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Effect of seed protectants on fungal disease pathogens when using different technologies of oilseed flax, *Linum usitatissimum* cultivation

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ABSTRACT

The study was carried out in 2021-2022 in the dry steppe zone of Northern Kazakhstan. The object of the study was the Kustanaysky yantar oilseed flax variety. Flax is a promising crop for this zone and requires an in-depth study of the diseases affecting it. The study aimed to evaluate the effect of Seedspor W and Olymp SC protectants on the seed infection pathogens, *Fusarium* ssp. and *Colletotrichum* ssp. against the background of different technologies of flax cultivation. Studies showed the high effectiveness of the complex use of protectants, where the degree of seed contamination decreased by two to three times compared to the control variant. By this variant, the authors obtained the lowest indicator of the degree of seed contamination (2-6%), high laboratory germination (90-95%), germination energy (79-89%), and field germination (70-87%). When restraining and suppressing the spread and development of root rot of *Fusarium* ssp. and *Colletotrichum* ssp., Seedsport W bioprotectant was inferior in efficiency to the Olymp SC chemical protectant. During the plant vegetation period, the prevalence and development of Fusarium wilt and anthracnose were more intense with no tillage, while less intense by traditional tillage. Over the years of the study, high yields were obtained in the variant with the integrated use of protectants (Olymp SC + Seedspor W + Akiba WSC) and averaged 7.1 c/ha, which was 3.9 c/ha more than the control variant.

Keywords: Oilseed flax, flax diseases, seed protectants, yield.
Article type: Research Article.

INTRODUCTION

One of the most important technical cultures in the world and the Republic of Kazakhstan is flax (*Linum usitatissimum*; Kyzdarbekova *et al.* 2023). Linseed oil ranks first in the world in terms of production volume among technical oils. It is widely used in metalworking, electrical engineering, printing, leather and footwear, textile, food, medical, perfume, and many other industries (Sheng *et al.* 2022). A factor hindering the obtaining of a high volume and high-quality harvest of oilseed flax is the high prevalence of diseases. According to research results, the most common and harmful diseases during the vegetation period are fusariosis, alternaria leaf blight, polysporosis, anthracnose, pasmo, stem rot, and bacteriosis, as well as seed infections like fusariosis, anthracnose, ascochyta leaf blight, and polysporosis (Piven *et al.* 2011; Mussynov *et al.* 2019; Kanapin *et al.* 2020; Al-Enezi & Jamil 2023; Amini *et al.* 2023; Al-Masoodi *et al.* 2023). Fungal disease pathogens of *Fusarium* ssp. and *Colletotrichum* ssp. are considered one of the ten most dangerous plant pathogens in the world that cause such diseases as Fusarium wilt and anthracnose. These are complex pathogens that pose a constant threat to flax production worldwide (Guarnaccia *et al.* 2021; Samsonova *et al.* 2021). Different methods of protecting flax from diseases are acceptable in modern plant protection. Many scientists recommend seed disinfection and fungicidal treatment during the vegetation period as a compulsory measure to destroy the pathogens affecting flax. The application of fertilizers rich in microelements (Mukhomedyarova *et al.* 2023) and using the right means of

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agricultural technology (Kantarbayeva *et al.* 2017; Kondratenko *et al.* 2022; Yesmagulova *et al.* 2023) prevent physiological injuries in plants (Paul *et al.* 2015; Altaf *et al.* 2023). One of the most effective means against diseases is the breeding and cultivation of resistant varieties (Bacelis & Gruzdevienė 2001; Bacelis & Gruzdeviene 2003). Oilseed flax is the most important and promising crop in Kazakhstan. Its acreage is noticeably increasing and to date, amounts to over 1.3 million ha. Over the past 10 years, the crop area has increased from 0.369 million ha in 2012 to 1.260 million ha in 2021. In 2022, it amounted to a record of 1.343 million ha with seed production of 1.058 tonne, making Kazakhstan as a world leader (Karabanov 2021; Fig. 1).

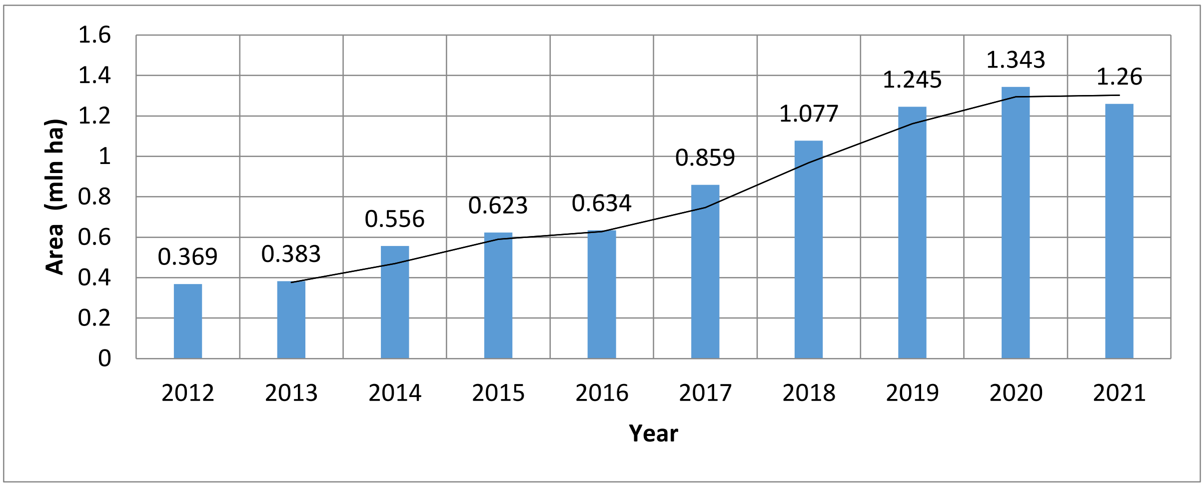

Fig. 1. Dynamics of increase in the acreage of oilseed flax over the past 10 years (2012-2021) in Kazakhstan (million ha).

In the cultivation of oilseeds in the northern regions of Kazakhstan in recent years, preference has been given to energy-saving technology, i.e., minimum tillage and no-tillage in crop rotations (Suleimenov *et al.* 2016; Haselow *et al.* 2020). However, when cultivating crops using energy-saving technology, the aggravation of the phytosanitary situation is observed. One can note an increased number of phytophages, and infestation of crops with millet-like as well as perennial root-spreading weeds, and the accumulation of pathogens that persists in plant residues and the soil. As a result of the negative impact of harmful organisms, crop yields and seed quality can decrease (Nasiyev & Dukeyeva 2023). When cultivating oilseeds with mini till and no-till, it is especially important to use protective measures, in particular, seed disinfection and crop treatment during plant vegetation against a complex of harmful organisms (Toropova *et al.* 2010; Ponomarev *et al.* 2022). Currently, the biological features of the flax pathogen species composition remain poorly studied (Kyzdarbekova *et al.* 2023). The issue of an insufficient assortment of fungicides registered in Kazakhstan is also acute. Thus, the study of the species composition and the system of protection against a complex of diseases with traditional and energy-saving technology in the dry-steppe zone of Northern Kazakhstan is an urgent task for increasing the quantity and quality of the oilseed flax crop. The purpose of our study was to evaluate the effect of protectants on the *Fusarium* ssp. and *Colletotrichum* ssp., the seed infection pathogens against the background of different flax tillage technologies used in Northern Kazakhstan. To achieve this goal, we set the following tasks: to determine the species composition of seed infections caused by oilseed flax pathogens; to define the prevalence and development of oilseed flax diseases with different tillage technologies; to identify the most effective seed protectants in protecting flax from the seed infection diseases during the vegetation period.

MATERIALS AND METHODS

The field experiments were established in 2021-2022 at the experimental field of A.I. Baraev Scientific and Production Center of Grain Farming (Shortandy district, Akmola region, Kazakhstan). Examining and all related analyses were carried out in the Laboratory of Plant Protection at the centre of the country. The experimental site was located in the dry steppe zone. The climate is harsh continental, characterized by long cold winters and dry, hot summers. During the years of study, the sum of active temperatures above +10°C during the vegetation period of oilseed flax was within the normal range and amounted to 2,325.2°C in 2021 and 2,280.0°C in 2022. According to the value of the hydrothermal coefficient (HTC), the studied years were characterized as very dry with an HTC of 0.4-0.5. In 2021, the low amount of precipitation in the initial phases of the vegetation period of oilseed flax from seedlings to the blooming phase (from the 3rd 10-day period of May to the 2nd 10-day period of June) negatively affected the formation of the herbage density as well as its further growth and development. The main amount of precipitation fell in the 2nd 10-day period of July (20.8 mm) and in the 1st 10-day period of August (21.0 mm). The further course of the vegetation period took place in very arid conditions. The lack of precipitation for July and August amounted to 27.1 mm, while the temperature regime in July and August was 0.5-2.2°C above the annual average, which, against the background of atmospheric drought, played a decisive role in the formation and ripening of the crop. In comparison with 2021, in 2022, the amount of precipitation that fell during the initial phases of crop vegetation from seedlings to the ripening phase (from the 3rd 10-day period of May to the 3rd 10-day period of July) was 29.1 mm more. The main amount of precipitation fell in the 3rd 10-day period of July (42.0 mm) and in the 1st 10-day period of August (23.9 mm), that contributed to the formation of optimal herbage density as well as intensive growth and development of vegetative mass. The further course of the vegetation period took place in arid conditions. At the end of the vegetation period in the 2nd and 3rd 10-day periods of August, 1.3 mm of precipitation fell, while the temperature regime in July was 1.2°C higher, and in August, was at the level of the average long-term value. Accordingly, this period turned out to be dry and warm, which contributed to the timely ripening of seeds (Figs. 2-3).

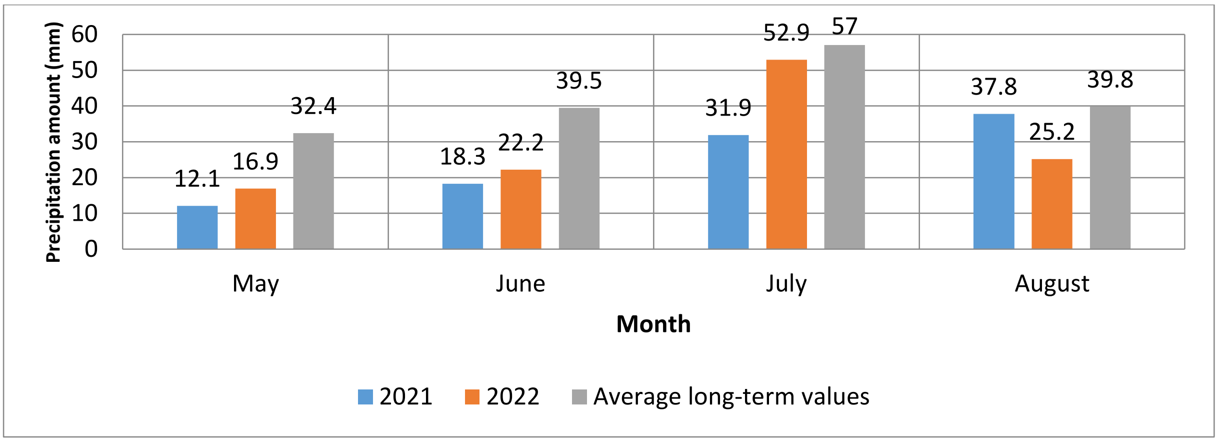

Fig. 2. The amount of precipitation (mm) during the vegetation period of oilseed flax.

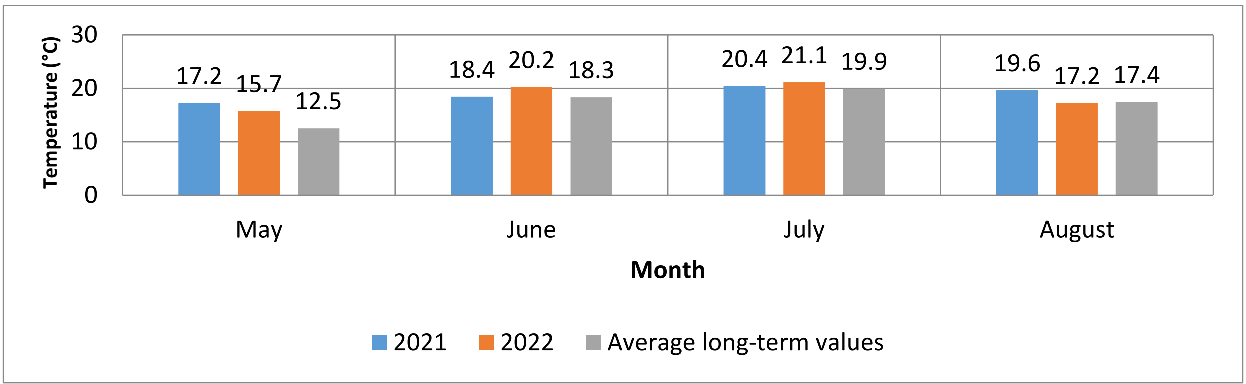

Fig. 3. The average monthly air temperature (°C) for the vegetation period of oilseed flax.

Based on the analysis of meteorological conditions, during the vegetation period of oilseed flax, the parameters of the precipitation and heat regime were relatively favourable in 2022 for the growth and development of plants and crop formation. The field experiment design was made according to the field experiment methods developed by B.A. Dospekhov (1985). The size of the plots was 100 m × 4.2 m = 420 m^2, the repetition was three-fold, and the accounting area was 100 m^2. The seeding rate was 40 kg ha^{-1}. Seeding was carried out at the optimal time for this zone (May 20), and the seeding method was ordinary. By the traditional technology and mini till, an SZS 2.1 seed drill was used (with claw colters) and with no-till Amazone (DMC, with anchor colters); the seeding depth was 5-6 cm. The preceding crop in the crop rotation was wheat after fallow. In the experiment, we used the Kustanaysky yantar oilseed flax variety. It was bred in Kazakhstan at the Karabalyk Agricultural Experimental Station based on the individual selection of fast-ripening plants from a hybrid combination (Mezheumok 39 × Oktyabr). The variety is medium ripening (the vegetation period is 75-90 days from the moment of mass germination). The bush is dense, compact, and 60-65 cm in height. Against the background of sowing oilseed flax, we studied the effectiveness of preparations used for pre-sowing seed treatment and during the vegetation period on different tillage technologies for oilseed flax according to the following design (Table 1).

Table 1. Seed pre-sowing treatment against the background of different tillage technologies for oilseed flax, 2021-2022.

Variants of the experiment		Repetitions		
Tillage technology	Pre-sowing seed treatment	I	II	III
Traditional	Control	1	13	25
	Olymp, suspension concentrate (SC) (0.55 L/t)	2	14	26
	Seedspor W (4.0 L/t)	3	15	27
	Olymp SC (0.55 L/t) + Seedspor W (4.0 L/t) + Akiba, water and suspension concentrate (WSC) (1.0 l/t)	4	16	28
Mini tillage	Control	5	17	29
	Olymp SC (0.55 L/t)	6	18	30
	Seedspor W (4.0 L/t)	7	19	31
	Olymp SC (0.55 L/t) + Seedspor W (4.0 L/t) + Akiba WSC (1.0 L/t)	8	20	32
No-till	Control	9	21	33
	Olymp SC (0.55 L/t)	10	22	34
	Seedspor W (4.0 L/t)	11	23	35
	Olymp SC (0.55 L/t) + Seedspor W (4.0 L/t) + Akiba WSC (1.0 L/t)	12	24	36

Experiment variant description

1. Variants of oilseed flax cultivation

1.1 In the case of traditional tillage, after harvesting the preceding crop, the following actions were performed:

- Autumn deep tillage up to 24-27 cm;
- Snow retention in the 2nd 10-day period of December;
- mulching when the soil was physically ripe in spring;
- Pre-sowing surface tillage up to 12-14 cm.

1.2 In the case of mini till in the spring, 2-3 weeks before sowing, the fields were treated with a continuous herbicide, i.e., glyphosate [Pharaoh Garant water-dispersable granules (WDG)] with glyphosate potassium salt as the active substance, 757 g kg^{-1} with a preparation consumption rate of 1.8 L ha^{-1} against annual and perennial dicotyledonous and cereal weeds. The soil was subjected to mechanical tillage only when sowing with the SZS 2.1 seed drill.

1.3 In the case of no-till in the spring, 2-3 weeks before sowing, the fields were treated with a continuous herbicide i.e., glyphosate (Pharaoh Garant WDG) with glyphosate potassium salt as the active substance, 757 g kg^{-1} with the preparation consumption rate of 1.8 L ha^{-1} against annual and perennial dicotyledonous and cereal weeds. The soil was not subjected to mechanical tillage.

2. Variants for pre-sowing treatment of flax seeds

Olymp SC: active ingredient: flutriafol 75 g L^{-1} + tiabendazole 50 g L^{-1} + imazalil 15 g L^{-1}. Manufacturer: Synthesia Chemi GmbH, Germany. This innovative fungicide is a system-contact protectant for the protection of legume seeds, oilseeds, and cereals from a complex of diseases transmitted through seeds, soil, and aerogenically.

Seedspor W is an innovative biological product consisting of living organisms (Mycorrhiza propagules: 10 colonies/mL, *Trichoderma* > 1 × 10^7 spores/mL), bacteria (*Bacillus subtilis*, *Bacillus megaterium* > 2 × 10^7 spores/mL), and trace elements: Fe (2%), Zn (0.5%), KO_2, P_2O_5, MgO, and CaO. Manufacturer: HANSE PLANT, Netherlands. It is a fertilizer containing nitrogen, phosphorus, potassium, and also trace elements such as iron and zinc as well as a 100% natural microbiological product for pre-sowing seed treatment. It is designed to maximize yield after a single application, even under adverse weather, environmental, and phytosanitary conditions. It is effective against nematodes and soil pathogens. *Akiba WSC*: active ingredient: imidacloprid, 500 g L^{-1}. Manufacturer: Agro Expert Group LLC, Russia. An insecticidal seed protectant for crops against a complex of pests that damage seedlings, as well as those living in the soil.

The general background of the experimental field treatment during the vegetation period of flax oil against harmful organisms

The general background of the experiment included herbicidal and insecticidal treatment during the vegetation period of flax. We did not show them on the experiment diagram (Table 1), since they were used in all variants of the experiment except for the control variant:

1. Herbicidal treatment was carried out in the three pairs of true leaves phase of the crop or at a height of 10-12 cm, with the Sekator Turbo herbicide in the dosage of 0.75 L ha^{-1} against dicotyledonous annual and perennial weeds and after 5 days with the Selekt herbicide (emulsion concentrate, EC) in the dosage of 0.5 L ha^{-1} against annual grass weeds.

Sekator Turbo, oil dispersion (*OD*): active ingredient: 25 g L^{-1} iodosulfuron-methyl-sodium, 100 g L^{-1} amidosulfuron, 250 g L^{-1} mefenpyr-diethyl (antidote). Manufacturer: Bayer Crop Science AG, Germany. A highly selective herbicide for use on crops of wheat, barley, corn, linen flax, and oilseed flax against annual and some perennial dicotyledonous weeds.

Selekt EC: active ingredient: Clethodim, 120 g L^{-1}. Manufacturer: Arista Life Science S.A.S., France. Herbicide of selective action. It suppresses all types of annual cereal weeds, including self-seeding of cereals and corn, as well as perennial cereals, including couch grass, devil's grass, Aleppo grass, etc. It is approved for use on beetroot, sunflower, soy, and rapeseed. It is effective against a wide range of cereal weeds.

2. Insecticidal treatment was carried out at the beginning of the budding phase against flax thrips, *Thrips linarius,* with the Engio 247 insecticide (0.2 L ha^{-1}).

Engio 247: active ingredient: Thiamethoxam, 141 g L^{-1} + lambda-cyhalothrin, 106 g L^{-1}. Manufacturer: Syngenta Crop Protection AG, Switzerland. A combined insecticide with contact and systemic activity against a wide range of pests at all life stages, from larvae to imago. It is highly effective against pests on a wide range of crops.

Following the tasks set, it was planned to carry out the following recordings, observations, and analyses

Phytopathological analysis of flax seeds was performed in a wet chamber and when sowing seeds on nutrient media. Four samples of 50 seeds each were selected. The seeds germinated for 7 days at a temperature of 25°C. The seeds were not disinfected before planting. Filter paper in three layers was used. The viewing was carried out on day 7, each germinated seed (seed lobes, root) and all un-grown seeds were viewed. The total infection rate of seeds with flax diseases was calculated (Gosstandart of Russia 1995). The determination of the seeding qualities of seeds was carried out according to the Methodology of the State Variety Network (Gossortset). Laboratory germination and germination energy were determined according to State Standard (GOST) 12038-84: flax seeds were germinated on moistened filter paper with two layers in Petri dishes. Four samples of 100 seeds each were taken from the weight samples. The laboratory germination of seeds (the percentage of normally germinated seeds in the sample taken for analysis) was determined on day 7, and the seed germination energy (an indicator of the uniformity of germination) was determined on day 3 (Fedin 1983; Gosstandart of USSR, 1986; Mozhaev *et al.* 2014). The identification and accounting of flax diseases were carried out according to the methods of the All-Union Scientific Research Institute of Oilseeds throughout the vegetation period (starting from the period of germination to full ripening). The prevalence and development of diseases in flax crops were determined using the formulas developed by Drakhovskaya (1962). The prevalence of diseases was calculated using formula 1:

$$P = \frac{n}{N} x100 \quad \textbf{(1)}$$

where:

P is the prevalence of the disease;

n is the number of affected plants or organs;

N is the total number of analysed plants or organs.

The percentage of development or the degree of plant infestation was determined using formula 2:

$$\mathrm{R} = \frac{\sum(\mathrm{ab})}{\mathrm{N} \cdot \mathrm{K}} \mathrm{x}100 \quad \textbf{(2)}$$

where:

R is the percentage or degree of disease development;

N is the number of registered plants, leaves, fruits, tubers, or other organs;

K is the highest score on the scale on which the assessment was conducted.

When determining the degree of disease development, a single universal four-point scale was used for diseases affecting oilseed flax (Lukomets *et al.* 2013). Yield accounting was carried out by harvesters with a conversion to 100% purity and 12% humidity (Wintersteiger selection harvesters; Arinov *et al.* 2016). Mathematical data processing was carried out using the SNEDECOR software. A one-way analysis of variance (ANOVA) was carried out to consider the least significant difference LSD_{05}, which indicates the limit of possible random deviations in the experiment. This is the smallest difference that in this experiment is recognized as significant at a 5% significant level. If the actual difference between the variants is greater than $LSD_{0.5}$ ($d \geq LSD_{0.05}$), then it is significant; if it is less than $LSD_{0.5}$ ($d \leq LSD_{0.5}$), then it is insignificant (Programma paketa prikladnoi statistiki 2004).

RESULTS

Currently, when cultivating crops, much attention is paid to the pre-sowing treatment of seeds for their complex protection. When choosing a preparation for seed disinfection, the phytopathological analysis of seeds for the presence of pathogens is considered. In our studies conducted in 2021-2022, phytopathological analysis of oilseed flax seeds showed that seed material was one of the transmission sources of the main flax disease pathogens. The results showed that oilseed flax seeds were not resistant to fusariosis and anthracnose. As a result of phytopathological analysis, the infection of flax seeds with *Fusarium* ssp. and *Colletotrichum* ssp. were observed. According to the results of the 2021 analyses, the treatment of seeds with preparations of chemical (Olymp SC) and biological (Seedsport W) origin showed a positive effect. In comparison with untreated seeds, there was a decrease in infection with *Fusarium* ssp. (20-22%), *Colletotrichum* ssp. (8-10%), and Penicillium (6-8%). High efficiency was observed in the variant with the complex use of these preparations with the addition of an insecticidal protectant (Akiba WSC). Similar results were obtained in 2022. The difference compared to the control variant in the variants with protectants was significant since it exceeded the $LSD_{0.05}$, which ranged from 1.63 to 2.54 (Table 2).

Table 2. Infection of oilseed flax seeds with fungal diseases.

Variants of the experiment	2021						2022					
	***Fusarium* ssp.**		***Colletotrichum* ssp.**		***Penicillium***		***Fusarium* ssp.**		***Colletotrichum* ssp.**		***Penicillium***	
	pcs.	**%**	**pcs.**	**%**	**pcs.**	**%**	**pcs.**	**%**	**pcs.**	**%**	**pcs.**	**%**
Control	14	28	9	18	5	10	20	40	13	26	7	14
Olymp SC	4	8	5	10	2	4	7	14	6	12	4	8
Seedspor W	3	6	4	8	1	2	6	12	5	10	3	6
Olymp SC + Seedspor W + Akiba WSC	1	2	2	4	1	2	2	4	3	6	1	2
$LSD_{0.05}$	*2.30*		*2.54*		*1.63*		*1.88*		*2.30*		*2.31*	

Analyses on the sowing qualities of seeds indicated that chemical preparations did not negatively affect the laboratory germination of oilseed flax seeds and suppressed the development of diseases well. Disinfection of oilseed flax seeds showed different data on indicators of seed sowing qualities, which were determined in laboratory conditions. The determination of the effect of chemical and biological protectants on the germination of oilseed flax seeds revealed that the germination energy for the variants ranged from 81.0 to 89.0% in 2021 and from 70.0 to 79.0% in 2022. The pre-sowing treatment of flax seeds with oilseed protectants, regardless of the type, had a positive effect on their germination energy. Laboratory evaluation of seed germination by types of protectants showed that it ranged from 87.0 to 95.0% in 2021 and from 80.0 to 90.0% in 2022. The studied oilseed flax seeds treated with a combination of protectants exhibited the high laboratory germination rates and germination energy. Seedsport W was 1-3% more effective for seed germination than Olymp SC. The difference compared to the control variant in the variants with protectants was significant since it exceeded the $LSD_{0.05}$, ranging from 2.30 to 2.97 (Table 3).

Table 3. The effect of seed treatment with protectants on the sowing qualities of seeds.

Variant of the experiment	2021		2022	
	Germination energy (%)	**Laboratory germination (%)**	**Germination energy (%)**	**Laboratory germination (%)**
Control	81.0	87.0	70.0	80.0
Olymp SC	86.0	92.0	75.0	85.0
Seedspor W	85.0	93.0	74.0	88.0
Olymp SC + Seedspor W + Akiba WSC	89.0	95.0	79.0	90.0
$LSD_{0.05}$	2.87	2.97	2.66	2.30

In our experiments, the length of the seedlings varied depending on the disinfection. The complex use of protectants contributed to an increase in the length of the seedling to 9.6-9.8 cm, which is 4.5-4.6 cm more than the control variant and 1.2-1.4 cm more than the rest of the studied variants. The length of the roots grown from the disinfected seeds exceeded the control variant. All variants of the experiment stimulated the development of the root system of the culture. The number of seedlings increased by 7-16 pieces, which contributed to the intensive development of plants in the field. The influence rate of the studied variants for pre-sowing treatment was high. The $LSD_{0.05}$ ranged from 0.03 to 2.30 in the experiments in 2021 and from 0.02 to 1.88 in 2022, exhibiting the high significance of the studied variants (Table 4).

Table 4. The effect of protectants on the growth performance of oilseed flax.

Variant of the experiment	Number of seedlings on day 10	Seedling length (cm)	Spine length (cm)	Seedling weight (g)	
				Raw weight (g)	Dry weight (g)
2021					
Control	85.0	5.3	2.1	0.62	0.43
Olymp SC	92.0	8.4	3.2	1.23	0.95
Seedspor W	94.0	8.6	3.3	1.25	0.97
Olymp SC + Seedspor W + Akiba WSC	96.0	9.8	5.7	1.59	1.23
$LSD_{0.05}$	2.30	0.18	0.23	0.22	0.03
2022					
Control	79.0	5.0	1.3	0.58	0.34
Olymp SC	89.0	8.2	2.7	1.12	0.83
Seedspor W	86.0	8.3	2.7	1.13	0.86
Olymp SC + Seedspor W + Akiba WSC	91.0	9.6	3.8	1.42	1.13
$LSD_{0.05}$	1.88	0.23	0.38	0.02	0.02

Optimal plant density in the agrobiocenosis ensures the formation of high yields with good technological quality. Therefore, we studied the effect of protectants against the background of different tillage technologies. Studies in 2021-2022 revealed that the influence of chemical and biological protectants applied individually or in combination, regardless of crop tillage technologies, provided an increase in field germination of plants compared to the control variant. In the case of no-till, there was a slight increase in field germination (2.2-4.1%), compared to the traditional and mini till variants. On average, for two years, the high field germination was provided by the variant with complex protectant use (74.4-78.5%). The $LSD_{0.05}$ was 1.00 by traditional technology, 0.64 by mini till, and 0.96 by no-till. This confirms the high significance of the studied variants (Table 5).

Table 5. The effect of flax seed protectants on field germination with different tillage technologies.

Variants of the experiment		Herbage density by seedlings				
Tillage technology	Pre-sowing seed treatment	2021		2022		Average (%)
		Pcs. m^{-2}	%	Pcs. m^{-2}	%	
Traditional	Control	347.0	60.9	387.0	67.9	64.4
	Olymp SC	369.0	64.7	427.0	74.9	69.8
	Seedspor W	370.0	64.9	438.0	76.8	70.9
	Olymp SC + Seedspor W + Akiba WSC	381.0	66.8	467.0	82.0	74.4
	$LSD_{0.05}$					1.00
Mini till	Control	352.0	61.8	393.0	68.9	65.4
	Olymp SC	370.0	64.9	428.0	75.1	70.0
	Seedspor W	375.0	65.8	444.0	77.9	71.9
	Olymp SC + Seedspor W + Akiba WSC	387.0	67.9	473.0	83.0	75.4
	$LSD_{0.05}$					0.64
No-till	Control	359.0	63.0	411.0	72.1	67.6
	Olymp SC	376.0	66.0	445.0	78.0	72.0
	Seedspor W	381.0	66.8	456.0	80.0	73.4
	Olymp SC + Seedspor W + Akiba WSC	399.0	70.0	496.0	87.0	78.5
	$LSD_{0.05}$					0.96

In the seedlings phase, we determined the infestation of primary and secondary plant roots with root rot, the pathogens of which were various fungi of the genera *Fusarium* ssp., *Alternaria* spp., and others which can cause partial loss and even complete death of flax seedlings. In 2021, the degree of prevalence and development of root rot was low compared to 2022, which may be explained by weather conditions with low precipitation and high air temperature. In the case of no-till, the degree of prevalence and development of the disease was higher compared to traditional and mini till. The accumulation of plant residues of crops and weeds with no-till may serve as a place of storage and overwintering of pests and fungal disease pathogens. When restraining and suppressing the prevalence and development of root rot, Seedsport W was less efficient than Olymp SC. The variant with the integrated use of protectants showed high efficiency. The $LSD_{0.05}$ ranged from 0.18 to 2.19 in 2021 and from 0.18 to 2.30 in 2022, indicating the high significance of the studied variants (Table 6). In our experiments during the vegetation period of oilseed flax, one of the most rapidly progressing diseases was the fusarium wilt of oilseed flax. In the experimental field, the prevalence of the disease was widespread. The first obvious symptoms were revealed at the seedlings and three pairs of true leaves phases; the cotyledonous leaves bent inward, then the leaves turned yellow, and soon the plant turned brown and completely died.

Table 6. The effectiveness of protectants against flax root rot, depending on the crop tillage technology.

Variants of the experiment	Technologies					
	Traditional		Mini till		No-till	
	Root rot (%)					
	P	R	P	R	P	R
2021						
Control	35.5	1.9	37.0	2.0	37.5	2.3
Olymp SC	17.0	0.5	19.3	0.7	20.0	0.9
Seedspor W	20.3	0.7	24.0	0.9	25.0	1.0
Olymp SC + Seedspor W + Akiba WSC	15.0	0.3	19.0	0.5	19.0	0.7
$LSD_{0.05}$	2.19	0.18	1.87	0.18	1.68	0.21
2022						
Control	40.0	2.6	42.0	3.6	40.0	3.8
Olymp SC	20.0	0.7	24.0	0.9	24.0	1.2
Seedspor W	23.0	1.1	27.5	1.3	28.0	1.5
Olymp SC + Seedspor W + Akiba WSC	18.0	0.6	23.0	0.8	22.0	1.1
$LSD_{0.05}$	2.30	0.36	1.67	0.18	2.30	0.21

Note: P: prevalence, R: development.

In comparison with the control variant, in the variants where the seeds were disinfected with various preparations for pre-sowing seed treatment, the plants were less affected by fusarium wilt. Flax plants were less affected by the pathogen in the variants treated with Olymp SC + Seedspor W + Akiba WSC (in the germination phase: 27.0%, in the three pairs of true leaves phase: 40.7%, in the budding phase: 42.3%, in the blooming phase: 44.0%, and in the ripening phase: 45.7%). The preparations used for seed disinfection in recent years not only protect plants from soil infection, but also may exhibit a stimulating effect on the plant growth and development during the vegetation period. It was shown by Seedspor W, which was as good in fungicidal action as Olymp SC. A high degree of prevalence and the development of the disease were detected in the variant with no-till. The mathematical processing carried out exhibited the accuracy and reliability of the obtained data (Table 7). Flax anthracnose exhibited itself in the form of bordered rusty-orange spots on cotyledonous leaves throughout the vegetation period. The disease spread intensively on the stems of ripening plants, more often on the lower part in the form of marble spotting. The pathogen of this disease is the fungus imperfectus, *Colletotrichum lini* Manns et Bolley. In wet years, spots can cover the entire stem and side branches and can reach the level of epiphytotics. Due to the rapid spread and development, anthracnose competes with other diseases and overcomes them. The prevalence in the control variant during the vegetation period reached on average 34.3 to 54.0% with traditional technology, 35.0 to 54.7% with mini till, and 35.7 to 55% with no-till. The development ranged, respectively, from 15.0 to 27.0, from 15.7 to 28.0, and from 16.0 to 29.0 respectively. A high degree of prevalence reduction compared to the control variant was shown by the variant with the complex use of protectants and amounted to 13.0 to 32.0% with the traditional technology, from 13.5 to 32.5% with mini till, and from 15.0 to 33% with no-till. The development ranged from 2.0 to 7.3, from 2.7 to 7.5, and from 3.0 to 8.0 respectively. A high degree of prevalence and development of the disease was observed in the variant with no-till. The mathematical processing carried out shows the accuracy and reliability of the data obtained during the study (Table 8). According to the study results, depending on the tillage technologies, the studied variants for pre-sowing seed treatment, and the prevailing weather conditions, the yield varied on average from 3.1 to 7.1 kg ha^{-1}. In 2021, in conditions of drought with low seed yields, relatively high indicators were obtained in variants using the no-till. Compared with traditional and mini till, the yield was higher by 0.3-0.6 and 0.4-0.7 c/ha, respectively. Under favourable weather conditions in 2022, there was no significant difference between the tillage technologies in terms of yield. However, a slight advantage was observed in variants using the traditional tillage technology. Flax treatment with preparations caused a tendency to increase the yield of seeds. Thus, the maximum increase in yield compared to the control variant was noted in the variant with the complex use of protectants and amounted to 3.7-3.9 c/ha (Table 9).

Table 7. The development and prevalence of *Fusarium* ssp. during the vegetation period of flax (average for 2021-2022).

Variants of the experiment		**Development phase**									
Tillage technology	**Seed treatment**	**Seedlings**		**Three pairs of true leaves**		**Budding**		**Blooming**		**Ripening**	
		P	**R**	**P**	**R**	**P**	**R**	**P**	**R**	**P**	**R**
Traditional	Control	45.0	24.3	56.0	27.5	63.4	29.0	66.7	30.5	70.3	31.7
	Olymp SC	30.3	6.5	44.3	8.0	47.5	10.3	49.0	12.0	49.7	13.5
	Seedspor W	32.5	7.0	45.0	8.5	50.6	11.0	52.3	13.5	53.5	14.6
	Olymp SC + Seedspor W + Akiba WSC	27.0	5.7	40.7	7.3	42.3	8.7	44.0	10.3	45.7	11.5
	$LSD_{0.05}$	1.35	0.33	1.00	0.23	0.46	0.49	1.34	0.59	0.70	0.54
Mini till	Control	47.3	25.3	58.0	28.7	65.0	30.5	68.0	31.3	71.0	32.0
	Olymp SC	32.0	7.0	45.0	9.0	49.0	11.3	50.3	13.0	50.5	14.3
	Seedspor W	33.5	7.5	47.0	9.3	51.3	11.7	53.0	14.5	54.7	15.0
	Olymp SC + Seedspor W + Akiba WSC	28.0	6.0	41.3	7.5	44.0	9.0	45.3	11.0	47.0	12.0
	$LSD_{0.05}$	1.13	0.39	0.65	0.41	0.53	0.32	0.49	0.37	1.49	0.48
No-till	Control	48.0	26.0	58.5	29.0	65.3	31.0	68.7	32.0	72.0	32.3
	Olymp SC	32.3	7.3	46.0	9.0	50.0	11.3	51.0	13.5	51.3	14.7
	Seedspor W	34.0	7.0	47.3	9.5	51.5	12.0	53.0	15.0	55.0	16.0
	Olymp SC + Seedspor W + Akiba WSC	28.7	6.5	42.0	8.0	44.7	9.5	45.0	11.0	48.0	12.3
	$LSD_{0.05}$	0.54	0.65	0.44	0.46	0.79	0.48	1.04	0.59	0.65	0.48

Note: P: prevalence, R: development.

The variant with Seedspor W, along with high environmental safety, also had high efficiency, which allows us to recommend it for use in the cultivation of oilseed flax, as well as in further research by other scientists in this area, since the advantage of biological systems is their environmental safety reducing the chemical load on plants and a lower cost.

DISCUSSION

According to scientists (Yadav *et al.* 2022), biotic and abiotic stress factors are the main obstacles to increasing flax production worldwide. The productivity of flax is strongly influenced by fungal diseases such as fusarium wilt, *Alternaria* leaf blight, late blight, powdery mildew, rust, and pasmo in European countries, while oilseed flax, grown mainly in Asia, especially in India and other Asian countries, suffers from drought, salinization, and heat combined with various diseases and pests. In addition, the warmer climate of these tropical countries is not suitable for growing flax, which requires a long cool season for effective yield and fibre quality. As a result, yields in these countries remain at the same level (Yadav *et al.* 2022). In our studies conducted in the dry-steppe zone of Northern Kazakhstan, the dominant diseases were fusarium wilt and anthracnose (caused by *Fusarium* ssp. and *Colletotrichum* ssp.) which were initially found in the seed material and later manifested during the vegetation period. In our studies, seed treatment against fungal diseases exhibited a significant impact on the formation of the yield of oilseed flax seeds. In the variants with the complex use of protectants (Olymp SC + Seedspor W + Akiba WSC), the increase in seed yield compared to the control variant was 41.5-54.9%.

Table 8. Development and prevalence of anthracnose (*Colletotrichum* ssp.) during the flax vegetation period (average for 2021-2022).

Variants of the experiment		**Development phase**									
Tillage technology	**Seed treatment**	**Seedlings**		**Three pairs of true leaves**		**Budding**		**Blooming**		**Ripening**	
		P	**R**	**P**	**R**	**P**	**R**	**P**	**R**	**P**	**R**
Traditional	Control	34.3	15.0	42.3	17.5	48.7	19.5	51.7	23.5	54.0	27.0
	Olymp SC	16.7	3.0	28.7	4.7	31.3	6.5	34.0	8.0	36.7	9.3
	Seedspor W	17.3	3.5	29.0	5.0	32.0	7.0	35.7	8.7	37.0	9.7
	Olymp SC + Seedspor W + Akiba WSC	13.0	2.0	23.0	3.5	26.5	5.3	29.0	6.5	32.0	7.3
	$LSD_{0.05}$	0.53	0.50	0.75	0.61	0.64	0.61	0.69	0.77	0.82	0.58
Mini till	Control	35.0	15.7	43.0	18.3	49.0	20.0	52.0	24.0	54.7	28.0
	Olymp SC	17.3	4.0	30.0	5.0	31.5	7.3	34.7	8.3	37.0	9.5
	Seedspor W	18.0	4.3	31.3	5.3	32.7	7.7	36.0	9.0	38.0	10.0
	Olymp SC + Seedspor W + Akiba WSC	13.5	2.7	23.7	4.0	27.0	5.5	30.3	7.0	32.5	7.5
	$LSD_{0.05}$	1.34	0.56	0.98	0.69	1.43	0.57	0.63	1.06	0.61	0.81
No-till	Control	35.7	16.0	43.7	19.0	50.0	21.0	52.7	24.7	55.0	29.0
	Olymp SC	18.0	4.5	31.0	5.7	32.0	8.0	35.0	9.0	37.5	9.5
	Seedspor W	19.3	4.7	31.5	6.0	32.7	8.3	36.3	9.5	38.0	10.3
	Olymp SC + Seedspor W + Akiba WSC	15.0	3.0	24.0	4.5	28.0	5.7	30.5	7.3	33.0	8.0
	$LSD_{0.05}$	1.09	0.79	0.91	0.98	1.42	1.14	0.75	0.48	0.58	0.65

Note: P: prevalence, R: development.

As practice shows, in modern agriculture, it is impossible to obtain a big and high-quality harvest without pre-sowing seed treatment against the above fungal diseases, although according to many scientists (Suleimenova, 2018), breeding for the resistance of oilseed flax varieties against fusariosis and other diseases is underway and has achieved some success. However, according to the results of other scientists, yield losses from fungal diseases reach up to 80-100% (Rashid 2003). According to the description by Rashid (2003), fungal microconidia penetrate the cells of the flax root and then move intracellularly into the vascular tissue. They germinate and, thus, block blood vessels and prevent the movement of water and nutrients, which leads to epinasty with subsequent progressive withering and death. In our experiments with different technologies of oilseed flax cultivation, there was no significant difference in the degree of prevalence and development of diseases. However, with traditional technology (with mechanical tillage), there was a slight natural decrease in the development and prevalence of fusariosis and anthracnose compared to mini till and no-till. Seedspor W tested by us, along with high environmental safety, also had high efficiency in pathogen containment, which allows us to recommend it for use in production and further research. The advantage of biological systems is their environmental safety reducing the chemical load on crops and the stress phytotoxicity of fungicides.

Table 9. The effect of protectants on the yield of oilseed flax seeds with different tillage technologies (average for 2021-2022).

Variants of the experiment		Yield (c/ha)			Yield increase	
Tillage technology	**Pre-sowing seed treatment**	**2021**	**2022**	**Average**	**c/ha**	**%**
Traditional	Control	0.87	5.6	3.2	-	-
	Olymp SC	2.8	8.3	5.6	2.4	42.9
	Seedspor W	2.9	8.5	5.7	2.5	43.8
	Olymp SC + Seedspor W + Akiba WSC	5.2	8.9	7.1	3.9	54.9
	$LSD_{0.05}$	0.26	0.23	0.18		
Mini till	Control	0.91	5.3	3.1	-	-
	Olymp SC	2.6	8.2	5.4	2.3	42.5
	Seedspor W	2.8	8.1	5.5	2.4	43.6
	Olymp SC + Seedspor W + Akiba WSC	5.1	8.4	6.8	3.7	54.4
	$LSD_{0.05}$	0.21	0.26	0.28		
No-till	Control	1.3	4.9	3.1	-	-
	Olymp SC	3.1	7.5	5.3	2.2	41.5
	Seedspor W	3.3	7.5	5.4	2.3	42.5
	Olymp SC + Seedspor W + Akiba WSC	5.8	7.7	6.8	3.7	54.4

CONCLUSION

As a result of studies from seed material, we identified fungal disease pathogens *Fusarium* ssp., *Colletotrichum* ssp., and *Penicillium*, which during the vegetation period of oilseed flax affected it in the form of root rot, fusarium wilt, and anthracnose. Using chemical and biological protectants stopped the further spread and development of diseases, contributing to the formation of healthy seedlings of the crop. The low degree of prevalence and development of root rot in the seedlings phrase and three pairs of true leaves phase, as well as the manifestation in the following phases of vegetation of oilseed flax, was observed in the variants with the complex use of preparations (Olymp SC + Seedspor W + Akiba WSC), which in arid conditions with traditional tillage technologies provided high seed yield (5.6 to 7.1 c/ha).

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