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Reducing the harmfulness of the main phytophages of oilseed flax

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ABSTRACT
Production of oilseed flax, *Linum usitatissimum* L. in Kazakhstan is severely threatened by the losses inflicted by its key phytophages, namely the leaf beetle, *Aphthona euphorbiae*, the flax moth, *Helcystogramma triannulella*, and the peach green aphid, *Myzus persicae*. The study was conducted as a field experiment during two vegetation periods (2023-2024) in northern Kazakhstan to evaluate vulnerability reduction measures. Five treatments of management including chemical control (T_1), biological control by release of *Trichogramma evanescens* (T_2), combination of T_1 + T_2 + 1.5% potassium silicate mixture (T_3), resistant cultivars (cultivar "Lina-3"; T_4), and control (T_5) were compared in a randomized complete block design with four replicates. The results indicated that integrated treatment (T_3) was the best treatment with 68-54% reduction in pest density, 72.4% increase in defensive phenolic compounds (18.7 mg GAE/g DW) and peroxidase enzyme activity (4.92 units). The treatment significantly increased grain yield by 1.82ton ha^{-1} (63.7% greater than control). Resistant cultivar "Lina-3" (T_4) was also found to be a suitable option for low-input systems with a 5.1:1 benefit-cost ratio. The findings confirm the effectiveness of the integrated approach on the grounds of fortification of plant defense mechanisms, conservation of natural enemies and rational chemical treatment as a sustainable model of pest management in oilseed flax agroecosystems of Kazakhstan.

Keywords: Integrated pest management, Oilseed flax, Key phytophages, Sustainable agriculture in Kazakhstan.
Article type: Research Article.

INTRODUCTION
Flaxseed, *Linum usitatissimum* L. holds a prominent place in modern agriculture, economies of the majority of countries due to the fact that the seeds carry omega-3 fatty acids and possess multi-dimensional industrial uses in oil, fibre, animal nutrition, and pharmacy drug production (Rashid *et al.* 2020; Akhmedov 2025). Nonetheless, realizing the complete yield and quality potential of this precious crop is always subjected to some problems, the most significant of which is the injury caused by infestations of herbivorous (phytophagous) insects. Through their consumption of various plant organs, including stems, leaves, flowers, and seeds, the insects not only reduce the quantity and quality of the crop directly, but also predispose the plants to secondary infections and eventually confront the sustainability of crop systems (Cappelli *et al.* 2021; Muslima & Dilrabo 2024). Among the extreme majority of oilseed flax-related insects, flax leaf beetles (especially *Aphthona euphorbiae* and genus *Opetiopalpus* species), flax

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moths (*Helcystogramma* spp., and *Anarsia* spp.), aphids (especially *Aphis craccivora* and *Myzus persicae*), and some damaging insects are designated as main pests and cause serious damages to a significant amount of areas of this crop, including susceptible areas of Kazakhstan (Jankeviciene & Baliukoniene 2019; Khasenov 2022; Zilola *et al.* 2025; Sadriddin *et al.* 2025). Injury caused by these insects may appear as a sharp decline in the intensity of photosynthesis, overall weakening of the bushes, flower and bud abortion, decrease in the number of pods and thousand-seed weight, and even seedling death in extreme instances. It has been traditionally controlled with high application of chemical pesticides, which, while effective in the short term, have presented negative impacts such as resistance development in pest populations, disruption of the normal ecosystem balance of enemies, chemical residues on the crop and environment, and increased production costs (Zheljazkov *et al.* 2020; Widjaja *et al.* 2025). Therefore, the need to design and implement integrated pest management (IPM) strategies grounded in ecologically-based principles that reduce dependence on chemical inputs but maintain efficiency, fostering agroecosystem sustainability and environmental integrity becomes more and more evident. The research will study and suggest scientific and timely solutions to reduce the vulnerability of oilseed flax plantings in Kazakhstan to its major pests using eco-friendly and sustainable practices such as using resistant or tolerant crops, biological control practices, precision agriculture practices, and optimizing the timing of application. Such solutions are possible to have an influential position in higher productivity, improved crop quality, reduced costs, and maintaining the long-term sustainability of oilseed flax production in this important agricultural region. Harmful impacts caused by the major phytophages of oilseed flax have been under the center of enormous amounts of investigation in various parts where this crop is grown. Recent studies prove that leaf-feeders (mainly *A. euphorbiae* and *Opetiopalpus* species) significantly reduce the photosynthetic capacity of the plant by devouring leaf parenchyma and disrupt the movement of photosynthetic products to seeds (Jankeviciene & Baliukoniene 2019). At the same time, flax moths (*Helcystogramma* spp., and *Anarsia* spp.) harm yield factors by feeding their larvae on buds, flowers, and developing seeds. Field studies in Kazakhstan have revealed that heavy damage by the above insects can lead to a 25-40% loss of thousand-seed weight (Khasenov 2022; Alrashedi *et al.* 2024). Aphids (e.g., *A. craccivora* and *M. persicae*) are also plant virus vectors and cause nutrient stress, which is detrimental to fiber quality and grain quality along with a reduction in plant growth. The excretion of honeydew by these insects encourages a favorable environment for the growth of sooty molds, affecting the process of photosynthesis twice (Cappelli *et al.* 2021; Razmara *et al.* 2022). Conventional chemical control methods, though curtailing pest numbers in the short run, have been confronted with serious issues. The Eastern Europe and Central Asia long-term studies have established the resistance of *A. craccivora* populations against different insecticide classes especially pyrethroids and neonicotinoids (Zheljazkov *et al.* 2020; Nie & Rezvani 2025). In addition, indiscriminate application of pesticides severely reduces populations of native predators such as ladybirds (*Coccinella septempunctata*), green beetles (*Chrysoperla carnea*), and parasitoid wasps (*Aphidius colemani*) and in turn causes secondary outbreaks of pests (Ismailov *et al.* 2020; Violet & Hazarika 2024; Htet *et al.* 2025). In an effort to overcome these disadvantages, integrated pest management (IPM) strategies based on ecological concepts have gained more research interest. Biological control-associated studies have found that selective release of *Trichogramma evanescens*, a parasitoid wasp of egg parasitoids of moths, has been shown to increase the egg parasitization of cotton bollworms by 70% and lead to a significant reduction in larval damage (Singh *et al.* 2021; Kumar *et al.* 2024). Pest-resistant varieties are also being bred simultaneously. Evaluation of Russian and Kazakh genotypes of oilseed flax led to the identification of genotypes with high levels of secondary defense compounds (such as lignans and phenols) possessing antixenosis resistance to leaf beetles and aphids (Golubkina *et al.* 2022; Mitschek *et al.* 2024). Crop management is also tasked with curbing the pest population. From research, effective crop rotation (especially the skipping of successive cropping of flax with other common host crops of pests such as rapeseed) and plowing of crop residues at harvest time can effectively disrupt the life cycle of soil-dwelling pests such as overwintering larvae of some beetles (Rashid *et al.* 2020; Nguyen *et al.* 2024). Implementation of precision agriculture (i.e., implementation of satellite images and drones for identification of primary areas of contamination) opens possibilities for selective control and reduced application of pesticides (Smith *et al.* 2023). Moreover, maximum nutrition of plants (especially nitrogen, potassium and silicon elements ratio balance) has the potential to stimulate physiological resistance of plants against biotic stresses (Cappelli *et al.* 2021; Dube *et al.* 2024). Finally, regular surveillance of pest infestations and their natural antagonists using pheromone traps and monitoring of important stages of damage (i.e., budding and development of bolls) are important for proper timing of control operations (if necessary). This multi-strategy approach optimizes sustainability in oilseed rape agroecosystems without maximizing chemical pesticide use.

MATERIALS AND METHODS

Field study area and plant materials

The trial was conducted as a field trial during two consecutive crop years (2023-2024) at the Agricultural Research Station in Northern Kazakhstan (coordinates: 54°16′N, 69°04′E). The experimental site featured a dry continental climate with a mean annual rainfall of 250 to 300 mm and a mean annual temperature of 3.5 °C. The field soil was of chernozem type with chemical characteristics like 4.2% organic matter, pH 6.8, and cation exchange capacity 32 cmol kg^{-1}. Oilseed flax cultivar "Sairan" was used, which has been brought into Kazakhstan by Kazakh Research Institute of Grain Farming (KazNIIZiR) as a cultivar adapted to the climatic conditions in Kazakhstan (Khasenov 2022).

Experimental design and treatments

The experiment was designed with a randomized complete block (RCBD) design with four replications and five management treatments. Each experimental plot received a size of 10 × 10 m and a plant density of 450 plants per m^2. The methods of treatment: chemical treatment (T_1) by deltamethrin spraying (2.5% EC at 0.5 L ha^{-1}) at the economic threshold (3 larvae per plant) of cotton bollworm; biological treatment (T_2) by releasing the *Trichogramma evanescens* parasitoid wasp with a population of 50,000 bees per ha during the full budding stage; combined treatment (T_3) as the combination of $T_1 + T_2$ along with foliar spraying with potassium silicate fertilizer (1.5%) during the stemming stage; sowing a resistant variety (T_4) with the resistant genotype "Lina-3" as developed by Golubkina *et al.* (2022); and control treatment (T_5) with no use of any pest control method.

Pest damage and monitoring assessment

Monitoring of the populations of three key pests, i.e., flax leaf beetle (*Aphthona euphorbiae*), flax moth (*Helcystogramma triannulella*), and peach green aphid (*Myzus persicae*), was conducted weekly from 4-leaf stage up to the physiological maturity. For flax leaf beetles and flax moth larvae, adult and immature stage counts were taken directly on 20 randomly selected plants per plot. For the monitoring of male flax moths, commercial Pherolure® pheromone traps at a trap density of 15 traps per hectare were installed and inspected weekly. Aphid infestation was expressed as a percentage according to EPPO standard PP 1/135 (2021). Damage indexes like percentage area of damaged leaves (read from ASD FieldSpec handheld spectrometer), bud fall rate, thousand-seed weight loss, and final seed yield were recorded for each treatment.

Measurement of physiological and biochemical parameters

Parameters related to the mechanism of plant resistance were evaluated at full flowering stage. Total phenolic compounds content in the leaves was measured according to the Folin-Ciocalteu method as per Singleton *et al.* (1999) procedure. The Defence enzyme peroxidase and polyphenol oxidase activities were measured using guaiacol and pyrocatechol substrates, respectively, and as per the absorbance assay procedure of Kar and Mishra (1976). LAI was determined using LAI-2200C (LI-COR) and shoot total dry matter. WUE was calculated by measuring the net photosynthesis and transpiration rate at the same time using the portable gas analyzer (Li-6400XT, LI-COR).

Statistical analysis

All the measurements of morphological, biochemical and functional attributes were analyzed using analysis of variance (ANOVA) after normality (Shapiro-Wilk) and equal variances (Levene) tests using SAS version 9.4 statistical package. Treatment means were contrasted at 5% level of significance using Tukey's multi-domain test. Main effects of treatment, year and their interaction were evaluated in terms of a linear mixed model. Linear and multiple regression analysis were employed to analyze the interrelations between damage indices and pest density.

RESULTS

Pest population dynamics and damage reduction

The two-year study demonstrated significant variations in pest population suppression across management strategies. Table 1 presents mean seasonal densities of key phytophages under different treatments. Chemical control (T_1)

provided rapid knockdown of *Helcystogramma triannulella* larvae (1.2 ± 0.3 larvae plant^{-1}), but showed declining efficacy against aphids in the second year. The biological treatment (T_2) achieved 68.7% parasitization of moth eggs, substantially reducing larval populations (1.8 ± 0.4 larvae plant^{-1}). Notably, the integrated approach (T_3) demonstrated synergistic effects, maintaining pest densities below economic injury levels throughout both growing seasons.

Table 1. Mean pest densities (± SE) during critical phenological stages.

Treatment	*Aphthona euphorbiae* (adults plant^{-1})	*H. triannulella* (larvae plant^{-1})	*Myzus persicae* (colonies plant^{-1})
T1	0.8 ± 0.1^b	1.2 ± 0.3^c	2.1 ± 0.4^b
T2	2.3 ± 0.3^a	1.8 ± 0.4^b	3.4 ± 0.5^a
T3	0.5 ± 0.1^c	0.9 ± 0.2^d	1.0 ± 0.2^c
T4	1.1 ± 0.2^b	1.5 ± 0.3^{bc}	1.3 ± 0.3^c
T5	3.6 ± 0.4^a	4.2 ± 0.6^a	5.8 ± 0.7^a

^{Means followed by different letters within columns differ significantly (Tukey's HSD, p<0.05)}.

The resistant cultivar (T_4) exhibited intrinsic resistance mechanisms, particularly against *M. persicae*, with 57.3% lower aphid colonization compared to the susceptible control. Damage assessment revealed that foliar injury was most severe in control plots (T_5), where 42.7 ± 3.1% of leaf area showed feeding damage, while T_3 limited damage to 11.3 ± 1.8%.

Physiological and biochemical responses

Plants under different management regimes exhibited distinct biochemical profiles (Table 2). The integrated management (T_3) and resistant cultivar (T_4) stimulated significant enhancement in defense compounds. Total phenolic content in T_3 reached 18.7 ± 0.9 mg GAE/g DW, representing a 72.4% increase over control plants. Peroxidase (POD) and polyphenol oxidase (PPO) activities showed strong treatment effects ($F = 23.6$, $p < 0.001$), with synergistic induction observed in T_3 plants.

Table 2. Defense-related biochemical parameters at flowering stage.

Treatment	Total Phenolics (mg GAE/g DW)	POD Activity (ΔA470/min/mg protein)	PPO Activity (ΔA420/min/mg protein)
T_1	12.3 ± 0.7^c	3.21 ± 0.18^b	2.05 ± 0.12^b
T_2	14.1 ± 0.8^b	3.85 ± 0.21^a	2.87 ± 0.16^a
T_3	18.7 ± 0.9^a	4.92 ± 0.27^a	3.64 ± 0.19^a
T_4	16.9 ± 0.8^a	4.03 ± 0.22^a	3.12 ± 0.17^a
T_5	10.8 ± 0.6^d	2.14 ± 0.15^c	1.43 ± 0.11^c

Water use efficiency (WUE) measurements revealed that T_3 plants maintained 28% higher photosynthetic rates under pest pressure compared to T_1 ($p = 0.003$). The resistant cultivar (T_4) showed superior compensatory growth after herbivory, with LAI values 22.4% higher than the susceptible variety under equivalent pest densities.

Yield performance and economic parameters

Capsule abortion and seed yield demonstrated treatment-dependent patterns (Table 3). The control plots (T_5) experienced 41.2% capsule loss, primarily due to *H. triannulella* larval feeding. The integrated approach (T_3) produced the highest seed yield (1.82 ± 0.11 ton ha^{-1}), representing a 63.7% increase over untreated plots. Regression analysis indicated a strong negative correlation between aphid days and thousand-seed weight ($r = -0.86$, $p < 0.001$).

Table 3. Yield components and economic parameters.

Treatment	Capsule abortion (%)	1000-seed weight (g)	Seed Yield (ton ha^{-1})	Benefit-cost ratio
T_1	18.7 ± 1.8^b	5.21 ± 0.31^b	1.58 ± 0.09^b	2.8:1
T_2	22.3 ± 2.1^b	5.04 ± 0.29^b	1.49 ± 0.08^b	3.2:1
T_3	9.4 ± 1.1^c	6.37 ± 0.35^a	1.82 ± 0.11^a	4.6:1
T_4	14.2 ± 1.5^c	5.98 ± 0.33^a	1.73 ± 0.10^a	5.1:1
T_5	41.2 ± 3.2^a	4.12 ± 0.26^c	1.11 ± 0.07^c	1.0:1

The resistant cultivar (T_4) demonstrated exceptional yield stability across both years with minimal input requirements, achieving the highest benefit-cost ratio (5.1:1). Significant treatment × year interaction ($F = 6.24$, $p = 0.002$) indicated that T_3 maintained consistent performance despite 34% higher pest pressure in the second year, confirming its climate resilience.

Natural enemy conservation and ecological impact

The implementation of reduced-risk strategies significantly influenced beneficial arthropod communities. Table 4 quantifies the treatment effects on key natural enemies, revealing that the integrated approach (T_3) enhanced biocontrol services by maintaining predator-prey balance. Coccinellid populations in T_3 plots were 3.2-fold higher than in chemical control plots (T_1), demonstrating ecosystem recovery. Notably, T_2 and T_3 preserved 78-84% of parasitoid diversity compared to 42% in T_1.

Table 4. Natural enemy abundance (individuals m^{-2}) under different management regimes.

Treatment	*Coccinella septempunctata*	*Chrysoperla carnea*	*Aphidius colemani*	Shannon Diversity Index (H')
T_1	1.8 ± 0.2^c	0.7 ± 0.1^c	0.9 ± 0.1^c	1.21 ± 0.08^c
T_2	4.3 ± 0.4^b	2.6 ± 0.3^b	3.8 ± 0.4^b	2.17 ± 0.11^b
T_3	5.8 ± 0.5^a	3.9 ± 0.4^a	5.2 ± 0.5^a	2.84 ± 0.14^a
T_4	3.7 ± 0.3^b	1.9 ± 0.2^b	2.4 ± 0.3^b	1.98 ± 0.10^b
T_5	2.1 ± 0.2^c	1.2 ± 0.1^c	1.3 ± 0.2^c	1.45 ± 0.09^c

Parasitism rates of *Helcystogramma* eggs reached 68.3 ± 4.1% in T_3, significantly correlating with larval population suppression (r = -0.92, $p < 0.001$). The predator-prey ratio remained optimal (1:35) only in T_3 throughout the growing season, while T_1 plots showed predator crashes after insecticide applications.

Phenological development and stress recovery

Table 5 demonstrates how pest pressure altered crop developmental physiology. The integrated system (T_3) accelerated recovery from herbivory stress, with flowering initiation occurring 6.2 days earlier than chemical control plots. The resistant cultivar (T_4) maintained stable photosynthetic rates (PN) even under high pest densities, showing 37% less reduction in net assimilation than the susceptible variety.

Table 5. Phenological parameters and stress response indices.

Treatment	Days to flowering	Net photosynthesis (μmol CO_2 m^{-2} s^{-1})	Stomatal Conductance (mol H_2O m^{-2} s^{-1})	Stress recovery index*
T_1	62.3 ± 1.1^b	14.7 ± 0.9^c	0.28 ± 0.02^b	0.72 ± 0.04^b
T_2	59.8 ± 1.0^c	17.2 ± 1.0^b	0.31 ± 0.02^{ab}	0.81 ± 0.05^{ab}
T_3	56.1 ± 0.9^d	21.6 ± 1.2^a	0.35 ± 0.03^a	0.93 ± 0.06^a
T_4	60.5 ± 1.0^{bc}	19.3 ± 1.1^{ab}	0.33 ± 0.02^a	0.89 ± 0.05^a
T_5	67.4 ± 1.3^a	11.2 ± 0.8^d	0.21 ± 0.02^c	0.58 ± 0.04^c

^{*Calculated as [(Post-stress PN / Pre-stress PN) × 100]}.

The silicon-amended T_3 treatment exhibited remarkable resilience, with plants regenerating 89% of damaged leaf area within 14 days post-infestation. Regression analysis confirmed that every 1 mg g^{-1} increase in leaf silicification reduced larval feeding damage by 18.7% ($R^2 = 0.86$).

Soil Health and rhizosphere interactions

Management strategies differentially influenced belowground ecosystem services. Table 6 reveals that T_3 enhanced microbial functional diversity (AWCD) by 63% compared to conventional management. Notably, chitinase activity – a key indicator of pest-suppressive soils – showed 2.8-fold elevation in T_3 plots, correlating with reduced pupal viability of *Aphthona euphorbiae* (r = -0.79). Path analysis demonstrated that soil health parameters collectively explained 74% of variance in plant resistance ($\chi^2 = 12.7$, $p = 0.002$). The integrated system increased arbuscular mycorrhizal colonization by 48%, enhancing phosphorus uptake efficiency (r = 0.68) and systemic resistance induction.

Table 6. Soil biological properties at 0-15 cm depth (flowering stage).

Treatment	Organic matter (%)	Microbial biomass C (μg g^{-1})	FDA Hydrolysis (μg fluorescein g^{-1} h^{-1})	Chitinase Activity (nmol g^{-1} h^{-1})
T_1	3.8 ± 0.2^c	412 ± 24^c	4.7 ± 0.3^c	18.3 ± 1.2^c
T_2	4.1 ± 0.2^b	538 ± 31^b	6.9 ± 0.4^b	34.7 ± 2.1^b
T_3	4.9 ± 0.3^a	723 ± 42^a	9.3 ± 0.5^a	51.6 ± 3.2^a
T_4	4.3 ± 0.2^b	587 ± 34^b	7.1 ± 0.4^b	29.4 ± 1.8^b
T_5	3.6 ± 0.2^c	384 ± 22^c	4.1 ± 0.3^c	15.8 ± 1.1^c

DISCUSSION

The results of this research show the remarkable superiority of the integrated method (T_3) in controlling oilseed pests, which was achieved by a synergism of three elements: targeted chemical control, release of parasitoid wasps, and induction of plant resistance with silicon fertilizer. The 78% reduction in leaf damage inflicted by T_3-related feeding compared to the control (Table 1) was not merely due to direct pest population suppression, but also a significant increase in the level of phenolic compounds (18.7 mg GAE/g DW) and defence enzyme activity (4.92 peroxidase units), pointing towards the induction of inducible resistance mechanisms in the plant (Golubkina *et al.* 2022). This finding is consistent with the research of Cappelli *et al.* (2021) in Canada, where they proved that silicon develops antixenosis resistance by reinforcing the cell wall and inducing phytoalexin production. Population viability of natural enemies in T_3 (5.8 ladybirds m^{-2}) compared to their 68% reduction in T_1 (Table 4) confirms the reduction in the detriments of pesticides to terrestrial food webs. This result supports a study by Ismailov (2020) in Russia, where *Trichogramma* wasps in integrated systems had 3.7 times higher parasitism efficiency. Moreover, the high correlation between healthy soils and pest management (Table 6) shows that the 63% increase in chitinase activity in T_3 most likely inhibited the survival of *Aphthona euphorbiae* nymphs by degrading the cuticle of terrestrial insects (Zheljazkov *et al.* 2020). The benefit of resistant cultivar Lina-3 (T_4) to maintain the yield at a stable level (1.73 tons ha^{-1}) under pest pressure is due to the buildup of some lignans such as secoisolaricirsinol that are feeding deterrents for leaf-eating beetles (Golubkina *et al.* 2022). Though the present study was conducted in the Kazakhstani climate, the significant year × treatment interaction effect on yield ($p = 0.002$) warns that global climate change can limit the efficacy of single methods. The main weakness of the study is the lack of estimation of long-term effects of these methods on the buildup of pesticide residues and development of pest resistance, which should be controlled by 3-5 years.

CONCLUSION

This study validates the effectiveness of an integrated pest management strategy as a model of choice for reduction of damage caused by key phytophages of oilseed flax under the Kazakhstan existing climatic conditions. The precise combination of releasing the parasitoid *Trichogramma evanescens* in a density of 50,000 bees ha^{-1}, limited application of the insecticide deltamethrin only up to the economic threshold (3 cotton bollworm larvae per plant), and plant resistance improvement by foliar spraying with potassium silicate (1.5%) not only decreased the population of key pests by 54-68%, but also increased grain yield by 63.7% over the control treatment by activating the plant's built-in defence mechanisms (72.4% increase in phenolic compounds and enhancing the activity of the peroxidase enzyme) and maintaining the population of natural enemies at a stable level (3.2-fold increase in ladybugs over the control). The resistant variety "Lina-3" is also a cost-effective and eco-friendly alternative, and the benefit-cost ratio of 5.1:1. It renders a suitable choice for poor farmers. One practical recommendation derived from the results is the prevention of repeated cropping of oilseed flax with common host crops of pests (especially rapeseed) to break the life cycle of soil insects. Replacement of regular spraying with weekly monitoring through pheromone traps in pest populations and control at economic thresholds is necessitated initially. Regular substitution of silicon application with biocontrol agents is also recommended to prevent pest acclimatization and promote ecosystem stability. In further research, production of multigenic resistant cultivars with other biochemical foundations and estimation of climate change impact on efficiency of integrated management practices in the long run are proposed. Results of this study can be extrapolated to other Central Asia regions growing oilseed flax with analogous climatic conditions.

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