EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(9), 315–325
https://doi.org/10.12912/27197050/209606
ISSN 2719–7050, License CC-BY 4.0

Received: 2025.07.29
Accepted: 2025.08.18
Published: 2025.09.01

Productivity of oilseed flax varieties with the use of microbiological preparations in the system of organic farming in southern Ukraine

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ABSTRACT

Experimental studies on the use of microbiological preparations in the cultivation of oil flax in the system of organic farming are relevant, as they address the needs for sustainable development. The work aims to summarize experimental studies on the effect of microbiological preparations on the elements of the crop structure and yield of oil flax in the crop rotation of organic farming in the southern steppe of Ukraine. Experimental studies were conducted in 2023-2024 at the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine according to the Methodology for State Variety Testing of Crops (2000) and the Methodology for Field Experimentation (Irrigated Agriculture) (2014) and recommendations for organic farming. It was found that the treatment of oil flax seeds and plants led to an increase in the number of bolls by 7.1–19.6% and 5.2–9.0%, the number of seeds by 1.2–11.5% and 1.8–16.2%, the weight of 1000 seeds by 0.2–6.7% and 0.7–2.7%, and the weight of seeds per plant by 4–12% and 9.5–19.0%, compared to the control. The use of microbiological preparations contributed to the reliable preservation of seed yields in 'Orfei' and 'Zhyvynka' varieties within 0.04–0.16 t/ha and 0.05–0.19 t/ha, respectively. In most cases, two–time application of "Ekofosforyn" (*Az. chroococcum, Az. vinelandii, Agr. radiobacter* and *B. Megaterium*) together with "Biospektr BT" (*Pseudomonas* with a titer of at least 5.0–109 CFU/cm^3) and "Metarizin BT" (*Metarhizium* with a titer of at least 2.0. 109 CFU/cm^3) also led to an increase in the number of capsules and seeds per plant in both varieties by 12.5–13.4% and 6.6–14.0%, and the weight of 1000 seeds and seed weight per plant by 4.9–1.3% and 10.7–16.0%. The treatment with such a biological complex additionally preserved the yield at the level of 0.16 t/ha in the 'Orfei' variety and 0.19 t/ha in the 'Zhyvynka' variety.

Keywords: microbiological preparations, oilseed flax (*Linum usitatissimum* L), varieties, weather conditions, crop structure, yield.

INTRODUCTION

Sustainable agricultural development is a strategic direction that ensures stable food production while maintaining the health of the ecosystem and improving the welfare of the population of different countries [Arthur, 2021; Zinchuk, 2020]. In Ukraine and around the world, there is a need to introduce new technologies that can minimize the negative impact of abiotic and biotic factors on the environment and increase production efficiency [Colombo et al., 2019; Dobriak et al., 2013].

The priority of such technologies is the long-term preservation of the environment and soil fertility to ensure crop productivity in the future. Therefore, it is vital for agricultural producers to find a balance between maximizing profits and maintaining environmental sustainability. For example, excessive expansion of sunflower crops can have a detrimental effect on the region's ecology, soil fertility, and even the crop itself. In this case, the choice of oilseed flax as an alternative to sunflower may be justified from an economic and environmental perspective [Hamayunova et al., 2019; Ponomarova and Chyhryn, 2021].

Given that oilseed flax is highly plastic and drought-resistant, it can provide a stable harvest even in difficult weather conditions [Yeremenko and Todorova, 2018]. In addition, this crop is not susceptible to some specific pests and diseases, which requires reducing the use of chemical pesticides and mineral fertilizers [Hubenko, 2019; Poliakov and Poliakova, 2009]. This approach facilitates its cultivation under organic farming systems, which can have a positive impact on human health, the environment, and the overall sustainability of the ecosystem [Onay and Tilkat, 2024; Sirat, 2016; Roy et al., 2024; Kaundal et al., 2024].

In recent years, interest in the consumption of flaxseed oil in the diet has grown significantly worldwide due to its medicinal properties, high content of linolenic acid, which is beneficial for improving cardiovascular and skin health, and helps prevent a number of diseases [Dominska, 2015; Kajla et al., 2015; Parikh et al., 2019].

Microbiological agents in agricultural production are becoming increasingly popular due to their ability to reduce the ecological footprint of agricultural activities and increase the efficiency of crop cultivation [Zaiets and Melnyk, 2024]. The inclusion of microbiological preparations in the technology of oil flax cultivation will help restore soil fertility, reduce the pesticide load on agrocenoses, and enhance the natural immunity of plants against fungal diseases, which ultimately has a positive effect on the formation of crop productivity [Geissen et al., 2021; Chaika and Korotkova, 2024; Konovalova et al., 2020].

Modern research by foreign and Ukrainian scientists shows that the use of microbiological agents has a wide range of applications. In Ukraine, as well as around the world, the search for new effective methods of organic nutrition and control of crop pests and diseases, as well as methods of increasing yields with the help of biological products, continues. The results of scientific studies indicate a significant potential of microbiological agents in increasing plant resistance to stress factors and improving the productivity of crops, in particular oilseed flax. According to the research of Syabruk et al. [2021], the use of biological preparations contributed to the greatest positive impact on the formation of productivity elements of oil flax compared to the control variant, which ultimately provided the highest yield for pre-sowing seed treatment with organic fertilizer Bio-gel 0.99 t/ha and microbiological preparation "Ekofosforyn" 0.86 t/ha.

The pre-sowing application of the biostimulant Fitostim on oilseed flax, due to an increase in the number of bolls per plant and the weight of 1000 seeds, increased the yield by 21%, and the spraying of crops – by 17% [Khodanitska and Khodanitsky, 2015].

According to the research of Shuvar et al. [2021], the greatest increase in oil flax yield was obtained by treating seeds before sowing with the biostimulant 'Vitazyme' (1.0 l/t), which was 14.1%, and the use of other stimulants and complex microfertilizers was less pronounced – 3.8–10.9%. Field trials conducted on organic farms located in the Podlasie region and on conventional farms located in the Greater Poland and Lower Silesia provinces of the Republic of Poland with the oilseed flax variety Bukoz indicate that larger seeds were obtained on organic farms, where the weight of 1000 seeds was higher compared to the weight in conventional farming [Heller and Wielgusz, 2011].

Biologically active preparations can be used individually, as well as in combinations, to treat both seeds and vegetative plants. For example, research in Uttarakhand, India, has shown that the combined use of organic and biological fertilizers (a complex of microbial strains) has a more effective impact on both quantitative and qualitative indicators of crop structure, compared to their separate use. This contributed to the enhancement of vegetative growth of plants and the formation of a higher total seed yield [Singh et al., 2021].

It should be noted that complex preparations of microbiological origin are an important tool in modern agronomic production, especially in the cultivation of crops such as oilseed flax. These preparations can be useful for optimizing plant growth conditions, increasing their resistance to stress factors, improving nutrient absorption, and reducing the need for chemical fertilizers.

Scientific studies, particularly those of scientists from Ukraine and abroad, demonstrate the prospects of using microbiological complexes to improve the yield and quality of oil flax [Fernie and Sonnewald, 2021; Glick, 2012; Uniyal et al., 2025]. However, the issue of using microbiological preparations in agronomy, in particular for oil flax, requires more detailed research, since most modern works are mainly focused on general aspects of the use of biological products in agriculture, and specialized research on optimizing agrotechnologies for oil flax cultivation in the organic farming system is still limited.

The purpose of the article is to summarize experimental studies on the effect of microbiological preparations on the elements of the crop structure and yield of oil flax in the crop rotation of organic farming in the southern Steppe of Ukraine.

MATERIALS AND METHODS

The research was conducted according to generally accepted methods and recommendations [Volkodav, 2000; Ushkarenko et al., 2014] during 2023–2024 at the Institute of Climate-Smart Agriculture of the National Academy of Sciences of Ukraine in the system of organic crop rotation. The predecessor of oil flax is winter durum wheat. With the exception of studied factors, all other elements of crop cultivation were generally accepted for organic farming in the southern zone of Ukraine. Seeds of the varieties 'Orfei' and 'Zhyvynka' (food) were sown in 2023 on 30 March, and in 2024 on 1 April using a selective precision seeder 'Klen-1.5' with a row spacing of 15 cm and a depth of 3–5 cm. The seeding rate was 5 million seeds per hectare.

Before sowing the seeds and during the growing season, the plants were treated with microbial preparations according to the experimental scheme (Table 1).

Table 1. Experiment scheme of oil flax

№.	Variant name	Application rate, l/t	Application phase		
			Seeds	" herringbone " BCHH-19	" budding" BCHH-60
1	Chemicals on the background of N_{45}	1.5 1.2 0.5+0.14	”Supervin”	”Agrostar”	”Ajax”+”Borey”
2	Dry clean seeds	-	-	-	-
3	Control (treatment of seeds with water)	10	-	-	-
4	Seed inoculation	1.0	*Bacillus* sp.4	-	-
5	Seed inoculation	1.0+0.05	*Bacillus* sp.4 + ”Fitovit”	-	-
6	Seed inoculation	1.0+0.05+0.1	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	-	-
7	Variant 6 (seed inoculation) + plant treatment with BCHH-19	1.0+0.05+0.1 1.0	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4	-
8	Variant 7 (seed inoculation + plant treatment with BCHH-19)	1.0+0.05+0.1 1.0+0.1	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4 + ”Fitovit”	-
9	Variant 8 (seed inoculation + plant treatment with BCHH-19)	1.0+0.05+0.1 1.0+0.1+0.1	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	-
10	Variant 9 (seed inoculation + plant treatment with BCHH-19) + BCHH-60	1.0+0.05+0.1 1.0+0.1+0.1 1.0	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4
11	Variant 10 (seed inoculation + plant treatment with BCHH-19) + BCHH-60	1.0+0.05+0.1 1.0+0.1+0.1 1.0+0.1	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4+ ”Fitovit” + Avercom^N	*Bacillus* sp.4+ ”Fitovit”
12	Variant 11 (seed inoculation + plant treatment with BCHH-19) + BCHH-60	1.0+0.05+0.1 1.0+0.1+0.1 1.0+0.1+0.1	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4 + ”Fitovit” + Avercom^N	*Bacillus* sp.4 + ”Fitovit” + Avercom^N
13	Seed inoculation	1.0	”Ekofosforyn”	-	-
14	Option 13 (seed inoculation) + plant treatment with BCHH-19	1.0 1.0	”Ekofosforyn”	”Ekofosforyn”	-
15	Option 13 (seed inoculation) + plant treatment with BCHH-19	1.0 1.0+3.0	”Ekofosforyn”	”Ekofosforyn”+ Biospekctr BT	-
16	Option 13 (seed inoculation) + plant treatment with BCHH-19 + BCHH-60	1.0 1.0+3.0 3.0+3.0	”Ekofosforyn”	”Ekofosforyn”+ ”Biospektr BT”	”Biospektr BT” + Metarizin BT

Different strains of nodule and endophytic bacteria from the culture collection of the Department of General and Soil Microbiology of the D.K. Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine were used: *Bacillus sp.4*; ”Fitovit” (*S. netropsis* IMV AS-5025); ”Avercom^{N}” (Streptomyces avermitilis IMV AS-5015 + chitose); ”Ekofosforyn” (*Azotobacter chroococcum, Azotobacter vinelandii, Agrobacterium radiobacter* and *Bacillus megaterium*), as well as biological preparations from the Biotechnology Engineering Institute: ”Biospektr BT” (*Rhizosphere bacteria* of the genus *Pseudomonas* with a titer of at least 5.0-109 CFU/cm^3, BAR: acids of the genus phenazine-carboxylic, a complex of active pigments that are active factors in the preparation) and ”Metarizin BT” (conidia of the fungus *Metarhizium* with a titer of at least 2.0.109 CFU/cm^3).

The experiment also includes the recommended technology for growing oil flax with the use of chemicals (variant 1): ”Supervin”, h.p. – fungicidal treatment, active ingredient*: thiabendazole*, 45 g/l + *flutriafol*, 30 g/l; ”Agrostar”, p.c. – herbicide, active ingredient *MCPA* in the form of an amine salt, 500 g/l; ”Ajax”, CS - fungicide, active ingredient: *thiophanate-methyl* 310 g/l + *epoxiconazole* 120 g/l + *tebuconazole* 70 g/l; ”Borey”, CS - insecticide, active ingredient *imidacloprid* 150 g/l + *lambda-cyhalothrin* 50 g/l. The crops were sprayed using a Forte CL-16A hand-held sprayer. The experiments were laid out in triplicate, with a systematic plot layout. The area of the plots was 30 m^2, and the accounting area was 25 m^2.

RESULTS

It is worth noting that the spring and summer periods in the years of research differed in terms of temperature and precipitation. In 2023, the air temperature in March was 3.5 °C higher than average, and in April and May corresponded to typical long-term indicators (Table 2).

In early spring, there was very little precipitation, and in April, it was almost twice the climatic norm, which significantly replenished soil moisture reserves, but insufficient heat supply slowed down plant growth.

Precipitation on some days in May was of varying intensity and did not contribute to the accumulation of moisture in the soil, but rather resulted in its loss through plant absorption and evaporation. In June, rainfall was 25.1 mm, and the air temperature was close to the climatic norm of 21.7 °C. As a result of such harsh conditions, oilseed flax plants developed a weak aboveground mass, which affected the deterioration of the structural elements of the oilseed flax crop.

In early spring, there was very little precipitation, and in April, their amount was almost twice the climatic norm, which significantly replenished the soil moisture reserves, but insufficient heat supply slowed down the growth processes of plants.

A distinctive feature of the growing season of oilseed flax in 2024 was that the air temperature in March and April was 2.2 and 5.3 °C higher than normal, and in May it was 1 °C lower than the long-term average. In May and April, precipitation was almost 3.4 and 1.9 times higher than the climatic norm, which significantly improved the conditions for the initial growth of oilseed flax plants. Due to such productive precipitation, moisture reserves were significantly replenished, which, together with warm weather, contributed

Table 2. Air temperature and precipitation for March-July 2023 and 2024 and the norm [Average long-term precipitation and temperature by month from 2012 to 2021; Meteorological indicators for 2023–2024]

Month	Average monthly temperature, °C			Average monthly precipitation, mm		
	2023	2024	Average	2023	2024	Average
March	7.0	3.7	3.5	9.7	96.8	28.6
April	10.5	9.6	9.8	72.6	61.0	32.4
May	16.4	15.9	16.7	38.9	42.5	45.6
June	21.7	23.8	21.9	29.3	37.0	54.4
July	25.4	22.8	25.4	47.8	16.5	35.2
Average t for the period, °C	16.2	15.2	15.5			
Total precipitation for the period, mm				198.3	253.8	196.2

to the growth processes of plants. However, the lack of precipitation in June and high air temperatures led to accelerated maturation of plants, which was reflected in the formation of crop structure elements. It is worth noting that their values were slightly better than in 2023.

Under such weather conditions, the use of microbial preparations had a positive effect on changes in the elements of the crop structure (Table 3). Thus, inoculation of seeds of 'Orfei' variety with *Bacillus sp.4* and ”Ekofosforyn” (*Azotobacter chroococcum, Azotobacter vinelandii, Agrobacterium radiobacter* and *Bacillus megaterium*) increased the number of bolls per plant by 0.4 and 0.5 pcs. and the number of seeds formed by the plant by 3.7 and 0.7 pcs.

The treatment of seeds of the food 'Zhyvynka' variety with these preparations also increased the number of capsules and seeds per plant by 0.3 and 0.6 pcs. and 3.7 and 0.7 pcs. respectively. The treatment of seeds with *Azotobacter chroococcum, Azotobacter vinelandii, Agrobacterium radiobacter* and *Bacillus megaterium* was more effective in the formation of bolls on both varieties, and *Bacillus sp.4* was more effective in increasing the number of seeds. The treatment of flax seeds with *Bacillus sp.4* and ”Fitovit” (*S. netropsis* IMV AS-5025) resulted in an increase in the number of bolls by 12.5% and 7.9% in 'Orfey'

Table 3. Number of bolls and seeds per flax plant depending on variety and microbial preparations (average for 2023–2024)

Name of preparations (factor B)	Number of capsules per plant, pcs.		Number of seeds per plant, pcs.	
	Varieties (factor A)			
	'Orfei'	'Zhyvynka'	'Orfei'	'Zhyvynka'
Supervin (1.5 l/t) + N_{45} + chemical protection	6.4	6.6	59.1	57.6
Dry seeds (without treatment)	5.1	5.8	40.5	38.3
Seed treatment with water (control)	5.6	5.8	40.9	38.8
Seed treatment with *Bacillus* sp.4 (1.0 l/t)	6.0	6.1	44.6	42.5
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t)	6.4	6.3	43.3	40.4
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t) +”Avercom^{N}” (0.1 l/t)	6.4	6.6	42.5	44.0
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t) +”Avercom^{N}” (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha)	6.4	6.7	41.8	42.0
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t) +”Avercom^{N}” (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +”Fitovit” (0.1 l/ha)	6.3	6.7	41.7	44.0
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t) +”Avercom^{N}” (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +”Fitovit” (0.1 l/ha)+ ”Avercom^{N}” (0.1 l/ha)	6.5	6.7	41.7	40.4
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t) +”Avercom^{N}” (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +”Fitovit” (0.1 l/ha)+ ”Avercom^{N}” (0.1 l/ha)+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)	6.5	6.7	41.6	41.8
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t) +”Avercom^{N}” (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1,0 l/ha) +”Fitovit” (0,1 l/ha)+ ”Avercom^{N}” (0,1 l/ha)+BCHH-60 *Bacillus* sp.4 (1,0 l/ha)+”Fitovit” (0.1 l/ha)	6.6	6.7	41.6	42.3
Seed treatment with *Bacillus* sp.4 (1.0 l/t) +”Fitovit” (0.05 l/t) +”Avercom^{N}” (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +”Fitovit” (0.1 l/ha)+ ”Avercom^{N}” (0.1 l/ha))+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)+”Fitovit” (0.1 l/ha)+”Avercom^{N}” (0.1 l/ha)	6.7	6.9	41.7	41.8
Seed treatment ”Ekofosforyn” (1.0 l/t)	6.1	6.4	41.6	39.5
Seed treatment ”Ekofosforyn” (1.0 l/t), BCHH-19 ”Ekofosforyn” (1.0 l/ha)	6.3	6.5	42.2	40.6
Seed treatment ”Ekofosforyn” (1.0 l/t), BCHH-19 ”Ekofosforyn” (1.0 l/ha)+”Biospektr BT” (3.0 l/ha)	6.4	6.5	42.9	42.1
Seed treatment ”Ekofosforyn” (1.0 l/t), BCHH-19 ”Ekofosforyn” (1.0 l/ha)+”Biospektr BT” (3.0 l/ha) BCHH-60 ”Biospektr BT” (3.0 l/ha)+”Metarizin BT” (3.0 l/ha)	6.4	6.7	43.8	45.1
$LSD_{05,}$ pcs	0.2		2.5	

and 'Zhyvynka' varieties, respectively, compared to the control, but it did not affect the formation of seed numbers. The addition of "Avercom^{N}" (*Streptomyces avermitilis* IMV AS-5015 + chitose) to the above microbial preparations only to the 'Zhyvynka' variety provided a positive effect, with the number of bolls increasing by 12.2% and seeds by 11.8%.

After treating the seed with microbial preparations, spraying plants with them at different stages of growth and development increased the number of capsules, while no effect was found on the number of seeds. Thrice application of Bacillus sp.4 + ”Fitovit” (*S. netropsis* IMV AS-5025) + ”Avercom^{N}” (*Streptomyces avermitilis* IMV AS-5015 + chitose) had high efficiency, when the number of bolls increased to the highest values in the experiment - 16.4% in the 'Orfei' variety and 15.9% in the 'Zhyvynka' variety.

In the case of double application of ”Ekofosforyn” (*Az. chroococcum, Az. vinelandii, Agr. radiobacter and B. Megaterium*) and compared to the control variant (water treatment only), the number of capsules and seeds per plant in the variety 'Orfei' increased by 11.1% and 3.1%, and in the 'Zhyvynka' variety - by 10.8% and 4.4%. Subsequently, with the introduction of "Biospektr BT" (*Pseudomonas* with a titer of at least 5.0–109 CFU/cm^3) and "Metarizin BT" (*Metarhizium* with a titer of at least 2.0.109 CFU/cm3), there was a tendency to increase the quantitative indicators of the yield structure. However, it is worth noting that in the 'Orfei' variety the use of microbial preparations in the 'herringbone' (BCHH-19) and 'budding' (BCHH-60) phases did not affect the number of capsules, but only increased the number of seeds by 6.6%, while in the 'Zhyvynka' variety these structural elements increased by 13.4% and 14.0% and were reliable, since the differences between the variants exceeded LSD_{05}.

Under the traditional technology of oil flax cultivation with the use of chemical preparations, the number of bolls did not exceed the best variants with microbial preparations, but, compared to the control variant, the number of seeds per plant increased significantly - up to 30.6% in the 'Orfey' variety and 34.4 % in the 'Zhyvynka' variety.

Seeds were formed somewhat larger in the 'Orfei' variety, in which the average weight of 1000 seeds was 6.20 g, which is 0.64 g more than in the 'Zhyvynka' variety (Table 4).

With the use of microbial preparations, the weight of 1000 seeds increased by 0.09–0.40 g in the 'Orfei' variety and by 0.02–0.15 g in the 'Zhyvinka' variety. A significantly pronounced effect on the growth of 1000 seeds weight on the 'Orfei' variety was caused by thrice application of *Bacillus sp.4* + ”Fitovit” (*S. netropsis* IMV AS-5025) + ”Avercom^{N}” (*Streptomyces avermitilis* IMV AS-5015 + chitose), and on 'Zhyvynka' variety - inoculation of seeds with *Bacillus sp.4* + ”Fitovit” (*S. netropsis* IMV AS-5025), resulting in 0.40 g and 0.13 g larger seeds. Compared to this variant, the use of ”Ekofosforyn” twice (*Az. chroococcum, Az. vinelandii, Agr. radiobacter* and *B. Megaterium*) together with ”Biospektr BT” (*Pseudomonas* with a titer of at least 5.0–109 CFU/cm^3) and ”Metarizin BT” (*Metarhizium* with a titer of at least 2.0. 109 CFU/cm^3) resulted in smaller increases in the weight of 1000 seeds, but the highest was the average weight of seeds per plant, which was 0.28 g more than in the control variant in the 'Orfei' variety and 0.25 g in the 'Zhyvynka' variety.

Thus, in most cases, thrice application of *Bacillus sp.*4 + ”Fitovit” (*S. netropsis* IMV AS-5025) + ”Avercom^{N}” (*Streptomyces avermitilis* IMV AS-5015 + chitose), or twice ”Ekofosforyn” (*Az. chroococcum, Az. vinelandii, Agr. radiobacter* and *B. Megaterium*) together with ”Biospektr BT” (*Pseudomonas* with a titer of at least 5.0–109 CFU/cm^3) and ”Metarizin BT” (*Metarhizium* with a titer of at least 2.0. 109 CFU/cm^3) showed the greatest positive effect on the formation of productivity elements of oil flax of both varieties compared to the control variants

Growing oilseed flax with the use of chemical preparations provided almost the same and even lower weight of 1000 seeds as the best biological preparations, but, due to the formation of more seeds, had a significantly higher weight of seeds per plant, which in both varieties, compared to the control, increased by 0.11 g.

It was found that, on average for 2023 and 2024, the yield of oil flax of 'Orfei' and 'Zhyvynka' varieties was influenced by both varietal characteristics and seed treatment with microbial preparations. Thus, the grain yield of the 'Orfei' variety was 0.82–1.24 t/ha, and that of the 'Zhyvynka' variety was 0.69–1.11 t/ha, which is 10.5–15.8% lower (Table 5).

In the control variants, where no treatment was carried out or only water was used, the lowest yields were obtained, which in the 'Orfei' and 'Zhyvynka' varieties were 0.82 t/ha and 0.69–0.70 t/ha, which is 0.04–0.16 t/

Table 4. Weight of oil flax seeds of different varieties depending on microbial preparations (average for 2023–2024)

№	Name of preparations (factor B)	Weight of 1000 seeds, g		Seed weight per plant, g	
		Varieties (factor A)			
		'Orfei'	'Zhyvynka'	'Orfei'	'Zhyvynka'
1.	Supervin (1.5 l/t) + N_{45} + chemical protection	6.17	5.63	0.36	0.32
2.	Dry seeds (without treatment)	6.05	5.50	0.25	0.21
3.	Seed treatment with water (control)	6.00	5.50	0.25	0.21
4.	Seed treatment with *Bacillus* sp.4 (1.0 l/t)	6.01	5.61	0.27	0.24
5.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t)	6.09	5.65	0.26	0.23
6.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^{N}" (0.1 l/t)	6.19	5.52	0.26	0.24
7.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^{N}" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha)	6.20	5.54	0.25	0.23
8.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^{N}" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)	6.22	5.63	0.26	0.25
9.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^{N}" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^{N}" (0.1 l/ha)	6.29	5.62	0.26	0.23
10.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^{N}" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1,0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^{N}" (0.1 l/ha)+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)	6.33	5.55	0.26	0.23
11.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^{N}" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^{N}" (0.1 l/ha)+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)+"Fitovit" (0.1 l/ha)	6.33	5.52	0.26	0.23
12.	Seed treatment with *Bacillus* sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^{N}" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^{N}" (0,1 l/ha))+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)+"Fitovit" (0,1 l/ha)+"Avercom^{N}" (0.1 l/ha)	6.40	5.54	0.26	0.23
13.	Seed treatment "Ekofosforyn" (1.0 l/t)	6.23	5.59	0.24	0.21
14.	Seed treatment "Ekofosforyn" (1.0 l/t), BCHH-19 "Ekofosforyn" (1.0 l/ha)	6.13	5.52	0.26	0.22
15.	Seed treatment "Ekofosforyn" (1.0 l/t), BCHH-19 "Ekofosforyn" (1.0 l/ha)+"Biospektr BT" (3.0 l/ha)	6.19	5.55	0.27	0.23
16.	Seed treatment "Ekofosforyn" (1.0 l/t), BCHH-19 "Ekofosforyn" (1.0 l/ha)+"Biospektr BT" (3.0 l/ha) BCHH-60 "Biospektr BT" (3.0 l/ha)+"Metarizin BT" (3.0 l/ha)	6.31	5.57	0.28	0.25
LSD_{05}, g		0.07	0.03	0.02	0.02

ha and 0.05–0.19 t/ha less than when using microbiological preparations. It is worth noting that, with the exception of the variant with seed treatment with "Ekofosforyn" of 'Orfei' and 'Zhyvynka' varieties, where the increase was only 0.04 t/ha and 0.05 t/ha, in all other variants the use of microbiological preparations contributed to a reliable preservation of seed yields in the range of 0.09–0.16 t/ha and 0.09–0.19 t/ha, respectively (LSD_{05} for partial differences B = 0.04–0.08 t/ha).

In the 'Orfei' variety, the best results were obtained by treating seeds with Bacillus sp.4 (1.0 l/t), which provided an increase in yield by 0.12 t/ha, since no yield increase was detected on this variety with two and three times of *Bacillus sp.4* + "Fitovit" (*S. netropsis* IMV AS-5025) + "Avercom^{N}" (*Streptomyces avermitilis* IMV AS-5015 + chitose).

Whereas, in the 'Zhyvynka' variety, the most significant increase of 0.18 t/ha was observed with the double application of *Bacillus sp.4* (1 l/t and 1 l/ha) and "Fitovit" (*S. netropsis* IMV AS-5025) (0.05 l/t and 0.1 l/ha) and a single application of "Avercom^{N}" (*Streptomyces avermitilis* IMV AS-5015 + chitose) (0.1 l/t) in BCHH-19.

However, the maximum yield of both oilseed flax varieties with the use of microbial preparations was formed on variants where "Ekofosforyn" (*Az. chroococcum, Az. vinelandii, Agr. radiobacter* and *B. Megaterium*) (1 l/t and 1 l/ha) with the addition of "Biospektr BT" (*Pseudomonas with* a titer of at least 5.0-109 CFU/cm^3) (3 l/ha) and "Biospektr BT"

Table 5. Yield of oil flax varieties depending on microbial preparations, t/ha (average for 2023–2024)

№	Name of preparations (factor B)	Yield		+,- to control	
		varieties (factor A)			
		'Orfei'	'Zhyvynka'	'Orfei'	'Zhyvynka'
1.	Supervin (1.5 l/t) + N_{45} + chemical protection	1.24	1.11	0.42	0.41
2.	Dry seeds (without treatment)	0.82	0.69	0.01	-0.01
3.	Seed treatment with water (control)	0.82	0.70	0.00	-
4.	Seed treatment with *Bacillus* sp.4 (1.0 l/t)	0.93	0.83	0.12	0.13
5.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t)	0.93	0.81	0.12	0.11
6.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^N" (0.1 l/t)	0.94	0.86	0.13	0.16
7.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^N" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha)	0.91	0.84	0.09	0.14
8.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^N" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)	0.92	0.88	0.10	0.18
9.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^N" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^N" (0.1 l/ha)	0.94	0.82	0.12	0.12
10.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^N" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^N" (0.1 l/ha)+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)	0.94	0.84	0.13	0.14
11.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^N" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^N" (0.1 l/ha)+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)+"Fitovit" (0.1 l/ha)	0.92	0.84	0.11	0.14
12.	Seed treatment with Bacillus sp.4 (1.0 l/t) +"Fitovit" (0.05 l/t) +"Avercom^N" (0.1 l/t)+ BCHH-19 *Bacillus* sp.4 (1.0 l/ha) +"Fitovit" (0.1 l/ha)+ "Avercom^N" (0.1 l/ha))+BCHH-60 *Bacillus* sp.4 (1.0 l/ha)+"Fitovit" (0.1 l/ha)+"Avercom^N" (0.1 l/ha)	0.94	0.84	0.12	0.14
13.	Seed treatment "Ekofosforyn" (1.0 l/t)	0.86	0.75	0.04	0.05
14.	Seed treatment "Ekofosforyn" (1.0 l/t), BCHH-19 "Ekofosforyn" (1.0 l/ha)	0.91	0.79	0.10	0.09
15.	Seed treatment "Ekofosforyn" (1.0 l/t), BCHH-19 "Ekofosforyn" (1.0 l/ha)+"Biospektr BT" (3.0 l/ha)	0.94	0.83	0.12	0.13
16.	Seed treatment "Ekofosforyn" (1.0 l/t), BCHH-19 "Ekofosforyn" (1.0 l/ha)+"Biospektr BT" (3.0 l/ha) BCHH-60 "Biospektr BT" (3.0 l/ha)+"Metarizin BT" (3.0 l/ha)	0.98	0.89	0.16	0.19
LSD_{05}, t/ga		For partial differences: A =0.06-0.08; B=0.04-0.05;			
		For the average (main) effects: A=0.02-0.03; B=0.02-0.05;			

(*Pseudomonas with* a titer of at least 5.0–109 CFU/cm^3) (3 l/ha) in VSNN-19 and "Metarizin BT" (*Metarhizium with* a titer of at least 2.0. 109 CFU/cm^3) (3.0 l/ha). As a result of this complex application of microbiological preparations, the yield of seeds of 'Orfei' and 'Zhyvynka' varieties was additionally preserved at 0.16 t/ha and 0.19 t/ha, which is 19.5% and 27.1% higher than the control variant (without the use of preparations).

It is worth noting that the difference in seed yield between these varieties was 0.09 t/ha and was within the error of the experiment (LSD_{05} for partial differences in factor A (variety) was 0.06–0.08 t/ha). This indicates that the food grade 'Zhyvynka' variety was inferior to the 'Orfei' variety.

With the help of correlation analysis, the relationship between yield and yield structure indicators was established. It was found that the yield of oil flax varieties increased with the increase in number of formed bolls on the plant, and the close relationship is represented by the correlation coefficient, which was 0.76 and 0.75 for the 'Orfei' and 'Zhyvynka' varieties (Figure 1). An even closer relationship was obtained when studying the dependence of oil flax seed yield on seed weight per plant (r = 0.81–0.92). The highest correlation coefficient was obtained for the Zhyvynka variety r = 0.92 (Figure 2).

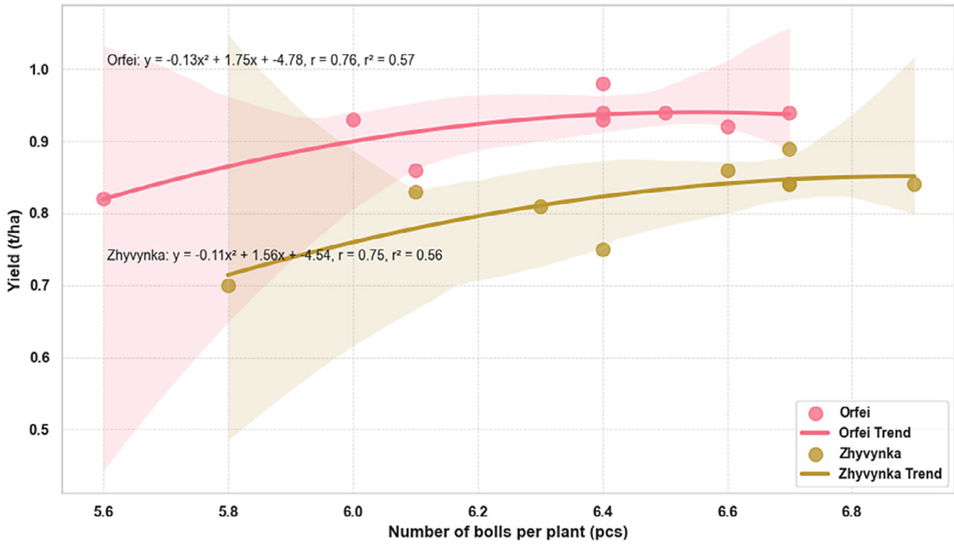

Figure 1. Dependence of seed yield of oilseed flax varieties on the number of bolls per plant, average for 2023–2024

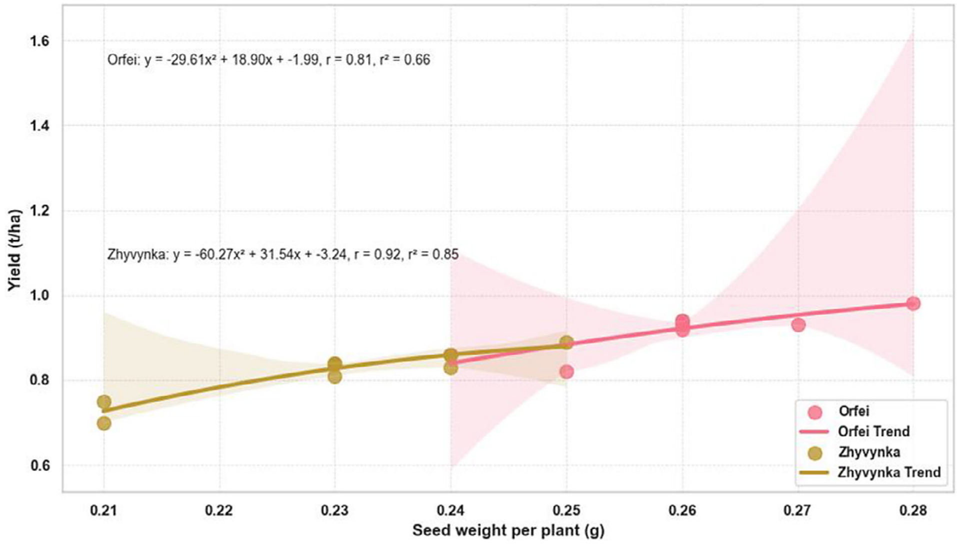

Figure 2. Dependence of seed yield of oilseed flax varieties on seed weight per plant, average for 2023–2024

The relationship between yield and number of seeds per plant was also found to be strong in 'Zhyvynka' (r = 0.92) and medium in 'Orfei' (r = 0.60), while the relationship between yield and weight of 1000 seeds was weak (r = 0.11) and medium (r = 0.50) in the varieties, respectively.

The highest yields for both varieties were achieved under traditional oilseed flax cultivation technology with the use of mineral fertilizers and chemical plant protection products: 1.29 t/ha for 'Orfei' and 1.23 t/ha for 'Zhyvynky'. That is, 0.42 t/ha and 0.41 t/ha were additionally saved compared to the control, and 0.26 t/ha and 0.22 t/ha were saved with the best variants of microbiological preparations.

CONCLUSIONS

The use of microbial preparations in the cultivation of oil flax 'Orfei' and 'Zhyvynka' varieties has a positive effect on the formation of elements of the crop structure. The thrice application of *Bacillus sp.4* + "Fitovit" (*S. netropsis* IMV AS-5025) + "Avercom^{N}" (*Streptomyces avermitilis* IMV AS-5015 + chitose) was highly effective, which increased the number of bolls by 16.4% in the 'Orfey' variety and 15.9% in the 'Zhyvynka' variety. With such a complex of microbial preparations, 'Orfei' variety formed larger seeds by 6.3%, while in 'Zhyvynka' variety, the largest weight of 1000 seeds was created only when seeds were treated with *Bacillus sp.4* + ”Fitovit” (*S. netropsis* IMV AS-5025), which is 0.15 g or 2.7% more than in the control variant. At the same time, the yield increase in the ‘Orfei’ and ‘Zhyvynka’ varieties was 0.09–0.13 t/ha and 0.11–0.18 t/ha.

In most cases, the double application of ”Ekofosforyn” (*Az. chroococcum, Az. vinelandii, Agr. radiobacter* and *B. Megaterium*) together with ”Biospektr BT” (*Pseudomonas with* a titer of at least $5.0 \cdot 10^9$ CFU/cm^3) and ”Metarizin BT” (*Metarhizium with* a titer of at least $2.0 \cdot 10^9$ CFU/cm^3) also led to an increase in the number of capsules and seeds per plant in both varieties by 12.5–13.4% and 6.6–14.0%, and the weight of 1000 seeds and seed weight per plant by 4.9–1.3% and 10.7–16.0%. The treatment with such a biological complex additionally preserved the yield at the level of 0.16 t/ha in the ‘Orfei’ variety and 0.19 t/ha in the ‘Zhyvynka’ variety.

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