Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Efficacy of biological products in an integrated pest and disease management system for tomato

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ABSTRACT
Tomato, *Solanum lycopersicum* L. is a vital vegetable crop, but open-field productivity is hampered by various diseases and pests. This study aimed to develop and assess an integrated tomato protection system using protective-stimulating seed treatments in Southeastern Kazakhstan. Laboratory work involved assessing seed health and the impact of formulations on seed quality and pathogen contamination. Field trials investigated the biological and agronomic efficacy of integrated protection schemes against major tomato diseases and pests. Results showed tomato seeds carried significant bacterial infection. Formulation PSF No. 3 completely suppressed this infection and improved seed quality. Integrated protection schemes effectively reduced the development of root rot and early blight (*Alternaria* spp.), with scheme No. 2 resulting in the highest yield. These findings highlight the potential of integrated, biologically-based tomato protection as a sustainable alternative to chemical controls.

Keywords: Tomato, Integrated pest management, Protective-stimulating formulations, Biofungicides, Bioinsecticides, Bacterial diseases, Early blight, Yield.
Article type: Research Article.

INTRODUCTION
Tomato, *Solanum lycopersicum* L. is a globally significant vegetable crop, cultivated for fresh consumption and processing. Its nutritional value and bioactive compounds contribute to food security and a balanced diet (Ali *et al.* 2020). However, biotic factors, including fungal, bacterial, and viral diseases, and insect pests, significantly limit tomato productivity, causing yield losses and reduced quality (Chapei *et al.* 2019; Panno *et al.* 2021). In open-field conditions, Fusarium wilt and early blight are the most damaging fungal diseases, with causal agents persisting in soil and thriving in high temperatures and water deficits (Rodrigues & Furlong 2022; Ma *et al.* 2023). Bacterial spot and speck are challenging to control due to pathogen adaptability and limited bactericide effectiveness (Butsenko *et al.* 2020; Khezri *et al.* 2021). Viral infections, such as Tomato torrado virus recently reported in Iran, further threaten tomato production, emphasizing increasing phytosanitary challenges in the region (Salehzadeh *et al.* 2022). Seed-borne pathogens are a major source of primary inoculum in tomatoes, leading to reduced germination, weakened seedlings, and early disease foci. Seed sanitation and early plant protection are thus critical for sustainable crop protection. Conventional tomato protection relies heavily on chemical pesticides, which can lead to pathogen resistance, harm beneficial insects, and increase environmental risks. Consequently, biological control methods and integrated disease management systems are gaining traction. *Bacillus* spp.-based biological products are particularly promising due to their multiple modes of action. However, comprehensive field evaluations of integrated tomato protection systems, from seed treatment to crop protection, remain limited,

especially in southeastern Kazakhstan. This study aimed to develop and evaluate an integrated tomato protection system using protective-stimulating seed treatments under open-field conditions in southeastern Kazakhstan.

MATERIALS AND METHODS

Study area and experimental conditions

Studies were conducted at the Kazakh Research Institute of Plant Protection and Quarantine named after Zh. Zhiyembaev (KazRIPPQ) laboratories and in open fields at the "Almas" private farm in the Zhambyl District of the Almaty Region, Kazakhstan. Field experiments focused on open-field tomato crops under the agroecological conditions of southeastern Kazakhstan, which are characterized by high temperatures and water scarcity during the growing season.

Climatic conditions of the study area

Research was conducted in the Almaty Region. The 2025 growing season exhibited meteorological variations from long-term averages (Table 1). Air temperatures generally exceeded normal levels, while total precipitation was mostly below average, except in May. Reduced relative air humidity was also observed during the summer. These conditions resulted in a warm and arid environment for tomato cultivation.

Table 1. Meteorological parameters of the 2025 growing season (Almaty Region, Kazakhstan).

Month	Air temperature, °C (actual)	Air temperature, °C (long-term mean)	Deviation from normal (°C)	Precipitation, mm (actual)	Precipitation, mm (long-term mean)	Deviation from normal (mm)	Relative humidity, % (actual)	Relative humidity, % (long-term mean)	Deviation from normal (%)
March	4.7	4.9	-0.2	24.0	27.0	-3.0	81	73	8
April	14.8	12.6	2.2	21.0	31.2	-10.2	68	64	4
May	20.3	18.0	2.3	25.0	23.2	1.8	61	56	5
June	25.2	23.0	2.2	6.5	14.8	-8.3	51	51	0
July	26.8	25.8	1.0	2.0	13.7	-11.7	38	43	-5
August	24.4	23.5	0.9	9.6	16.2	-6.6	42	45	-3
September	19.5	17.5	2.0	5.5	12.4	-6.9	47	48	-1

Plant Material and Experimental Design

This study investigated tomato (Solanum lycopersicum L.) cultivated via seedling transplanting in open fields. The experiment, encompassing laboratory, greenhouse, and field stages, aimed to develop and evaluate an integrated tomato protection system against diseases and insect pests. The experimental design included an untreated control, a chemical standard, and experimental treatments using protective-stimulating formulations (PSFs), biofungicides, and bioinsecticides.

Seed Health Analysis and Protective-Stimulating Formulations

Protective-stimulating formulations (PSFs) for tomato seed sanitation were developed under laboratory conditions using the seed treatment fungicide TMTD, FS (thiram, 400 g L^{-1}), the biofungicides Fitolavin, SL (phytobacteriomycin, BA-120000 IU mL^{-1}, 32 g L^{-1}) and Fitoplazmin, SL (macrolide tylosin complex, 200 g L^{-1}), and the antiviral product Farmayod 10%, SL (iodine, 100 g L^{-1}). Product concentrations were selected to effectively suppress fungal and bacterial infections without compromising seed sowing quality. Seeds were treated by soaking in working solutions according to standard phytopathological methods.

Seed Germination and Microbial Suppression Assessment

Following treatment, seed germination energy and capacity were recorded, along with the degree of fungal and bacterial microflora suppression. Standard phytopathological analyses were used to assess seed phytosanitary status. The most effective protective-stimulating formulations were selected for subsequent field trials based on laboratory results.

Seedling treatments and greenhouse experiments

Preventive treatments against damping-off and root rot were applied during the seedling stage. Seedlings were irrigated twice, at 7 and 14 days after emergence, with biofungicides and a chemical standard according to the experimental design. Integrated tomato protection schemes are presented in Table 2.

Table 2. Experimental schemes of the integrated tomato protection system against diseases and insect pests.

Stage/Treatment	Variant 1 (Control)	Variant 2 (Chemical standard)	Variant 3 (Biological scheme 1)	Variant 4 (Biological scheme 2)
Seed treatment	No treatment	Seeds treated by the manufacturer (fludioxonil)	TMTD, FS (0.5%) + Fitolavin, SL (3%) + Farmayod 10%, SL (0.01%)	–
Seedling irrigation against damping-off and root rot (7 and 14 days after emergence)	No treatment	Previcur Energy, SC (0.3%)	Fitolavin, SL (0.5%) + Farmayod 10%, SL (0.02%); application rate 3 L m^{-2}	–
Seedling irrigation before transplanting against a complex of diseases and soil pests	No treatment	Previcur Energy, SC (0.3%)	Prestige, SC (1%) + Fitolavin, SL (0.5%) + Farmayod 10%, SL (0.02%); application rate 3 L m^{-2}	Prestige, SC (1%) + Fitolavin, SL (0.5%) + Farmayod 10%, SL (0.02%); application rate 3 L m^{-2}
Seedling spraying before field transplanting against sucking pests	No treatment	-	Aktara 250, WG (0.6 kg ha^{-1})	Aktara 250, WG (0.6 kg ha^{-1})
Field spraying against fungal, bacterial, and viral diseases	No treatment	Metaxyl, WP (2.5 kg ha^{-1}, twice); Kocide 2000, WG (2.0 kg ha^{-1}, twice); spray volume 400-600 L ha^{-1}	Fitoplazmin, SL (0.5%) + Farmayod 10%, SL (0.02%) – twice; Fitolavin, SL (0.5%) – once; spray volume 400-600 L ha^{-1}	Fitolavin, SL (0.5%) – twice; Fitoplazmin, SL (0.5%) – once; Farmayod 10%, SL (0.02%) – three times; spray volume 400-600 L ha^{-1}
Spraying against tomato leafminer and cotton bollworm (timing based on pheromone traps)	No treatment	Engio 247, SC (0.2 L ha^{-1}) – twice; Coragen, SC (0.21 L ha^{-1}) – twice	Aktofit 1.8, EC (2.0 L ha^{-1}) – twice; Coragen, SC (0.21 L ha^{-1}) – once; spray volume 200-500 L ha^{-1}	Aktofit 1.8, EC (2.0 l/ha) – twice; Coragen, SC (0.21 L ha^{-1}) – once; spray volume 200-500 L ha^{-1}

Note: The control group consisted of plants grown without chemical or biological protection. The chemical standard involved conventional fungicides and insecticides, while biological treatments used biological products and protective-stimulating formulations. All treatments were applied according to the experimental design in the "Materials and methods" section, at rates per hectare. Spray volume, adjusted to crop growth stage, ranged from 200 to 600 L ha^{-1}. Pheromone traps dictated the timing of treatments against tomato leafminer (*Tuta absoluta*) and cotton bollworm.

Field treatments against diseases and pests

Under field conditions, tomato plants were protected against diseases using fungicides and biofungicides, including Metaxyl, WP (mancozeb 640 g kg^{-1} + metalaxyl 80 g kg^{-1}), Kocide 2000, WG (copper hydroxide 350 g kg^{-1}), Fitolavin, SL, Fitoplazmin, SL, as well as the antiviral product Farmayod 10%, SL.

Insect pests were controlled using insecticides and bioinsecticides, including Aktara 250, WG (thiamethoxam 250 g kg^{-1}), Coragen, SC (chlorantraniliprole 200 g L^{-1}), and Aktofit 1.8, EC (avermectin B_1 and B_2 complex). Treatments were applied upon the appearance of the first symptoms of diseases or pest infestation. The timing of sprays against tomato leafminer and cotton bollworm was refined using pheromone traps.

Disease and pest assessment

Disease incidence, expressed as the percentage of infected plants, was calculated using Equation (1):

$$P = n \times 100 / N, \quad \textbf{(1)}$$

where,

P: disease incidence;

n: number of diseased plants;

N: total number of assessed plants.

Disease severity (R), expressed as a percentage or score, was calculated using Equation (2):

$$R = \sum ab/KN, \quad \textbf{(2)}$$

where,

∑ab – sum of the products of the number of diseased plants and the corresponding disease severity score or percentage;

N: total number of assessed plants;

K: maximum score of the rating scale.

Statistical analysis

Experimental data were subjected to analysis of variance (ANOVA) using standard statistical procedures. Differences between mean values were considered statistically significant at $p \le 0.05$.

RESULTS

Phytosanitary status of tomato seeds

Phytosanitary examination of seeds of the tomato hybrid Lodgein F1 revealed the presence of bacterial infection in all analyzed samples, despite prior seed treatment by the manufacturer. Bacterial microflora was detected both on the seed surface and inside the seeds. No fungal infection was detected in the examined samples. The results of the phytosanitary assessment of tomato seeds are presented in Table 3.

Table 3. Bacterial contamination of tomato seeds (laboratory experiment, 2025).

Cultivar	Number of seeds analyzed (pcs)	Infected seeds (%)	Detection of fungal microflora (%)	Detection of bacterial microflora (%)
Lodgein F1	40	100	0	100

Note: Seed contamination was determined by phytosanitary examination on potato-glucose agar and Czapek media. A value of "0" indicates the absence of detected microflora.

Based on morphological assessment of bacterial colonies and pathogenicity tests, the isolated bacteria induced a hypersensitive reaction on geranium leaves and maceration of potato tubers. The isolated pathogens were preliminarily assigned to the genera *Pseudomonas*, *Xanthomonas*, and *Erwinia*, which are known causal agents of bacterial diseases of tomato.

Efficacy of protective-stimulating formulations for seed sanitation

All tested protective-stimulating formulations had a positive effect on seed sowing quality and seedling growth. However, complete suppression of bacterial infection was observed only in the treatment with protective-stimulating formulation PSF No. 3. This treatment was characterized by high germination energy, 100% laboratory germination, and the absence of detectable bacterial microflora. The effectiveness of tomato seed sanitation using protective-stimulating formulations is presented in Table 4. Based on the laboratory results, protective-stimulating formulation PSF No. 3 was selected for further field experiments, as it demonstrated the highest effectiveness in improving seed sowing quality and suppressing bacterial infection. This treatment was characterized by high laboratory germination, vigorous seedling growth, and the absence of bacterial microflora according to phytosanitary analysis (Fig. 1).

Efficacy of preventive measures during the tomato seedling stage

Under seedling production conditions, the control treatment showed the development of root rot with a disease incidence of 32% and a disease severity of 12%. In the chemical standard treatment, biological efficacy reached 87.5%. In the experimental treatment involving seed treatment with PSF No. 3 followed by double irrigation with a biofungicide, no root rot symptoms were observed, and biological efficacy reached 100%. The effectiveness of preventive measures against root rot in tomato seedlings is presented in Table 6.

Table 4. Effectiveness of tomato seed sanitation using protective-stimulating formulations (laboratory experiment, 2025).

Treatment	Germination energy (%)	Laboratory germination, (%)	Seedling growth intensity	Seed contamination with fungal microflora (%)	Seed contamination with bacterial microflora (%)	Intensity of bacterial growth
Control	98.6	98.6	++	100	0	+++
Commercial standard (fludioxonil)	98.6	98.6	++	100	0	+++
PSF No. 1: TMTD (0.5%) + Fitolavin (3%)	96.0	98.0	+++	1.7	0	+
PSF No. 2: TMTD (0.5%) + Fitoplazmin (3%)	98	100	+++	100	0	++
PSF No. 3: TMTD (0.5%) + Fitolavin (3%) + Farmayod 10% (0.01%)	93	100	+++	0	0	0
PSF No. 4: TMTD (0.5%) + Fitoplazmin (3%) + Farmayod 10% (0.01%)	93	100	+++	100	0	++

Note: seedling growth intensity was assessed visually: (+) weak; (++) moderate; (+++) high. A value of "0" indicates the absence of detectable microflora.

(a)
Commercial standard (seeds treated by the manufacturer with fludioxonil);

(b)
Experimental treatment (seeds treated with PSF: TMTD, FS + Fitolavin, SL + Farmayod 10%, SL).

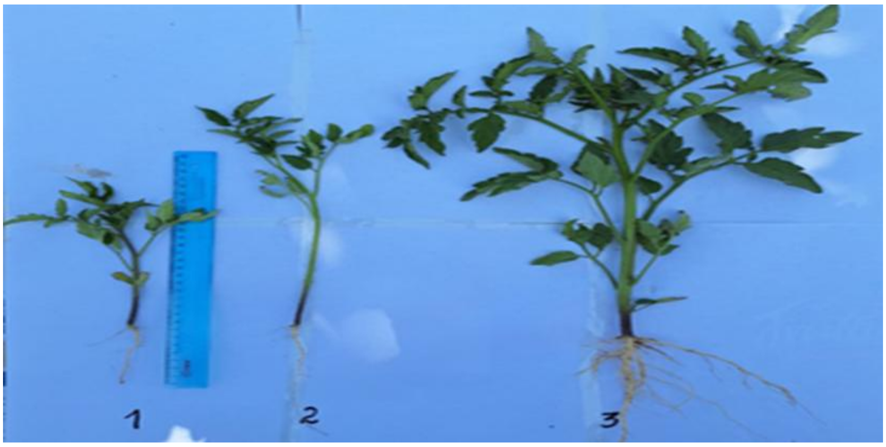
Fig. 1. Effects of tomato seed soaking with a protective-stimulating formulation on seed microflora and sowing quality (nutrient medium, 2025).

Table 6. Effectiveness of preventive measures against root rot in tomato seedlings (field experiment, "Almas" farm, 2025).

Treatment	Disease incidence (%)	Disease severity (%)	Biological efficacy (%)
Control (no treatment)	32.0	12.0	–
Chemical standard [seeds treated by the manufacturer with fludioxonil + double irrigation with Previcur Energy, SC (0.3%)]	12.0	1.5	87.5
Experimental treatment [seed treatment with PSF No. 3 + double irrigation with Fitolavin, SL (0.5%)]	0	0	100

Note: biological efficacy was calculated based on the reduction in disease incidence and severity compared with the control.

In the experimental treatment, uniform emergence and a higher growth intensity of tomato seedlings were observed compared with the control and chemical standard treatments (Figs. 2 and 3). Visual assessment of the morphophysiological status of plants indicated improved root system development and greater aboveground biomass in the treatment involving PSF No. 3 and the biofungicide.



control standard experimental

Fig. 2. Growth intensity of tomato seedlings in the control, chemical standard, and experimental treatments (field experiment, 2025).

Control Standard Experimental

Fig. 3. Visual appearance of tomato seedlings under different treatments: control; chemical standard; experimental (biological) treatment (field experiment, 2025).

Efficacy of integrated protection schemes under field conditions

Under open-field conditions, no root rot or *Fusarium* wilt symptoms were observed in the experimental treatments, whereas in the control treatment root rot incidence reached 15.8%. In the chemical standard treatment, disease incidence and severity were substantially lower but did not reach zero values. The effectiveness of preventive measures against root rot after transplanting tomato seedlings into open-field conditions is presented in Table 7.

Efficacy of integrated protection against a complex of insect pests

In all experimental treatments, a unified protection strategy against the pest complex consisting of cotton bollworm and South American tomato leafminer was applied. This strategy included two applications of the bioinsecticide Aktofit 1.8, EC (2.0 L ha^{-1}) and a single application of the insecticide Coragen, SC (0.21 L ha^{-1}). The application of integrated protection schemes resulted in a substantial reduction in pest infestation levels and plant damage compared to the untreated control. Biological efficacy in the experimental treatments ranged from 99.2 to 99.3%, which significantly exceeded the efficacy of the chemical standard (92.1-92.3%). The biological efficacy of different integrated tomato protection schemes against the pest complex is presented in Table 9.

Table 7. Effectiveness of preventive measures against root rot after transplanting tomato seedlings into open field conditions (field experiment, “Almas” farm, Almaty Region, 2025)

Treatment	**Disease incidence (%)**	**Disease severity (%)**	**Biological efficacy (%)**
Control (no treatment)	15.8	4.8	–
Chemical standard [seeds treated by the manufacturer with fludioxonil + triple irrigation with Previcur Energy, SC (0.3%)]	0.8	0.21	95.6
Experimental 1 [seed treatment with PSF No. 3 + single irrigation with Prestige, SC (1%) + triple irrigation with Fitolavin, SL (0.5%) + single irrigation with Farmayod 10%, SL (0.02%)]	0	0	100
Experimental 2 (seed treatment with PSF No. 3 + single irrigation with Prestige, SC (1%) + double irrigation with Fitolavin, SL [0.5%) + single irrigation with Fitoplazmin, SL (0.5%) + single irrigation with Farmayod 10%, SL (0.02%)]	0	0	100

Note*:* Biological efficacy was calculated based on the reduction in disease incidence and severity relative to the untreated control.

The application of integrated protection schemes resulted in a substantial reduction in tomato infection with early blight. The effectiveness of different integrated tomato protection schemes against early blight is presented in Table 8.

Table 8. Effectiveness of different integrated tomato protection schemes against early blight (field experiment, “Almas” farm, Almaty Region, 2025).

Treatment	**Disease incidence (%)**	**Disease severity (%)**	**Biological efficacy (%)**
Control (no treatment)	61.3	26.9	–
Chemical standard	3.8	0.8	96.9
Scheme No. 1	2.5	0.4	98.4
Scheme No. 2	1.3	0.2	99.2

Note*:* biological efficacy was calculated based on the reduction in disease incidence and severity relative to the control; differences among treatments were statistically significant ($p < 0.05$).

Biological efficacy in the experimental treatments ranged from 98.4 to 99.2%, whereas the chemical standard achieved 96.9% (Table 8). scheme No. 2 was the most effective, with disease severity reduced to only 0.2%.

Table 9. Biological efficacy of different integrated protection schemes against a complex of insect pests in tomato (field experiment, "Almas" farm, Almaty Region, 2025)

Pest/Treatment	Infestation (%)	Damage severity (%)	Biological efficacy (%)	*p*-value
Cotton bollworm – control (no treatment)	37.5	40.5	–	< 0.05
Cotton bollworm – chemical standard	1.9	3.1	92.3	< 0.05
Cotton bollworm – Scheme No. 1	0.6	0.3	99.2	< 0.05
South American tomato leafminer – control (no treatment)	35.5	40.8	–	< 0.05
South American tomato leafminer – chemical standard	1.0	3.2	92.1	< 0.05
South American tomato leafminer – Scheme No. 1	0.5	0.3	99.3	< 0.05

Note: biological efficacy was calculated based on the reduction in infestation level and damage severity relative to the untreated control; differences among treatments were considered statistically significant at $p < 0.05$.

Effect of integrated protection schemes on tomato yield

Integrated tomato protection schemes based on the combination of preventive measures, biofungicides, and bioinsecticides had a pronounced positive effect on crop yield compared with both the untreated control and the chemical standard. The lowest yield was recorded in the control treatment (21.3 tons ha^{-1}), indicating the substantial negative impact of the disease and pest complex on tomato productivity. The agronomic efficiency of different integrated tomato protection schemes is presented in Table 10.

Table 10. Economic effectiveness of combining preventive measures with biofungicides and bioinsecticides on tomato (Almas farm, Almaty Region, 2025).

Experimental treatment	Yield (ton ha^{-1})	Increase over control (ton ha^{-1})	Increase over control (%)	Increase over standard (ton ha^{-1})	Increase over standard (%)
Control (no treatment)	21.3	–	–	–	–
Chemical standard	27.6	6.3	29.5	–	–
Scheme No. 1	31.3	10.0	46.9	3.7	13.4
Scheme No. 2	34.5	13.2	61.9	6.9	25.0

Note: the least significant difference ($LSD_{0.05}$) for yield was 0.3 ton ha^{-1}. Differences between treatments were considered statistically significant at $p < 0.05$.

The application of the chemical protection scheme increased yield to 27.6 tons ha^{-1}, representing a 29.5% increase relative to the control. The use of integrated schemes No. 1 and No. 2 resulted in even higher yields. Under scheme No. 1, yield reached 31.3 tons ha^{-1}, exceeding the control by 46.9% and the chemical standard by 13.4%. The highest economic effectiveness was observed with scheme No. 2, where yield increased to 34.5 tons ha^{-1}, corresponding to a 61.9% increase over the control and a 25.0% increase over the chemical standard.

4. DISCUSSION

This study demonstrates the effectiveness of an integrated tomato protection system against major diseases and pests. Consistent with prior research (Walters et al. 2013; Kumar et al. 2018; Khezri *et al.* 2021), 100% seed contamination confirms seed material as a key source of primary inoculum. The complete suppression of bacterial infection with PSF No. 3 suggests the potential of combining chemical seed treatments with biological and antiviral agents, mirroring synergistic effects reported in other integrated protection systems (Walters *et al.* 2013; Poveda *et al.* 2020; He *et al.* 2021; Helmy & Parang 2023). The high effectiveness against root rots at the seedling stage emphasizes the importance of early preventive measures, supported by previous findings on the ability of *Bacillus* spp. and other antagonists to suppress soil-borne pathogens and promote root development (Fira *et al.* 2018; Mousa *et al.* 2021; Devi *et al.* 2022; Dong *et al.* 2023). Under field conditions, integrated protection significantly reduced the incidence and severity of early blight more effectively than the chemical standard, aligning with studies on integrated management using biological products and reduced chemical inputs (Pretty *et al.* 2018; Chapei *et al.* 2019; Negesa & Ayana 2023; Ramakrishna *et al.* 2024). This reinforces the potential of biologically based integrated systems for open-field tomato production. Effective pest suppression, including control of cotton bollworm and tomato leafminer, led to yield increases. This aligns with existing research indicating that bioinsecticides can reduce pesticide use without compromising control or harming beneficial insects (Gnanamanickam 2002; Desneux *et al.* 2007). The significant yield increase from integrated schemes, particularly scheme No. 2, confirms their economic and environmental benefits, a finding supported by other studies showing that biological plant protection products improve disease control and plant resilience (He *et al.* 2021; Ma *et al.* 2023). These results suggest that an integrated tomato protection system using seed sanitation, biofungicides, and bioinsecticides offers a sustainable and effective alternative to conventional chemical approaches, suitable for arid regions.

CONCLUSION

The results of this study confirm the high effectiveness of the developed integrated tomato protection system, which combines seed sanitation using protective-stimulating compositions with the application of biofungicides and bioinsecticides during the growing season. Tomato seeds were found to be a significant source of bacterial infection, emphasizing the need for preventive measures at the early stages of crop development. The application of the protective-stimulating composition PSF No. 3 completely suppressed bacterial seed infection, improved seed germination rates, and enhanced seedling viability. During the seedling stage, the use of biological approaches effectively prevented the development of root rots. Under field conditions, the integrated protection schemes significantly reduced the incidence and severity of major tomato diseases, such as early blight, and effectively controlled populations of key pests. The highest biological and economic effectiveness was achieved with integrated scheme No. 2, which resulted in the maximum yield increase compared to both the untreated control and the chemical standard. The data obtained demonstrate the feasibility of implementing this developed system as an environmentally safe and economically efficient alternative to traditional chemical tomato protection methods, particularly in arid conditions.

ACKNOWLEDGEMENTS

The research was conducted within the framework of budget program No. 267 “Increasing the accessibility of knowledge, scientific research, and activities” and the scientific and technical program BR22885887 “Improvement and implementation of a pest management system” for 2024-2026.

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