. Yang *et al.* (2022) and Y. Yu *et al.* (2022), the moisture content of freshly harvested chufa nodules reached about 43.5-47.4%. Due to the high moisture content, chufa is susceptible to rancidity and mould growth in the presence of enzymes and fungi, which, accordingly, reduced its quality and commercial value. Therefore, after harvesting, the tubers were dried to a moisture content of 15%.

During 2019-2021, the highest average yield of nodules after drying was obtained in variants with a plant density of 28 and 33 thousand units/ha with a spacing of 60×60 and 60×50 cm and was 3.35 and 2.99 t/ha, which was 0.58 and 0.22 t/ha or 20.9 and 7.8% significantly higher than the control, respectively (Fig. 6).

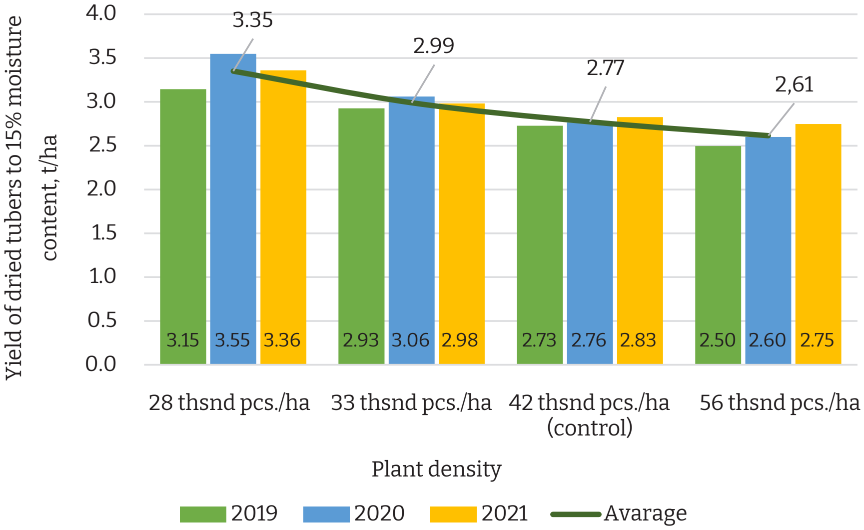

Figure 6. Yield of tubers dried to 15% moisture content (2019-2021) (HIP$_{05}$ 0.18), t/ha

Source: compiled by the authors

Understanding the impact of changing row spacing on crop growth and the soil environment is essential to balancing yields and soil sustainability. It will also provide a basis for future soil moisture and fertiliser management (Schmidt *et al.*, 2021). Chufa can return more organic matter to the soil earlier and faster than traditional crops such as maize in R. Yang *et al.* (2020). Tests show that the heterogeneous distribution of nutrients in the soil has a significant impact on the underground organs of plants. In the case of chufa, this heterogeneity can have an important impact on planting in the following year by promoting root growth (Zhang *et al.*, 2020). A row spacing of 30 cm resulted in the highest yield of chufa nodules, but the highest spatial heterogeneity of soil nutrients. The row spacing of 50 cm had the lowest spatial heterogeneity of nutrients in the soil. At the same time, the 40 cm row spacing had no obvious advantages and was not a suitable choice for planting. Therefore, to achieve the same yield and reduce the spatial heterogeneity of soil nutrients, it is better to use a row spacing of 50 cm (Tan *et al.*, 2020). In addition, the results showed that the highest yield of chufa nodules was with 60 cm row spacing and 50 and 60 cm plant spacing in the row. This may be because more intense interspecific competition contributes to lower plant yields when the plant feeding area is reduced.

High temperatures, infertile soils, and severe wind erosion limit the development of crops in extremely arid regions. T. Wube *et al.* (2020) and J. Zhang *et al.* (2021), suggested that row spacing can play an important role in increasing crop yields by changing microclimatic conditions and improving soil quality. In addition, narrow row spacing can reduce wind speeds and improve soil surface roughness, enhancing plant growth (Pan *et al.*, 2021). Plant height, plant density and number of bushes, and leaf carbon concentration were highest at 30 cm row spacing, indicating that narrow row spacing favoured chufa growth and development. There was also a relationship between plant height and wind erosion, which supports the previous view that plant height is one of the main reasons that can reduce wind erosion (Liu *et al.*, 2022). However, while narrow row spacing can have a positive impact on plant yields in arid regions, plant densification can lead to soil moisture deficits. Sparse crops also cause drought by increasing soil evaporation, so a balance between plant cover and soil evaporation is important to reduce wind erosion and improve soil quality. However, in the years of these studies, the weather conditions were unstable in terms of moisture and were characterised by high air temperatures during the growing season, and we observed a greater accumulation of chufa leaf mass with a plant density of 28-33 thousand units/ha.

Chufu is mainly grown by ridge planting or conventional flat planting (Zhao *et al.*, 2019). For planting the nodules, ridges 20 cm high and 60 cm apart were used, with an interval of 10 cm within the ridge (corresponding to 120 kg/ha of nodules), three nodules per hole (equally spaced 10 cm apart) (Pascual-Seva & Pascual, 2021). Ridges can also be formed as follows: the width of the bottom is 60 cm, the distance between ridges is 60 cm, the distance between rows on the ridges is 20 cm, the distance between hills is 15 cm and the height of ridges is 13 cm. Two rows are placed on each ridge and three bulbs are planted in one hole. The depth at which the chufa nodules grow is between 8 and 12 cm. Therefore, the outer dimensions of the crawler belts on both sides and the width of the digging devices of the chufa harvester should be 18 cm, and the digging depth of the digger blades should be adjusted between 0 and 20 cm (Qu *et al.*, 2023). Existing chufa harvesters require a lot of labour and assistance during harvesting, resulting in low harvesting efficiency. In addition, the harvested nodules need to be re-sieved as they do not meet current market requirements (Wang *et al.*, 2022). Therefore, the development of chufa harvesters should combine the digging, lifting, harvesting, screening and sorting of the nodules. Further research should investigate the applicability of the basic mechanisms in different soil zones and consider the suitability and reliability of the machinery in different working conditions to meet market demands to improve the overall usability and versatility of the harvesters.

In a study of the effect of row spacing (30 cm, 60 cm, 90 cm, 120 cm) on chufa growth and soil quality in an extremely arid area in the South Tarim Basin of Xinjiang, it was found that the yield of vegetative mass and nodules initially decreased and then increased with increasing row spacing (Guo *et al.*, 2021). The highest values of plant height, leaf, nodule, and root biomass yields were observed at 30 cm row spacing, the lowest at 90 cm row spacing, and there were no obvious differences between 60 cm and 120 cm row spacing. At 30 cm row spacing, the amount of N, P and K absorbed was significantly higher than in the other treatments, but the availability of N, P and K in the soil in the 0-20 cm layer was lower than in the other treatments. The chufa plantation reduced soil salinity at a depth of 20-40 cm. In the 0-20 cm row spacing, soil salinity increased to moderate salinity in the 90 cm and 120 cm row spacings, while there were no significant changes in the 30 cm and 60 cm row spacings. The results showed that a row spacing of 30 cm could improve the yield of chufa leaves and nodules as well as soil salinity, and therefore, Y. Liu *et al.* (2021) recommended using it for chufa planting. In general, the study showed that to obtain a consistently high yield of chufa in the northern part of the Forest-Steppe on soddy-medium podzolic soil, it is recommended to adhere to the planting scheme of 60×50 and 60×60 cm. The 60×30 cm plant spacing demonstrates the highest values of plant height, leaf and nodule yields and root biomass. The trial highlights the importance of proper chufa plant placement to achieve optimal yield results and ensure soil quality in this region.

CONCLUSIONS

Different density of chufa plants affects the formation of their vegetative organs since during the growing season there is competition for light, moisture, and nutrients between plants. In the variety "Pharaoh", it was found that the intensity of aboveground mass formation was higher in sparse crops with a plant density of 28-33 thousand plants/ha, where the number of leaf bundles was 145.2-147.4 with a height of 50.4-52.3 cm. A decrease in plant density led to an increase in the size of the nodules. The largest nodules developed on plants with a spacing of 60×60 cm (28 thousand pcs./ha) with the largest length (3.1 cm), width (1.0 cm) and thickness (1.2 cm).

The chufa plants of the "Pharaoh" variety are characterised by a high weight of 1000 pieces of nodules 420-607 g under all schemes of placement. At the same time, a larger size of nodules was found in the variety with a plant density of 28-33 thousand units/ha 590-607 g, which is 72-89 g more than the control. On crops with the indicated density, a higher mass of nodules influenced their higher productivity and yield. A significantly higher weight of 1000 nodules (607 g) were obtained in the 60×60 cm plant spacing, which influenced their higher yield. Lower economically valuable indicators were found in chufa on thickened crops. Under the 60×30 and 60×40 cm planting schemes with a plant density of 42-56 thousand plants/ha, smaller nodules were formed with a weight of 1000 seeds of 420-518 g.

The variety of chufa "Pharaoh" was distinguished by high economic and valuable indicators under the schemes of plant placement 60×50 and 60×60 cm with a density of 28-33 thousand pcs./ha, which resulted in the highest marketable yield of freshly harvested bulbs of 4.2-4.6 t/ha with an average weight of 1000 pcs. 590-607 g and dried bulbs of 3.35 and 2.99 t/ha, which was 0.58 and 0.22 t/ha or 20.9 and 7.8% higher than the control, respectively. Promising areas for research are molecular genetic studies aimed at obtaining the maximum size of chufa nodules to optimise processing technology and medical studies of the impact of chufa products on the human body to improve the nutritional structure of the population and increase the share of natural and environmentally friendly products in the daily diet.

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CONFLICT OF INTEREST

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Оптимізація густоти рослин чуфи (*Cyperus esculentus* L.) в Київській області

Анотація. Для того, щоб досягти оптимального компромісу між врожайністю та родючістю ґрунту, який допоможе збалансувати дві важливі аспекти сільськогосподарського виробництва – високий врожай культур і збереження родючості ґрунту на тривалий період, необхідно розуміти вплив зміни ширини міжрядь на ріст овочевих культур та ґрунтове середовище. Метою досліджень було встановлення адаптивних властивостей рослин сорту «Фараон» шляхом вивчення площі живлення й густоти рослин для отримання якісних бульбочок чуфи в Київській області. Провідні методи досліджень – польові дослідження та дисперсійний аналіз морфологічних ознак та господарсько-цінних показників чуфи. Встановлено, що різна густота рослин мала вплив на розвиток вегетативних органів чуфи через конкуренцію за ресурси під час вегетаційного періоду. Сорт «Фараон» показав високу інтенсивність формування надземної маси в розріджених посівах з густотою рослин в діапазоні 28-33 тисячі штук на гектар, при чому кількість листкових пучків досягає 145,2-147,4 штук, а їхній середній зріст складає 50,4-52,3 сантиметри. Водночас, розмір бульбочок збільшувався з меншою густотою рослин, оскільки за більшої площі живлення рослини формувалися більш потужніші з листкових пучків товстішого розміру. На рослинах, розміщених за схемою 60×60 см (28 тис. шт./га), утворювалися більші бульбочки, які мали найбільші розміри: довжину – 3,1 см, ширину – 1,0 см та товщину – 1,2 см. Обґрунтовано, що вищими господарсько-цінними показниками характеризувалась чуфа сорту «Фараон» за схем висаджування бульбочок 60×50 і 60×60 см. Висока товарна врожайність свіжозібраних бульбочок формувалась за густоти рослин 28-33 тис. шт./га та становила 4,2-4,6 т/га. За схеми розміщення рослин 60×60 та 60×50 см отримано й найвищу середню урожайність бульбочок після висушування, яка становила 3,35 та 2,99 т/га, що відповідно на 20,9 і 7,8 % істотно перевищувало контроль. Чуфа є перспективною культурою з точки зору продовольчої безпеки та створення доходу, а точний менеджмент розміщення рослин допоможе збалансувати врожайність і родючість ґрунту

Ключові слова: бульбочки; схема розміщення; кущ; листкові пучки; кореневище; продуктивність; урожайність

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Influence of drugs produced by electropulse ablation methods on the development of soybean phytopathogenic bacteria

Abstract. The causative agents of soybean blotch (*Pseudomonas savastanoi pv. glycinea*) and soybean pustular bacteriosis (*Xanthomonas axonopodis pv. glycines*) are common phytopathogenic bacteria. However, the lack of officially registered drugs against them stimulates the search for new solutions. The research aims to determine the effect of these micronutrient preparations

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obtained by electropulse ablation on bacteria during artificial infection of soybean with museum strains of pustular bacteriosis and angular spot pathogens. The antibacterial activity of the studied preparations was compared with the untreated variants and the effect of traditional chemical pesticides based on Fludioxonil and Metalaxyl-M. The spread and development of the disease were assessed by the number of affected plants using a scale from 0 to 4 points. It was found that varietal characteristics of soybeans affect the degree of infection by phytopathogenic bacteria. It was found that weather conditions, in particular air temperature, are a significant factor in the development of disease manifestations. It was proved that seed treatment with a chemical pesticide based on Fludioxonil and Metalaxyl-M in the absence of additional foliar treatment does not reduce the manifestations and degree of damage compared to the control (without treatment). Dressing and foliar treatment with a chemical pesticide based on Fludioxonil and Metalaxyl-M only partially reduce the manifestations of bacteriosis compared to the control variants (by about 15%). At the same time, the use of preparations obtained by electropulse ablation methods is promising against phytopathogenic bacteria in the system of soybean cultivation technology – namely, it was determined that under the condition of soybean plants treatment with experimental preparations according to the Comfort scheme (consumption – 150 ml/t of seeds) + Dobrodiy fertilizer (consumption – 2, 4 l/t of seeds) + microelement preparation "Micro Protect" (consumption of 500 ml/t of seeds) + two foliar treatments with the specified mixture of microelement preparations, the delay in the manifestation of plant damage until the time of harvesting is increased, which in turn is likely to lead to an increase in yields. The practical significance of the work is to determine effective methods of controlling phytopathogenic bacteria that harm soybeans

Keywords: bacterial plant pathogens; legumes; angular spot; pustular bacteriosis; nanoaquahelaths; ablation technologies

INTRODUCTION

Phytopathogenic bacteria that cause economic losses to agriculture usually exhibit significant resistance to chemical and often biological agents, which hinders plant protection against bacteriosis (Kolomiiets *et al.*, 2019). Plant pathogens, disrupting the normal course of physiological processes of the plant organism, lead to its partial or complete death. This worsens product quality and significantly reduces yields. Therefore, the issue of effectively limiting their spread, minimising or even preventing significant economic losses, remains relevant and worthy of attention (Martins *et al.*, 2018).

Among the legume plants, soybeans are the most widely used in agriculture and are economically and environmentally beneficial. According to T.T. Hnatiuk *et al.* (2019), the most common bacterial phytopathogens that can cause legume epiphytoties in Ukraine are *Pseudomonas savastonoi pv. glycinea* (the causative agent of soybean angular spot) and *Xanthomonas axonopodis pv. glycinea* (the causative agent of desert bacteriosis), and the most common ones are *Curtobacterium flaccumfaciens pv. flaccumfaciens* (rusty brown spot or wilt of soybean), *Xanthomonas fuscans subsp.fuscans* (small brown spot of soybean), *Pantoea agglomerans* (stem stripe).

Phytopathogenic *Pseudomonas* bacteria have a high adaptive potential in different agroecological conditions and cause significant damage to the host plant organism but are also resistant to the toxic effects of chemical and biological agents (Yin *et al.*, 2022). The causative agents of bacterial diseases of leguminous plants of the *Pseudomonas* family are both highly specialised groups of bacteria (*P. savastanoi pv. phaseolicola, P. savastanoi pv. glycinea*) and polyphages (*P. syringae pv. syringae, P. syringae pv. tabaci*) (Hnatiuk *et al.*, 2019), which do not always show the same sensitivity to certain pesticides.

According to K.A. Abo-Elyousr *et al.* (2022), the pathogens of soybean pustular bacteriosis (*Xanthomonas axonopodis. pv. glycines*) and brown bean bacteriosis (*Xanthomonas axonopodis. pv. phaseoli*) are highly active and widespread among yellow-pigmented pathogens of legume bacterioses, affecting the aerial parts of plants and seeds. When using pesticides of both chemical and biological origin, these phytopathogens show sensitivity or resistance to them in a wide range of population heterogeneity, which leads to the continuing search for fundamentally new approaches to crop protection technologies (Varympopi *et al.*, 2022; Oliveira *et al.*, 2023; Halfeld-Vieira *et al.*, 2023). As of 2023, there are no officially registered drugs against phytopathogenic bacteria in Ukraine and the world, which increases the urgency of finding such drugs (Atiq *et al.*, 2022, Taheri *et al.*, 2023).

With the development of integrated plant protection ideas, the use of preparations obtained by electropulse ablation (preparations based on metal nanoaccumulates) is becoming increasingly popular. In particular, they are characterised by antimicrobial properties, contribute to increasing plant resistance to adverse abiotic and biotic factors, and complement and enhance the effect of traditional plant protection products (Pruntseva, 2018; Huliaieva *et al.*, 2018). M. Alavi *et al.* (2022) also noted that bacteria cannot develop resistance to several metals.

Thus, given the aforesaid properties, nanoaccitrates are promising agents capable of restraining and counteracting the development of large-scale epiphytoties caused by bacteria and microsporidia. The research relevance is determined as large-scale epiphytoties caused by bacteria and micromycetes pose a serious threat to soybean cultivation and can lead to significant yield losses. Given the absence of officially registered drugs against phytopathogenic bacteria in agriculture, the search for new effective solutions becomes extremely important. Thus, the research aims to determine the effect of preparations obtained by electropulse ablation on the main phytopathogenic bacteria of soybean under artificial infection *in vivo*.

MATERIALS AND METHODS

The study was conducted in temporary field experiments based on the Mohyliv-Podilskyi territorial community in 2021 and 2022. The soil is dark grey podzolic, coarse-dusted, and light loamy. The soybean predecessor in 2021 is black fallow, and in 2022 – soybeans. Agricultural practices for soybean cultivation are common. The sowing rate is 450 thousand germinating seeds per 1 ha, the sowing method is wide row, with a row spacing of 45 cm. The soybean varieties to be released in 2021 are Strike and Drayton and in 2022 Kyoto.

During the research in July 2021, the average ten-day temperature in the research area was 1.1°C above normal, and significant daily temperature fluctuations were recorded. Despite the above favourable temperature conditions for bean formation, in July 2021, in Mohyliv-Podilskyi district, an excess of the average monthly rainfall was recorded (250-300% of the norm), which in turn contributed to the development of soybean phytopathogens.

During the experiment in 2022, the average daily temperature in the Mohyliv-Podilskyi district was close to normal, but during the experiment, the highest seasonal temperatures of 31-33°C were recorded for 5 days, and the amount of precipitation was 150% of the annual average.

The pathogens of angular spot (*Pseudomonas savastanoi pv. glycinea* UCM B-9190) and pustular bacteriosis (*Xanthomonas axonopodis pv. glycineaes* UCM B-9192) of common soybean, which is stored in the Ukrainian Collection of Microorganisms (UCM) of the Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine, Department of Phytopathogenic Bacteria. For inoculation of common soybean plants, a suspension of one- to two-day-old bacterial cultures with a density of 1×10^9 CFU (Number of Optical Units) per ml of purified tap water was used, which was applied to the leaf surface followed by a triple needle wound or injected into the stems and beans of plants by syringe injection (Klement *et al.*, 1990).

The experiments were repeated five times, and the recordings were made on days 7, 15 and 30. Purified tap water was used as a control.

The effect of drugs obtained by electropulse ablation was studied, namely:

1) Microelement preparation "Comfort Universal" (Ukraine) based on nanoaccitrates of S, Se, Cu, I, Al, V, Ni, Co.

2) Organo-mineral fertiliser "Dobrodiy" (Ukraine). Component characteristics (g/kg): (N) nitrogen – Nitrogen-containing compounds in terms of nitrogen – 330, K – in terms of K_2O – 60,

Trace elements chelated with carboxylic acids: B – 0.36, Mo – 0.013, Fe – 1.44, Mn – 1.44, S – 9.6, Cu – 2.4, Zn – 1.2, Mg – 33, Co – 0.037; Humic and fulvic acids 30 g/kg.

3) Micronutrient preparation "Protect Micro" (Ukraine). The drug is produced using an original technology by chelation of active elements with natural di- and tricarboxylic organic acids (including succinic, tartaric, and malic acids): Cu – 15, Zn – 16, Mn – 7.2, Mo – 2, Co – 1.5, Fe – 8.

A comparison of the two field trials in 2021 and 2022 is shown in Table 1.

Table 1. Field experiments in 2021-2022

For the first field trial (in 2021), a variant scheme was used:		For the second field experiment (in 2022), a modified scheme was used. Soybean seeds of the Kyoto variety were treated according to the variants:	
1.	Plants treated with Comfort (consumption – 250 ml/tonne of seeds) + Dobrodiy organic-mineral fertiliser (consumption – 2.4 litres/tonne of seeds).	1.	A chemical disinfectant based on Fludioxonil and Metalaxyl-M (recommended consumption – 1 l/t).
2.	Plants without preliminary treatment.	2.	Treatment with Comfort (consumption – 150 ml/t of seeds) + Organo-mineral fertiliser "Dobrodiy" (consumption – 2.4 litres/t of seeds) + microelement preparation "Micro Protect" (consumption – 500 ml/t of seeds)
		3.	A chemical disinfectant based on Fludioxonil and Metalaxyl-M (recommended dose of 1 l/t) + two foliar treatments with the same drug.
		4.	Treatment with Comfort (consumption – 150 ml/t of seeds) + Organo-mineral fertiliser "Dobrodiy" (consumption – 2.4 litres/t of seeds) + microelement preparation "Micro Protect" (consumption – 500 ml/t of seeds) + two foliar treatments with the specified mixture of micronutrient drugs.
		5.	Control (without preliminary treatment).

Source: compiled by the authors

Two foliar treatments were carried out as follows: the first foliar treatment was carried out (with appropriate concentrations of drugs) before artificial infection of plants, and the second – 14 days after inoculation with bacterial phytopathogens. Artificial infection occurred at the beginning of bean formation. Under conditions of natural infection, the spread of the disease by the number of affected plants and the development of the disease on a 5-point scale (from 0 to 4 points) were considered. The symptoms of plants in the corresponding points are presented in Table 2.

Table 2. Gradations (by points) of the degree of development of artificial injury

Score	Symptoms
0	No lesions, no injection marks
1	The onset of lesions, small necrotic spots/strips
2	Development of lesions and necrotic spots increase
3	A fairly high degree of damage
4	The high degree of lesion development: increase in the size and spread of necrotic spots/strips, possible complete death of the affected parts

Source: compiled by the authors

The software packages used for calculations were Statistica and Microsoft Excel-365. The study was conducted following the requirements of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The preliminary results of the *in vitro* study indicate that phytopathogenic bacteria show a fairly high sensitivity to the studied micronutrient preparations, unlike chemical pesticides, regardless of the genus and species of pathogens at a significant dilution, without causing toxic effects on the inoculant bacteria of the genus *Bradyrhizobium* and *Rhizobium*. This indicates the potential for positive use of such preparations in the field. The need for research is caused by the fact that under natural conditions, the activity of the applied preparations is influenced by a significant number of biotic and abiotic factors, which can level the effect of the preparations.

Thus, after these results were obtained in laboratory studies, it became necessary to conduct *in vivo* experiments. The results of field studies on artificial infection with soybean phytopathogenic bacteria in 2021 are presented in Table 3.

Table 3. The results of artificial damage by bacterial pathogens of soybeans with pre-treatment with a mixture of the studied preparations in comparison with the control

Plant treatment options and varieties	*P. savastanoi* pv. *glycinea* (pcs. 9190)						*X. axonopodis* pv.*glycines* (pcs. 9192)					
	Leaves			Stems/beans			Leaves			Stems/beans		
	Day											
	7	14	30	7	14	30	7	14	30	7	14	30
Seeds pre-treated with a mixture of test products												
“Drayton”	1.6	2.2	2.2	-	1.8/2.2	2.4/2.6	0.6	0.4	1.8	-	2.2/2.2	2.8/2.6
“Strive”	0	1.8	2.0	-	1.0	2.4	0	0	0	-	0	2.2
No treatment												
“Drayton”	1.6	2.8	3.4	0	3.2/1.8	4/3.6	1.0	1.4	2.4	0	2.4/2.4	2.2/2.2
“Strive”	1.0	1.8	3.2	-	2.6	2.8	0	0.6	0.8	-	1.8	2.0

Note: “digital mark” – level of plant infection (arithmetic mean of all plots), “0” – no infection, injection mark, “n/y” – n – assessment of stem damage, and y – assessment of bean damage, “-” – no data available
Source: compiled by the authors

The results of field studies on artificial infection of soybean with phytopathogenic bacteria in 2021 (Table 2) indicate, first of all, the positive effects of the use of experimental micronutrient compositions. As can be seen from the results obtained, traditional seed treatment with experimental preparations shows a positive trend towards plant resistance to the main pathogens of soybean bacterial diseases (the causative agent of angular spot and the causative agent of pustular bacteriosis) and also allowed for comparative resistance of the soybean varieties used in the experiments to phytopathogens.

It is necessary to note the differences in the development of the pathological process depending on the varietal characteristics of plants. As a result, it was found that common soybean plants of the Drayton variety showed lower resistance to the disease in terms of the level and speed of its manifestation compared to the Strive variety. Despite the identified varietal characteristics, the results obtained demonstrate a general trend in the reactions of the plant organism to infection, in particular, in the variant with the treatment with the studied preparations, the lesions develop more slowly, partially having a lower intensity, compared to the variant without treatment. Moreover, on the variety “Strive” with the treatment for *Xanthomonas axonopodis* pv. *glycine* infection, no infection was observed on the leaves at all.

Regarding the phytopathogenic activity of the studied microorganisms, its manifestation in the bacteria *Xanthomonas axonopodis* pv. *glycines* (9192 pcs.) was noted to be weaker compared to *P. savastanoi* pv. *glycinea* (9190 pcs.), which is consistent with the literature data (Baltrus *et al.*, 2016). At the same time, a decrease in the intensity of infection with *Xanthomonas axonopodis* pv. *glycines* were observed after treatment with the studied preparations. This can be explained by the fact that both microorganisms differ in virulence factors. After all, the main factor of aggressiveness of *Xanthomonas axonopodis* pv. *glycines* are indirectly caused by extracellular polysaccharides, which from the very first steps of plant development begin to move through the vessels and gradually clog them. At the same time, obligate phytopathogenic pathogens of the genus *Pseudomonas* gradually accumulate in the plant and produce a significant amount of toxins that either gradually or instantly poison or kill the plant organism, which can lead to significant crop losses (Hnatiuk, 2019; Sánchez-Hernández *et al.*, 2023).

The obtained results confirmed the conclusions of previous laboratory tests of the investigational drugs regarding the effectiveness of delaying the growth of bacterial colonies by the investigational drugs and their complexes.

In the variant with seed treatment, regardless of varietal characteristics, a delay in the appearance of pronounced symptoms of the disease was observed for up to 15 days. Compared to the control, the level of plant infection was significantly lower (on average by one position), but after 15 days of observation in the experimental variant and control, the infection of plants increased significantly. We assume that weather conditions also had a minor impact on the duration of infection symptoms in the experimental plants. It is noted in the sources (Muluneh, 2021) that even an increase in the average monthly temperature by 0.798°C with significant waterlogging affects the number of pathogens and their activity, and also reduces the ability of plant organisms to resist the development of bacterial diseases, which in turn leads to a decrease in yield by more than 30%.

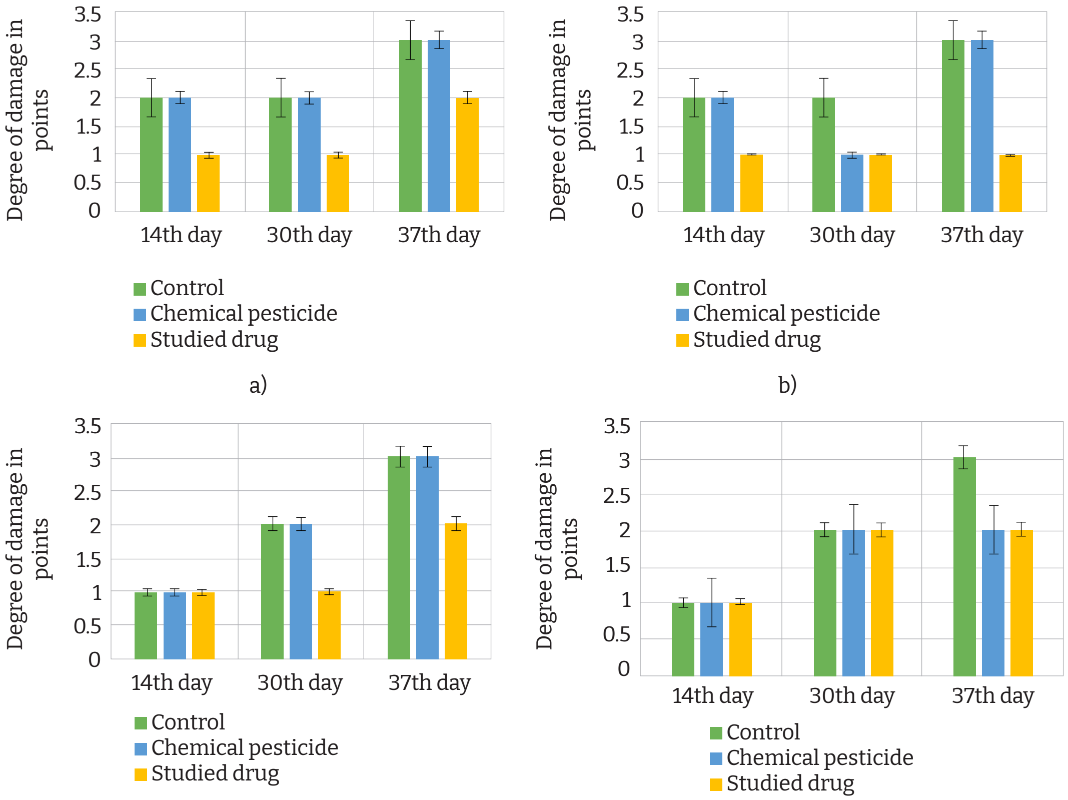
Taking into account the results of the previous experiment (in all the results of the 2021 experiment, there is a pattern that the manifestation of disease symptoms increases on days 14-15, i.e. the intensity of inhibition of the pathogen decreases), it became necessary to compare the effect of the studied drugs with traditional chemical pesticides and repeated treatments. Therefore, the second stage of the study was conducted in 2022 on the same field, but with two additional foliar treatments in terms of variants (one treatment was carried out before artificial infection, the second – on the 14th day after infection) and compared with the variant where plants were treated with a traditional chemical pesticide.

According to G. Otálora *et al.* (2018), foliar feeding strategies can achieve greater nutrient use efficiency, reduce negative environmental impacts, and potentially increase consumer health benefits.

The use of foliar treatments was also since, according to N. Novytska *et al.* (2020), foliar feeding of soybeans increases the intensity of chlorophyll synthesis in leaves, promotes photosynthetic activity and stimulates the growth of the number of microorganisms that ensure the synthesis of auxins and other root stimulating substances. Thus, foliar nutrition triggers the so-called “pumping system” of the plant, increasing the volume of nutrient absorption from the soil.

The need for additional foliar treatments was since, based on the work of W.F.A. Mosa *et al.* (2021), seed treatment followed by foliar treatment with metal nanoparticles was highly effective not only against pathogens of the root system and root zone of plants, but also had a significant antibacterial effect on phytopathogens that affect leaves, stems, and fruits during the growing season.

The need for foliar treatment was based on the fact that at high temperatures (the period when artificial infection took place), some of the most important macro- and microelements for soybean development, namely potassium, calcium, copper, boron, etc., are poorly absorbed, so additional foliar treatments can be seen as a promising solution to this problem. Another important component of soybean protection technologies is their permeability and ability to stay on the leaves. Foliar application of the chelated form of the products ensures better absorption and biological activity of trace elements, their better compatibility with other chemicals and low toxicity (Niu *et al.*, 2021). The results of the study conducted in 2022 are shown in Figure 1.



a) b) c) d)

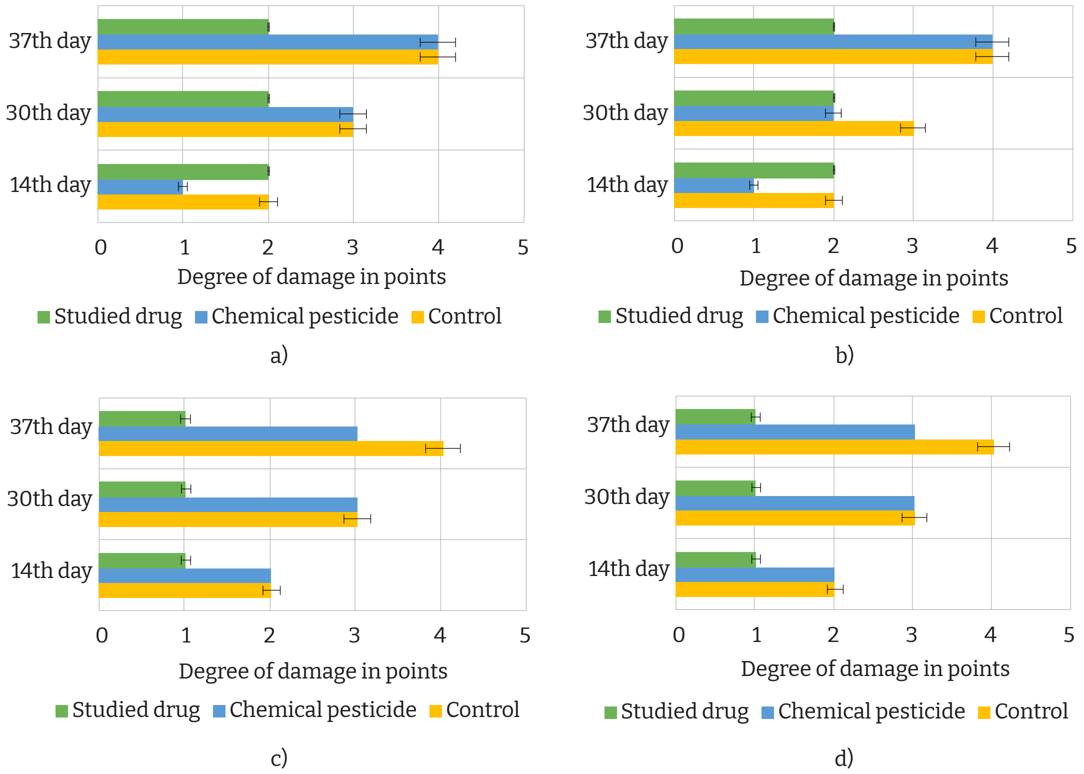
Figure 1. Degrees of plant damage under artificial inoculation with *P. savastanoi pv. glycinea*

Note: a – the degree of damage on the leaves (in variants without re-treatment); b – the degree of damage on the leaves (in variants with re-treatment); c – the degree of damage on the stems (in variants without re-treatment); d – the degree of damage on the stems (in variants with re-treatment)

Source: compiled by the authors

The dynamics of the indicators indicate the advantage of seed treatment with a mixture of preparations obtained by electropulse ablation compared to a chemical pesticide and control. In addition, it was found that after 14 days, the results of plant damage under the condition of chemical pesticide treatment and control values mostly coincide. Meanwhile, the mixture of the studied substances demonstrates a stable effect on the inhibition of the development of *P. savastanoi pv. glycinea* colonies, and, if re-treated on the 14th day, can restrain their further development, prolonging the period of resistance of common soybean plants. As can be seen from Figure 1, when applying the dressing with additional foliar treatments for artificial infection of plant parts, the level of disease manifestation by day 37 (harvesting period) did not exceed 1 point, i.e., only single necrotic spots were observed in the places of inoculation. At the same time, in plants without treatment and with treatment and treatment with a pesticide based on Fludioxonil and Metalaxyl-M, a significant increase in the size and spread of necrotic spots was recorded, and in some places complete drying and falling of the artificially affected leaf or bean. As for the degree of damage on the stems, up to 30 days in all variants the degree of damage was estimated at 2 points, but after that, a rapid spread of necrotic spots was observed in the control. At the same time, in the variant with repeated foliar treatment, this effect was not observed, which indicates the correct strategy for foliar feeding. Probably, during repeated treatment, there is also a direct contact effect with the components of the experimental preparations, which exhibit antimicrobial activity against bacterial pathogens.

Although beans and leaves are the most sensitive plant organs, in the case of the 2022 soybean trials, the stems were the most intense. This may be due to varietal characteristics or unfavourable abiotic factors. A similar series of experiments was conducted to determine the effect of primary and secondary seed treatment under artificial infection of soybean with phytopathogenic bacteria *X. axonopodis pv. glycines* 9192 pcs. The results are shown in Figure 2.



a) b) c) d)

Figure 2. Degrees of plant damage under artificial inoculation with *X. axonopodis pv. glycines pcs*. 9192

Note: a – the degree of damage on the leaves (in variants without re-treatment); b – the degree of damage on the leaves (in variants with re-treatment); c – the degree of damage on the stems (in variants without re-treatment); d – the degree of damage on the stems (in variants with re-treatment)

Source: compiled by the authors

As can be seen from Figure 2, the results of artificial inoculation with xanthomonads and pseudomonads are similar – it is the composition of the studied preparations that showed the greatest efficiency in all variants. The low efficiency of the treatment (without additional treatments) with a pesticide based on Fludioxonil and Metalaxyl-M in restraining the development of pustular bacteriosis was shown since the indicators of damage did not differ from the control values (Table 2, Figs. 1-2). With additional treatment, the degree of damage was reduced by about 15% compared to the control. At the same time, it should be noted that there was significant suppression of the development of soybean plant infection under artificial infection with phytopathogenic bacteria when their leaves and stems were treated with a mixture of trace element preparations. The degree of damage on the leaves did not exceed 2 points, and only single necrotic spots were observed on the stems. In addition, in contrast to the experiments with pseudomonads, only dressing without additional treatments was sufficient to restrain the development of *X. axonopodis pv. glycines*.

It should be noted that the chemical pesticide showed higher efficiency on the leaves during the first 14 days of the experiment and restrained the development of the disease, however, its efficiency by day 37 of the experiment was significantly reduced compared to the studied preparations. Thus, this confirms the probable heterogeneous effectiveness of the drugs obtained by ablation technology.

Usually, representatives of phytopathogenic bacteria of the genus *Pseudomonas* are more resistant to the effects of drugs of different origins compared to representatives of the genus *Xanthomonas*, which was consistent with laboratory controls (Kravchenko *et al.*, 2021) and field studies conducted in 2021. At the same time, in 2022, angular spot lesions developed more slowly and less intensively compared to the development of pustular bacteriosis. This may be due to abiotic factors, in particular, increased air temperature during the field experiment. According to the literature search, it can be argued that this feature of the effect is because representatives of the genus *Pseudomonas* develop better at 21-27°C under conditions of high humidity, and *Xanthomonas* spread faster and affect the plant to a greater extent at high temperatures of 30-33°C (Velasquez *et al.*, 2018; Burdon & Zhan, 2020), which is consistent with the climatic conditions recorded at the time of the experiment in August 2022.

At the same time, the development of disease symptoms on the stem under artificial infection with *X. axonopodis pv. glycines*, both without and with repeated treatment with micronutrient preparations, do not exceed 1 point (unlike variants with artificial infection with *P. savastanoi pv. glycinea*, where the manifestation of the lesion was from 1 to 2 points over time). This may mean that the pathogen will not circulate through the plant and infect new organs, and in particular the beans, which are the most important indicator for yield.

Thus, studies have shown that preparations obtained by electropulse ablation are promising tools in the soybean protection system. Their undoubted advantage is a pronounced antipathogenic effect and the simultaneous absence of toxic effects on symbiotic microorganisms of common soybean.

CONCLUSIONS

Soybean varietal characteristics have been found to affect the degree of infection with phytopathogenic bacteria. According to the results of the 2021 experiments, it was found that common soybean plants of the Drayton variety showed lower resistance to the disease in terms of the level and speed of its manifestation compared to the Strike variety. It was also found that the features of the Kyoto variety affect the damage to various plant organs.

A significant factor in the development of disease manifestations is weather conditions, in particular, exceeding the average ten-day air temperature, significant temperature fluctuations during the day and humidity at the level of 150-200% of the average annual norm.

It was determined that seed treatment with a chemical pesticide without additional treatments does not reduce the manifestations of pustular bacteriosis and angular spot of soybean compared to the control (no treatment) variant. The treatment and foliar treatment with a chemical pesticide based on Fludioxonil and Metalaxyl-M only partially reduce the manifestations of bacteriosis compared to the control variants (by about 15%), and the chemical pesticide show the greatest effectiveness only in the first 14 days, while its effectiveness significantly decreases in the period of 14-30 days after artificial infection.

Micronutrient drugs based on metal aqua-chelates were found to significantly slow down the development and reduce the intensity of soybean damage by the main bacterial diseases – angular spot (pathogen *Pseudomonas savastanoi pv. glycinea*) and pustular bacteriosis (pathogen *Xanthomonas axonopodis pv. glycines*) when treating seeds.

Treatment of soybean plants with experimental preparations according to the Comfort scheme (at consumption of 150 ml/t of seeds), fertiliser “Dobrodiy” (at consumption of 2.4 l/t of seeds) and microelement preparation “Micro Protect” (at a consumption of 500 ml/t of seeds), as well as two foliar treatments with the specified mixture of microelement preparations, delays the manifestation of plant damage until the time of harvest, which is likely to increase yields. The probability of coordination of foliar treatment of plants with the peculiarities of the functioning of pathogens of different systematic groups of bacterial pathogens of soybean diseases was noted.

The results obtained pointed to several promising tasks for further research. Firstly, the results of 2022 indicate a pronounced effectiveness of additional foliar treatments during the growing season along with traditional seed treatment, however, the question of their number remains open. Secondly, comparing the results of 2021 and 2022, the effectiveness of further combining the products was noted. However, the creation of composite preparations is impossible without thorough laboratory research to determine effective doses and concentrations. Thirdly, since Comfort has already received the Organic Standard certificate, the next step may be to enter the European and global markets for innovative medicines. At the same time, this requires further research on their bio- and eco-safety, as well as clarification of the mechanism of action of these compositions. Finally, there is the issue of checking the effectiveness of such micronutrient preparations obtained utilizing electropulse ablation for seeds and adult plants already affected by bacterial pathogens.

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CONFLICT OF INTEREST

None.

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Вплив препаратів, отриманих методами електроімпульсної абляції, на розвиток фітопатогенних бактерій сої

Анотація. Збудники плямистості сої (*Pseudomonas savastanoi pv. glycinea*) та пустульного бактеріозу сої (*Xanthomonas axonopodis pv. glycines*) є поширеними фітопатогенними бактеріями. Проте відсутність офіційно зареєстрованих препаратів проти них стимулює пошук нових рішень. Метою дослідження було визначення впливу вказаних мікроелементних препаратів, отриманих електроімпульсною абляцією, на бактерії за штучного зараження сої музейними штамами збудників пустульного бактеріозу та кутастої плямистості. Антибактеріальну активність досліджених препаратів порівнювали з варіантами без обробки й дією традиційного хімічного пестициду на основі Флудиоксонілу та Металаксилу-М. Поширення і розвиток хвороби оцінювали за кількістю уражених рослин, використовуючи шкалу від 0 до 4 балів. З'ясовано, що сортові особливості сої впливають на ступінь ураженості фітопатогенними бактеріями. Виявлено, що значимим фактором у розвитку проявів хвороби є погодні умови, зокрема температура повітря. Доведено, що протруєння насіння хімічним пестицидом на основі Флудиоксонілу та Металаксилу-М за відсутності додаткової позакореневої обробки не зменшує прояви та ступінь ураження, порівняно із контролем (без протруювання). Протруювання та позакоренева обробка хімічним пестицидом на основі Флудиоксонілу та Металаксилу-М лише частково зменшують прояви бактеріозів, порівняно з контрольними варіантами (приблизно на 15 %). В той же час, застосування препаратів, отриманих методами електроімпульсної абляції, є перспективним проти фітопатогенних бактерій в системі технології вирощування сої – а саме визначено, що за умови протруювання рослин сої дослідними препаратам за схемою Комфорт (витрата – 150 мл/т насіння) + добриво «Добродій» (витрата – 2,4 л/т насіння) + мікроелементний препарат «Мікро протект» (витрата 500 мл/т насіння) + дві позакореневі обробки вказаною сумішшю мікроелементних препаратів посилюється затримка прояву ураженості рослин до часу збору врожаю, що в свою чергу найімовірніше призведе до підвищення показників урожайності. Практичне значення роботи полягає у визначенні ефективних методів боротьби з фітопатогенними бактеріями, що шкодять сої

Ключові слова: бактеріальні патогени рослин; бобові; кутаста плямистість; пустульний бактеріоз; наноаквахелати; абляційні технології

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Peculiarities of *Bacillus Subtilis* strains influence on the development of *Triticum Aestivum* L. in inoculative cultures

Abstract. The research relevance is predetermined by the need to study strains of *Bacillus subtilis* bacteria that have a positive effect on plant growth and development and exhibit a stimulating effect at optimal bacterial loads. The research is of great importance for agriculture, ecology, and sustainable development. The research aims to determine the effect of new strains of *B. subtilis* (H3, H10, H13, H36, H38, H40, H43, H45) on the development of winter wheat (*Triticum aestivum* L.) seedlings when inoculated with inoculated crops. Laboratory, vegetation, and mathematical and statistical methods were used in the study: deep cultivation of strains, roll method of germination of test plant seeds, and data processing using Statistica 8.0 and MS Excel. The results of the model experiment on the effect of culture liquids of *B. subtilis* strains under different technological forms and dilutions on the growth and development of wheat test plants are summarised. It has been established that at dilutions of 1:10, 1:50, 1:100, and 1:500, the stimulating effect of bioagents is observed, and the maximum effect is achieved at a dilution of 1:100. It has been shown that the greatest positive effect on wheat seed germination was observed for *B. subtilis* inoculants applied to seeds in mature technological forms (spore culture, 2.0×10^7 cells per seed). The germination energy of *Triticum aestivum* L. seeds increased by 96.5% when interacting with *B. subtilis* inoculants, and the raw weight of seedlings increased by 84.0-109.6% depending on the experiment variant compared to the control, which indicates the

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growth-stimulating properties of the new strains. It was proved that the use of mature cultures of *B. subtilis* H38, H40 and H45 resulted in an increase in root weight by 4.8-11.3% compared to the control without bacterisation. When treated with culture fluids of *B. subtilis* H3, H10, H13, H36, and H43 in the form of vegetative cells, the root mass decreased by 11.8-44.0% compared to the control. The use of the studied strains of *B. subtilis* effectively affects the development of winter wheat and is a promising inoculant with a growth-stimulating effect. The practical significance of the study is to understand and determine the potential benefits of using *Bacillus subtilis* bacterial strains to enhance the growth and development of plants, in particular winter wheat (*Triticum aestivum* L.)

Keywords: bacterial inoculant; plants; seeds; winter wheat; growth; stimulating properties

INTRODUCTION

Sustainable development of crop production and increased crop yields in the face of climate change are possible through the use of highly effective biological products based on active strains of microorganisms. The action of the products promotes the synthesis of natural antidepressants and anti-stress factors of resistance to drought, waterlogging and other adverse environmental conditions in the soil and directly in the plant itself (Verma *et al.*, 2018; Vorobei & Logosha, 2021). Biological products inhibit pathogenic microbiota and form an "induced resistance system" in plants, which prevents the development of diseases from phytopathogenic organisms (Gadzalo *et al.*, 2019).

The creation of inoculants consisting of associations of bacteria with additive and synergistic effects on plants and increasing the resistance of the plant-bacterial system is very promising. In addition, when using different inoculants, it is necessary to calculate the bacterial load on the seed, as well as the technological parameters of the formulations selected for use (Borko *et al.*, 2022).

S.F. Kozar (2021) showed a positive synergistic effect of the introduction of mixed cultures of soil microorganisms into various agrocenoses, which is promising both for physiological indicators of plant growth, activation of the biological system "soil-plant-microbiome", and for the possibility of soil improvement, reducing the pesticide burden on the environment (Borko *et al.*, 2022). Due to targeted selection and optimisation of production technologies for the manufacture of modern microbial preparations, beneficial soil microorganisms – the basis of biological products – acquire higher activity, reproduction rate, resistance to temperature fluctuations, light intensity, etc. A promising scientific and practical area of agricultural microbiology is the formation of multifunctional associations of microorganisms that, when introduced into the metagenome of native soil communities, would return non-commodity crop products to biological cycles, and improve soil properties, increasing their fertility (Kopylov *et al.* 2020). The analysis of competitiveness to anthropogenic stress factors creates opportunities for the creation of innovative knowledge-intensive developments for the management of biological processes in agrocenoses. Thus, the selective formation of the diversity of the soil and rhizosphere microbial complex is important for increasing competitiveness and research of complex complexes of plant physiological characteristics.

To ensure the effective introduction of soil microorganisms into crop agrocenoses in the form of various preparative forms, it is necessary to consider several aspects related to the characteristics of the producer strain, the peculiarities of its interaction, the preservation of stability and viability for a long period, as well as the peculiarities and technology of growing a particular crop into the root zone of which beneficial microorganisms are introduced. The methods of seed inoculation used for research purposes are often impossible to use on an industrial scale, and there are significant technical problems with maintaining viable microbial inocula on seeds during seed processing and storage, as noted in several studies by I.K. Kurdish (2018). Other studies show the positive effects of seed inoculation with *Bacillus* bacteria, such as

A.F. Santos *et al.* (2021), where scientists concluded that an inoculant based on a composition of *Bacillus subtilis* and *B. megaterium* is effective for grain yields, as well as for increasing protein content and improving plant fibre digestibility. In other studies, V.F. Guimarães *et al.* (2021) showed that by using similar inoculants, high efficiency can be achieved in the cultivation of legumes, resulting in productivity statistically higher than the control without inoculation.

Most bacteria (including spore-forming bacteria of the genus Bacillus sp.) released from rhizosphere soil form stable associations, which allows microorganisms to gain several competitive advantages when introduced into the root zone of plants (Mawarda *et al.*, 2020). As a result of the introduction, biological agents are exposed to abiotic and biotic factors that can have both positive and negative effects on bacterial activity. Given the current research on understanding the relationship between rhizobacteria and plants, J. Poveda & F. González-Andrés (2021) and T. Tsotetsi *et al.* (2022) summarise the current knowledge base on the key metabolites released by both bacteria and plants, their role in the interaction between organisms and responses to various environmental stresses.

According to scientists, bacteria from the *Bacillus* genus produce secondary metabolites and can be used as natural insecticides for the biocontrol of pathogens through the production of compounds with aseptic activity, synthesis of enzymes that lysate fungal cell walls, and induction of systemic reactions in host plants, and have a positive impact on the soil ecosystem (Saxena *et al*, 2020), enhance plant growth and development through the production of phytohormones, increase the availability of essential nutrients (nitrogen, phosphorus, iron), and increase ethylene levels through ACC deaminase (Oleńska *et al.*, 2020).

Studies by H. Li *et al.* (2021) show that biostimulation of maize crops with *Bacillus sp.* MGW9 strain improves seed germination on saline soils and increases the length of the main root by 7% due to better water uptake, higher chlorophyll, proline, soluble sugar, superoxide dismutase, catalase, peroxidase and ascorbate peroxidase activity, while reducing malondialdehyde content.

In this regard, the search for highly active and new strains of soil microorganisms is relevant for microbiology, biotechnology, soil indication and diagnostics, as well as for screening producers of physiologically active substances.

The research aims to determine the peculiarities of the influence of new strains of *B. subtilis* on the development of test plants (winter wheat seedlings *Triticum aestivum* L.) in the case of using inoculated bacterial cultures.

LITERATURE REVIEW

The gram-positive bacterium *Bacillus subtilis* has a powerful extracellular protein secretion system and does not release any toxic metabolic by-products into the environment. A variety of metabolic processes, and genetic and biochemical variability have led to the widespread use of *B. subtilis* bacteria in various fields of agriculture, medicine, industry (GRAS status – *generally regarded as safe*), and in the production of probiotics, immunoreactive factors, enzymes, amino acids, vitamins, etc. It has been proven to increase the decomposition of plant residues (Avdeeva *et al.*, 2016) and the resistance of barley crops to disease development (Kriuchkova & Patyka, 2020).

Significant efforts of scientists are aimed at both studying and developing ways to control and change the metabolism, gene expression and protein activity of this bacterium (Cui *et al.*, 2018; Chuiko *et al.*, 2021).

Spore-forming bacteria *B. subtilis* (as well as other representatives of the *Bacillus* genus – *B. megaterium, B. atrophaeus, B. licheniformis, B. amiloliquefaciens, B. pumilus, B. mojavensis*, etc.) are among the most sensitive and dynamic components of soil microbial communities, especially under anthropogenic load. Today, research is relevant to study the most active producers of metabolites that have a positive effect on plants – bacteria *B. subtilis, B. pumilus, B. brevis, B. megaterium*, etc., which promote plant growth through the production of phytohormones, dissolution of inorganic phosphates, synthesis of organic acids, antagonism to phytopathogenic micromycetes, etc. For example, under the influence of phytohormone-producing bacteria, changes in the endogenous hormonal balance of plants can occur (Patyka *et al.*, 2019).

A. Shrestha *et al.* (2014) showed that the adhesion and formation of biofilms by soil bacteria on plant surfaces has a phytopathogenic effect and helps to improve root-soil contact. Thus, the ability of bacteria to form biofilms on plants may be a promising area in agriculture to increase plant productivity.

Bacterisation with soil microorganisms has a positive effect on plant biometrics (height, plant length, root system formation) and dry biomass (Kots *et al.*, 2016). The decrease in inoculation efficiency due to the early application of soil microorganisms can be compensated by using a complex of organic substances (e.g., polysaccharide-protein complex as a stability matrix), which increases the viability of microorganism cells in a resting state. Scientists continue to deepen their knowledge of the regularities of the spatial, taxonomic and functional structure of plant-microbial communities in the root zone of plants and the processes underlying plant-microbial interactions (Krutylo *et al.*, 2017), as well as collect modern monitoring data on the soil microbial biome and carry out comprehensive work on analytical selection of soil microbial strains.

Using metabolomic profiling, they detected and identified molecules produced in roots and root hairs during their infection with rhizobia. Their analysis of soybean root hairs suggested that root hairs synthesise flavonoids, amino acids, fatty acids, carboxylic acids, and various carbohydrates in response to inoculation with the above bacteria, with a high content of trehalose (known as an osmoprotective sugar). To date, several compounds have been identified that are involved in various plant-microbe interactions. For example, g-amino butyric acid, hexahydrohexaoxybenzene-O-methyl, glutamine, and lauric acid, help bacteria overcome the plant's defences during infection. These isoflavonoids and fatty acids appear in free form mainly due to their signalling role in symbiosis, which requires the enhancement of cellular biosynthesis to create structural components necessary to support the development of symbiosis.

For the rational use of the potential of regulatory (signalling) plant-microbe interactions, it is necessary to pay attention not only to the effectiveness of new strains and their compatibility but also to know under what conditions inoculant strains can successfully compete with representatives of soil populations of specific bacteria and colonise the root system of plants.

MATERIALS AND METHODS

The research was conducted at the National University of Life and Environmental Sciences of Ukraine, Department of Soil Science and Soil Protection named after Professor M.K. Shykula. In a model laboratory experiment, the effect of bacterization of *Triticum aestivum* L. plants with strains H3, H10, H13, H36, H38, H40, H43, and H45, which in previous studies were isolated from the phylloplane and rhizosphere of the root system of winter wheat and typical black soil, identified and assigned to the genus *Bacillus* sp. *B. subtilis* (Honchar *et al.*, 2021).

Determination of the optimal load of *B. subtilis* bacteria on wheat seeds was carried out in a laboratory experiment. Bacterial inoculants in the form of a suspension of *B. subtilis* cultures were used both in the form of vegetative cells – the beginning of spore formation and complete sporulation (mature culture). *B. subtilis* strains were cultured on Luria-Bertani (LB) liquid nutrient medium for 72 hours in an orbital shaker incubator at a temperature of at least 28-30°C according to generally accepted methods in microbiology (Tepper *et al.*, 1979; Goldman & Green, 2021). There are treatment options with the following bacterial load: 1) $2.0{\times}10^8$ cells/1 seed; 2) $2.0{\times}10^7$ cells/1 seed; 3) $2.0{\times}10^6$ cells/1 seed; 4) control. Replication was performed four times.

The effectiveness of bacterial inoculants *B. subtilis* on the growth and development of *Triticum aestivum* L. was studied in a model experiment. The scheme of the experiment included: 1 – control (without bacterisation); 2-9 (treatment with the appropriate strain of spore-forming bacteria *B. subtilis* in the form of vegetative cells); 10-17 (treatment with the appropriate strain of *B. subtilis* bacteria in the form of technological maturity of the crop with complete spore release). In the experiment, the seeds of *Triticum aestivum* L. were germinated by the roll method. Two layers of moistened filter paper in the form of ribbons measuring 10×55 cm were used, on which seeds were laid out with the embryos down in one line at an interval of 1 cm and at a distance of 2.0 cm from the side edges and surface of the ribbons (70 pieces in one row). The seeds laid out on the paper were covered with moistened filter paper and polyethene tapes of the same size and rolled loosely. The wrapped rolls were placed vertically in beakers with *B. subtilis* culture fluid and placed in a thermostat at 23-250°C (DSTU 4138-2002..., 2004). The water level in the beakers was monitored to prevent drying out, and distilled water was added to the beakers with the rolls if necessary (water change every 3-5 days). The germination rate of the test culture (length of roots and seedlings) on day 10 was determined using a conventional centimetre scale. Statistical analysis was performed using Statistica 8.0 software, data were calculated using MS Excel.

Experimental studies of plants (both cultivated and wild), including the collection of plant material, were carried out following the requirements of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The main principle in the treatment of agricultural plants with microbial preparations with growth-stimulating activity is the need for a detailed study and establishment of the physiologically appropriate time for plant treatment (developmental stage) and determination of the rational inoculation load when applying them.

As a result of biotesting and studying the effect of the culture fluid of new *B. subtilis* strains on the growth and development of wheat plants, it was found that at dilutions of 1:10, 1:50, 1:100, and 1:500, the stimulating effect of bioagents was observed (Fig. 1). Thus, the lowest stimulatory effect of *B. subtilis* strains H3, H10, H13, and H36 was observed at a dilution of the culture fluid of 1:500, and the maximum stimulatory effect was observed at a dilution of 1:100. This confirms that the biological efficacy of *B. subtilis* bacteria is largely due to the production of auxin, cytokinin and gibberellin hormones, and hormonal substances synthesised by microorganisms are extracellular and are present directly in the culture fluid of the strains.

Thus, the study is confirmed by C. Accinelli *et al.* (2018), where the treatment with beneficial microorganisms *B. subtilis* increased shoot length (+7%) and root length (+10%) in maize for grain. The method used to achieve the positive effect was the incorporation of the bacteria into a bioplastic-based composition, rather than the use of biofilms or dilutions.

G.M. Teixeira *et al.* (2021) revealed a positive effect of the use of bacterial biostimulation of soybean seeds, which increased germination rate by 15%, root length by 33% and root mass by 27% compared to the control.

The results are generally positive but variable, so more scientific information is needed for different crops and cultivation technologies, considering different beneficial microbes (species and strains) and variable climatic conditions, to understand the impact of seed treatment.

Reports on studies of metabolites of soil microorganisms or physiologically active substances of microbial origin, which are more appropriate for regulating plant growth and development, can be found in studies (Kots' *et al.*, 2016).

The native culture fluid of *B. subtilis* strains H10, H13, H40, H43 and H45 was found to inhibit the growth of coleoptiles, the rate was lower than the absolute control by 17.0-35.0%. The results obtained indicate the high activity of strains producing auxin-like compounds in the culture fluid and the feasibility of using a diagnostic test for the auxin activity of *B. subtilis* exometabolites in studies.

In general, the dilution of the culture fluid had a positive effect on the growth of wheat coleoptiles (Fig. 1), which indicates the production of physiologically active compounds in different concentrations by *B. subtilis* strains (a manifestation of the stimulatory effect). The exogenous supply of active metabolites to plants under the introduction of *B. subtilis* can also contribute to the optimisation of organogenesis processes and, as a result, increase crop productivity.

It is worth noting that liquid forms of microbial preparations make it possible to apply them with the help of special sprayers during the vegetation of plants in certain phases without additional manipulations. The optimal combination of pasteurisation and treatment of vegetative plants, considering the appropriate rates of preparation and the timing of treatments, is considered extremely important for the development of an effective method of applying microbial preparation. Following scientific, theoretical and practical studies, it has been proven that the signalling interaction between plants and microorganisms is associated with the regulatory functions of plants (especially concerning the rate of reproduction and the number of bacterial cells). Such regulation is very important because the potential rate of reproduction and metabolic activity of bacterial cells is much higher than that of plant cells. Therefore, the interaction of plants and microorganisms is a complex process that is implemented through molecular mechanisms and metabolic integrations (Patyka *et al.*, 2019).

It is known that the morphometric parameters of the growth and development of cultivated plants do not change significantly depending on the method of using microbial preparations, both when treated with the culture fluid of the producer strain and the supernatant of the bacterial culture fluid (O'Callaghan, 2016; Gadzalo *et al.*, 2019). Scientists from around the world have shown that such treatments equally contribute to the improvement of biometric parameters of the culture. In addition, the formation of growth parameters of agricultural plants depends on the rate of application of the microbial preparation. Microbiological regulation of growth processes is an effective means of increasing the resistance of cultivated plants to adverse environmental factors and increasing crop productivity (Pandey *et al.*, 2018) by mobilising the potential capabilities of the plant organism.

The study of O. Lastochkina *et al.* (2020) confirms the results (Fig. 1) and proves the protective effect of Bacillus subtilis (strain 10-4) against drought stress. The bacterium was applied by biopriming to wheat seeds that were either sensitive (T. aestivum cv. Salavat Yulaev) or tolerant (cv. Ekada 70) to drought conditions during the germination phase. B. subtilis promoted germination and plant growth of 6-day-old seedlings (both length and fresh/dry weight of roots and shoots) under normal growth conditions and rapidly activated specific metabolic adaptations to drought stress conditions by reducing lipid peroxidation, proline content and electrolyte leakage in 21-day-old seedlings.

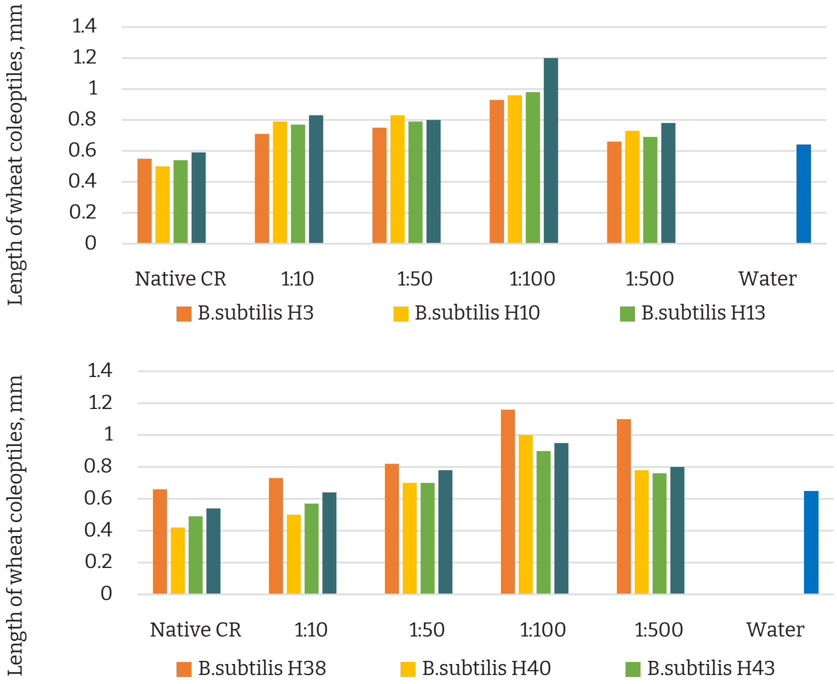

Figure 1. The activity of physiologically active metabolites of *B. subtilis* strains and their influence on wheat coleoptiles growth

As a result of the studies, the complex parameters of stimulation of *B. subtilis* bacteria were determined by analysing the germination parameters of the test crop *Triticum aestivum* L., namely: energy, germination, speed, and friendliness of germination, as well as seedling weight and root weight (based on the cell load per seed). The most positive effect on wheat seed germination was observed for *B. subtilis* inoculants applied to seeds in mature technological forms (spore culture) and at the rate of 2.0×10^7 cells per seed (Table 1).

Table 1. Biometric indices of germination of the test culture *Triticum aestivum* L. under the influence of inoculation cultures of spore-forming bacteria *B. subtilis*, model experiment

Experiment variants	Germination energy, %	Root system length, cm	% to control	Length of seedlings, cm	% to control
for the use of vegetative cells					
Control (water treatment)	89.0±1.4	12.7±1.9	-	9.8±2.6	-
B. subtilis H3	90.2±2.8	13.6±1.9	107.0	9.0±2.0	91.8
B. subtilis H10	90.6±2.4	12.0±1.9	94.5	8.6±2.1	87.8
B. subtilis H13	90.0±2.8	12.2±1.7	96.1	8.3±2.0	84.7
B. subtilis H36	90.0±2.8	14.3±1.6	112.6	10.4±1.6	106.1
B. subtilis H38	89.3±1.4	14.0±1.6	110.2	8.5±2.0	86.7
B. subtilis H40	89.7±1.4	12.8±1.9	100.8	9.6±2.0	98.0
B. subtilis H43	90.5±2.8	13.0±1.7	102.4	11.5±3.5	117.3
B. subtilis H45	91.0±2.4	14.0±1.6	110.2	11.2±3.5	114.3
for using a mature spore culture					
B. subtilis H3	90.7±2.8	14.3±1.6	112.6	11.8±1.9	120.4
B. subtilis H10	96.0±1.5	14.8±1.7	116.5	11.5±1.6	117.3
B. subtilis H13	96.4±1.5	13.7±1.9	107.9	11.6±1.6	118.4
B. subtilis H36	96.5±1.5	14.1±1.1	111.0	12.0±1.8	122.4
B. subtilis H38	96.2±1.5	13.8±1.9	108.7	12.3±2.0	125.5
B. subtilis H40	90.7±2.8	13.5±2.3	106.3	10.3±1.6	105.1
B. subtilis H43	93.5±3.8	14.3±1.6	112.6	12.0±1.8	122.4
B. subtilis H45	91.7±2.4	14.5±1.6	114.2	12.2±3.5	124.5

Source: compiled by the authors

The positive effect of microbial preparations based on *Bacillus subtilis* sp. on the biometric parameters of winter wheat plants was also noted in the works of other authors (Liu *et al.*, 2017). Several scientists have described the positive effect of both synthetic growth stimulants (Calvo *et al.*, 2014) and microbial preparations with growth-stimulating effects (Yadav & Chandra, 2014) on plant growth and development. However, microbial preparations are usually used classically, namely for seed bacterisation.

The laboratory germination rate of winter wheat seeds was more than 92.5% and tended to actively form future seedlings and roots. In general, the germination rate of the test crop met the requirements for the seed. A slight decrease in seed germination under the roll method is compensated by its rapid germination, higher seedling formation index and relatively better growth and development rate.

The germination energy of winter wheat (*Triticum aestivum* L.) seeds increased by 96.5% when using *B. subtilis* inoculant bacteria. It should be noted that the use of spore-forming bacteria activates the growth of primary roots of winter wheat plants and, in general, increases the length of the root system (by 6.3-16.5%, respectively, compared to the variant without treatment with the strains).

The treatment of the biotest with inoculated cultures of *B. subtilis* led to an increase in the raw weight of seedlings by 84.0-109.6%, depending on the experiment variant, compared to the control (Table 2), which indicates the growth-stimulating properties of the new strains.

The data obtained indicate the biological characteristics of the experimental strains of *B. subtilis*, which are associated with the formation of effective plant-microbe interactions through the exchange of exometabolites. The mechanisms of interaction between bacteria and plants are controlled by both partners and provide them with mutual benefit. This interaction results in the stimulation of plant growth and development and stabilisation of its production process.

It is known that the inoculation of plants with cytokinin-synthesising bacteria stimulates the accumulation of biomass of both shoots and roots (Liu *et al.*, 2017). According to the studies, it was found that the mass of roots using *B. subtilis* cultures in the form of vegetative cells (*B. subtilis* strains H3, H10, H13, H36, H43) was 11.8-44.0% lower than in the control. The use of mature spore culture of *B. subtilis* (*B. subtilis* H38, H40 and H45) resulted in an increase in root weight by 4.8-11.3% compared to the control variant without bacterisation. Thus, the effect of the studied inoculant strains on the weight of the primary roots of test plants was unequal, and bacterisation of *Triticum aestivum* L., in general, promotes better development of the root zone of test plants (which may further affect the activation of the adsorption capacity of roots to absorb nutrients from the substrate medium, soil) (Table 2).

Table 2. Influence of *B. subtilis* inoculation cultures on the wet weight of seedlings and roots of *Triticum aestivum* L.

Experiment variants	Raw weight of roots, mg	% to control	Raw weight of seedlings, mg	% to control
for the use of vegetative cells				
Control (water treatment)	85.0±3.6	-	103.5±6.3	-
B. subtilis H3	75.0±10.4	88.2	110.0±4.1	106.3
B. subtilis H10	55.5±4.5	65.3	89.0±18.0	86.0
B. subtilis H13	56.0±4.5	65.9	87.3±18.4	84.0
B. subtilis H36	76.0±7.4	89.4	104.8±6.0	100.5
B. subtilis H38	89.0±3.4	104.7	102.7±5.8	99.2
B. subtilis H40	87.5±14.4	102.9	102.5±5.5	99.0
B. subtilis H43	76.4±7.0	89.9	108.5±5.1	104.8
B. subtilis H45	94.0±9.8	110.6	107.8±8.6	104.2
for using a mature spore culture				
B. subtilis H3	76.3±7.0	89.8	110.2±4.0	106.5
B. subtilis H10	75.8±11.1	89.2	105.3±6.6	101.7
B. subtilis H13	79.0±5.7	92.9	105.5±6.6	101.9
B. subtilis H36	83.2±3.6	97.9	113.0±4.1	109.2
B. subtilis H38	90.0±9.6	105.9	113.4±4.1	109.6
B. subtilis H40	89.1±3.4	104.8	106.0±5.1	102.4
B. subtilis H43	80.3±3.7	94.5	110.5±4.0	106.8
B. subtilis H45	94.6±5.9	111.3	110.0±4.1	106.3

Source: compiled by the authors

Summarising the results of the research, it can be noted that new strains of *B. subtilis* in the form of inoculated cultures had a positive effect on the development of winter wheat *Triticum aestivum* L., which indicates the production of extracellular hormonal substances by bioagents in different concentrations, the so-called stimulatory effect. The mature technological forms of *B. subtilis* inoculants accelerated the germination of wheat seeds and activated the growth of primary plant roots and the formation of their root system. The growth-stimulating properties of the new *B. subtilis* strains were also confirmed by the increase in the biomass of both seedlings and plant roots.

CONCLUSIONS

The signalling response of plants to bacterial inoculants *in vivo* depends on several environmental factors, including plant genotype, which can significantly reduce the efficiency of their practical use. However, pre-sowing seed treatment remains the most affordable and effective agricultural measure today. Since plant-microbial interaction (colonisation of the rhizosphere, plant phylloplane; production of antimicrobial metabolites, physiologically active, phytohormonal substances of auxin, gibberellin, cytokinin nature and vitamins; induction of systemic resistance in the plant, etc.) is considered an important mechanism of biological control of agricultural systems.

Following research results, it is shown that the data obtained at the level of model testing of *B. subtilis* bioagents on winter wheat (*Triticum aestivum* L.) plants allow us to identify the positive effect of inoculants associated with the main indicators of plant growth and development and to trace the stimulating effect when using optimal dilutions of the culture fluid. The exogenous supply of active metabolites to plants upon introduction of *B. subtilis* strains makes it possible to optimise the processes of organogenesis. It was found that at dilutions of 1:10, 1:50, 1:100, 1:500, the stimulating effect of bioagents was observed: from minimal (*B. subtilis* strains H3, H10, H13, H36 in the case of dilution of the culture fluid 1:500, to the maximum stimulating effect at dilution 1:100). Thus, the biological efficacy of *B. subtilis* strains is largely due to the production of exometabolites that are concentrated in the culture medium. At the same time, the native culture fluid of *B. subtilis* strains H10, H13, H40, H43 and H45 inhibits growth processes, which indicates the activation of auxin-like compounds producers in the culture fluid. In the analysis of the effectiveness of plant-microbial interaction in the case of inoculation with different technological cultures of *B. subtilis*, the expediency of using mature spore cultures of *B. subtilis* spore cultures (2.0×10^7 cells per seed), which makes it possible to manifest the growth-stimulating properties of new strains, in particular, according to the parameters of the raw weight of seedlings and roots of *Triticum aestivum* L. Thus, the knowledge about the peculiarities of the influence of new strains of *B. subtilis* on the development of winter wheat as promising inoculants with the effect of growth stimulation has been expanded.

The search for new producer strains with a protective and stimulating effect and the study of their peculiarities of influence on the plant organism is a promising scientific direction. This will reveal new patterns of spore-forming bacteria and their role in the nutrition of cultivated plants and is also necessary for improving microbial inoculants to increase their manufacturability and efficiency when used in modern crop cultivation technologies.

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CONFLICT OF INTEREST

None.

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Особливості впливу штамів *Bacillus Subtilis* на розвиток *Triticum Aestivum* L. у разі застосування інокуляційних культур

Анотація. Актуальність дослідження полягає у необхідності вивчення штамів бактерій *Bacillus subtilis*, які позитивно впливають на ріст і розвиток рослин та проявляють стимулювальний ефект за оптимальних бактеріальних навантаженнях. Дослідження має велике значення для сільського господарства, екології та сталого розвитку. Мета дослідження полягає у визначенні впливу нових штамів *B. subtilis* (Н3, Н10, Н13, Н36, Н38, Н40, Н43, Н45) на розвиток проростків пшениці озимої (*Triticum aestivum* L.) у разі застосування інокуляційних культур. В роботі використано лабораторні, вегетаційні та математично-статистичні методи: глибинне культивування штамів, рулонний метод пророщування насіння тест-рослин, обробка даних за програмами Statistica 8.0, MS Excel. Узагальнено результати модельного досліду стосовно впливу культуральних рідин штамів *B. subtilis* за різних технологічних форм і розведень на ріст і розвиток тест-рослин пшениці. Встановлено, що при розведеннях 1:10, 1:50, 1:100, 1:500 спостерігається стимулювальна дія біоагентів, а максимальний ефект досягається при розведенні 1:100. Показано, що найбільший позитивний вплив на проростання насіння пшениці мали інокулянти *B. subtilis*, які наносили на насіння у зрілих технологічних формах (спорова культура, $2{,}0 \times 10^7$ клітин на насінину). Енергія проростання насіння *Triticum aestivum* L. підвищується при взаємодії з інокулянтами *B. subtilis* до 96,5 %, а також збільшується сира маса проростків на 84,0-109,6 % залежно від варіанту досліду порівняно з контролем, що свідчить про рістстимулювальні властивості нових штамів. Доведено, що за використання зрілих культур *B. subtilis* Н38, Н40 і Н45 відбувається зростання маси коренів на 4,8-11,3 % порівняно з контролем без бактеризації. При обробці культуральними рідинами *B. subtilis* Н3, Н10, Н13, Н36, Н43 у формі вегетативних клітин маса коренів зменшується на 11,8-44,0 % порівняно з контролем. Використання досліджених штамів *B. subtilis* ефективно впливає на розвиток пшениці озимої і є перспективним інокулянтом з ефектом рістстимуляції. Практичне значення дослідження полягає у розумінні та визначенні потенційних користей від застосування штамів бактерій *Bacillus subtilis* для підвищення росту і розвитку рослин, зокрема озимої пшениці (*Triticum aestivum* L.)

Ключові слова: бактеріальний інокулянт; рослини; насіння; пшениця озима; ріст; стимулювальні властивості

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Development of biologically engineered corn growing technologies

Abstract. Agricultural producers use large quantities of mineral fertilisers and plant protection products, which leads to soil, seed and environmental pollution and reduces the profitability of production. Modern agriculture starts to shift its focus to biologisation, which includes the development and implementation of environmentally friendly alternative systems, the reduction of chemicals, the introduction of energy and resource-saving technologies, use of biological plant protection products and bio-organic fertilisers. The research aims to investigate the effectiveness of biological technologies for growing maize in an environmentally friendly way using various organic fertilisers. The following methods were used to study the new corn growing technology: analysis, synthesis, analogy, comparison, and generalisation; field and laboratory; calculation – assessment of economic and bioenergy efficiency. To study the effect of organic fertilisers of different biological origins on the assessment of the humus state of typical chernozems, field experiments were conducted to assess the impact on corn grain yield in the Ukrainian Steppe. After the application of organic fertiliser, the limits of organic carbon content in humus were 3.2-3.5%, humic acid 1.9-2.2%, and fulvic acid 0.7-1.0%. In the experimental samples of maize grain, the content of crude protein ranged from 13.5 to 14.0%, crude fat from 2.4 to 2.7%, crude fibre from 2.1 to 2.4%, crude ash from 1.3 to 1.7%, and nitrogen-free extractives from 64.7 to 67.4%, moisture from 12.0 to 14.9%. The grain yield in the control variant was 9.7 t/ha, and in the experimental plots, it was 11.5-13.4 t/ha. The data obtained can help in the development of biologically based maize cultivation technology following the ecological gradient of cultivation and yield with optimisation of the studied agrotechnical methods

Keywords: yield; humus; organic fertiliser; environmentally friendly products; grain quality

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INTRODUCTION

Climatic conditions have been changing rapidly in recent years, but to continue sustainable harvesting, it is necessary to improve crop production technologies. Modern grain growing technologies harm the technical, biochemical, and hygienic quality of the grain, and they also pollute the soil and the environment with toxic substances that reduce its biological activity and contribute to the accumulation of hazardous chemicals in groundwater. The dependence on chemicals and their indiscriminate use in modern agriculture can cause serious environmental problems: water eutrophication, soil acidification and air pollution.

Maintaining soil fertility with sufficient organic matter of animal origin and growing environmentally friendly products is one of the ways to develop cost-effective crop production. The use of biobased technologies to produce high-quality crops requires improving fertiliser systems and addressing the issue of plant protection against pests and diseases, so the development of new elements of environmentally friendly grain-growing technology and the improvement of existing ones is of great importance.

Demand for organic crop production and certified organic food is growing rapidly in economically developed countries, and according to the Organic Trade Association (2023), corn production is growing steadily every year. Ukraine needs to develop a strong production and scientific potential in the field of crop production with large-scale application of biological farming methods and production of environmentally friendly agricultural products, and a developed organic agriculture sector.

Corn is the main grain and fodder crop in Ukraine and is of strategic importance in agricultural production, as its grain is used in large volumes in the food, industrial, livestock and medical sectors. O. Garazha (2021) considers that an increase in the gross harvest of corn should be achieved exclusively by increasing crop yields and by introducing the latest innovative cultivation technologies that ensure the efficient use of agroclimatic, material and technological resources.

Where agronomic and biological weed control measures are ineffective, one of the most acceptable methods of control in maize crops is the use of chemical protection products. O.H. Milenko *et al.* (2020) report that intensive cultivation of modern high-yielding maize hybrids involves the application of effective herbicides for weed control – Tornado, Zenkor, Prima, Roundup, Stellar, Harness, Master Power, Primexra Gold, but their main difference from other plant protection products is their high toxicity, in addition, they contain toxic organic and inorganic compounds that quickly penetrate weed tissues through the leaf apparatus and roots, inhibiting the synthesis of amino acids and stopping the vegetative processes of plants. According to B. Fuchs *et al.* (2022), the scope of application of biochemical herbicides is increasingly being improved, which are conventionally divided into four groups: microbial preparations of toxic action; crude extracts of plant or microbial origin; individual natural compounds and their mixtures with varying degrees of purification; synthetic analogues of natural compounds. Practical trials by O.P. Stetsiuk *et al.* (2022) reported that it is better to use effective herbicides but to mitigate the negative impact on the culture, it is recommended to use them in tank mixtures with Biocomplex AT, which is a culture liquid of living soil microorganisms *Azotobacter chroococcum, Bacillus subtilis, Bacillus megaterium* and organic elements in the form of chelated organic compounds.

Following T.Yu. Marchenko *et al.* (2021), biological products are used in the cultivation of corn for grain by treating seeds with Ecolist-grain at a dose of 4 l/t, Rostok-grain – 4 l/t, Nanomix-corn-seed treatment – 4 l/t, Reakom-SR-grain – 4 l/t, Quantum-grain – 4 l/t. According to K. Bhatt *et al.* (2022), organic production uses plant protection products against diseases and pests based on microbial biological products of endophytic bacteria *Azotobacter; Bacillus subtilis; Bacillus polymyxa; Latobacillus; Enterococcus* at the recommended dose for seed treatment before sowing – 2.0 l/t, during the growing season – 0.8 l/ha. The biopolymer and effective adhesive Liposam are applied at doses of 0.3 l/t and 0.4 l/ha. To ensure control of pests such as corn and meadow butterflies, Lepidocid is used – a biopesticide of spore protein crystals of bacteria *Bacillus thuringiensis var. Kurstaki*, which is sprayed on crops during the growing season at a dose of 3.0 l/ha. Z. Zhang *et al.* (2022) found that to promote the degradation of cellulose residues and to reduce soil phytotoxicity, it is necessary to use complex biodegraders of stubble-containing enzyme complexes of cellulosolytic action.

Given the analysed studies, the question of the effective use of available organic fertilisers of animal and plant origin arises, with a comparison of the main chemical parameters of soil composition and the impact on the yield of various crops. The research aims to study the effectiveness of biological technologies using organic fertilisers in growing corn for grain in an environmentally friendly way.

LITERATURE REVIEW

Global yields and productivity of corn (*Zea mays L.*) have doubled since the early 90s of the last centuries, and the significant increase in yields is mainly due to chemical fertilisers, breeding and crop care. According to the Agrarian Information Agency (Korol, 2022), a record corn harvest of 12.1 million tonnes was harvested in 2021-2022, which is 7.4% more than in previous seasons. About 32% of the world's corn is used for food, while the remaining 60% is used to produce livestock and poultry feed.

Maize is a plant with independent inflorescences, the structure of which differs from that of other cereals. The male inflorescence (anthers) is a pinnate inflorescence, and the female inflorescence (pistil) is a pointed inflorescence with three or four ears per plant, of different sizes and shapes. According to L. Wang *et al.* (2022), the characteristics of maize hybrids are given, they are represented by cobs of cylindrical and slightly conical shape, but the number of rows of grains in one ear varies from 8 to 20, but sometimes up to 30. Maize kernels are single-seeded fruits consisting of an endosperm embryo and an outer fruit coat. The colour of the seeds can be white, cream, yellow, orange, red, or even black. Depending on the maize hybrid, the weight of 1000 seeds ranges from 100-150 g to 300-400 g.

The commonly used system in Ukraine is the Food and Agricultural Organisation (2016) (FAO) maize hybrid classification, where the variety of varieties is divided into 900 units from 100 to 999. There are five maturity groups of corn hybrids: FAO 100-200, early maturity – 90-100 days; FAO 201-300 medium early maturity – 105-115 days; medium late maturity FAO 301-400 – 115-200 days; medium late maturity FAO 401-500 – 120-130 days; late maturity FAO 501-600 – 135-140 days.

Haphazard implementation of these measures and failure to consider predecessors and crops sown in subsequent years leads to low efficiency and field abandonment. According to S. Maitra *et al.* (2022), proper crop rotation is of great importance in biobased crop production technology, which provides favourable conditions for soil fertility and crop yields. Crop rotation is used for fertilisation systems, mechanical tillage or crop protection against weeds, pests, and pathogens. Since corn has a high nitrogen requirement, the main precursors should be legumes (peas, soya beans, fodder beans, chickpeas, and lupins), one- to two-year artificial grasses, green manure, and compost.

According to the study of J. Wagemans *et al.* (2022), biological plant protection products are selective, rapidly biodegradable chemicals for plant protection that are safe for the environment due to their properties. Biological plant protection products can be divided into the following groups: based on crude extracts of natural origin: alcohol extracts, aqueous extracts, essential oils, etc.; purified or individual natural compounds; the effect on pests is caused by toxins produced by microorganisms; synthetic derivatives or analogues of substances of natural origin.

Biological plant protection products can act as immune inducers, growth regulators, and detergents to help plants avoid serious damage from pest infestations. According to M.H. Saleem *et al.* (2022), minerals play an important role in the life of maize plants, as maize growth in the early stages before the formation of the first aboveground node is very slow, and the root system is poor and cannot intensively absorb nutrients from the soil. According to research by O. Voloshchuk *et al.* (2021), when developing fertiliser systems, it is necessary to consider that developing maize plants need zinc, boron, molybdenum, cobalt, manganese, and copper. The critical period of maize growth is the formation of seven to eight leaves, but mineral nutrition at this stage improves grain quality by increasing the grain size of the cobs.

W. Shi *et al.* (2020) noted that the use of different doses of mineral fertilisers on podzolic chernozems in field crop rotations can increase corn yields by up to 77%, with the highest figure reaching 13 t/ha and achieved when applying $N_{110}P_{60}K_{80}$ mineral fertilisers per 1 ha of crop rotation area, but the removal of the nitrogen component reduces corn yields by 47%, phosphorus by 25% and potassium by 19%.

Humus, peat, ash, compost, and poultry manure are common types of organic fertilisers, and sapropel, an organic silt, is relatively new. According to a study by C. Andorf *et al.* (2019), the use of organic fertilisers is an effective way to enrich the soil with organic matter, which turns into humus and significantly increases fertility, especially since 1 tonne of organic fertiliser produces 35-50 kg of humus. Organic fertilisers produce fulvic and humic acids in the soil, which directly affect plant productivity and resistance to stressful growing conditions.

MATERIALS AND METHODS

Theoretical methods were used in the study of biologically enhanced maize cultivation technologies: analysis and synthesis, comparison – to assess the economic and bioenergy efficiency of maize hybrids; statistical – to establish the reliability of the research results and their dependence on the influence of anthropogenic factors. Empirical methods: field – analysis of the interaction between the object and the natural environment in combination with yield measurement and biometric data; laboratory – measurement of soil and grain moisture, key grain quality indicators.

The meteorological conditions during the years of research fully reflected the climate of the Mykolaiv region. The climate is arid continental, hot, and windy, with frequent dry winds; the maximum direct solar radiation occurred in July with an average temperature ranging from 25 to 39°C.

The study was carried out at the Oasis farm in Ivanivka village, Pervomaiskyi district, Mykolaiv region, in 2021. The object of the study was a high-yielding medium-early hybrid of corn DN Slavytsia FAO 270, with an average yield of 10-12 t/ha. The recommended density for the harvesting period for the Southern Steppe region was 40-50 thousand plants/ha. According to the recommendations made by M.I. Bakhmat *et al.* (2022), the seeding rate of maize in organic farming should be 10-11 seeds/m^2. The experimental variants were arranged in a split-plot design in three replications. The total experimental area was 2.44 hectares. During the research, we used the corn cultivation techniques recommended for the conditions of the region. During the experiment, a weed control strategy was developed: after sowing, blind harrowing was performed, and when the first, third and sixth leaves appeared, scheduled cultivation was carried out. To stimulate growth and avoid the harmful effects of the herbicide on maize seeds, they were treated with a culture liquid containing a composition of live soil microorganisms and organic elements *Azotobacter chroococcum, Bacillus subtilis, Bacillus megaterium* at a dosage of 1.5 l/t.

The maize parameters were determined by methods established by quality standards following the current regulatory documentation DSTU-4525:2006 (2007). During the laboratory test, special methods were used following generally recognised standards in biology and complex biochemical research edited by V.V. Vlizlo (2012): total Nitrogen content converted to crude protein by the Kjeldahl method; crude fat by the method of extraction with organic solvents, crude fibre, or dietary fibre; crude ash, nitrogen-free extractives (NFE).

The soil of the experimental site is a podzolised heavy loamy chernozem, characterised by a groundwater depth of 20-22 m, a humus percentage of 3.1-3.2%, acidity by pH 5.7-6.8, hydrolytic acidity 4.4-4.8 mg/equivalent, absorption capacity – 25.1-28.9 mg/equivalent, base saturation – 84-87%, alkaline-hydrolysed nitrogen compounds, mobile phosphorus, and potassium compounds – 8-11 mg, 9-12 mg, 12-16 mg per 100 g of soil, respectively.

Low natural soil fertility in the study area is one of the factors contributing to low maize yields, but increasing crop productivity can be achieved by using a balanced plant nutrition system (organic fertilisers and micronutrient fertilisers) that considers the hybrid's response to the proposed rates and adjustments at different stages of crop development. To improve the yield of maize hybrids in the arid zones of the Steppe, seven variants of control and experimental plots were laid out in three replications with the application of high-quality organic fertiliser:

- 10 t/ha of semi-rotted cattle manure;
- 15 t/ha of semi-rotted cattle manure;
- 7 t/ha of semi-rotted sheep manure;
- 14 t/ha of semi-rotted sheep manure;
- grain straw in doses of 8 t/ha and 16 t/ha.

The experiment used a simply improved corn hybrid DN Slavytsia for grain, developed by the Institute of Grain Farming of the National Academy of Agrarian Sciences of Ukraine, which is characterised by high yield, and drought resistance and is recommended for cultivation in the Ukrainian Steppe. The corn hybrid DN Slavitsa is characterised by a powerful root system that effectively uses the natural fertility of soils; it is resistant to root and stems rot, callus, helminths, rust, and lodging; it is suitable for cultivation with minimal or no tillage; it forms a flinty-toothed grain type suitable for cultivation technology in areas of insufficient moisture; it quickly releases moisture when fully ripe.

Semi-rotted manure was used as organic fertiliser, which is formed 3-4 months after manure collection and storage, resulting in a homogeneous mass with losses of nitrogen and organic matter of up to 50%. Humus is a source of energy for all biological processes and an adsorbent for pesticides and heavy metals in the soil. Organic fertilisers applied: semi-rotted cattle manure, semi-rotted sheep manure, and grain straw. Table 1 shows the quality of typical chernozem in the 0-20 soil layer.

Table 1. Humus fractional composition

Experiment variant	Total humus content, %	Organic contents of carbon footprint, %	Humic acid content, %	Fulvic acid content, %
Control	5.28	3.07	1.81	0.81
Semi-rotted cattle manure 10 t/ha	5.41	3.54	1.87	0.92
Semi-rotted cattle manure 15 t/ha	5.28	3.48	1.98	0.97
Semi-rotted sheep manure 7 t/ha	5.67	3.49	2.10	0.84
Semi-rotted sheep manure 14 t/ha	5.80	3.45	2.21	0.89
Cereal straw 8 t/ha	5.82	3.38	2.00	0.75
Cereal straw 16 t/ha	5.48	3.18	2.05	0.80

Source: compiled by the authors

Soil quality was determined according to DSTU 7855:2015 (2016), based on the group composition of humus by the Turin method as modified by Kononova and Belchikova. Harvesting and accounting of the crop were carried out manually from each experimental plot using the gravimetric method at the stage of whole grain ripening. Grain moisture was measured from samples of 30 cobs taken during harvesting. The sowing qualities of maize hybrid seeds were determined according to DSTU 2240-93 (1994) and DSTU 4138-2002 (2004). The results of the study were processed using a computer and information systems software, using the methods of analysis of variance, correlation, and statistical analysis. The study was conducted in compliance with the requirements of the Convention on Biological Diversity (1992).

RESULTS

Technical process planning should consider the realisation of weather and economic conditions, clearly define the potential of the growing area of specific fields and reduce the impact of stress factors. Since improper selection and inappropriate use of hybrids are one of the reasons for low yields, it is necessary to study ways to optimise growing conditions for different plant biotypes, as well as the adaptive function and agronomic stability of hybrids. The situation at each experimental site requires careful development of weed control technology, and one of the most commonly used methods in maize crops is currently the use of chemical protection products. At the beginning of the growing season, maize plants develop very slowly and are unable to compete with weed species adapted to cool spring days. In biobased organic production technology, the main soil cultivation is carried out by ploughing, harrowing, and then planning the sowing, allowing weed seeds to move to deeper layers that cannot germinate from a depth of 1 cm – by 30%, from a depth of 4 cm – by 95%.

The agro-climatic conditions and the length of the growing season of maize hybrids allow for the cultivation of different maturity groups of maize hybrids. Corn hybrids should be selected based on their adaptability to the conditions of a particular soil and climatic zone, high and stable yields, and low pre-harvest moisture content. In the Southern Steppe zone, 30-35% of corn grain is recommended for early and mid-season groups and 50-70% for medium-late groups. Medium and late-ripening corn varieties differ in the total temperature required to achieve biological ripeness from the panicle ejection phase to the onset of biological ripeness of the grain. In 2021, the sum of the active temperatures from sowing to harvesting of corn varied from 2644°C to 2758°C.

The influence of organic fertilisers on the qualitative composition of humus showed that the content of humic acid fractions changed in all studied varieties compared to the control. All maize hybrids did not show a tendency to decrease the total content of humic substances in the soil compared to the control. However, it should be noted that the limits of organic carbon content were 3.2-3.5%, compared to the control of 3.1%; humic acids – 1.9-2.2% compared to the control of 1.8%; fulvic acids – 0.7-1.0% compared to the control of 0.8%.

Phenological observations indicate that hydrothermal conditions during the growing season of 2021 influenced the timing of the main phases of maize hybrids' development. As a result of the research, the timing of the interphase period of maize hybrid development was established: when the hybrid was sown on 22 April, the sowing-germination period was maximum and equal to 12 days; from germination to panicle flowering, it was noted as long – 59 days; from panicle flowering to milk ripeness of grain – 14 days; from milk ripeness to full grain ripeness – 27 days.

Organic fertilisers are one of the most important elements of modern crop cultivation technologies, allowing not only to significantly increase yields but also to improve their quality. For maize, as a crop with high individual productivity and low ability to compensate for nutrient deficiencies, it is important to evaluate the following parameters: cob length, cob diameter, number of rows of seeds, number of seeds per row, weight of 1000 seeds of the structure is the average number of seeds per cob, the data of the experiment are shown in detail in Table 2.

Table 2. Elements of maize yield structure under organic fertiliser application

Experiment variant	Cob length, cm	Cob diameter, cm	Number of rows of seeds, pcs.	Number of seeds per row, pcs.	Mass of 1000 seeds, g
Control	15.2	3.7	13.5	30.4	223
Semi-rotted cattle manure 10 t/ha	16.2	3.8	13.7	34.1	263
Semi-rotted cattle manure 15 t/ha	16.6	3.9	13.9	34.6	267
Semi-rotted sheep manure 7 t/ha	16.1	3.0	13.8	33.9	263
Semi-rotted sheep manure 14 t/ha	16.8	4.0	13.0	33.0	270
Cereal straw 8 /ha	15.4	3.7	13.3	30.1	238
Cereal straw 16 /ha	15.6	3.8	13.5	30.9	244

Source: compiled by the authors

The number of rows of seeds in a cob is a genetically determined always paired trait, in different hybrids it is more often from 12 to 14 pcs., but to a lesser extent depends on the growing conditions. In the experiment, the number of seeds in a row ranged from 30.4 to 34.6 pcs. Analysis of the number of rows of seeds (13.0-13.9 pcs.) significantly affects the supply of plants with moisture and temperature, but also affects the efficiency of the use of applied nutrients.

An important structural indicator characterising productivity was the weight of 1000 seeds, which depended on the morphological characteristics of the hybrid itself and fertiliser options. The control sample without fertilisers and irrigation had the lowest weight of 1000 maize seeds – 223 g, but with the introduction of 15 t/ha of semi-rotted cattle manure, the figure was 267 g, which is 44 g more than in the control. When analysing the weight of 1000 seeds by years of research, it should be noted that weather conditions during the growing season of 2021 affected the efficiency of nutrient use from the soil.

Grain yield is an important final indicator of the efficiency of maize cultivation technology, which informs how efficiently the plant absorbed solar energy and used energy resources at the end of the growing season, as shown in Table 3.

Table 3. The yield of corn grown for grain in 2021, t/ha

Experiment variant	Repetition			Average
	1	2	3	
Corn grain, control	9.45	10.13	9.53	9.70±0.37
Corn grain, semi-rotted cattle manure 10 t/ha	12.19	13.37	12.01	12.52±0.74
Corn grain, semi-rotted cattle manure 15 t/ha	12.90	14.28	13.15	13.44±0.74
Corn grain, semi-rotted sheep manure 7 t/ha	11.15	12.56	11.82	11.84±0.71
Corn grain, semi-rotted sheep manure 14 t/ha	12.00	13.88	12.67	12.85±0.95
Corn grain, grain straw 8 t/ha	11.15	12.46	10.86	11.49±0.85
Corn grain, grain straw 16 t/ha	11.34	12.16	11.44	11.64±0.45

Source: compiled by the authors

The data in Table 3 show that the grain yield of maize hybrid DN Slavytsia in three replications, which in the control variant was 9.7 t/ha, in the experimental variant – 11.9 t/ha. The use of bioorganic fertilisers in the form of semi-rotted cattle manure, semi-rotted sheep manure and grain straw increased the yield by 1.4-2.8 t/ha compared to the control. A common analysis in agriculture is the determination of the main nutrients listed in Table 4: protein, fat, ash, fibre, and NFE. Nutrient components are called crude because they are not pure and contain impurities.

Table 4. Chemical composition of corn kernels in terms of natural substance, %

Experiment variant	Humidity	Protein	Fat	Fibre	Ash	Nitrogen-free extractives
Corn grain, control	13.18	13.19	2.63	2.40	1.60	67.00
Corn grain, semi-rotted cattle manure 10 t/ha	12.88	13.50	2.74	2.33	1.65	66.90
Corn grain, semi-rotted cattle manure 15 t/ha	14.87	13.88	2.68	2.20	1.66	64.71
Corn grain, semi-rotted sheep manure 7 t/ha	13.66	13.50	2.57	2.23	1.74	66.30
Corn grain, semi-rotted sheep manure 14 t/ha	13.88	14.00	2.49	2.12	1.34	66.17
Corn grain, grain straw 8 t/ha	12.96	13.56	2.75	2.24	1.57	66.92
Corn grain, grain straw 16 t/ha	12.03	13.94	2.74	2.15	1.69	67.46

Source: compiled by the authors

T.P. Shepilova *et al.* (2021) found that fertilisation increases grain moisture and may require additional drying costs. During the harvesting period, the moisture content of corn hybrids can reach more than 40%, and drying 1 tonne of corn grain to a conditional moisture content of 14% requires a large amount of energy, i.e. fuel consumption is 60-70% of the total demand for corn growing, so when growing corn, it is necessary to rely on externally controlled factors to create optimal conditions for the growth, development and maturation of corn. In the control, the moisture content was 13.2%, and in the experimental corn grain, it ranged from 12.0% to

14.9%, while the use of organic fertilisers provided an increase in moisture content in the experiments with the addition of semi-rotted cattle and sheep manure compared to the control.

The actual content of nutrients provides reliable information about the amount but does not guarantee a more complete absorption by the animal. In terms of natural substances, the crude protein content of corn grain in the experimental samples ranged from 13.5 to 14.0%, especially in the control, where it was 13.2%, indicating a progressive accumulation of nitrogen-containing substances. The crude fat content was in the range of 2.4-2.7%, crude fibre – 2.1-2.4%, crude ash – 1.3-1.7% and NFE – 64.7-67.4%.

According to the results of the research, it was found that the early maturing hybrid DN Slavytsia, with the addition of semi-rotted cattle manure to the soil, obtained the highest yield of 13.4 t/ha, which is 27.6% higher than the control. The prospect of further research is the study of biologically based technologies for growing hybrids in different maturity groups in the Southern Steppe of Ukraine, with the improvement of plant protection methods and soil cultivation from weeds.

DISCUSSION

The high popularity of corn is the result of the interaction of genetic, environmental, and agronomic factors. The growth in overall corn yields in Ukrainian agriculture is driven by an increase in sown areas and the rational use of hybrid varieties with different growing season lengths. The focus on improving cultivation technology with an emphasis on preserving soil fertility and improving the ecological state of the environment is currently a relevant direction outlined in experimental studies. According to R. Ostapenko *et al.* (2020), in Ukraine, farmers who choose organic production earn higher profits than conventional production. For example, the price of organic corn is 29% higher than that of conventional corn, as well as winter wheat by 26%, pork by 45%, and milk by 7%. However, as the differences in profitability show, the price difference is not yet high enough to support the development of organic agriculture. S. Zhang *et al.* (2019) also confirmed the need to address the complex set of interrelated issues related to increasing yields on organic farms while reducing prices and preserving the environmental benefits of organic farming.

According to the established technology, regardless of the previous crop, semi-rotted manure and straw were applied in recommended doses of 7 to 25 t/ha during tillage. It should be noted that organic fertilisers applied in autumn can mineralise after harvest, contributing to the risk of nitrate nitrogen leaching in winter. Therefore, it is usually recommended to apply pre-sowing treatments in spring to promote better growth efficiency. When growing maize, the elements of nitrogen, phosphorus and potassium introduced into the soil are of great importance, so organic fertilisers were added to the experimental plots according to the established norms: semi-rotted cattle manure at doses of 10 t/ha and 15 t/ha; semi-rotted sheep manure at 7 t/ha and 14 t/ha; grain straw at 8 t/ha and 16 t/ha.

In addition, it was established that all by-products from crop cultivation should remain on the field, namely straw, stalks, tops, etc. Y. Hamid *et al.* (2020) report on an effective organic soil amendment containing: 40% manure, 10% plant residues, 20% residues from agricultural processing, 25% silt from clean water bodies, and 5% poultry manure. At the same time, the height of the corn plant at the time of harvesting in the control variant without fertilisers was 228.6 cm, the average weight of the cobs was 102 g, and the weight of 1000 seeds was 229 g.

Maize hybrids fertilised with more nitrogen had lower relative stem yields and significantly increased the specific size of cobs and kernels per plant. According to D.M. Zeffa *et al.* (2019), corn should be fertilised with organic fertilisers, as soil enrichment with nutrients contains the elements necessary for plant nutrition: total nitrogen – 3.2%, phosphorus – 2.6%, potassium – 2.0%.

R.P. Lollato *et al.* (2019) argue that at least 40 t/ha of organic fertiliser should be applied to the soil, if possible, with 1 t of fertiliser, the soil receives 5 kg of nitrogen, 2.5-3 kg of phosphorus, 5-6 kg of potassium and a certain amount of macro- and microelements. As noted by C.B. Lobo *et al.* (2019), corn is quite demanding for increased mineral nutrition, as it is a slow-forming crop, i.e., to grow 1 tonne of corn grain, on average, 25-28 kg of nitrogen, 11-13 kg of phosphorus and 26-29 kg of potassium are required. Thus, to produce 10-12 t/ha of corn, an average of 145-185 kg of nitrogen, 65-85 kg of phosphorus and about 140-185 kg of potassium are removed from the soil.

When growing maize, additional labour costs must be considered, mainly related to mechanical weed control. In maize, the period from germination to the emergence of three or four leaves is the most critical for high yields and stress resistance, as the root system is actively developing during this period, planning its potential yield level. If weeds are not controlled at this time, there is a risk of at least 10% yield loss, gradually increasing to 50%. Y. Shang *et al.* (2019) note that the transpiration coefficient of corn is 320, but that of weeds: couch grass – 470, wheatgrass – 560, thistle – 666, quinoa – 805, mustard – 865.

According to P. Yu *et al.* (2021), it is added that during biobased maize cultivation, rotary harrows or cultivators should be used as a relatively inexpensive but effective solution. Rotary harrows are used before and after emergence. The needle-shaped working part gently combs out the first wave of weeds and dead wood, providing good conditions for the growth of corn seedlings. Ridge harrows, on the other hand, not only loosen the soil between the rows to optimise the conditions for corn seedlings to grow but also physically destroy most weeds and litter. According to C.F. Chukwuneme *et al.* (2020), the use of herbicides against dicotyledonous weeds is allowed to a certain extent, depending on the stage of crop development and the type of harmful plant, in tank mixtures with systemic herbicides: Prima 911 Special Edition (SE) with an application rate of 0.4-0.6 l/ha; Esteron 600 ES – 0.7-0.8 l/ha; Pik 75 WG 0.7-0.8 l/ha; Lancelot 450 WG 0.4-0.5 l/ha; Callisto 480 SC – 0.4-0.6 l/ha.

It should be noted that it is possible to discover herbicides that can be used in organic agriculture in the future. During the experimental study of seeds and stimulation of crop growth, the treatment with a culture liquid in the composition of live soil microorganisms and organ elements *Azotobacter chroococcum, Bacillus subtilis, Bacillus megaterium* at a dosage of 1.5 l/t was carried out. In B. Kumari *et al.* (2019) reported that a rather complex multicomponent symbiotic preparation, including 86 regenerative microorganisms, was created to activate maize growth. The preparation, when applied to the soil, gives a healthy direction to the rest of the microbiota, contributing to the fertility of any soil, and even the poorest soil can be revived in 4-5 years.

It should also be noted that climate experts emphasise that climate change in Ukraine will develop in the direction of continental and even sharp continental, and therefore moisture deficit will increase, especially in southern Ukraine. The experiment was quite successful in using a simple modified corn hybrid developed by the Grain Institute of the National Academy of Agrarian Sciences – DN Slavytsia, which was noted for its high productivity in arid regions. One of the ways to increase drought tolerance in maize is to widely use early maturing genotypes that correspond to the FAO 200-290 mid-early hybrid group (2016).

L. Muntean *et al.* (2022) report that to date, breeders have created new maize hybrids with FAO scores ranging from 200 to 500, which are capable of yielding more than 12.0-14.0 t/ha. At the same time, the grain moisture content of the new corn hydrides averages 12-14%, providing opportunities for energy-saving harvesting with minimal drying costs. Given the biological characteristics of corn, it is necessary to implement modern cultivation methods without harming the environment, but the production of the latest breeding hybrids will help to significantly increase grain yields, adjust the length of the growing season, and resist adverse environmental conditions. However, corn productivity can also decline by 20-50% after prolonged stress caused by a lack of nutrients and water in the climatic conditions of the Southern Steppe of Ukraine.

CONCLUSIONS

The biologisation of crop production and farming involves the introduction of environmentally friendly alternative systems and resource-saving technologies with a reduction in the use of mineral fertilisers, herbicides, insecticides, and fungicides. As a result of the research, corn-growing technology elements were optimised, with organic fertiliser added to the experimental soils.

As a result of the proposed technology, the regularities of crop productivity formation were revealed, and the relevant conclusions were drawn. The maize cultivation process was based on weed control by blind harrowing, with 1, 3, and 6 leaves by planned cultivation. Organic fertilisers of semi-rotted cattle and sheep manure and grain straw were applied to the soil, and the seed was saturated with live soil microorganisms. Soil testing revealed that the organic carbon content ranged from 3.2-3.5%, humic acids from 1.9-2.2%, and fulvic acids from 0.7-1.0%. In the corn grain samples, the crude protein content ranged from 13.5 to 14.0%, crude fat from 2.4 to 2.7%, crude fibre from 2 to 2.4%, crude ash from 1 to 1.7%, NFE from 64.0 to 67.4%, and moisture from 12.0 to 14.9%. Corn grain yield was 9.7 t/ha in the control and 11.5-13.4 t/ha in the experimental plots. The elements of the maize yield structure under the application of organic fertilisers were evaluated by the following indicators: cob length, cob diameter, number of rows of seeds, number of seeds per row, weight of 1000 seeds, which increased by 6.2%, 2.6%, 1.5%, 10.9%, 15.2%, respectively, compared to the control.

The information on the use of biological corn-growing technology is of practical importance and indicates the need for further research on the productivity of corn for grain. The use of microbiological preparations due to the activity of compositions of microorganisms *Azotobacter chroococcum, Bacillus subtilis, and Bacillus megaterium* increase the amount of nutrients available to maize plants, promoting the activation of cell division and enhancing photosynthetic activity with the growth of the leaf surface of crops.

The data obtained can be used to optimise agronomic practices that are currently relevant. Therefore, one of the promising areas for future research is a detailed study of new drugs to develop biologically based technologies for growing maize according to the ecological gradient of cultivation and maintaining high yields.

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CONFLICT OF INTEREST

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Розроблення біологізованих технологій вирощування кукурудзи

Анотація. Сільськогосподарські виробники використовують багато мінеральних добрив та засобів захисту рослин, що призводить до забруднення ґрунту, насіння та навколишнього середовища та знижує рентабельність виробництва. Сучасне сільське господарство починає звертати увагу на біологізацію, що включає розробку та впровадження екологічно чистих альтернативних систем, зменшення використання хімікатів, впровадження енерго- та ресурсозберігаючих технологій, використання біологічних препаратів для захисту рослин та біоорганічних добрив. Метою цього дослідження є вивчення ефективності біологізованих технологій для вирощування кукурудзи в екологічно чистий спосіб за допомогою різноманітних органічних добрив. Під час дослідження нової технології вирощування кукурудзи використовували методи: аналізу, синтезу, аналогії, порівняння та узагальнення; польові та лабораторні; розрахунку – оцінкп економічної та біоенергетичної ефективності. Для вивчення дії різного біологічного походження органічних добрив на оцінку гумусного стану типових чорноземів було проведено польові досліди впливу на врожайність зерна кукурудзи в умовах українського Степу. Після внесення органічного добрива межі вмісту органічного вуглецю у гумусі становили 3,2-3,5 %, гумінової кислоти 1,9-2,2 %, фульвокислоти 0,7-1,0 %. В експериментальних зразках зерна кукурудзи вміст сирого протеїну коливався від 13.5 до 14.0 %, сирого жиру від 2,4 до 2,7 %, сирої клітковини від 2,1 до 2,4 %, сирої золи від 1,3 до 1,7 % та безазотисті екстрактивні речовини від 64,7 до 67,4 %, вологості від 12,0 до 14,9 %. Урожайність зерна у контрольному варіанті становила – 9,7 т/га, дослідних ділянках в межах – 11,5-13,4 т/га. Отримані дані можуть допомогти в розробці біологізованої технології вирощування кукурудзи відповідно до екологічного градієнта обробітку та врожайності з оптимізацією досліджуваних агротехнічних прийомів

Ключові слова: урожайність; гумус; органічне добриво; екологічно чиста продукція; якість зерна

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Pumpkin fruit selection of different types and varieties for the production of functional food products

Abstract. Consumers in Ukraine and around the world are increasingly interested in healthy lifestyles and functional foods with high biological value. For the production of such foods, it is important to select raw materials that meet a range of quality requirements. Pumpkin fruits have a high content of nutrients, vitamins, essential amino acids, and minerals that largely meet these requirements. The research aims to comprehensively evaluate pumpkin fruits of eight varieties of

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different types: large-fruited *(Cucurbita maxima Duch)* and butternut *(Cucurbita moschata Duchex Poir)*, grown in the forest-steppe of Ukraine, to identify the most suitable for drying and production of functional foods. The experimental method was used following the research plan, the laboratory method was used to determine biochemical, biometric, and organoleptic quality indicators, and the statistical method was used to conduct dispersion and correlation analyses of the studied indicators. It has been established that when large-fruited pumpkin varieties are used for convective drying, 16.1-20.3% of dry products with a sugar content of 48.6-51.6% and 11-14 and 34.5-40.2% of nutmeg varieties, respectively, can be obtained. For the production of functional food products with a β-carotene content of 40-41 mg/100 g (in terms of dry matter), it is advisable to use the fruits of nutmeg varieties Gilea and Divo, and vitamin C at the level of 28 mg% – large-fruited varieties Slavuta and Polyovychka. The study revealed that with the increase in fruit weight, the content of dry matter (r=-0.68), sugars (r=-0.67) and the yield of finished products (r=-0.74) significantly decreases. A significant direct relationship between the content of dry matter and sugars (r=0.98), as well as the content of dry matter and the yield of finished products (r=0.94), was established. The materials of the article are of practical value for breeders, vegetable growers, and specialists of processing enterprises when choosing a type and variety of pumpkin for the production of functional foods

Keywords: quality; vitamin C; carotene; processing; drying; raw materials

INTRODUCTION

The research relevance of pumpkin fruit is determined by the growing interest in functional foods, especially in the context of the growing attention to a healthy lifestyle. The study of their medicinal and antioxidant properties can contribute to the development of new products to maintain health and prevent diseases, which is especially important in the context of the impact of various negative factors on the health of modern Ukrainians, such as stressful situations, the COVID-19 pandemic, fast pace of life and climate change. Such research is essential for providing quality and healthy food products to consumers and maintaining their health in the modern world (Kaur *et al.*, 2020).

In ancient times, Hippocrates expressed the well-known idea that food should be medicine and medicine should be food. This is the principle that guides manufacturers of functional foods. Today, many countries around the world have government programmes to create them. Functional foods are foods for systematic consumption that, in addition to nutrients, contain ingredients that, when consumed regularly, have a positive effect on the body, help to adapt to adverse environmental conditions and strengthen the immune system (Hussain *et al.*, 2022). They have a wide range of health effects, including cardioprotective, hypoglycaemic, antioxidant, anticancer, antibacterial, immunomodulatory, neuroprotective, and anti-inflammatory effects, and prevent the development of cardiovascular and oncological diseases (Djiogue *et al.*, 2018; Villamil *et al.*, 2023). The properties of such products are determined primarily by the biological and biochemical compounds that make up their composition. V. Khareba *et al.* (2019) noted that the development and production of functional foods is "the only way to solve the global problem of optimising nutrition, maintaining health and prolonging human life".

Pumpkin fruit is an important food product with high nutritional and biological value, antioxidant and medicinal properties, and raw materials suitable for the production of products with functional properties (Sharma *et al.*, 2020, Koprualan *et al.*, 2021). The medicinal properties of pumpkin have been known since ancient times. The ancient Greek physician Diogenes mentioned them in the first century AD, and Ibn Sina, better known as Avicenna, described them in detail in his medical treatises. P. Ramachandran *et al.* (2022) used pumpkin pulp, seeds, and oil in their research to make medicines. The use of pumpkin pulp as a natural pigment in powder form added to confectionery, bakery, pasta, and dairy products is a fairly new area of processing. These inexpensive powders from pumpkin fruit can be used as a potential source for the production of functional foods and nutraceuticals in the food and healthcare industry (İzli *et al.*, 2022).

The research aims to comprehensively evaluate pumpkin fruits of different varieties and species *(Cucurbita maxima Duch* and *Cucurbita moschata Duchex Poir*) grown in the forest steppe of Ukraine to identify the most suitable for drying and production of functional foods.

LITERATURE REVIEW

A growing interest in pumpkin cultivation in Ukraine, especially for the production of seeds and oil using Styrian hybrids (Cucurbita pepostyriaca) can be noted. However, pumpkin fruit is also used to create a wide range of healthy, nutritious, and functional food products, which include juices, soups, cereals, chips, cookies, bread, cakes, bars and noodles (Rózyło *et al.*, 2014). The flesh is used for various types of processing: stewed, boiled, baked, dried, pickled, frozen, mashed, chips, caviar, porridge, soups, jams, jams, candied fruits, juices, smoothies, etc. (Hussain *et al.*, 2022). The fruits of table pumpkins, which include large-fruited (*Cucurbita maxima Duch*) and butternut (*Cucurbita moschata Duchex Poir*) species, are mostly used for food processing. These are the types of pumpkins used in the research.

The biologically valuable and medicinal properties of pumpkin fruits are determined by the rich chemical composition of the pulp and seeds. Pumpkin mesocarp contains 78-92% water, and 4-12% sugars, starch is almost absent in some varieties, and in others, it reaches 5%; the content of pectin substances is 2.6-3.9%; fibre is 0.5-1.3%, 0.2-10%, about 1% proteins, 0.1% organic acids. The pulp also contains a significant number of vitamins, mg/100 g: B_3 – 0.3-0.4, B_6 – 0.10-012, B_9 – 14.0-14.2, E – 0.3-0.5, PP – 0.5-0.7, vitamin C – 8-25 and β-carotene 6-35, micro- and trace elements (Hussain *et al.*, 2022). B. Kulczynski & A. Gramza-Michałowska (2019) note that the most common minerals in pumpkin pulp were potassium, calcium, and sodium. The fruit is characterised by low-calorie content (21-30 kcal/100 g) and is widely used in various diets. Pumpkins with orange flesh are especially valuable because they are high in carotenoids, especially β-carotene and lutein.

Pumpkin seeds contain about 20% of oil, which is used as an effective anthelmintic and diuretic for heart disease, kidney disease, hypertension, and cholecystitis (Ahmed *et al.*, 2022). Pumpkin seeds contain 92% of dry matter, %: dry protein – 41.85; crude lipids – 45.35; crude fibre – 1.95; ash – 4.7; extractives – 6.15; calcium – 0.55; phosphorus – 1.12 (Hussain *et al.*, 2022). Pumpkin seed oil is valued for its high content of fatty polyunsaturated acids, %: myristic – 12.0; palmitic – 15.9; stearic – 8.7; oleic – 41.0; linoleic – 34.3; linolenic – traces. Such a complex of acids has antioxidant properties, stimulates fat metabolism in the human body, binds cholesterol into a form easily absorbed in the body, and prevents it from settling on the walls of blood vessels, thereby preventing the development of cardiovascular diseases (Kulczynski & Gramza-Michałowska, 2019; Ahmed *et al.*, 2022). M.A. Gedi (2022) found that phenolic compounds, fatty acids, tocopherols, minerals, and carotenoids contained in pumpkin oil are involved in lowering cholesterol levels, and have anticarcinogenic, anti-inflammatory, anti-diabetic, and antimicrobial effects. Thanks to their excellent oxidative stability, pumpkin seed cake-based films prevent lipid oxidation in food products and can be successfully used for their packaging (Hromis *et al.*, 2022).

Drying is a promising method of processing pumpkin pulp, as it preserves biological valuable elements contained in fresh raw materials (Seifu *et al.*, 2018). Dried pumpkin is produced in the form of pieces, cubes, strips, granules, and powder. Dry pumpkin powder, as a concentrate of fibre, minerals, and vitamins, is used as a natural dietary supplement to improve organoleptic characteristics, increase their biological value and antioxidant properties (Indrianti *et al.*, 2021). The main effect of adding pumpkin dry powder on the physicochemical properties of bakery products, dairy products, beverages, and snacks is to increase the energy, protein, iron, calcium, and carotene content and improve textural properties (hardness, chewiness, tensile strength, and viscosity) (Villamil *et al.*, 2023).

Air-solar, convective, microwave, infrared, freeze-drying, or a combination of these are used to dry pumpkin fruit. To maximise the preservation of biologically active components in pumpkin chips, it is most advisable to use a combination of freeze-drying and microwave drying (Koprualan *et al.*, 2021). E. Chao *et al.* (2022) note that drying pumpkin pulp with infrared radiation allows for preserving the highest polyphenol content and the ability to scavenge free radicals. Blanching the raw materials before drying and using the freeze-drying method minimises the loss of carotenoids, consistency, taste, and colour of the finished product (Kaur *et al.*, 2020).

Convective drying with heated air remains one of the most common methods of drying vegetables, including pumpkins. According to S. Chikpah *et al.* (2022), the quality of dry pumpkin products during air convection drying depends on the thickness of the particles and air temperature. The content of β-carotene and ascorbic acid was higher in pumpkin dried at 60°C than at 50°C and 70°C. To increase the biological value and organoleptic characteristics of dried pumpkin products G. İzli *et al.* (2022) recommend combining convective drying with microwave drying.

MATERIALS AND METHODS

The research was conducted in 2014-2015 at the National University of Life and Environmental Sciences of Ukraine. The experimental crops were grown on the plots of the Agronomic Experimental Station of the National University of Life and Environmental Sciences of Ukraine, a separate subdivision of the National University of Life and Environmental Sciences of Ukraine, using the technology generally accepted in production. The farm is located in the right-bank forest-steppe zone of Ukraine. The soil of the site is typical low-humus black soil. The climate of the zone is moderately continental with moderately cold winters and rather warm summers. According to long-term data, the annual air temperature is 7.1°C. The average long-term temperature of the coldest month (January) is -6.8°C, and the warmest month (July) is +19.9°C. The sum of active temperatures above 10°C is in the range of 2500-2800°C.

Precipitation in this zone is high, with an annual rate of 550-600 mm. Most of the precipitation falls in summer in the form of rain. In the years of the study, the amount of precipitation during the growing season was 120-154 mm higher than the average long-term data. In general, the soil and climatic conditions of the zone are favourable for growing pumpkins and obtaining a quality harvest.

Eight varieties of Ukrainian production were selected for the experiment, in particular: four varieties of large-fruited pumpkin (Zhdana, Slavuta, Yubilee of the Dnipro Experimental Station and Polevychka of the Southern Institute of Vegetable and Melon Production), and four varieties of butternut pumpkin (Gilea, Divo, Yanina of the Southern Institute of Vegetable and Melon Production and Dolya of the Dnipro Experimental Station). The large-fruited pumpkin variety Polevychka and the butternut pumpkin variety Gilea, which are listed in the Register of Plant Varieties and are common in production, were used as controls (n.d.).

Biometric, organoleptic, and biochemical parameters were determined in the educational and scientific laboratory of the Lesyk Department of Technology of Storage, Processing and Standardisation of Plant Production according to generally accepted methods (Skaletska *et al.*, 2014). To determine the biometric parameters of the ratio of bark, seeds, and pulp, five typical fruits of each variant were selected in triplicate. The dry matter content was determined according to the requirements of DSTU ISO 751:2004 (2005); thermogravimetric analysis by drying in an oven at a temperature of 100-105°C to a constant weight; dry soluble matter – using a refractometer by the requirements of DSTU ISO 2173: 2007 (2009); sugar content (total) – by Bertrand according to DSTU 4954:2008 (2009); β-carotene – by photometric method according to DSTU 4305:2004 (2005); vitamin C – using a solution of 2,6 dichlorophenolindophenol. The organoleptic evaluation was carried out by tasting baked pieces, dry and reconstituted pumpkin products on a 9-point scale.

For drying, 3 kg of fresh pumpkin fruit was selected in 3 replicates, cut into segments, weighed, washed, and peeled from the bark, seeds, and fibrous part; the difference between before and after cleaning was used to determine the amount of waste. The prepared raw materials were cut into strips of the following sizes using a mechanical chopper SIRMAN (Italy): length 5-6 mm, width 2-3 mm, thickness 2-3 mm. The resulting strips were evenly placed on dryer pallets at a rate of 3 kg/m² and loaded into a preheated chamber. For drying, a convective batch-type dryer "Sadochok 2M" (Ukraine) was used. The products were dried at a temperature of 60°C until they were completely dry. This drying temperature ensures maximum preservation of organoleptic characteristics and biologically valuable substances (Chikpah *et al.*, 2022). The yield of the finished product was converted to a standard moisture content of 10%.

The research results were processed mathematically, confidence intervals, the smallest significant difference, and correlations between the studied indicators were determined using generally accepted methods. The strength of the relationship was assessed according to the following gradation: if r (correlation coefficient) was equal to 1, the calculated relationship between the attributes was complete; if r was 0.66-0.99, the relationship was strong (significant); if r was in the range of 0.33-0.65, the relationship was medium; if r was less than 0.33, the relationship was weak, insignificant. The study was conducted following the requirements of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973).

RESULTS AND DISCUSSION

The research results indicate that the ratio of morphological components of pumpkin fruit is genetically determined, depending on both the botanical variety and the species (Fig. 1).

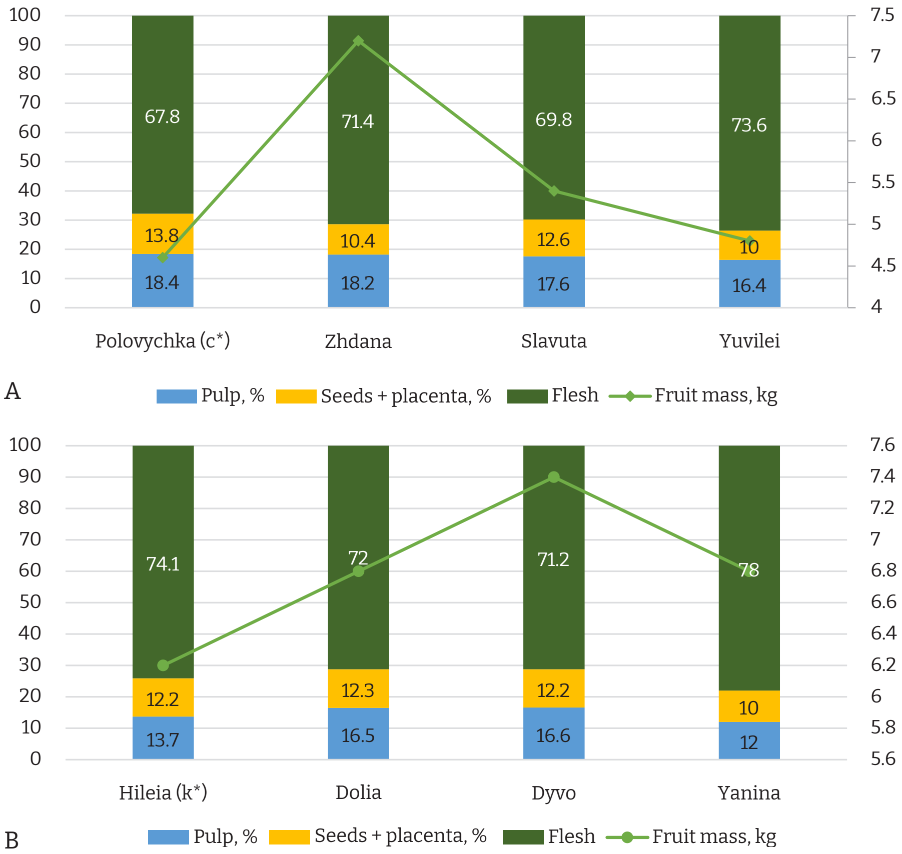

Figure 1. Average fruit weight and ratio of morphological parts of pumpkin fruit (average for 2013-2014)

Note: A – varieties of large-fruited pumpkin; B – varieties of butternut pumpkin; *control

Source: compiled by the authors

Fruit weight is a variable indicator that significantly depends not only on varietal characteristics but also on soil and climatic conditions and cultivation technology. The fruit weight of large-fruited pumpkins can vary from 1 to 60 kg or more (Khareba & Kokoiko, 2022). It was found that plants of butternut pumpkin varieties formed heavier fruits in weight compared to large-fruited ones. Thus, the average fruit weight of large-fruited pumpkins ranged from 4.6-7.2 kg (the average for the group was 5.5 kg), and that of nutmeg pumpkins – 6.2-7.4 kg (the average was 6.7 kg). Among the large-fruited varieties, the largest fruits were in plants of Zhdana variety – 7.2 kg, which is 2.6 kg more than in the control (significant difference), and among the nutmeg varieties – in Divo variety 7.4 kg, which is significantly more than in the control variety. In general, the weight of 1000 seeds were higher in the fruits of large-fruited varieties (average value 284.8 g), and significantly lower in nutmeg varieties – an average of 136.8 g.

Nutmeg pumpkin fruits varieties *(Cucurbita moschata Duch)* had a higher pulp content (71.2-78.0%), and lower bark content (12.0-16.5%) compared to large-fruited varieties *(Cucurbita maxima Duch)*. The content of the soft part in the fruits of large-fruited varieties ranged from 67.8-73.6%, the share of bark – 16.4-18.4%, and seeds with placenta – 10-13.8%. The Zhdana and Yubilei varieties stood out among large-fruited pumpkins in terms of pulp content – 71.4 and 73.6%, respectively, and among butternut squash – Yanina and Gilea (control) – 78 and 74.1%, respectively. The fruits of large-fruited pumpkin varieties Polevychka (67.8%) and Slavuta (69.8%) contained the least amount of pulp.

Thus, the formation of morphological features of pumpkin fruit, which determine its quality, physical characteristics, anatomy and cell structure, content and ratio of morphological parts depends on the type and varietal characteristics. The Zhdana and Yubilee varieties stood out among the large-fruited species in terms of indicators that characterise marketability and suitability for processing, and the Janina and Gilea varieties (control) among the nutmeg varieties. The pulp content in the fruits of these varieties exceeded 70%.

Evaluation of pumpkin fruit quality by biochemical parameters is relevant, as its chemical composition and flavour properties significantly affect its suitability for processing and the quality of finished products. In addition, the content of carotene and vitamin C determines their biological value and the possibility of using them for the production of functional foods. The results of the study are shown in Table 1.

Table 1. The content of the main elements of the biochemical composition of fresh pumpkin pulp and tasting score, depending on the type and variety, average for 2014-2015

Variety	Flesh contents					Taste test, mark**
	dry matter, %	of dry soluble matter, %	sugars (sum), %	β-Carotene, mg/100 g	vitamin C mg %	
Large-fruited *(Cucurbita maxima Duch)*						
Polovychka (control)	14.3±0.5*	12.2±0.2	7.9±0.3	7.2±1.2	15.2±0.8	8.1±0.3
Zhdana	13.4±0.4	11.3±0.2	7.4±0.3	9.4±1.1	14.8±2.1	7.4±0.2
Slavuta	14.5±0.6	12.3±0.1	8.0±0.4	7.6±0.8	17.4±1.2	7.8±0.3
Yuvilei	13.6±0.4	11.6±0.1	7.6±0.2	8.8±0.6	12.5±1.4	7.5±0.2
Nutmeg *(Cucurbita moschata Duch)*						
Hileia (control)	10.4±0.5	9.0±0.2	6.3±0.2	15.8±1.2	6.7±0.5	8.4±0.2
Dolia	10.2±0.4	8.8±0.1	6.1±0.1	12.4±1.5	7.5±0.8	8.5±0.2
Dyvo	9.3±0.6	8.2±0.1	5.5±0.1	14.2±0.4	9.8±1.0	7.8±0.3
Yanina	9.8±0.6	8.4±0.2	5.6±0.2	13.5±0.5	8.0±0.4	7.6±0.2

Note: *biochemical parameters are mean values ± standard deviation (n=3); **on a 9-point scale
Source: compiled by the authors

During the vegetation period, the fruits of large-fruited pumpkin (*Cucurbita maxima Duch*) accumulated 13.4-14.5% of dry matter (the average value in the group was 14.2%). Most of them were contained in pumpkins of the Slavuta variety – 14.5±0.6%, and significantly less, compared to the control, in the fruits of the Zhdana variety – 13.4±0.4%. There was no significant difference in dry matter content between the Slavuta and Polyovychka (control) varieties. The dry matter content of butternut squash (*Cucurbita moschata Duch*) was significantly lower in them compared to large-fruited varieties and ranged from 9.3-10.4% (average in the group 9.9%). The fruits of the Gilea (control) and Dolya varieties contained the highest amount of dry matter – 10.4±0.5 and 10.2±0.4%, respectively. The dry soluble matter was also higher in the fruits of large-fruited pumpkins – 11.3-12.3%. Among the nutmeg pumpkin varieties, the fruits of Gilea (control) and Dola varieties contained the highest amount of dry soluble matter – 9.0±0.2 and 8.8±0.1%, respectively.

The total sugar content ranged from 5.5±0.1 in the fruits of nutmeg varieties to 8.0±0.4% in large-fruited varieties. Their higher content, as well as dry matter, was in the fruits of large-fruited pumpkin varieties – from 7.4±0.3 to 8.0±0.4%. The fruits of the Slavuta variety accumulated the most sugars among the studied varieties during the growing season – 8.0±0.4%. At the same time, monosaccharides prevailed in the composition of sugars in the fruits of large-fruited pumpkins. Muscat pumpkin varieties accumulated 5.5-6.3% of sugars (total). They did not show a predominance of monosaccharides, and sucrose prevailed in the fruits of the Divo and Yanina varieties. Among the butternut pumpkin varieties, the Gilea (control) and Dolya varieties stood out in terms of sugar content, with 6.3±0.2 and 6.1±0.1, respectively.

B. Kulczynski & A. Gramza-Michałowska (2019) noted that the content of carotenoids, which are the main biologically valuable components in fresh pumpkin fruits, depends on the variety and degree of ripeness. Our research confirmed their data and showed that the content of β-carotene depends on both the variety and the botanical type of pumpkin. Thus, in terms of β-carotene content, the fruits of the nutmeg varieties Gilea and Divo prevailed – 15.8±1.2 and 14.2±0.4 mg/100 g, respectively. The fruits of large-fruited varieties contained much less of this element – 7.2-9.4 mg/100 g.

As noted by M. Ouyang *et al.* (2022), the biological value of fruit and vegetable products also depends on the vitamin C content. It plays a positive role as an antioxidant, can protect the body from viral infections and strengthen the immune system. The above-mentioned researchers claim that the content of ascorbic acid in fruit and vegetables significantly depends on varietal characteristics. Similar data were obtained in their research with onion bulbs (Zavadska *et al.*, 2021). Studies with pumpkin fruits have shown that, in addition to varietal characteristics, the content of vitamin C, like β-carotene, also depends on the botanical species. However, while β-carotene was higher in pumpkin fruits of nutmeg varieties, vitamin C, on the contrary, was higher in large-fruited pumpkins. Thus, the content of this element in the fruits of pumpkin varieties of nutmeg was in the range of 6.7-9.8 mg%, and large-fruited – 12.5-17.4 mg%. Fresh fruits of large-fruited pumpkin of Slavuta and Polyovychka varieties (control) contained the most vitamin C – 17.4±1.2 and 15.2±0.8 mg%, respectively.

The nitrate content in the fruits of the studied varieties did not exceed the maximum permissible level (200 mg/kg). A greater amount of nitrates was accumulated in the fruits of nutmeg varieties, in particular, the highest amount was found in the fruits of the Dolya variety (123 mg/kg). In the fruits of large-fruited varieties, nitrates accumulated on average from 66.5 to 82 mg/kg. The lowest amount was in the fruits of the Zhdana variety (66.5 mg/kg).

Thus, the content of the main biochemical parameters in pumpkin fruits of the studied varieties differed significantly and depended more on the species than on the variety. The fruits of large-fruited varieties accumulated a greater amount of dry matter (13.4-14.5%), dry soluble matter (11.3-12.3%), sugars (7.4-8.0%) and vitamin C (12.5-17.4 mg%). Large-fruited varieties prevailed in terms of β-carotene content, with the amount ranging from 12.4-15.8 mg/100 g.

Studies on the suitability of pumpkin fruit for drying are relevant, as this processing method allows for the production of biologically valuable products. Previous studies have shown that the quality, amount of waste, and yield of dry carrot and onion products are significantly affected by varietal characteristics (Zavadska *et al.*, 2020; 2021). Similar data were obtained when studying the suitability of pumpkin fruit for this processing method. In addition to varietal characteristics, the yield and quality of finished pumpkin products were also influenced by their type (Fig. 2).

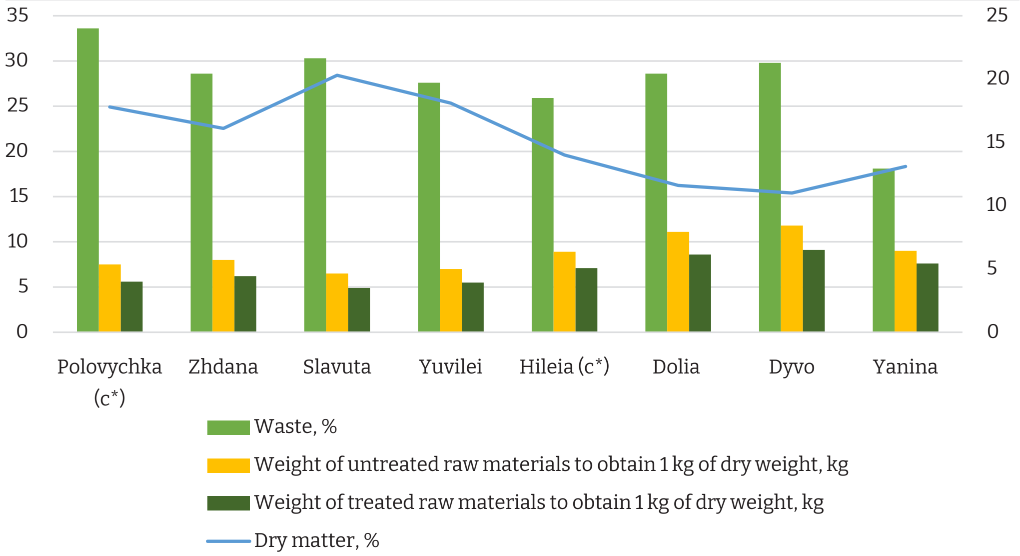

Figure 2. Amount of waste, the yield of dry products and the required weight of fresh raw materials to produce 1 kg of dry pumpkin fruit of different types and varieties, average for 2014-2015

Note: *control

Source: compiled by the authors

The total amount of waste in the process of preparing raw materials for drying varied significantly and ranged from 18.1-33.6%. Waste included bark, placenta, and seeds, which were removed during cleaning. The largest amount of them was in large-fruited pumpkin varieties – 27.6-33.6%, which is due to the ratio of morphological components of the fruit. In the fruits of large-fruited varieties, the bark, placenta, and seeds occupy a larger part compared to nutmeg (see Fig. 1). Among large-fruited varieties, the lowest amount of waste was in the Yubilee variety – 27.6%, and among nutmeg varieties – in the Yanina variety – 18.1%, which is 7.8% less than in the control (significant difference).

The yield of dried products was calculated at a standard 10% moisture content. More dry products could be obtained from large-fruited pumpkin varieties – 16.1-20.3%. Among the studied varieties, pumpkin fruits of the Slavuta variety stood out by this indicator – the yield of dry products was 20.3%, which is 2.5% more than in the control. From pumpkin fruits of nutmeg varieties, it was possible to obtain 11-14% of dry products, the highest yield was obtained using the Gilea variety (control). No significant difference was found between the varieties Dolya and Divo in terms of finished product yield.

Based on the aforementioned data, 6.5-11.8 kg of fresh unpeeled fruit or 4.9-9.1 kg of peeled fruit was required to produce 1 kg of dried product. Less raw materials were consumed when large-fruited pumpkin varieties were used for drying. The Slavuta variety stood out by this indicator. If the fruit of this variety is used for drying, 6.5 kg of unpeeled fruit or 4.9 kg of peeled fruit is required to produce 1 kg of dry product.

For consumers of dried and reconstituted pumpkin products, the content of biochemical parameters in them is of great importance (Fig. 3).

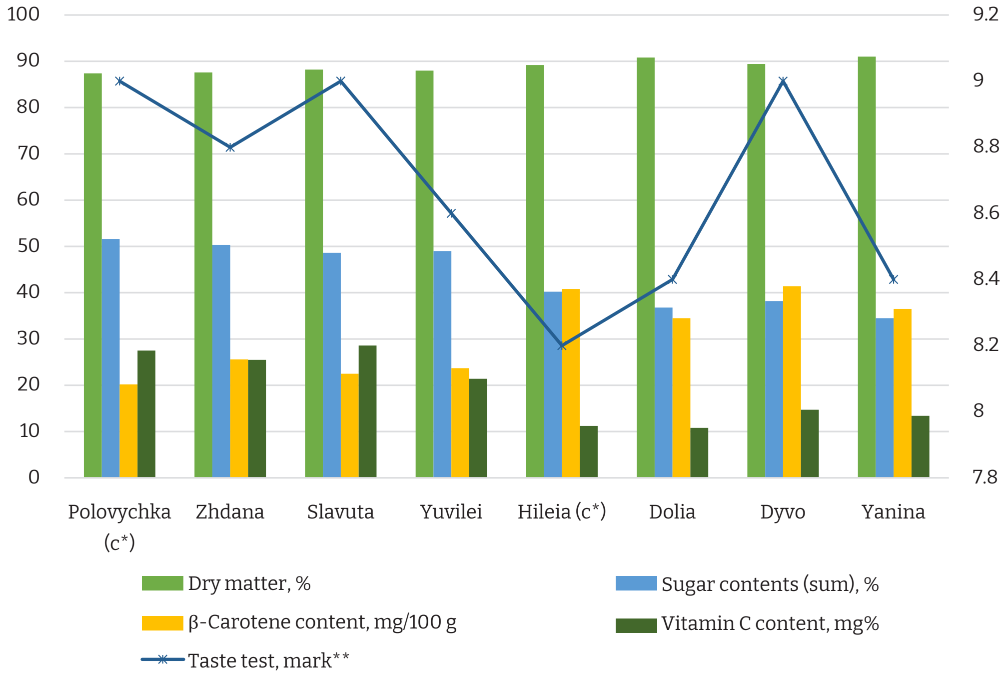

Figure 3. The content of the main biochemical parameters (in terms of dry matter) and tasting evaluation of dried pumpkin products of different types and varieties, average for 2014-2015

Note: *control **on a 9-point scale

Source: compiled by the authors

According to the results of the research, dried pumpkin products are a concentrate of dry matter, as they contain 87.4 to 91% of it, which is on average 6.3-8.4 times higher than the content in the raw material. The samples of dry products made from large-fruited pumpkin varieties had more dry matter – 11.6-12.8%. This is due to the higher content of sugars that bind moisture in dried products. During the research on the suitability of onion varieties for drying, it was found that the sugar content in dried products in some variants even increased compared to fresh raw materials (by 1.2%). This indicates that during the drying process, poly sugars can be converted to mono- and disaccharides (Zavadska *et al.*, 2021). Regarding dry pumpkin products, more sugars (total) were found in samples of large-fruited varieties (48.6-51.6%) compared to nutmeg varieties (34.5-40.2%). The highest number of sugars (total) was found in the dry products of large-fruited varieties Polyovychka (control) and Zhdana – more than 50%.

Based on the literature, dried pumpkin products contain a fairly significant amount of β-carotene and vitamin C, substances that determine the biological value and suitability of raw materials for the production of functional foods (Sharma *et al.*, 2020; Ouyang *et al.*, 2022). According to A. Hussain *et al.* (2022), due to the presence of significant amounts of functional ingredients, the use of dried pumpkin products has a wide range of applications. Our research has confirmed the presence of a significant amount of β-carotene (202-41.4 mg/100 g) and vitamin C (10.8-28.6 mg%) in dry pumpkin products, which gives grounds to recommend them as raw materials for the production of functional foods.

S. Chikpah *et al.* (2022) found that the content of β-carotene and ascorbic acid in dry pumpkin products also depends on the drying temperature and the thickness of the slices. Thus, the amount of β-carotene in dry samples in their studies ranged from 43.8-58.15 mg/100 g, and vitamin C – from 37.62-50.13 mg/100 g. More of these biologically active components were found in products dried at 60°C with a slice thickness of 3 mm than at 50°C and 70°C with a slice thickness of 5 mm – 58.15±1.75 mg/100 g of β-carotene and 50.13±2.03 mg/100 g of vitamin C. An increase in the thickness of the pumpkin slice prolonged the drying time and caused a more significant loss of bioactive compounds and antioxidant activity of dry products. The lower values of β-carotene in pumpkins dried at air temperatures below and above 60°C may be due to longer drying time at lower drying temperatures and thermal degradation at higher temperatures (Chikpah *et al.*, 2022).

During the convective drying of pumpkin strips 5-6 mm long and 2-3 mm thick at a temperature of +60°C, the content of β-carotene ranged from 20.2-41.4 mg/100 g, and vitamin C – 10.8-28.6 mg% and significantly depended on the type of pumpkin. In terms of β-carotene content, dry samples of butternut pumpkin varieties significantly exceeded large-fruited varieties and contained 34.5-41.4 mg/100 g (large-fruited varieties – 20.2-25.6 mg/100 g). By the content of this biologically valuable component, the varieties of butternut squash Divo and Gilea stood out – more than 40 mg/100 g. However, in the dry products of large-fruited pumpkins, a significantly higher content of vitamin C was found compared to nutmeg pumpkins – 21.4-28.6 mg% (in nutmeg pumpkins – 10.8-14.7 mg%).

During the convective drying of pumpkin at a temperature of +60°C, it was found that there was a significant loss of biologically valuable substances compared to fresh raw materials, which confirms the data of other researchers and our previous studies. The recalculations revealed that the loss of vitamin C during drying was more significant than that of β-carotene and amounted to 56-70% depending on the variety, while that of β-carotene was 36-40%. According to S. Chikpah *et al.* (2022), the decrease in the content of β-carotene and vitamin C during drying can be attributed to oxidative and thermal degradation, as well as their isomerisation due to exposure to oxygen, heat and light during drying. Similar losses of vitamin C and β-carotene were observed in our studies on the suitability of carrot and onion roots for drying (Zavadska *et al.*, 2020; Zavadska *et al.*, 2021). According to A. B. Armand *et al.* (2018), the loss of vitamin C during the convective drying of onions was 72.5-78.1%. In these studies, on the suitability of onions for drying, the loss of this biologically valuable element depended on the variety and ranged from 48-60% (Zavadska *et al.*, 2021).

The experimental samples of all varieties received high scores during the tasting – 8.2-9.0 points on a 9-point scale. They had a crispy texture, intense uniform colour, and a pleasant taste. In the samples of dried products of nutmeg varieties Dolya and Yanina, the taste was less intense, which is why the scores were slightly lower – 8.2-8.4 points. A direct significant correlation was found between the sugar content and the tasting score of dried products (r=0.69).

Thus, dried pumpkin products are a biologically valuable substance suitable for the production of functional foods, as they contain from 20.2 to 41.4 mg/100 g of β-carotene and 10.8-28.6 mg/100 g of vitamin C. To do this, we recommend using the fruits of the nutmeg varieties Divo and Gilea, whose dry products contain more than 40 mg/100 g of β-carotene, and the large-fruited Slavuta and Polevichka, whose vitamin C content is 28.6 and 27.5 mg/100 g, respectively.

Correlation relationships were calculated between the studied quality indicators of fresh fruits and dry pumpkin products, the results of which are presented in Table 2.

Table 2. Matrix of correlation relationships between the studied indicators of pumpkin (calculated using average values)

Indicator	Fruit mass, kg	Flesh contents, %	Dry matter, %	Sugar contents, %	Carotene content, mg/100 g	Vitamin C content, mg/100 g	Dry matter, %	Tasting evaluation of dry products, points
Fruit mass, kg	1							
Flesh contents, %	0.45	1						
Dry matter, %	-0.68*	-0.66	1					

Table 2. Continued

Indicator	Fruit mass, kg	Flesh contents, %	Dry matter, %	Sugar contents, %	Carotene content, mg/100 g	Vitamin C content, mg/100 g	Dry matter, %	Tasting evaluation of dry products, points
Sugar contents, %	-0.67*	-0.71*	0.98*	1				
Carotene content, mg/100 g	0.65	0.58	-0.73*	-0.87*	1			
Vitamin C content, mg/100 g	-0.41	-0.72*	0.84*	0.85*	-0.58	1		
Dry matter, %	-0.74*	-0.51	0.94*	0.92*	-0.54	0.62	1	
Tasting evaluation of dry products, points	-0.18	-0.76*	0.52	0.69*	-0.54	0.64	0.42	1

Note: *a strong correlation exists between the attributes
Source: based on own research

The calculations of correlation dependence revealed an inverse significant relationship between fruit weight and dry matter content (r=-0.68), sugar content (r=-0.67) and dry product yield (r=-0.74). The obtained results confirm the data of other researchers, namely: with an increase in fruit weight, the content of dry matter, sugars and dry product yield significantly decreases; smaller fruits contain more dry matter and sugars. Fruit weight did not significantly affect the content of carotene and vitamin C, as well as the tasting evaluation of dry products. A similar pattern was found between the pulp content and biochemical parameters: with an increase in the amount of pulp in the fruit, the content of dry matter (r=-0.66), sugars (r=-0.71) and vitamin C (r=-0.72) significantly decreased, and the tasting score of dry products worsened (r=-0.76). A significant direct relationship between the dry matter content and the yield of finished products was established (r=0.94).

Significant correlations were found between the biochemical parameters contained in pumpkin fruits, namely: an increase in dry matter content leads to a significant increase in the content of sugars (r=0.98), vitamin C (r=0.84) and a decrease in β-carotene (r=-0.73). The tasting score of dry products significantly increased with the increase in the content of sugars (r=0.69) and vitamin C (r=0.78) and decreased with the increase in the proportion of pulp in the fruit (r=-0.76).

The identified positive and negative correlations between them may be the result of their antioxidant and prooxidant effects. According to B. Kulczynski & A. Gramza-Michałowska (2019), a strong correlation was observed between the content of carotenoids and flavonols (r=0.91, p<0.001). That is, with an increase in carotenoid content, the flavonol content increases significantly, which can be used to predict the flavonol content in these studies. The studies of S. Chikpah *et al.* (2022) found that antioxidant activity has a direct positive correlation with β-carotene (r=0.752), total phenols (r=0.903), flavonoids (r=0.917), and ascorbic acid (r=0.441). Using the results of our correlation calculations and the data of other researchers, it can be argued that dried pumpkin products containing a high amount of carotenes and ascorbic acid will be characterised by high antioxidant properties and can be recommended as raw materials for the production of functional foods.

CONCLUSIONS

Pumpkin fruits of nutmeg varieties formed heavier fruits (6.2-7.4 kg), containing less bark (12.0-16.5%) and more pulp (71.2-78.0%), compared to large-fruited ones. The content of pulp used directly for drying among large-fruited pumpkins was 71.4 and 73.6%, respectively, and among nutmeg pumpkins – 78 and 74.1%, respectively, and muscovy pumpkins – Yanina and Gilea (control).

The content of the main biochemical parameters in fresh pumpkin fruits differed significantly and depended more on the species than on the variety. The fruits of large-fruited varieties accumulated a greater amount of dry matter (13.4-14.5%), dry soluble matter (11.3-12.3%), sugars (7.4-8.0%) and vitamin C (12.5-17.4 mg%). According to the content of β-carotene, which is the main biologically valuable component in fresh fruits and dried pumpkin products, large-fruited varieties prevailed over large-fruited ones and accumulated it in the range of 12.4-15.8 mg/100 g.

The fruits of the Gilea and Divo varieties contained the highest amount of this element – 15.8±1.2 and 14.2±0.4 mg/100 g, respectively.

To obtain 1 kg of dried products, 6.5-11.8 kg of fresh, unpeeled fruit or 4.9-9.1% of peeled fruit was required. More dried products could be obtained from large-fruited pumpkin varieties – 16.1-20.3%. According to the technological indicators that determine the profitability of drying, the large-fruited pumpkin variety Slavuta stood out: the yield of finished products was 20.3%, which is 2.5% more than in the control, and for the production of 1 kg of dried products, 6.5 kg of unpeeled fruits of this variety or 4.9 kg of peeled fruits were required.

Dried pumpkin products are a concentrate of dry matter, a biologically valuable food product, as it contains 87.4 to 91% dry matter, 34.5-50.3% sugars (total), 20.2-41.4 mg/100 β-carotene and 10.8-28.6 mg% vitamin C. For the production of functional foods, the most suitable are the fruits of the nutmeg varieties Divo and Gilea, whose dry products contain 41.4 and 40.8 mg/100 g of β-carotene, respectively, and the large-fruited Slavuta and Polevichka, whose vitamin C content is 28.6 and 27.5 mg%.

Promising areas for further research could be the creation of food products (bakery, confectionery, pasta, etc.) with increased biological value with the addition of dried pumpkin products in various doses to the recipe. The study may also include the suitability of fresh pumpkin fruit for fermentation (pickling), as this method of processing will ensure maximum preservation of nutrients.

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CONFLICT OF INTEREST

None.

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Підбір плодів гарбуза різних видів та сортів для виробництва функціональних харчових продуктів

Анотація. З кожним днем в Україні та світі зростає зацікавленість споживачів до здорового способу життя та функціональних харчових продуктів з підвищеною біологічною цінністю. Для виробництва таких продуктів харчування важливо підібрати сировину, що відповідає комплексу вимог щодо якості. Плоди гарбуза мають високий вміст поживних елементів, вітамінів, незамінних амінокислот та мінералів, що значною мірою відповідають цим вимогам. Метою досліджень була комплексна оцінка плодів гарбуза восьми сортів різних видів: великоплідних *(Cucurbita maxima Duch)* та мускатних *(Cucurbita moschata Duchex Poir)*, вирощених в умовах лісостепу України, для виділення найпридатніших для сушіння та виробництва функціональних продуктів харчування. Під час проведення досліджень використано метод експерименту, відповідно до схеми досліджень, лабораторний метод – для визначення біохімічних, біометричних та органолептичних показників якості, статистистичний – для проведення дисперсійного та кореляційного аналізів досліджуваних показників. Встановлено, що при використанні для конвективного сушіння плодів гарбуза великоплідних сортів можна отримати 16,1-20,3 % сухої продукції з вмістом цукрів 48,6-51,6 %, а мускатних – 11-14 та 34,5-40,2 % відповідно. Для виробництва функціональних харчових продуктів з вмістом β-каротину 40-41 мг/100 г (у перерахунку на суху речовину) доцільно використовувати плоди мускатних сортів «Гілея» та «Диво», а вітаміну С на рівні 28 мг % – великоплідних сортів «Славута» і «Польовичка». Виявлено, що зі збільшенням маси плодів суттєво зменшується вміст у них сухої речовини (r=-0,68), цукрів (r=-0,67) та вихід готової продукції (r=-0,74). Встановлено суттєвий прямий зв’язок між вмістом сухої речовини й цукрів (r= 0,98), а також вмістом сухої речовини й виходом готової продукції (r=0,94). Матеріали статті становлять практичну цінність для селекціонерів, овочівників, спеціалістів переробних підприємств при виборі виду та сорту гарбуза для виробництва функціональних продуктів харчування

Ключові слова: якість; вітамін С; каротин; переробка; сушіння; сировина

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Assessment of the tillage impact on soybean productivity

Abstract. Modern crop production technologies depend on the intensity of soil cultivation. Traditional cultivation methods increase production costs and harm the environment. The research relevance is determined by the need to find effective and environmentally friendly alternative tillage technologies that will reduce the cost of agricultural production and have a positive impact on the environment. The research aims to determine the influence of the soil tillage system on the formation of soybean plant productivity. Research methods: long-term stationary experiment, laboratory determination of soil agrophysical properties, statistical data processing. The field research was carried out at the Agronomic Research Station, a separate subdivision of the National University of Life and Environmental Sciences of Ukraine, in a stationary experiment of the Department of Agriculture and Herbology. Soybean yields under the No-till system were found to be 22.7% higher than under the conventional system, which in absolute terms was 2.81 t/ha under the No-till system and 2.29 t/ha under the conventional system. No-till provided higher soil moisture content and the share of agronomically valuable aggregates at a higher soil density than the traditional system. In general, the efficiency of moisture use by soybean plants under the shelf tillage system was 16.0% lower compared to the no-till system. The use of the conventional tillage system on average in 2020-2022 led to a decrease in the structural structure of the 0-30 cm soil layer studied by 8-33%. The amount of agronomically valuable aggregates (0.25-10 mm) depended on the tillage system. The No-till system increased the agronomically valuable structure in the 0-10 cm soil layer by 15.5%, the 10-20 cm layer by 10.3% and the 20-30 cm layer by 9.1% compared to the conventional tillage system at the beginning of the growing season and by 4.2%, 7.3% and 4.7%, respectively, at the end of the growing season. The practical significance of the obtained research results is to determine the optimal soil cultivation system for the realisation of the genetic potential of soybean to form its stable productivity

Keywords: density; soil structure; water consumption; cultivation; crop; plant

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INTRODUCTION

Soybeans are a unique protein and oilseed crop that is in high demand. Ukraine has significant potential to increase its soybean production and generate higher profits from its sales. Current technologies do not fully realise their yield potential due to the parity of fuel prices, crop protection products and fertilisers, which increases technological costs and prompts the search for new soybean growing technologies. Soil cultivation is a fundamental factor in terms of its impact on soil quality and, consequently, on sustainable crop productivity (Vozhehova *et al.*, 2021). Among the measures to increase soybean productivity is the effective use of the basic tillage system. Therefore, it is important to improve existing and develop new tillage measures and systems, considering the soil and climatic conditions of the region.

Variability in climatic conditions, especially temperature and precipitation during the growing season, are factors that limit soybean productivity (Nendel *et al.*, 2023; Elmerich *et al.*, 2023). Adapting crop production technologies to climate change is particularly important for pulses, which are characterised by low productivity stability (Reckling *et al.*, 2018; Zong-Sheng *et al.*, 2023). When there is insufficient moisture, it is important to prepare the soil in such a way as to ensure that the maximum possible amount of precipitation is retained. In particular, the study by V. Kyryliuk *et al.* (2020) shows that no-till works best in dry conditions, with yields often equal to or higher than those obtained with conventional tillage.

The priority task of modern agricultural production is not only to produce high-quality products but also to increase the level of soil fertility (Litvinova *et al.*, 2019). Conservation tillage technologies are considered to be one of the most effective methods of managing soil fertility, as well as reducing the energy and economic costs of tillage (Mondal *et al.*, 2020; Achankeng & Cornelis, 2023). However, it is necessary to point out the problematic issues of obtaining stable crop productivity and soil fertility indicators when using conservation tillage in crop production technology. F. Tshuma *et al.* (2021) noted that No-till leads to a layered placement of nutrients in the soil, with a predominant amount in the upper horizon. This can hurt the supply of nutrients to crops, especially in the dry season. Y. Shen *et al.* (2021) reported that No-till improved soil structure compared to conventional tillage, with the content of macro-aggregates increasing by 4.8%, the AOS (cultivating sowing unit) by 8.3%, and the AMWS (minimum moisture sowing unit) by 18.3%, but conventional tillage provided higher crop yields compared to No-till. J.C. Calonego *et al.* (2017) indicate that the No-till system has a favourable effect on soil quality, improving its structure and increasing biological activity, water retention capacity and water use efficiency.

The research relevance is determined by the need to reduce the negative impact of agricultural activities on the environment and optimise production costs. The introduction of the No-till system can help preserve soil cover, reduce erosion and pollution, and reduce energy and labour consumption, which will help increase agricultural production efficiency (Page *et al.*, 2020; Bulygin *et al.*, 2021). The research aims to determine changes in the agrophysical parameters of typical chernozem, the efficiency of moisture used by plants and their impact on soybean yields depending on the tillage system.

MATERIALS AND METHODS

The determination of soil tillage efficiency for high soybean yields and improvement of soil agrophysical properties was carried out over three years, from 2020 to 2022. To evaluate the effectiveness of different tillage systems, agricultural and physical soil parameters, crop water consumption, and yield formation were studied. An integral indicator of the efficiency of a tillage system is the level of crop productivity. The field research was carried out at the stationary experimental plot of the Department of Agriculture and Herbology, which is located at the Separate Subdivision "Agricultural Research Station" of the National University of Life and Environmental Sciences of Ukraine. The experimental plot was in crop rotation and included the following crop rotations:

1. Soy;
2. Spring barley;
3. Grain corn.

Two tillage systems were chosen for the study: No-till – a no-tillage system in which no plough or disc is applied after harvesting the previous crops, and the remains of plant mass are retained on the soil surface; traditional system – involving disking at a depth of 8-10 cm after harvesting the previous crop (corn for grain), ploughing to a depth of 23-25 cm, early spring moisture closure, and pre-sowing cultivation to a depth of 6-8 cm. The area of the town plot was 52 m^2, and the accounting plot was 22 m^2.

The studied soil was a typical low-humus chernozem and had the following characteristics: granulometric composition: coarse-dust light loam and contained 37% physical clay and 63% sand; equilibrium bulk density of the soil was 1.16-1.30 g/cm^3; stable wilting moisture (SWM) was 10.8%. The thermostat-weight method was used to determine the total reserves and available moisture in the soil to a depth of 1 m. The average sample was dried in a thermostat at 105°C by DSTU ISO 16586:2005 (2008). Soil samples were taken with a drill from layers 0-10, 10-20, 20-30, 30-50, 50-70, and 70-100 cm. In each variant, the total moisture reserve and the moisture reserves available to plants were calculated. The structural-aggregate state of the soil was determined by the Savvinov method according to DSTU 4744:2007 (2008), and the density of soil composition was determined by the cutting ring method according to DSTU ISO 11272-2001 (2003).

To account for the soybean harvest, the researchers used the method of continuous threshing, which involved threshing the entire area of the accounting plot without dividing it into separate parts. After harvesting all replications of each variant, the harvested plants were threshed to separate the seeds from the rest of the plant mass. To obtain accurate results, the researchers brought the harvest to 100% purity, i.e., eliminated all impurities and unnecessary elements from the harvested material. They also standardised the moisture content of the harvested crop for each variant to eliminate the effect of moisture on seed weight. Soybean harvesting was carried out at the stage of full plant maturity, which means that the plants had reached the maximum level of development and were ready for seed harvesting. This allowed to obtain the most accurate data on the crop yield.

The researchers also considered the requirements of the Convention on Biological Diversity (1992) when conducting their research. This convention aims to conserve biological diversity and sustainable use of nature's components. These requirements helped to ensure the ecological adaptation of the studied tillage systems and allowed the research to be carried out with due regard for environmental aspects.

RESULTS AND DISCUSSION

According to the results of the research for the period from 2020 to 2022, the highest average yield of soybean plants, which amounted to 2.81 tonnes per hectare, was obtained using the no-till tillage system. On the other hand, the traditional tillage system, which involved ploughing to a depth of 23-25 cm, yielded 2.29 tonnes per hectare (Fig. 1).

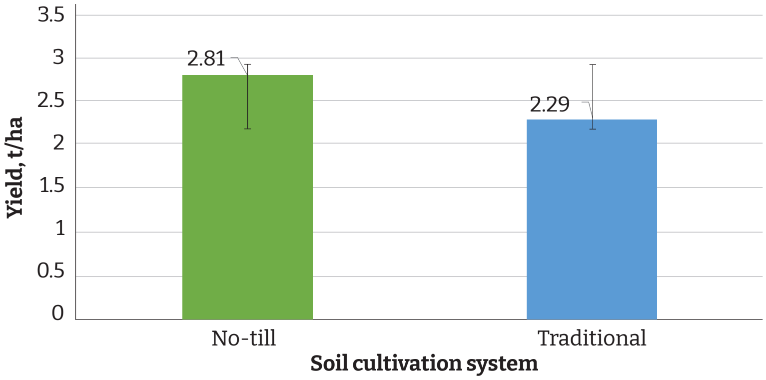

Figure 1. Soybean productivity under different tillage systems, average for 2020-2022
Source: compiled by the authors

However, D. Gawęda *et al.* (2020) found that soybeans produced higher yields (by 10.3%) under conventional tillage (ploughing), although soybean grain grown under No-till had a higher protein content (by 1.4%). J. Singh *et al.* (2021) indicated that long-term use of No-till reduced corn yields, but increased soybean yields under a two-year rotation compared to the traditional tillage system. S. Adamič & R. Leskovšek (2021), despite significant differences in plant condition and individual plant productivity, no significant differences in grain yield were observed between conventional and no-till cultivation systems. Yields for conventional and No-till systems were 4.54 and 4.48 t ha, respectively, with only a slight decrease in yield for the no-till system.

The results of the effective soil fertility study suggested that the use of different tillage systems causes changes in potential soil fertility, which determine the level of soybean yields. To substantiate the yield data in detail, the impact of different tillage systems on agrophysical parameters and crop moisture consumption was analysed. An important and urgent issue not only in the context of modern agricultural development, but also in the context of climate change is to study and determine the impact of various agrotechnical measures on the accumulation of available moisture in the soil and, as a result, obtaining stable crop yields. Considering the climatic conditions of the region, biological characteristics of crops in terms of water consumption and, accordingly, the water regime of the soil under crops, it is possible to identify ways to rationally use soil moisture and precipitation by crops in the process of growing them. An important measure to manage the use of water by plants is to optimise tillage. The processes of dry matter accumulation in the vegetative mass of agricultural plants are most active when there are sufficient reserves of available moisture in the soil.

According to the results of the research conducted in 2020-2022, on average, during the years of research, during the period of soybean sowing, the reserves of available moisture in the 0-100 cm soil layer under the No-till system were 160.4 mm, while under the traditional system – 134.3 mm. During the growing season, soil moisture was mostly used for the formation of soybean crops and partially for physical evaporation from the soil surface. At the time of soybean harvesting, the soil moisture reserves in the No-till system were 66.1 mm, and in the conventional system – 53.8 mm. This indicates a more efficient use of moisture by plants when implementing the No-till system, which affects the increase in soybean yields.

Studies of the efficiency of moisture consumption by soybean plants depending on soil tillage showed that the total moisture consumption from the soil during the growing season of soybean plants, depending on the tillage system, ranged from 319.1 to 332.9 mm, with higher values obtained with the No-till technology (Fig. 2). This means that the No-till system provides more efficient use of moisture by soybean plants compared to conventional tillage. The increase in moisture consumption in the No-till system may be due to the preservation of soil cover and its structure, which contributes to the preservation of moisture and its efficient use by plants. The No-till system allows to achieve optimal use of moisture from the soil under soybean plants, which in turn can have a positive impact on crop yields and lead to higher performance in growing this crop.

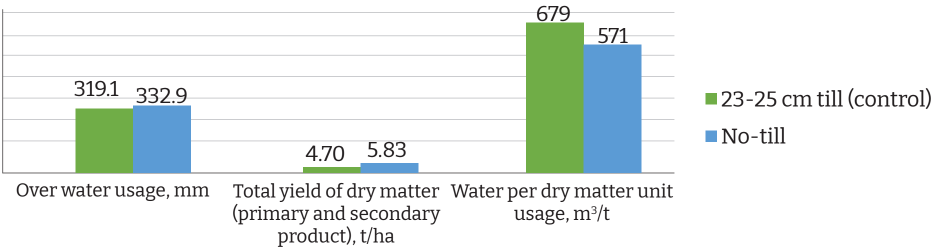

Figure 2. Total soybean water consumption depending on tillage, average for 2020-2022
Source: compiled by the authors

The calculations of the total moisture consumption for the formation of a unit of dry matter of the crop showed that in the variant with the traditional tillage system (ploughing at 23-25 cm), higher rates of total moisture consumption for the creation of a unit of dry matter of the crop were obtained, which amounted to 679 m^3/t, while in the No-till tillage system, they were 571 m^3/t. The opposite results were obtained in the studies of V.V. Sinchenko *et al.* (2019), who found that on typical black soil, the total moisture consumption for the formation of a unit of dry matter of soybean crop when placed after corn for grain was 475 m^3/t in the variant with ploughing and 623 m^3/t under No-till.

It is known that the most favourable conditions for growing soybeans are created when the soil density is in the range of 1.1-1.3 g/cm^3. M.T. Moraes *et al.* (2020) point out that soil density has always been a problem for agricultural productivity, mainly with minimum tillage technologies, in particular No-till. The determination of this indicator shows that in the No-till system, it was higher compared to conventional tillage (ploughing at 23-25 cm), where the soil density was 121-1.32 g/cm^3, while in the traditional tillage, it was in the range of 0.95-1.23 g cm^3 (Table 1).

Table 1. The density of soil layer 0-30 cm in soybean crops under different tillage systems (average for 2020-2022), g/cm^3

Soil layer, cm	vegetation beginning		vegetation ending	
	ploughing by 23-25 cm (control)	No-till	ploughing by 23-25 cm (control)	No-till
0-10	0.95	1.21	1.22	1.41
10-20	1.17	1.30	1.35	1.44
20-30	1.23	1.32	1.37	1.35
HiP_{05}	0.04	0.02	0.04	0.03

Source: compiled by the authors

During the growing season, soil compaction is observed in all variants of the experiment. It is natural that in the variant with deep shelf tillage, the density of soil compaction increased to 1.35 g/cm^3, or 28.4%, while in the No-till technology, it increased by 16.5%. It should also be noted that both in the top (0-10 cm) and in the 10-20 and 20-30 cm horizons, the soil texture density indicators had critical limits and significantly exceeded the optimal parameters for soybeans. Similar results were obtained by R.A. Vozhehova *et al.* (2021), who found that the lowest level of soil density (1.23 g/cm^3) was formed under chisel tillage to a depth of 28-30 cm of soil, which is 1.6% lower than the control (ploughing at 28-30 cm), and the highest (1.29 g/cm^3) was obtained under the No-till system, which is 3.2% higher than the control. However, S.R. Silva *et al.* (2023) found that the No-till system had a better effect on soybean productivity and was less harmful to soil physical quality.

Soil structure is crucial for the formation of air, water, nutrient and other regimes, and ultimately for obtaining high and sustainable crop yields. Structural and aggregate composition, as a complex factor in the formation of crop productivity, can be regulated within certain limits by basic tillage measures and generally contributes to better preservation of the structure of the cultivated layer. The study of seasonal changes in the structural state of typical chernozem in soybean crops depending on the tillage system was carried out at the beginning and end of the growing season (Table 2).

Table 2. Influence of primary tillage on the distribution of structural features in the 0-30 cm soil layer (average for 2020-2022)

Soil layer, cm	Ploughing by 23-25 cm (control)				No-till			
	number of units, %			structure coefficient	number of units, %			structure coefficient
	>10 mm	10-0.25 mm	<0.25 mm		>10 mm	10-0.25 mm	<0.25 mm	
Vegetation beginning								
0-10	22.3	63.8	14.3	2.86	19.6	79.3	6.9	2.99

Table 2. Continued

Soil layer, cm	Ploughing by 23-25 cm (control)				No-till			
	number of units, %			structure coefficient	number of units, %			structure coefficient
	>10 mm	10-0.25 mm	<0.25 mm		>10 mm	10-0.25 mm	<0.25 mm	
10-20	23.6	70.2	7.8	2.97	20.8	80.5	4.5	3.18
20-30	23.8	69.6	7.3	2.92	18.7	78.7	4.7	3.36
HiP$_{05}$	0.04	0.10	0.18		0.05	0.11	0.21	
Vegetation ending								
0-10	19.2	71.3	9.5	2.48	18.1	75.5	6.4	3.08
10-20	21.4	72.0	6.6	2.57	16.5	79.3	4.2	3.83
20-30	20.5	72.7	6.8	2.66	18.2	77.4	4.4	3.42
HiP$_{05}$	0.03	0.15	0.20		0.1	0.17	0.21	

Source: compiled by the authors

It was established that the highest content of agronomically valuable aggregates (10-0.25 mm in size) was formed in soybean crops under No-till technology. At the beginning of the growing season, the content of aggregates in the 0-10 cm layer was 79.3% in the 0-10 cm soil layer under this technology. In the soil layer 10-20 cm and 20-30 cm, respectively, it was 80.5 and 78.7%. Under shelf cultivation (ploughing at 23-25 cm), their share was 63.8%, 70.2% and 69.9%, respectively, 64.54-66.70%. The results obtained are confirmed by L. Gao *et al.* (2019), found that in the soil layers of 0-10 cm and 10-20 cm, the No-till system and deep soil loosening showed a significantly higher proportion of aggregates >250 μm (macroaggregates) compared to the traditional tillage system, and the proportion of aggregates <53 μm (microaggregates) was significantly higher in the traditional system compared to No-till and deep soil loosening. The opposite results were obtained by V. Kyryliuk *et al.* (2020), who found that minimising tillage, namely surface mouldboard tillage, worsened the soil structure compared to ploughing, especially in the 0-20 cm soil layer.

The highest coefficient of topsoil structure (0-10 cm) at the beginning of soybean vegetation was recorded in the No-till variant – 2.99, while in the ploughing variant, it was 2.86. In the horizons 10-20 and 20-30, the structural coefficient prevailed in No-till compared to ploughing, respectively, 3.18 vs. 2.97 and 3.36 vs. 2.92. It was determined that during the growing season of the crop, there was an increase in the share of agronomically valuable fractions due to a decrease in the dusty and cloddy fractions. When ploughing at 23-25 cm, the share of soil fraction (10-0.25 mm) was 71.3-72.7%, No-till – 75.5-79.3%. At the time of harvesting the crop, the structural coefficient increased in all variants regardless of the factors studied. Thus, optimisation of the soil tillage system has a significant impact on soil fertility and soybean yields on typical black soil.

CONCLUSIONS

Studies conducted on typical chernozem of the Right-Bank Forest-Steppe of Ukraine have established the positive impact of the No-till system on the management of soil agrophysical parameters and the formation of soybean plant productivity. It was found that the use of the No-till system ensures efficient (by 15.9%) use of moisture by soybean plants during the growing season, compared to the traditional tillage system.

Using No-till, an increase in the density of soil composition of 0-20 cm of the soil layer was observed compared to the traditional tillage system. At the beginning of the growing season, the density of the 0-20 cm soil layer under No-till exceeded the control variant (conventional tillage system) by 19.2%, and at the end of the soybean growing season by 11.1%.

It was found that the use of the traditional tillage system led to a decrease in the structure of the cultivated soil layer by 8.9-33.0% compared to the No-till system. At the beginning of the soybean growing season, the highest content of agronomically valuable aggregates in the 0-10 cm soil layer was formed in the No-till system (79.3%), while in the traditional system, the share of agronomically valuable aggregates decreased to 63.8%. During the growing season of soybean plants, an increase in the share of the agronomically valuable fraction was observed due to a decrease in the dusty and clumpy fraction. It was determined that due to the compaction of the cultivated soil layer and as a result of stronger contact of individual particles, the highest coefficient of the structural structure of the upper (0-10 cm) soil layer at the beginning of the soybean growing season was noted in the variant of the No-till system – 2.99, in the lower soil layers (10-20 and 20-30 cm) the coefficient was 3.18 and 3.36, respectively.

The tillage system influenced the density of the soil, the structural aggregate composition of the soil, and the moisture consumption of the crop, providing different conditions for the formation of soybean productivity. The use of the No-till system provided an increase in soybean yield by 22.7%, which in absolute terms was 0.52 t/ha compared to the traditional tillage system. A promising area for further research is the indicators of soil nutrition and the cycle of organic matter and nutrients.

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CONFLICT OF INTEREST

None.

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Оцінка впливу обробітку ґрунту на продуктивність сої

Анотація. Сучасні технології вирощування сільськогосподарських культур залежать від інтенсивності обробітку ґрунту. Традиційні методи обробітку збільшують собівартість виробництва та негативно впливають на навколишнє середовище. Актуальність дослідження полягає в необхідності знаходження ефективних та екологічно чистих альтернативних технологій обробітку ґрунту, які зменшать собівартість сільськогосподарського виробництва і мають позитивний вплив на стан навколишнього середовища. Метою досліджень було встановлення впливу системи обробітку ґрунту на формування продуктивності рослин сої. Методи досліджень: довготривалий стаціонарний дослід, лабораторне визначення агрофізичних властивостей ґрунту, статистична обробка даних. Польові дослідження виконано у Відокремлений підрозділ Національного університету біоресурсів і природокористування України «Агрономічна дослідна станція» у стаціонарному досліді кафедри землеробства та гербології. Встановлено, що урожайність сої за системи обробітку No-till була вищою на 22,7 % порівняно з традиційною системою, що у абсолютному значенні становило (2,81 т/га) за системи обробітку No-till, і 2,29 т/га за традиційної системи обробітку. No-till забезпечував більш високий уміст вологи в ґрунті, та частку агрономічно цінних агрегатів за вищого показника щільності складення ґрунту відносно традиційної системи. У цілому ефективність використання вологи рослинами сої за системи полицевого обробітку ґрунту була нижчою на 16,0 % порівняно з системою No-till. Застосування традиційної системи обробітку ґрунту у середньому за 2020-2022 рр. призвело до зниження структурності досліджуваного 0-30 см шару ґрунту на 8-33 %. Кількість агрономічно цінних агрегатів (0,25-10 мм) залежала від системи обробітку ґрунту. За системи No-till збільшувалась агрономічно цінна структура у шарі ґрунту 0-10 см на 15,5 %, 10-20 см шарі – на 10,3 % і 20-30 см – на 9,1 % порівняно з традиційною системою обробітку на початку вегетації і відповідно на 4,2 %, 7,3 % і 4,7 % у кінці вегетації. Практичне значення одержаних результатів досліджень полягає у визначення оптимальної системи обробітку ґрунту для реалізації генетичного потенціалу сої з метою формування стабільної її продуктивності

Ключові слова: щільність складення; структура ґрунту; водоспоживання; вирощування; сільськогосподарська культура; рослина

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Drought resistance of soft spring wheat varieties of different ecological and geographical origins in the Forest Steppe of Ukraine

Abstract. Wheat is one of the most important crops and the basis of human food and food security. Significant climate changes in recent years directly affect the formation of the level of wheat productivity. Therefore, the creation of varieties with increased resistance to drought at the initial stages of organogenesis, as well as the ability to form a high level of productivity in arid

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conditions is an urgent task in the modern selection of crops. The research aims to evaluate the level of drought tolerance wheat varieties different methods and to identify sources for involvement in crossbreeding during the selection of drought tolerance. Laboratory and field methods were used to study the researched varieties in response to drought: germination of seeds in a sucrose solution and determination of drought resistance indices by yield level. Varieties of spring wheat of different ecological and geographical origins have an increased productive potential in the conditions of the central part of the Forest Steppe of Ukraine. A wide range of variability in the degree of drought sensitivity of spring wheat was established. Varieties that have increased resistance to drought and can form a sufficient level of productivity under stress factors have been identified: Leguan (Czech Republic) and Koksa (Poland). The obtained results prove the possibility of combining in one variety an increased level of drought resistance and yield by classical breeding methods. According to the correlation coefficient between the productivity index and other studied indices of drought resistance, the effectiveness of using the Geometric Mean (proportional average) Productivity (GMP), Stress Tolerance Index (STI) and Yield Stability Index (YSI) indices in further breeding practice was noted. The practical research significance is determined by the combination of different methods for determining drought tolerance in crop breeding allowing for an objective assessment of resistance to stress factors and determination of viability at the initial stage of plant growth and development under the influence of the limiting factor – moisture

Keywords: *Triticum aestivum* L.; productivity; crops; productivity index; dryness

INTRODUCTION

Wheat holds significant importance in agriculture as a staple crop and a fundamental component of human nutrition and food stability. Among the complex factor groups that determine all life processes of plants, climatic factors occupy a special place, since they directly determine the conditions and limits of the life of organisms, their distribution, and reproduction. The influence of agroclimatic conditions on the yield level reaches 60-70% (Hladii & Luzan, 2020; Butenko *et al.*, 2020). V.V. Hamayunova *et al.* (2018) noted that the impact of climate change on agricultural production will only increase in the future. Due to the arid conditions that occur during the growth season of wheat, there is a need to determine the level of drought tolerance of varieties at different stages of their growth and development. Dry conditions during seed germination led to thinning of crops, and their insufficient amount during the growing seasons reduces productivity.

Air temperature will continue to rise, and dry periods will alternate with periods of normal moisture. The basis for the formation of the appropriate level of productivity is favourable weather conditions during the growing season (Sobko & Vozniuk., 2018). An important role in the life of all living things is played by water, an insufficient amount of which causes water stress, which leads to a violation of the life processes of the plant organism. M. Hou *et al.* (2022) considered water scarcity a serious challenge for wheat productivity in changing climates, especially in arid and semi-arid regions. Plants develop best with optimal provision of the necessary life factors and high-quality performance of all agrotechnical measures (Yurchenko *et al.*, 2020). Different approaches are used to overcome the problem of wheat drought resistance: agronomic, physiological, and molecular. It is noted that one of the most effective options for solving the problem of drought resistance is the creation of new varieties of wheat adapted to drought (Itam *et al.*, 2020; Chowdhury *et al.*, 2021; Ahmad *et al.*, 2022). Considering climate changes (Blyzniuk *et al.*, 2019), breeding for increased resistance to drought and heat is a promising direction for further increasing wheat productivity (Collins & Chenu, 2021).

Considering the aforementioned, the determination of the features of modern spring wheat genotypes by the level of drought resistance is an important and urgent task in breeding for adaptability. In H.U. Rehman *et al.* (2021) characterization of genotypes for adaptive traits can increase their selection for higher yield under drought conditions, and phenotypic and genetic study of drought-related traits will aid future gene discovery efforts and provide the basis for breeding drought-resistant wheat varieties (Lin *et al.*, 2019).

The study and research of the economic characteristics of the modern assortment of soft spring wheat allows to identify sources of valuable characteristics for their further involvement in breeding programs as valuable starting material (Lozinska *et al.*, 2018; Langridge & Reynolds, 2021). The research aims to evaluate the level of drought tolerance wheat varieties different methods and to identify sources for involvement in crossbreeding during the selection of drought tolerance.

MATERIALS AND METHODS

The research was conducted in 2016-2018 at the V.M. Remesla Myroniv Wheat Institute of the National Academy of Sciences. Fourteen varieties of soft spring wheat of different ecological and geographical origins were used: Elegia Myronivska, Struna Myronivska, Kharkivska 26, MIP Zlata, Panyanka, SimkodaMyronivska, Etud, Suite, Heroinya (Ukraine), Koksa, Yasna (Poland), Granny (Austria), Leguan (Czech Republic), Venera (Syria). Sowing was carried out on the experimental field with a CH-10C seeder in four repetitions. The registered area of the site is 10 m².

The variety Elehiia Myronivskawas used as a control sample. Laboratory and field methods were used to study the researched varieties in response to drought: germination of seeds in a sucrose solution and determination of drought resistance indices by yield level. Seed germination on a sucrose solution was carried out using a solution with a molar concentration corresponding to 14 atm of osmotic pressure (Dorofeyev *et al.*, 1974).

The seeds were disinfected with sodium hypochlorite (NaClO) solution. Seed germination was carried out on filter paper in Petri dishes for 7 days at a temperature of +20...21°C (Fig. 1a). The control sample seeds germinated under similar conditions in distilled water (Fig. 1b). Seed germination was determined as the percentage of germinated seeds compared to the control. The number of germinal roots was determined on the 7th day of germination in the control sample group.

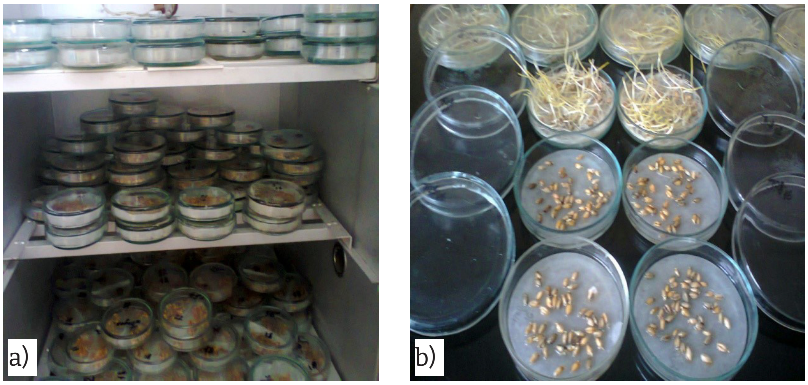


Figure 1. Determination of drought resistance by seed germination on sucrose solution

Note: a) seed germination in a thermostat; b) wheat seeds for germination on distilled water (with sprouts) and in sucrose solution (without sprouts)

Indices of drought resistance are calculated according to the formulas:

➤ the yield index (YI) characterizes the percentage of the yield of a specific sample in dry conditions to the average yield of the studied varieties during the drought period (Gavuzzi *et al.*, 1997):

$$YI = \frac{Y_s}{\bar{Y}_s} \times 100, \quad (1)$$

where *Ys* is the yield in drought conditions, $\bar{Y}s$ is the average yield of all studied samples in drought conditions;

➤ the average yield index (MP) characterizes the yield of the variety in dry and optimal years. (Ribaut & Poland, 1999):

$$MP = \frac{Y_p + Y_s}{2}; \quad (2)$$

➢ the geometric mean (proportional mean) of yield (Griffing, 1950):

$$GMP = \sqrt{Y_P \times Y_S}\,; \tag{3}$$

➢ the yield stability index (YSI) characterizes the ratio of yield under stress to yield under optimal conditions (Bouslama & Schapaugh, 1984):

$$YSI = \frac{Y_S}{Y_p}\,; \tag{4}$$

➢ the drought susceptibility index (DSI) characterizes how sensitive the variety is to the effects of drought, therefore, the lower its index, the greater the level of drought resistance of the sample (Fischer & Maurer, 1978):

$$DSI = \frac{Y_p - Y_s}{Y_p \times D}\,, \tag{5}$$

where: D (intensity of the stress factor) = 1-(HŶs/Ŷp); *Ys* – yield of a variety in drought conditions, *Yp* – yield of a variety in favourable conditions, HŶs – average yield level for all varieties in drought conditions, *Ŷp* – average yield level for all varieties in favourable conditions;

➢ the stress tolerance index (STI) characterizes the ability of a sample to maintain a stable yield level regardless of stress factors (Fernandez, 1992):

$$STI = \frac{Y_p \times Y_s}{(\bar{Y}_p)^2}\,, \tag{6}$$

where $\bar{Y}p$ is the average yield under optimal conditions;

➢ the drought tolerance index (TOL) determines the yield reduction under the influence of drought in absolute units. The optimal yield level of varieties with low indicators of this index was noted. (Hossain *et al.*, 1990):

$$TOL = Y_p - Y_s\,, \tag{7}$$

where *Yp* is yield in optimal conditions, Ys is yield in drought conditions;

➢ to characterize the hydrothermal conditions, the hydrothermal coefficient of Selyaninov (HCS) (Selyaninov, 1937) was calculated:

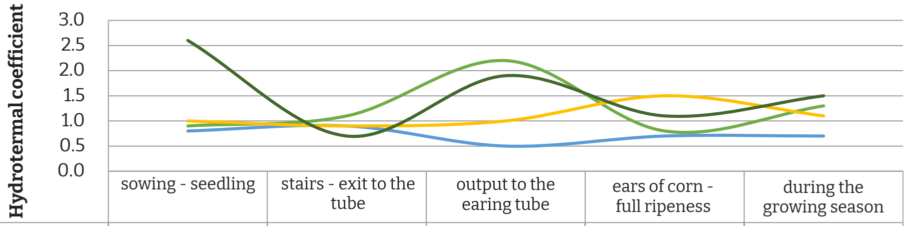
$$HCS = \frac{\sum r}{0{,}1 \times \sum t°C}\,, \tag{8}$$

where $\sum r$ is the sum of precipitation (in mm) for the period with an average daily air temperature above 10°C; $\sum t$ is the sum of active temperatures for the same period; 0.1 – constant coefficient.

Statistical analysis was performed using the Statistica 12.0 program (StatSoft, TIBCO, USA). The research was conducted following the requirements of the International Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The sum of temperatures during the growing season of 2016-2018 was 1666.7-1771.6°C, while the long-term indicator was 1550.7°C. The hydrothermal coefficient in 2016 (Fig. 2) was generally optimal (HCS=1.3), but in the interphase period "exiting the tube–earing" there was overwetting of the territory (HCS=2.2), and the period "earing–full ripeness", during which 70.60 mm of precipitation fell, was marked as dry (HCS=0.8). The total HCS for 2017 was 0.7 with a critical value (HCS=0.5) in the period "exit to the tube–earing", during which 14.74 mm of precipitation fell, and the average daily temperature was higher by 1.3°C. In 2018, the total value of HCS was noted at the level of 1.1, its decrease occurred in the interphase period "stairs – exit into the tube" (HCS=0.9).



	sowing - seedling	stairs - exit to the tube	output to the earing tube	ears of corn - full ripeness	during the growing season
🟩 2016	0.9	1.1	2.2	0.8	1.3
🟦 2017	0.8	0.9	0.5	0.7	0.7
🟨 2018	1	0.9	1	1.5	1.1
🟩 average multi-year indicator	2.6	0.7	1.9	1.1	1.5

Figure 2. Hydrothermal conditions of soft spring wheat vegetation in the Forest-Steppe Zone of Ukraine (MIP, 2016-2018)

Source: compiled by the authors

Considering climate changes, breeders are constantly increasing the level of drought resistance of crop genotypes by both traditional breeding methods and genetic engineering (Chebotar *et al.*, 2020; Motsnyi *et al.*, 2022). As scientists note, the use of laboratory methods for assessing drought resistance requires testing genotypes under natural growth conditions (Yurchenko *et al.*, 2020). The variation of the average yield level of the varieties over the years of research was noted from 2.94 to 4.00 t/ha (Table 1). The highest level of spring wheat yield was recorded in 2016, and the lowest in 2017, which proves optimal and unsatisfactory climatic conditions during the growing season. In selection for drought resistance, varieties that can form a sufficiently high level of productivity in unfavourable growing conditions should be prioritised. Thus, under dry vegetation conditions, the highest level of productivity was noted in wheat varieties: Suita (3.16 t/ha), Leguan (3.06 t/ha), Koksa (2.99 t/ha) and MIP Zlata (2.95 t/ha).

Table 1. Yield parameters of soft spring wheat varieties (± SE) for (2016-2018)

Variety, standard	Country of Origin	Productivity, t/ha			
		2016	2017	2018	
Elehiia myronivska- St	UKR	4.60±0.08	2.74±0.17	3.11±0.08	3.48±0.98
MIP Zlata	UKR	5.45±0.13	2.95±0.06	3.61±0.11	4.00±1.30
Struna myronivska	UKR	4.89±0.18	2.59±0.14	4.22±0.05	3.90±1.18
Koksa	POL	4.64±0.07	2.99±0.14	3.69±0.11	3.77±0.83
Leguan	CZE	4.60±0.08	3.06±0.14	3.64±0.15	3.77 ± 0.78
Simkoda myronivska	UKR	5.01±0.16	2.61±0.09	3.64±0.15	3.75±1.20
Yasna	POL	4.01±0.13	2.59±0.07	4.53±0.09	3.71±1.00
Paniyanka	UKR	5.00±0.14	2.62±0.05	3.53±0.11	3.72±1.20
Kharkivska 26	UKR	4.74±0.08	2.74±0.09	3.39±0.10	3.62±1.02
Granny	AUT	4.31±0.07	2.66±0.09	2.99±0.17	3.32±0.87
Heroinia	UKR	4.20±0.14	2.47±0.14	2.80±0.09	3.18±0.91
Venera	SYR	4.34±0.12	2.86±0.11	2.11±0.15	3.10±1.13
Siuita	UKR	3.86±0.30	3.16±0.06	2.14±0.11	3.05±0.87
Etiud	UKR	3.49±0.19	2.79±0.15	2.53±0.09	2.94±0.50

Note: St – standard, – three-year average

Source: developed by the authors based on their research (2016-2018)

Following the research methodology, to calculate the corresponding indices of drought resistance, the yield formed by varieties in two years with contrasting weather conditions was chosen. These were 2017 and 2016 when the minimum and maximum yield levels were obtained, respectively. The fluctuation range of the productivity index (YI) was 85-109 (Table 2). A high value of the productivity index was noted in the varieties Suita (YI=109), Leguan (YI=105), Koksa (YI=103), MIP Zlata (YI=101), Venera (YI=98), Etyud (YI=96). The obtained data testify to a higher level of yield in the indicated varieties in drought conditions.

Table 2. Characteristics of soft spring wheat varieties according to drought resistance indices

Variety, standard	YI	MP	GMP	YSI	SSI	STI	TOL
Elehiiamyronivska- St	94	3.60	3.49	0.60	1.00	0.60	1.71
MIP Zlata	101	4.20	4.01	0.54	1.19	0.79	2.50
Strunamyronivska	89	3.74	3.56	0.53	1.23	0.63	2.30
Koksa	103	3.82	3.72	0.64	0.93	0.69	1.65
Leguan	105	3.83	3.75	0.67	0.87	0.69	1.54
Simkodamyronivska	90	3.81	3.62	0.52	1.25	0.65	2.40
Yasna	89	3.30	3.22	0.65	0.93	0.51	1.42
Paniyanka	90	3.81	3.62	0.52	1.24	0.65	2.38
Kharkivska 26	94	3.74	3.60	0.58	1.10	0.65	2.00
Granny	91	3.49	3.39	0.62	0.99	0.57	1.65
Heroinia	85	3.34	3.22	0.59	1.07	0.51	1.73
Venera	98	3.60	3.52	0.66	0.89	0.61	1.48
Siuita	109	3.51	3.49	0.82	0.47	0.6	0.70
Etiud	96	3.14	3.12	0.80	0.52	0.48	0.70

Note: YI – productivity index, MP – average productivity index, GMP – geometric mean (proportional average) productivity, YSI – yield stability index, DSI – susceptibility index, STI – stress tolerance index, TOL – tolerance index. For TOL and DSI, lower values are desirable; For YI, MP, GMP, YSI and STI, higher values are desirable
Source: compiled by the authors

The MP index varied from 3.14 to 4.20. According to this indicator, the varieties MIP Zlata, Panyanka, Kharkivska 26 (UKR), Leguan (CZE), and Koksa (POL) were selected, which are capable of forming high yields under different weather conditions. Variations in the values of the yield stability index (YSI) were noted in the range of 0.52-0.82. Among the studied varieties, the lowest level of susceptibility to drought was found in the following varieties: Suite (DSI=0.47), Etude (DSI=0.52), Leguan (DSI=0.87), Venera (DSI=0.89). The range of variation according to the stress tolerance index (STI) was 0.48-0.79. A consistently high level of productivity was found in the following varieties: Simkoda Myronivska, Panyanka, MIP Zlata (UKR), Koksa (POL), and Leguan (CZE). The index of tolerance to stress in the specified varieties was from 0.65 to 0.79. The stress tolerance index (TOL) variation ranged from 0.70 to 2.50. As a result of the analysis, the optimal yield level under conditions of water deficit was found in the following varieties: Suite (TOL=0.70), Etude (TOL=0.70) and Yasna (TOL=1.42). According to most indices of drought resistance, the following varieties were selected: Koksa, Leguan, MIP Zlata and Etyud.

One of the determining factors of spring wheat yield level is moisture supply during the interphase periods of growth and development. In the studied years, dry conditions were observed during the germination period (Fig. 2). One of the methods that allow you to identify genotypes that can avoid the effect of drought in the early stages of development is the diagnosis of wheat varieties based on the indicator of seed germination on sucrose solution and the number of roots (Pour-Aboughadareh *et al.*, 2019; Khomenko, 2020).

During seed germination in a sucrose solution corresponding to 14 atm of osmotic pressure, differentiation of the investigated varieties was revealed by the percentage of germinated seeds (Fig. 3). Drought resistance at the level of the standard variety Elehiia Myronivska (according to Fisher's criterion) was noted in the following varieties: Koksa (91±2.9), Venera (91±2.9), Leguan (80±4.0), Simkoda Myronivska (75±4.3), Yasna (87±3.4) and Granny (87±3.4).

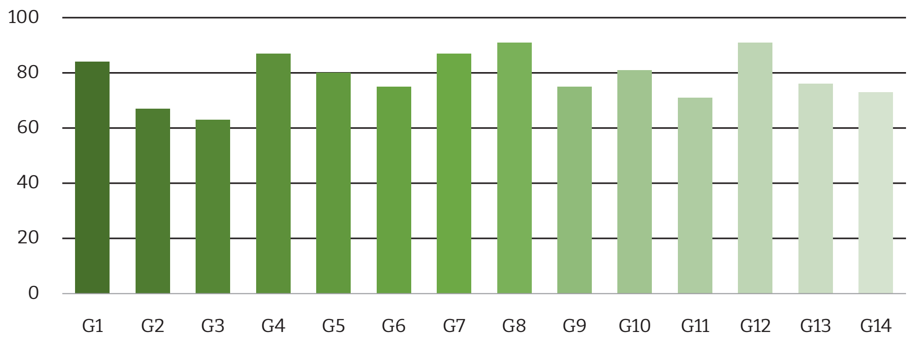


Figure 3. Distribution of spring wheat varieties by the percentage of germinated seeds on a 14 atm sucrose solution, 2016-2018

Note: G1 – Elehiia Myronivska, G2 – MIP Zlata, G3 – Struna Myronivska, G4 – Koksa, G5 – Leguan, G6 – Simkoda Myronivska, G7 – Paniyanka, G8 – Yasna, G9 – Kharkivska 26, G10 – Granny, G11 – Heroinia, G12 – Venera, G13 – Siuita, G14 – Etiud

Source: compiled by the authors based on their research (2016-2018)

The root plays an important role in providing water for the viability of plants at the germination stage (Khakwani *et al*, 2011; Wasaya *et al*, 2018; Terletskaya *et al.*, 2020), namely the number of germinating roots during seed germination since it is the root system that is responsible for providing plants with nutrients for their growth and development. Counting the number of germinal roots in spring wheat varieties showed a significant variation of this indicator depending on the genotype (Fig. 4). Within the studied set of varieties, from one to six germinal roots were noted, as well as a small percentage of seeds in the ringing phase.

In varieties (Koksa (91±2.9), Venera (91±2.9), Yasna (87±3.4), Granny (87±3.4), Leguan (80±4.0), Simkoda Myronivska (75±4.3), in which a high percentage of germinated seeds on sucrose solution was noted, the highest number of germinal roots was determined. The obtained data are consistent with the results of studies where it is noted that genotypes with a greater root biomass, and accordingly a greater number of roots, have a higher level of drought resistance (Mia *et al.*, 2020).

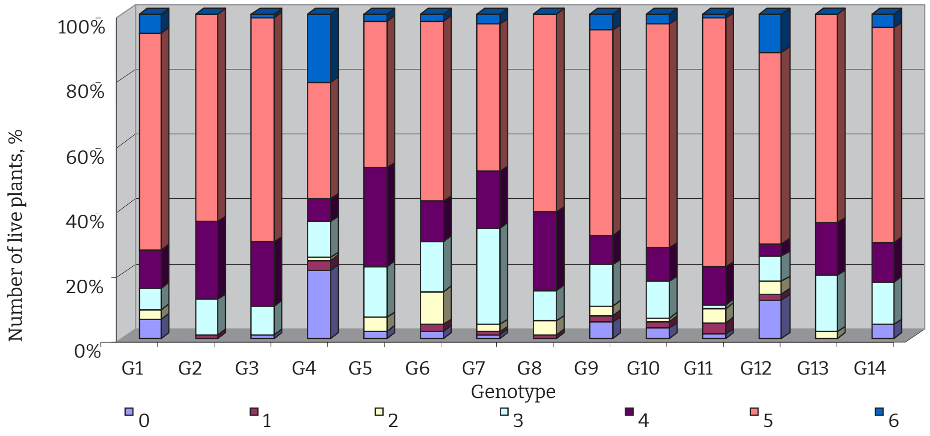


Figure 4. Distribution of spring wheat varieties by the number of germinal roots

Notes: G1 – Elehiia Myronivska, G2 – MIP Zlata, G3 – Strunam Myronivska, G4 – Koksa, G5 – Leguan, G6 – Simkoda Myronivska, G7 – Paniyanka, G8 – Yasna, G9 – Kharkivska 26, G10 – Granny, G11 – Heroinia, G12 – Venera, G13 – Siuita, G14 – Etiud

Source: developed by the authors based on their research (2016-2018)

The spring wheat varieties used in the study demonstrate a relatively wide range of drought resistance using the index approach and the laboratory method, which is also noted by other scientists (Grzesiak *et al.*, 2019). The obtained results prove the difficulty of combining high productivity and drought resistance in one genotype (Moskalets & Rybalchenko, 2015).

The correlation coefficient between productivity in optimal and drought conditions and drought resistance indices was determined. Variability of the strength and direction of the relationship between the indices of drought resistance and productivity in contrasting years in terms of vegetation conditions was revealed (Table 3). A strong relationship was established between the productivity of spring wheat varieties in the optimal growing season (2016) and drought resistance indices – MP (0.92±0.11). GMP (0.84±0.16), DSI (0.84±0.15), STI (0.85±0.15), TOL (0.93±0.10). A significant relationship between wheat yield in a dry year and drought resistance indices was noted only in the calculations: YI (1.00±0.00), YSI (0.58±0.24).

Table 3. Correlation coefficients of productivity with stability and drought resistance indices

Index, parameter	YI	MP	GMP	YSI	SSI	STI	TOL
$\overline{Y_p}$	-0.07±0.29	0.92±0.11**	0.84±0.16**	-0.85±0.15**	0.84±0.15**	0.85±0.15**	0.93±0.10**
Y_s	1.00± 0.00	0.31±0.10	0.48±0.25	0.58±0.24*	-0.58±0.24*	0.47±0.26	-0.42±0.26
YI	-	0.30±0.27	0.50±0.25	0.60±0.24**	-0.60±0.24**	0.50±0.26	-0.40±0.26

Notes: $\overline{Y_p}$ – optimal conditions; Ys – arid conditions; * – marked correlations are probable at p<0.05; ** – marked correlations are probable at p<0.01

Source: compiled by the authors

Correlations were also established between the yield index (YI) and the rest of the drought resistance indices: MP (r=0.30±0.27); with indices: GMP (r=0.50±0.25), YSI (r=0.60±0.24), SSI (r=-0.60±0.24), STI (r=0.50±0.26) and TOL (r=-0.40±0.26). Statistically significant correlations were determined between the yield index (YI) and the yield stability index (YSI) and the drought susceptibility index (DSI). When determining the correlations between the yield index (YI) and other calculated indices of drought resistance, a positive correlation (r=0.50±0.26) was noted between the yield index and the stress tolerance index (STI) and a negative correlation (r=-0.6±0.24) with the index of susceptibility to drought (DSI).

The obtained results of the correlation analysis coincide with the results of the research of other scientists, who also found a positive correlation between the yield and the stress tolerance index and a negative correlation between the yield and the drought susceptibility index (Pireivatlou *et al.*, 2010). Considering the research results, it should be noted that in selection for drought resistance, it is worth paying attention to the correlation between the yield index (YI) and the indexes of GMP, STI, and YSI, since there is a moderate and medium correlation, which may indicate the effectiveness of their use in further selection practice. S. Grzesiak *et al.* (2019) also note the effectiveness of using the stress tolerance index to determine resistant genotypes. At that time, other scientists note that the index approach characterizes genotypes by yield level and is considered an important addition to the classical methods of selection of agricultural plants (Peña-Gallardo *et al.*, 2019; Pykalo *et al.*, 2020).

Therefore, to determine the level of drought resistance of wheat varieties, it is advisable to use different methods of evaluating the specified trait, which provides a comprehensive approach and makes it possible to identify genotypes resistant to the influence of the limiting factor in different phases of growth and development.

CONCLUSIONS

The study showed that soft spring wheat varieties with different ecological and geographical origins demonstrate increased productivity potential in the central part of the Forest-Steppe of Ukraine. Among these varieties are those with increased resistance to drought and the ability to form a sufficient level of productivity under stress factors: Leguan (Czech Republic) and

Koksa (Poland). In varieties Koksa (91±2.9), Venera (91±2.9), Yasna (87±3.4), Granny (87±3.4), Leguan (80±4.0), Simkoda Myronivska (75±4.3) in which a high percentage of germinated seeds on sucrose solution was noted, the highest number of germinal roots was determined. The assessment of germination rates on sucrose solution and the number of germinal roots further supported this finding for varieties Koksa, Venera, Yasna, Granny, Leguan, and Simkoda Myronivska.

The results also show that it is possible to combine increased drought tolerance and favourable yields in one variety using traditional breeding methods. The correlation coefficients between the productivity index and the other drought tolerance indices studied (GMP, STI and YSI) underline the effectiveness of incorporating these indices into future breeding practices. The combination of different methods for assessing drought tolerance in crop breeding allows for an objective assessment of stress tolerance and viability at the initial stages of plant growth and development, especially under conditions of limiting factors such as moisture availability.

Determining the level of drought resistance of spring wheat makes it possible to identify the sources of this trait, which makes it possible to involve highly drought-resistant genotypes in the selection process and create drought-resistant varieties A promising direction of the research is the involvement of varieties of different ecological and geographical origin, in particular, Koksa, Venera, Yasna, Granny, Leguan and Simkoda Myronivska in crossbreeding, which will increase the level of drought resistance of new varieties of spring wheat and expand the range of their cultivation.

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CONFLICT OF INTEREST

None.

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Посухостійкість сортів м’якої ярої пшениці різного еколого-географічного походження в Лісостепу України

Анотація. Пшениця є однією з найважливіших сільськогосподарських культур і основою продовольства та продовольчої безпеки людства. В останні роки відмічаються значні зміни кліматичних умов, які безпосередньо впливають на формування рівня продуктивності пшениці. Тому створення сортів з підвищеною стійкістю до посухи на початкових етапах органогенезу, а також здатністю формувати високий рівень продуктивності в посушливих умовах є актуальним завданням сучасної селекції сільськогосподарських культур. Метою роботи було оцінити рівень посухостійкості сортів пшениці м’якої різними методами та виявити джерела для залучення в схрещування при селекції на посухостійкість. Для вивчення реакції досліджуваних сортів на посуху використовували лабораторні та польові методи: пророщування насіння в розчині сахарози та визначення індексів посухостійкості за рівнем урожайності. Встановлено, що сорти пшениці м’якої ярої різного еколого-географічного походження мають підвищений продуктивний потенціал в умовах центральної частини Лісостепу України. Встановлено широкий діапазон мінливості за ступенем посухостійкості пшениці м’якої ярої. Виділено сорти, які мають підвищену стійкість до посухи та здатність формувати достатній рівень продуктивності в умовах дії стресових факторів: Легуан (Чехія) та Кокса (Польща). Отримані результати доводять можливість поєднання в одному сорті підвищеного рівня посухостійкості та врожайності класичними методами селекції. За коефіцієнтом кореляції між індексом продуктивності та іншими досліджуваними показниками посухостійкості відзначено ефективність використання індексів Geometric Mean (proportional average) Productivity (GMP), Stress Tolerance Index (STI) та Yield Stability Index (YSI) у подальшій селекційній практиці. Практичне значення роботи полягаэ в тому, що поєднання різних методів визначення посухостійкості в селекції сільськогосподарських культур дозволяє проводити об’єктивну оцінку стійкості до стресових факторів та визначати життєздатність на початковому етапі росту і розвитку рослин в умовах дії лімітуючого фактора – вологи

Ключові слова: *Triticum aestivum* L.; продуктивність; сільськогосподарські культури; індекс продуктивності; сухість

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Biological, morphological and biochemical features of seeds of introduced genotypes of *Cicer arietinum* L.

Abstract. The research relevance is determined by the need to develop modern scientific and practical principles of involving little-known, rare, and newly created plant genotypes in the introduction process. This will help to warn of a possible phytoproduct crisis caused by climate change and rapid population growth on the planet. The research aims to determine the morphological characteristics and biochemical features of *Cicer arietinum* seeds for improving the germplasm of legumes and

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conducting further breeding and biotechnological research. The comparative morphological method was used for seeds of introduced plant genotypes from different regions of origin. The material for the study was 9 genotypes of *Cicer arietinum* originating from Australia, Afghanistan, Azerbaijan, and Ukraine, which were grown in experimental plots of the M.M. Gryshko National Botanical Garden. Morphometric parameters and some biochemical properties of plant seeds were studied depending on genotypic characteristics. Field, laboratory, and methods of analysis of variance and statistical evaluation of average data were used using Microsoft Excel (2010). In the course of the research, it was found that all introduced genotypes are characterised by high quantitative and qualitative indicators of seeds. In terms of linear seed dimensions (length to width ratio), the sample CAAFGK-1 was particularly distinguished – 17.12×14.38 mm, and in terms of weight of 1000 seeds CATADJK-1 – 584.5 g. Biochemical studies have shown that the highest amount of absolute dry matter was accumulated in the seeds of *C. arietinum* samples – CAAFGD-2, CAAFGK-1, CATADJD-2 and CATADJK-1 (from 89.04 to 89.68%). The level of total sugars was dominated by the samples of *C. arietinum* genotypes CATADJK-1 – 9.37%, and the accumulation of phosphorus was dominated by CAAZEUR-2 – 1.43%. The biochemical composition of plants makes it possible not only to characterise their value in terms of food crops but also to determine the most plastic genotypes to environmental factors. Thus, the results obtained indicate the prospects of using certain genotypes of *C. arietinum* as a starting material for breeding and biotechnological research and the creation of new plant forms, which will help to expand the range of highly productive chickpea genotypes in the northern regions of Ukraine

Keywords: climate; chickpea; germplasm; morphological characteristics; seed composition

INTRODUCTION

The *Fabaceae* (*Leguminosae*) family is one of the largest in the plant kingdom and includes more than 500 genera and about 17,100 species distributed almost all over the world. A large number of representatives are a valuable source of raw materials to meet the needs of the population, as well as an integral component in the proper functioning of natural ecosystems. In this regard, mankind has naturalised and cultivated several well-known species for thousands of years (including beans, beans, peas, soybeans, etc.), among which the representatives of the genus *Cicer* deserve special attention.

Chickpea, along with other pulses, is an extremely valuable and promising crop worldwide, with an area under cultivation of over 17.8 million hectares and a production of 17.2 million tonnes of seeds (Amina *et al.*, 2020; Durdane, 2022). In Ukraine, 70 thousand hectares are allocated for chickpea cultivation (Shcatula & Votyk, 2020). For example, global soybean acreage is 120 million hectares with a harvest of more than 300 million tonnes (FAOSTAT, 2021), while according to the Ministry of Agrarian Policy and Food of Ukraine (2022), soybean acreage in Ukraine is about 1,213 thousand hectares.

F. Boukid (2021) and S.E. Mathew *et al.* (2022) indicate that the protein content of chickpea seeds ranges from 17-30% of the absolute dry weight. In addition, they noted a high content of carbohydrates, vitamins, and minerals. Chickpea plays an important role in agriculture by increasing soil fertility through biological nitrogen fixation (Gediya *et al.*, 2019; Alok *et al.*, 2020). A global collection of approximately 100,000 accessions of *C. arietinum* is held in 120 national and international genebanks in 64 countries. In general, varietal resources include about 400 taxa (Piergiovanni, 2022), of which 38 varieties of Ukrainian selection are listed in the State register of varieties suitable for distribution in Ukraine (2022).

Ukraine is one of the largest agricultural countries supplying the world market with a significant number of agricultural products, including pulses. Its physical and geographical location allows for a further increase in pulses production through the introduction of plant genotypes that are not common in this area, such as *C. arietinum*. Therefore, enrichment of the gene pool and comprehensive introduction and breeding research is important in solving the problem of increasing the productivity and production of this crop, as well as providing the food market with the necessary raw materials.

Depending on the habitat, the morphological traits of any plant species vary. The ability of plants to form differentiated phenotypes that depend on environmental conditions is called phenotype modification or phenotypic plasticity (Khanna *et al.*, 2022). Seeds are the initial stage of plant ontogenetic development, so at this stage, it is possible to study the ability of a plant organism to form several different, relatively appropriate phenotypes in many environments (La *et al.*, 2022). In general, phenotypic plasticity, as a response to environmental factors, can be reflected both in the number of seeds produced and in their size among different populations of the same species due to differences in habitat (Zerfu *et al.*, 2021; Mehmetoglu *et al.*, 2022). In this case, the seeds of *C. arietinum* plants are also characterised by wide polymorphism. There are three groups of chickpeas in the world: Kabuli, Desi, and Bombay. Kabuli types have scoop-shaped, large, cream-coloured seeds, Desi types are angular, small, and dark in colour, Bombay is also dark in colour but larger than the Desi variety (Nisa *et al.*, 2020). Mobilising plants from different centres of origin and focusing on intraspecific seed variation is important for preserving germplasm of valuable genotypes in collection funds and creating varieties and forms with specified parameters (Mohanty *et al.*, 2022).

In this regard, the study aimed to determine the biological and morphological features and some structural, functional, and biochemical compounds in the seeds of different chickpea (*Cicer arietinum* L.) genotypes introduced in the M.M. Gryshko National Botanical Garden of the National Academy of Sciences (NAS) of Ukraine.

MATERIALS AND METHODS

The study was carried out in 2020-2021 at the experimental plots of the Department of Cultural Flora of the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, located at 50°24′45″N, 30°33′44″E, with an area of about 129 ha (Fig. 1).

Figure 1. Map of the location of the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine

The territory of the introduction plots is represented by grey forest podzolic soils. The depth of the arable layer is 20-22 cm. The humus content of the soil is 3.26%, pH is 6.7, nitrogen content is 98 mg/kg, phosphorus is 373 mg/kg, and potassium is 66 mg/kg.

This study was carried out within the framework of the National Research Foundation of Ukraine project "Influence of stress factors on the synthesis of proteins with prion properties in plants". Different genotypes of *C. arietinum* plants collected in the collection fund of the Department of Cultivated Flora of the M.M. Gryshko National Library of the National Academy of Sciences of Ukraine were used. Plants were grown in the open field in small plots (6 replications). At the end of the vegetation phase, the aerial part was cut off and threshed on a grain thresher. The resulting seeds were dried and randomly selected for further analysis. The most typical samples for each of the involved genotypes were selected for photographic recording.

The morphological description of the seed surface microsculpture of *C. arietinum* and *G. max* plants was performed according to the Illustrated guide to the morphology of flowering plants (Zyman *et al.*, 2012). The biometric and comparative methods of determining their external and internal features were also used, along with photographic recordings in length, width and cross-section using a SIGETA Expert 10-300x 5.0Mpx electric USB microscope (China) and a Canon 400 D digital camera (Japan). Linear dimensions were recorded using a Generic electronic digital calliper (China) and a Xiaomi Duka SD measuring tape (China). The weight of 1000 seeds were estimated on an AXIS ANG 200C electronic analytical balance (Poland) in ten replicates according to the international rules for seed testing (1999).

Based on the data obtained from the archives of weather monitoring of the Central Geophysical Observatory (2023), a comparative assessment of the weather and climatic conditions of the study area was made with the average long-term indicators (Fig. 2). During the growing season of 2020-2021, it was shown that the average monthly air temperature, starting in June, had a significant deviation from the norm in the direction of a significant increase.

Precipitation is essential for plant growth, development, and productivity. In 2020 and 2021, total precipitation was significantly above normal only in May and October, and in 2021 – only in May. For all other months of the growing season, the amount of precipitation was significantly below normal. The studied *C. arietinum* plants experienced a significant moisture deficit and high temperatures during a significant part of the growing season. Under these conditions, the plants successfully vegetated and provided high growth and productive performance.

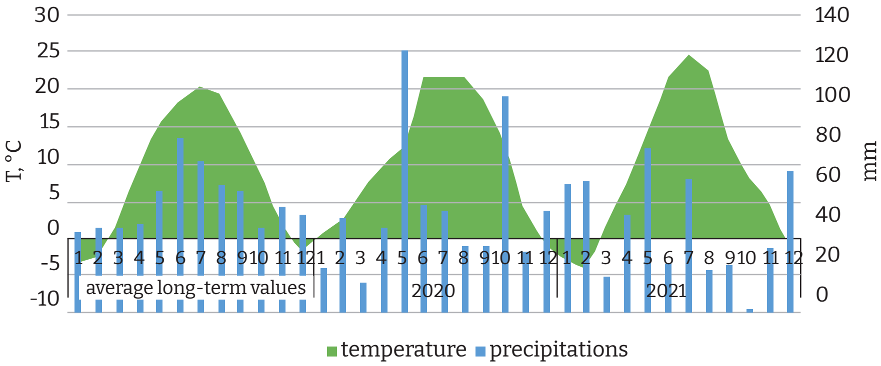

Figure 2. Dynamics of average monthly temperatures and precipitation (2020-2021) compared to long-term averages

Statistical data processing was carried out using Microsoft Excel 2010 (Data Analysis package). The minimum, maximum, mean, standard deviation and coefficient of variation were used to express the data obtained. The study was conducted following the requirements of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The effectiveness of breeders' creation of new competitive varieties with high levels of productivity, manufacturability, product quality, and adaptability are based on the correct selection of source material, which should be based on genetic resources that have been comprehensively studied and structured into appropriate collections.

The value of the selected genotypes is that they have different origins: Australia – *C. arientinum* ('Tyson'); Afghanistan – *C. arietinum* (CAAFGK-1 and CAAFGD-2); Azerbaijan – *C. arietinum* (CAAZEMR-1 and CAAZEUR-2); Tajikistan – *C. arietinum* (CATADJK-1 and CATADJD-2); Ukraine – *C. arietinum* (CAUKR and CAOCHL). (Fig. 3).

Figure 3. Seeds of the studied genotypes *Cicer arietinum* mobilised to the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine

Note: 1 – CAAFGK-1, 2 – CAAFGD-2, 3 – CAAZEMR-1, 4 – 'Tyson', '5 – CAOCHL, 6 – CAUKR, 7 – CAAZEUR-2, 8 – CATADJK-1, 9 – CATADJD-2, 10 – *Glycine max*, 'Soniachna' (for comparison)

The seed size of any legume crop is important in determining its market value and is also an important parameter for breeders who also rely on these parameters (Upadhyaya *et al.*, 2006; Houasli *et al.*, 2021). Therefore, we evaluated seeds by length, which is rarely found in the literature. The analysis of seeds by length allowed us to identify several differences between the involved genotypes and, based on the data obtained, to divide them into length groups. Thus, CAAFGK-1 has the largest seed length of 17.12 mm. The genotypes CAUKR, CATADJD-2, and CAAZEMR-1 were characterised by slightly smaller sizes (from 15.26 to 15.91 mm). 'Tyson', CAAZEUR-2, CAAFGD-2, CAOCHL, and CATADJK-1 were characterised by the shortest length (12.51 to 14.97 mm) (Fig. 4). In a study by O. Legesse *et al.* (2022) the linear dimensions of *C. arietinum* seeds (including length) on average range from 8.89 to 9.82 mm, which is significantly smaller than those of the introduced genotypes in the National Botanical Garden. This may indicate that the growing conditions are favourable for large seed sizes.

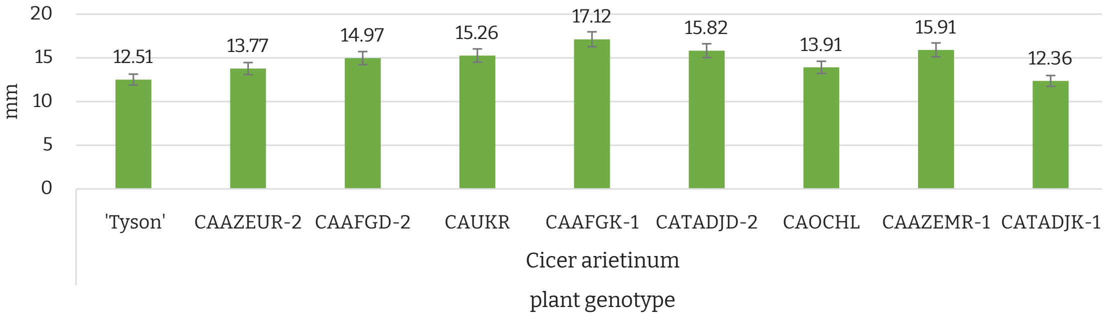

Figure 4. Seed length of *Cicer arietinum* depending on the genotypic characteristics of the source material

Source: compiled by the authors

The price of chickpeas depends on the quality of the product. The main criterion for chickpeas is grain size. Chickpeas with a grain diameter of 8 mm or more are valued (Kivrak *et al.*, 2020). Today, little attention is paid to the linear dimensions of the seeds, and only their weight is studied. In their research, M. Kaya *et al.* (2008) reported that the maximum size of the studied genotypes ranged from 7 to 9 mm. Evaluation of seeds by width also revealed that CAAFGK-1 (14.38 mm) had the highest value among other introduced genotypes. CAAFGD-2, CAUKR, CATADJD-2, and CAAZEMR-1 were characterised by smaller seed width (from 13.47 to 13.83 mm). The smallest seed width was in genotypes CATADJK-1, 'Tyson', CAAZEUR-2, CAOCHL (from 10.47 to 12.02 mm) (Fig. 5). Given the rather high performance, all introduced genotypes are promising for further breeding research and widespread use in agriculture.

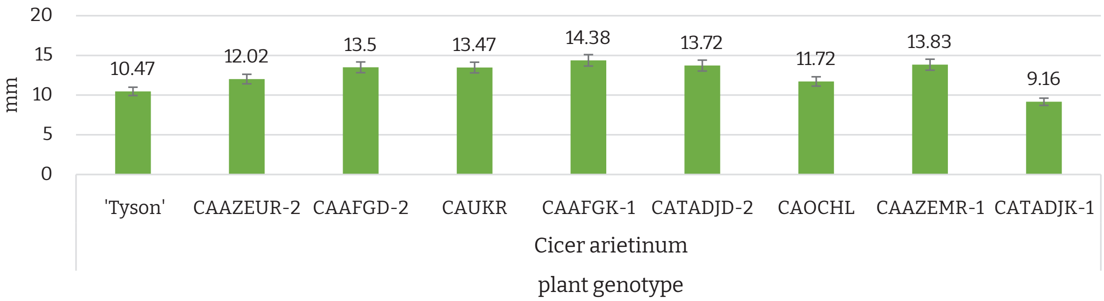

Figure 5. Seed width of *Cicer arietinum* depending on the genotypic characteristics of the source material

Source: compiled by the authors

The weight of 1000 seeds as one of the main elements of the yield structure varies depending on genotypic characteristics and growing conditions. As indicated by O. Legesse *et al.* (2022) and A.A. Igolkina *et al.* (2023), the weight of 1000 seeds ranges from 284.7 to 500.1 g for C. arietinum genotypes. In these studies, the highest values were recorded for *C. arietinum* seeds of CATADJK-1 – 584.5 g of Tajik origin and CAAFGK-1 – 566.0 g of Afghan origin. The average values were provided by the genotypes CAAFGD-2, CAUKR, CATADJD-2, and CAAZEMR-1 (from 399.5 to 485.0). CAOCHL seeds had the lowest weight of 200.5 g. Thus, considering the whole complex of evaluated morpho-physical parameters of seeds and comparative analysis with available literature data, we can make a preliminary conclusion about significant prospects of their introduction into breeding practice for the creation of new varieties and hybrids and introduction of *Cicer arietinum* genotypes into agricultural production in Ukraine (Fig. 6).

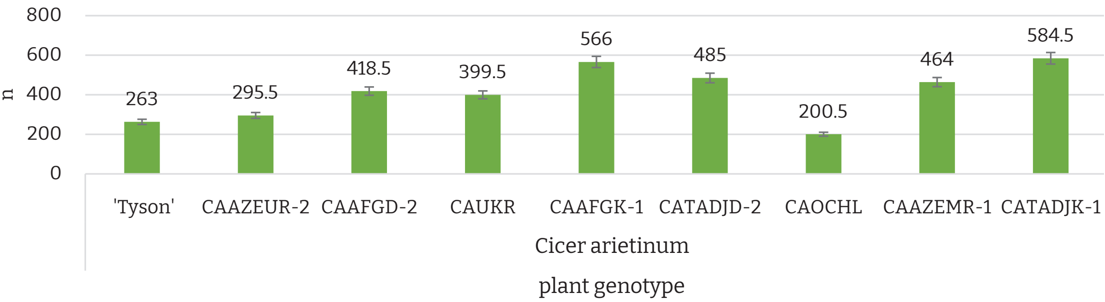

Figure 6. Mass of 1000 *Cicer arietinum* seeds depending on the genotypic characteristics of the source material

Source: compiled by the authors

The vast majority of morphological studies are aimed at dividing chickpea genotypes into three groups according to well-defined external features (Kabuli, Desi, Bombay) (Milan-Noris *et al.*, 2018; Mazur *et al.*, 2021). Given this, among the introduced genotypes in the NBS, there are clearly defined Kabuli and Desi groups. In this regard, it was necessary to trace the heterogeneity of morphological traits within each group, since this issue is not paid attention to in the literature, but these results can be successfully used in the selection of genotypes. Therefore, we conducted micromorphological studies of the seed characteristics of these representatives. It was found that the introduced genotypes have several differences: in the shape and surface of the seed; the colour of the seed coat and scar; colour and structure of the endosperm. Thus, the analysis resulted in the following groups of genotypes based on seed shape: elliptical – CAAFGK-1; round – CAAFGD-2, CAAZEUR-2, CATADJD-2; heart-shaped – CAAZEMR-1, 'Tyson', CAOCHL, CAUKR, CATADJK-1. According to the colour of the seed coat, the following were distinguished: white – CAAFGK-1, CAAFGD-2, CAAZEMR-1, CAUKR, CAAZEUR-2, CATADJK-1, CATADJD-2; black – 'Tyson', CAOCHL. In the samples of plants CAAFGK-1, CAAZEMR-1, CAUKR, and CATADJK-1, the seed surface is tuberous, angular – in genotypes 'Tyson', CAOCHL, in samples CAAFGD-2, CAAZEUR-2 – wrinkled. Regarding the features of the seed scar, it should be noted that in all the studied representatives it is located on the seed surface (slightly convex), in CAAFGK-1, CAAFGD-2, CAAZEMR-1, CAUKR, CAAZEUR-2, CATADJK-1, CATADJD-2 plants it has a light brown and sometimes yellowish colour, and in 'Tyson' and CAOCHL representatives it is black with an anthracite sheen.

As for the colour and structure of the endosperm, the cross-section of seeds revealed several differences. In the genotypes CAAFGK-1, CAAFGD-2, CAAZEMR-1, 'Tyson', CAOCHL, and CATADJD-2, the endosperm is hard, dense, and does not split into halves along the seed suture when split. In the other representatives of CAUKR, CAAZEUR-2, and CATADJK-1, the seed easily splits into two halves, characteristic of traditional legumes, along the seed suture. According to the colour of the endosperm, the seeds of the introduced genotypes are divided into the following groups: whitish yellow with a yellow surrounding near the seed coat – CAAFGK-1, CAUKR, CATADJK-1; yellow – CAAZEMR-1, 'Tyson', CAOCHL, CAAZEUR-2, CATADJD-2; whitish or pale – CAAFGD-2 (Fig. 7).

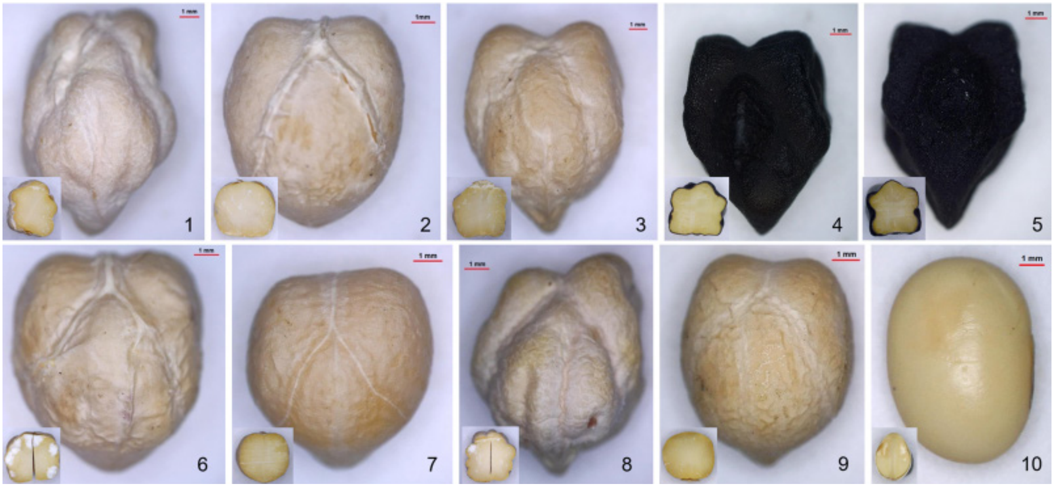

Figure 7. Seeds of the introduced genotypes *Cicer arietinum* mobilised to the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine

Note: 1 – CAAFGK-1, 2 – CAAFGD-2, 3 – CAAZEMR-1, 4 – 'Tyson'5 – CAOCHL, 6 – CAUKR, 7 – CAAZEUR-2, 8 – CATADJK-1, 9 – CATADJD-2, 10 – *G. max*, 'Soniachna' (for comparison)

Assessment of the biochemical composition of plants is of great scientific and practical importance not only for determining their economic value but also for determining the level of BAC (biologically active compounds) deposited in plant seeds, which allows to establish the manifestation of their adaptive capacity to biotic and abiotic environmental factors (Rakhmetov *et al.*, 2017). Therefore, along with the biological and morphological characteristics of plants, a comprehensive study of the phytochemical characteristics of introduced *Cicer arietinum* genotypes is an urgent task.

S. Soysal & M. Erman (2020) note that *C. arietinum* genotypes in Syria can accumulate a significant proportion of absolute dry matter in seeds in the range of 93.98-95.97%, which is achieved by treating crops with *Mesorhizobium ciceri* during the period of juvenile plant development. Under NBS conditions, all genotypes were not treated with any stimulant to objectively assess the biological potential of each of them. The seeds of the introduced plant genotypes were analysed for the content of certain structural and functional (absolute dry matter), biologically active compounds (total sugar) and macronutrients (phosphorus), which potentially reflect the level of adaptation ability of a particular genotype to environmental conditions at the initial stages of its ontogeny. A high level of absolutely dry matter indicates the deposition of plastic substances for the mobilisation of all vital processes in seeds. It was found that *Cicer arietinum* plants of CAAFGD-2, CAAFGK-1, CATADJD-2 and CATADJK-1 accumulated the highest level of absolutely dry matter (from 89.04 to 89.68%), and CAAZEMR-1 – 88.28% (Fig. 8).

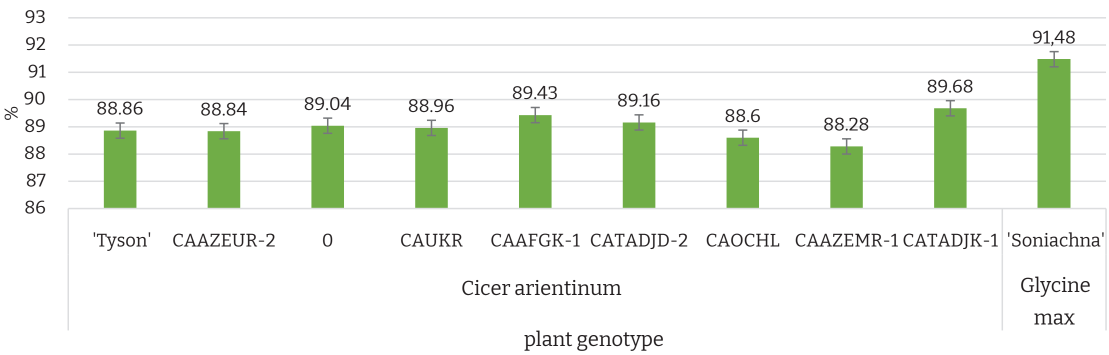

Figure 8. Absolute dry matter content in *Cicer arietinum* seeds depending on the genotypic characteristics of the source material

Source: compiled by the authors

The accumulation of sugars is of particular importance for the frost and drought tolerance of plants, which is important when sowing plants in early spring, as crops can be stressed by the climatic rhythms of the growing area (in particular, frost or drought). High levels of sugar in cells lead to an increase in the concentration of cell sap and a decrease in water potential, which results in a lower freezing point. At the same time, sugar ensures the preservation of proteins concentrated in the cell walls, which during drought significantly slow down the evaporation of water through the cell membrane. In this way, it plays a protective role in the initial stages of plant ontogeny and ensures the stable operation of vital processes in cells (Toker *et al.*, 2021). It was found that the highest level of total sugars was characterised by samples of *C. arietinum* genotypes CATADJK-1 – 9.37%, with the average content of 'Tyson', CAAZEUR-2, CAAFGD-2, CAUKR, CAAZEMR-1 (from 5.37 to 7.67%). The lowest content of total sugars was recorded in the samples CAAFGK-1, CATADJD-2 and CAOCHL (from 3.72 to 4.01%) (Fig. 9). It is worth noting that in comparison with the results of T. Kumar *et al.* (2023), which indicate that among the 20 analysed genotypes of *C. arietinum* in India, the content of total sugars in seeds ranges from 2.84 to 4.73%, which in some cases is two times less than in the data obtained under NBS conditions.

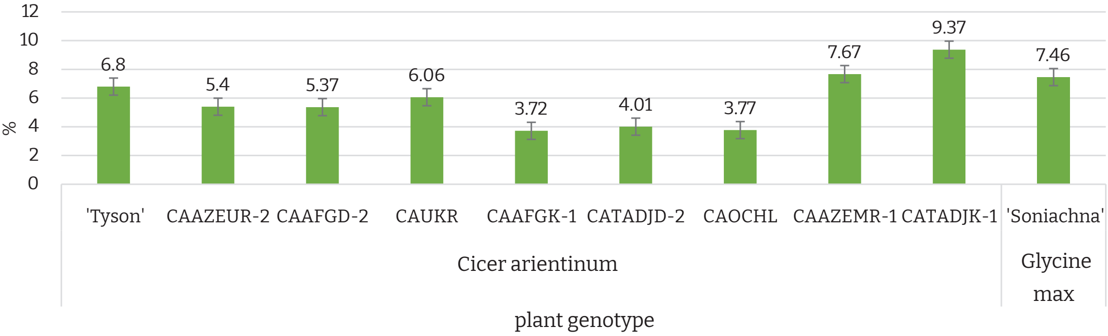

Figure 9. The total sugar content in *Cicer arietinum* seeds depending on the genotypic characteristics of the source material

Source: compiled by the authors

Phosphorus enhances the ability of cells to retain water and increases plant resistance to frost and drought. Also, a significant phosphorus content in seeds at the initial stages of their individual growth and development contributes to the active development of the root system, namely the rapid growth of the main root and the density of root hair formation (Dida & Urga, 2018; Zaimenko *et al.*, 2022). Of the analysed genotypes, the highest amount of phosphorus was accumulated in *C. arietinum* seeds in the CAAZEUR-2 sample – 1.43%, followed by genotypes with an average level of accumulation 'Tyson', CAUKR, CATADJD-2, CAOCHL and CAAZEMR-1. CAAFGD-2, CAAFGK-1 and CATADJK-1 accumulated the least phosphorus (from 0.89 to 0.99%) (Fig. 10). The data obtained are comparable to the results of M. Tomar *et al.* (2022).

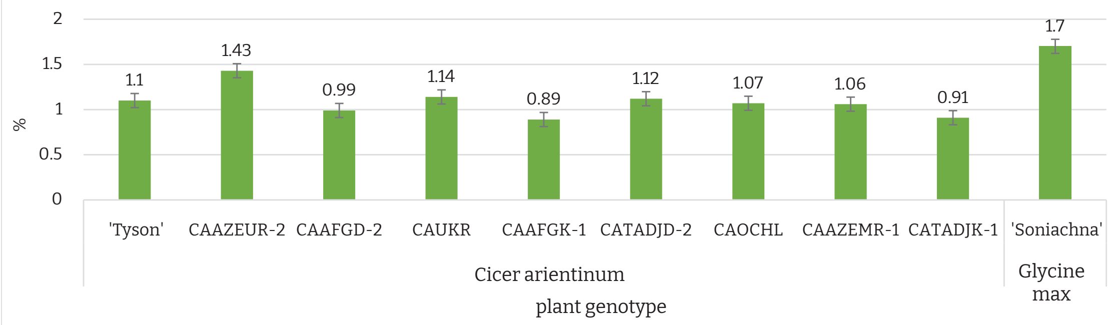

Figure 10. Phosphorus content in *Cicer arietinum* seeds depending on the genotypic characteristics of the source material

Source: compiled by the authors

Considering the obtained research results and comparing them with the literature of other authors, it should be noted that the introduced genotypes of *C. arietinum* plants have high biological potential, and several important morphophysical and biochemical features, which makes them promise for use in breeding as a valuable crop for enriching the range of legumes of domestic production.

CONCLUSIONS

Thus, the analysis of the seed material of *Cicer arietinum* genotypes mobilised in the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine showed a significant difference between them. A significant difference in the shape and morphosculpture of the seed surface of the studied samples was found and it was revealed that these representatives belong to two morphogroups:

Kabuli (CAAFGK-1, CAAFGD-2, CAAZEMR-1, CAUKR, CAAZEUR-2, CATADJK-1, CATADJD-2) and Desi: 'Tyson', CAOCHL.

Each of the evaluated chickpea genotypes differs in size and weight of 1000 seeds depending on the region of origin. All the studied chickpea genotypes provided high parameters for biometric parameters. CAAFGK-1 prevailed in terms of linear seed size – 17.12 mm long and 14.38 mm wide. The highest weight of 1000 seeds were characterised by the genotypes of *C. arietinum* sample CATADJK-1 – 584.5 g of Tajik origin and CAAFGK-1 – 566.0 g of Afghan origin.

Among the *C. arietinum* genotypes, the CATADJK-1 sample was found to have the highest content of absolute dry matter (89.68%) and total sugars (9.37%), and the CAAZEUR-2 sample was distinguished by a high phosphorus content (1.43%). Considering these biochemical parameters may be important for the use of individual plant samples in the breeding and biotechnological process to create highly adaptive plant forms that can successfully grow in the northern regions, which will expand the cultivated area of chickpeas in Ukraine.

Thus, considering the results of research on biological, morphological, and biochemical characteristics of seeds of introduced *Cicer* genotypes, the most promising for use in breeding and biotechnological practice are samples of the Kabuli morpho-group, which provide high qualitative and quantitative indicators in Ukraine. Representatives of the Desi group are also interested as source material for creating varieties with high environmental plasticity, which in turn will allow growing plants at earlier sowing dates or completing the growing season before full maturity after autumn frosts. Therefore, further in-depth research (breeding, genetic, biotechnological, etc.) and the development of strategies for introducing new *Cicer arietinum* genotypes into production will expand the range of high-yielding legumes and improve Ukraine's food security.

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None.

CONFLICT OF INTEREST

None.

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Біолого-морфологічні та біохімічні особливості насіння інтродукованих генотипів рослин *Cicer arietinum* L.

Анотація. Актуальність дослідження обумовлена необхідністю розробки сучасних науково-практичних засад залучення до інтродукційного процесу маловідомих, малопоширених, а також новостворених генотипів рослин. Це дозволить попередити про можливу фітосировинну кризу викликану кліматичними змінами та стрімким зростанням населення на планеті. У зв'язку з цим мета досліджень полягала у визначенні морфологічних ознак та біохімічних особливостей насіння роду *Cicer arietinum* для покращення гермоплазми зернобобових культур та проведення подальших селекційних і біотехнологічних досліджень. Використано порівняльний морфологічний метод для насіння інтродукованих генотипів рослин з різних районів походження. Матеріалом для досліджень слугували 9 генотипів *Cicer arietinum*, які походять з Австралії, Афганістану, Азербайджану, України, що були вирощені на експериментальних ділянках Національний ботанічний сад імені М.М. Гришка. Вивчали морфометричні показники та окремі біохімічні властивості насіння рослин залежно від генотипових особливостей. Використовували польові, лабораторні а також методи дисперсійного аналізу і статистичної оцінки середніх даних зі застосуванням програми Microsoft Excel (2010). У ході проведених досліджень встановлено, що усі інтродуковані генотипи характеризуються високими кількісними та якісними показниками насіння. За лінійними розмірами насінин (співвідношення довжини до ширини) особливо вирізнявся зразок CAAFGK-1 – 17,12×14,38 мм, а за масою 1000 шт. насінин CATADJK-1 – 584,5 г. Біохімічні дослідження показали, що найбільше абсолютно сухої речовини накопичувалось у насінні зразків рослин *C. arietinum* – CAAFGD-2, CAAFGK-1, CATADJD-2 та CATADJK-1 (від 89,04 до 89,68 %). За рівнем загальних цукрів переважали зразки генотипів *C. arietinum* CATADJK-1 – 9,37 %, а за накопиченням фосфору домінував CAAZEUR-2 – 1,43 %. Біохімічний склад рослин дає можливість не тільки характеризувати їх цінність з точки зору продовольчої культури, але й визначити найбільш пластичні генотипи до екологічних чинників довкілля. Таким чином, отримані результати свідчать про перспективність використання окремих генотипів *C. arietinum* як вихідного матеріалу для селекційних і біотехнологічних досліджень і створення нових форм рослин, що сприятиме розширенню асортименту високопродуктивних генотипів нуту у північних регіонах України

Ключові слова: клімат; нут; гермоплазма; морфологічні ознаки; склад насіння

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