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DETERMINATION OF THE EFFECTIVENESS OF FUNGICIDE PROTECTION SYSTEMS AS A RESERVE FOR SUSTAINABLE SUNFLOWER PRODUCTION IN SOUTH OF UKRAINE

Sunflower is a strategic crop in the agricultural sector of Ukraine, but its yield and seed quality are significantly reduced due to damage from phytopathogens. One of the main methods for their control is the use of fungicides. A study conducted in the southern regions of Ukraine established the impact of fungicide application schemes based on active substances from the classes of benzimidazoles, strobilurins, and triazoles on the spread and severity of dominant diseases and sunflower yield. The main diseases of the crop included white mold, downy mildew, black stem, and stem canker. In the absence of fungicidal protection, disease development at BBCH growth stage 91 was significant, reaching 17.5 % (white mold), 28.9 % (downy mildew), 15.3 %, and 14.5 % for black stem and stem canker, respectively. The best biological efficacy for controlling Sclerotinia sclerotiorum and Phoma macdonaldii at BBCH growth stage 16 was shown by Amistar Gold, 250 SC (1.0 l/ha) – 78.0 % and 84.3 %, respectively. Against Diaporthe helianthi and Plasmopara halstedii, the highest efficacy at the same growth stage was demonstrated by Thanos, 50 WG – 86.6 % and 92.7 %, respectively. The use of Amistar Gold, 250 SC and Acanto Plus SC at BBCH growth stage 51 showed high biological efficacy against black stem and stem canker, ranging from 88.8 % to 90.3 %. Against downy mildew, the efficacy of Acanto Plus SC was higher by 4.5 % compared to Amistar Gold, 250 SC, reaching 88.9 %. For white mold, the efficacy of these products ranged from 80.0 % to 85.7 %, with Acanto Plus SC being more effective. Alpha-standard SC did not affect the development of downy mildew and showed low efficacy against white mold – 17.1 %. For black stem and stem canker, it had average efficacy rates of 74.5 % and 77.2 %, respectively. The use of fungicide application schemes: Amistar Gold, 250 SC (BBCH 16; 51) and Thanos, 50 WG (BBCH 16) along with Acanto Plus SC (BBCH 51) provided maximum yields of 3.24 and 3.31 t/ha, exceeding the control by 1.63 and 1.99 t/ha, respectively. The recommended protection schemes using Amistar Gold, 250 SC (1.0 l/ha), Thanos, 50 WG (0.6 kg/ha), and Acanto Plus SC (1.0 l/ha) can be implemented in farms in southern Ukraine and adapted to other sunflower growing zones.

Keywords: *white mold, black stem, stem canker, downy mildew, disease development, fungicidal protection, sunflower, productivity.*

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1. Introduction

Sunflower is an important agricultural plant with an extremely wide range of applications for its main products (seeds and processed products), and can also be used as a fodder, honey-producing, and decorative crop. The significance of sunflower in today's agricultural production is underscored by the fact that even in the conditions of military actions in Ukraine, its cultivation remains marginal compared to other oil crops such as winter rape and soybean. The volume of its production largely determines the efficiency of the entire crop industry, which is facilitated by high purchase prices for both seeds and products of its downstream processing [1, 2]. This has a large economic impact and renders sunflower crop production a strategically important area of development of the Ukrainian agricultural sector [3]. At the same time, this economic attractiveness, resulting in a significant amount of cultivated areas (over 6 million hectares), has negative consequences. Excessive saturation of crop rotations with this crop creates conditions for the emergence of epidemics of the most dangerous diseases, including powdery mildew, white rot, black stem and stem canker.

Undoubtedly, the greatest global economic impact on the efficiency of sunflower cultivation among all diseases of the crop is downy mildew [4, 5]. Since the identification of the pathogen in crop varieties of sunflower in the United States in the 1920s [6], the disease has spread rapidly to all continents and can lead to the destruction of up to 95 % of the harvest [5]. It is practically impossible to get rid of this pathogen once it appears in agrobiocenosis, and although there are resistant sunflower hybrids to the downy mildew pathogen, new virulent pathotypes constantly arise in agrobiocenosis that can infect previously resistant hybrids [7].

Another disease of sunflower that claims to be the most damaging on a global scale is white rot (*Sclerotinia sclerotiorum* (Lib.) de Bary) [8–11]. The wide range of plants affected by this pathogen, various forms of disease manifestation, the ability to colonize plants almost throughout the entire vegetation period, and high aggressiveness (just 1 sclerotium per 800 cm^3 of soil is enough to infect 40 % of plants in the field [12]) make controlling the pathogen extremely challenging.

Phoma black stem of sunflower (*Phoma macdonaldii* Boerema) is a destructive disease that is found in many countries cultivating sunflowers and can lead to serious crop losses [13]. The pathogen was first described as *Phoma oleracea* var. *helianthi tuberosi* in Canada in 1964 [14]. According to various researchers, crop losses can range from 10 to 30 %, and field identification is complicated because the symptoms can be mistaken for natural physiological aging of plants, as typical signs of infection usually appear in the reproductive phase of ontogenesis [13].

Another one of the most dangerous diseases of sunflower worldwide is Phomopsis stem canker, caused by the fungus *Diaporthe helianthi Munt.-Cvet.* et al. [15]. In Europe, this pathogen was first registered in former Yugoslavia and later spread to practically all sunflower-producing countries, including Hungary, Bulgaria, the USA, France, Ukraine, Moldova, and others [16]. The high harmfulness of stem canker is evidenced by its ability to cause epidemics that destroy a significant amount of the crop [17].

An important aspect of the successful cultivation of sunflower is the protection against diseases to assure high and sustainable yields [18, 19]. Deterioration of the phytosanitary situation on sunflower crops in recent years in Ukraine is associated with many factors, which mainly include the non-compliance with the principles of crop rotation (i. e., sunflower cultivation in monoculture), the accumulation of plant residues on the fields, an increase in the number of weeds, that act as reservoir hosts for pathogens [20].

To ensure a reliable protection of sunflower crops against diseases, all technological methods must be of high quality and implemented in a timely manner, while considering the biological features of the grown variety or hybrid, and the features of pathogens and their interactions with other microorganisms [21]. The phytopathogenic complex of sunflower crops in Ukraine encompasses more than 70 pathogenic microorganisms. Diseases such as powdery mildew, white and grey mold, Phomopsis and Alternaria leaf blight can be observed as early as the seedling stage. Spots of various etiologies, including Septoria leaf spot, Alternaria leaf blight, black stem, and rust, appear on the aerial parts of plants, and especially on the leaves, mostly in June, and tend to develop significantly during the subsequent stages of organogenesis. The harmfulness of these diseases is manifested by the premature death of leaves, lower yields, and deterioration of the seed quality. For instance, there is a decrease in the fat content of seeds, changes in the fatty acid composition of the oil, an increase in the number of acids, and decrease of seed thickness. Significant spread of white mold and Verticillium wilt of sunflower is associated insufficient rotations by using crops that have shared pathogens capable of persisting in the soil [22, 23].

In regions with sufficient moisture or under the arid conditions of the south of Ukraine, the risk of damage to sunflower crops by pathogens increases with irrigation. Phytopathogenic microorganisms find optimal conditions and multiply and survive well in soils, which cause damage to sunflower crops and lead to the development of pathogens.

Therefore, protection of sunflower crops against diseases is an important task in the technology of growing this crop. Reasonable use of plant protection products will be reducing the risk of damage to crops caused by diseases and will ensure the formation of high and stable sunflower yields with high-quality seed indicators. Research conducted by us is dedicated to accomplishing this task.

The aim of research was to determine the main diseases, the extent of their spread and development during sunflower cultivation in short-term crop rotations in the south of Ukraine, and the effectiveness of fungicides for curbing the development of phytopathogenic microflora.

2. Materials a nd Methods

2.1. Materials

Research to determine the effects of fungicides on the spread and harmfulness of dominant diseases, and on the yield of sunflower was conducted in 2023 at the State Enterprise "Experimental farms "Reconstruction" of The Plant Breeding and Genetics Institute – National Center of Seed and Cultivar Investigation. The enterprise is located in the Bashtanka district of the Mykolaiv region.

The objective of the research was to determine the main diseases, the extent of their spread and development during sunflower cultivation in short-term crop rotations in the south of Ukraine, and the effectiveness of fungicides for curbing the development of phytopathogenic microflora.

The soil of the experimental plots was dark-chestnut, heavy loam with a humus content of 3.2 % in the arable layer. The early-ripening cultivar Yason was provided by the Plant production institute named after Yuriev V. Ya. The crop preceding the sunflower in the experiment was winter wheat. Sowing was carried out at a row width of 70 cm; the density of plants was 50 thousand/ha. The total area of the experimental plot was 100 m^2, the investigated area was 50 m^2.

Fungicidal treatment of sunflower crops was performed twice: A – micro-stage BBCH 16 (6 leaves); B – micro-stage BBCH 51 (beginning of budding – star stage). In the experiment, 5 conditions were studied:

1. Control (water treatment) – A+B.
2. Alpha-standard SC (carbendazim 500, 0.5 l/ha) – A+B.
3. Cymoxyl WP (symoxanil 300+flutriafol 210, 0.5 l/ha) – A+B.
4. Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) – A+B.
5. Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha) – A; Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha) – B.

Generally, recognized methods were used to determine the development of sunflower diseases and the effectiveness of fungicides [24, 25]. The dynamics of the development of sunflower diseases was determined by carrying out systematic records of plants, according to the phases of the ontogenesis of the culture.

Sunflower seeds were harvested using direct combining (Sampo-500) with subsequent adjustments for 100 % purity and 8 % moisture. The computer program "Agrostat" was used for statistical analyses of yield data [26].

2.2. Methods

Field research, route-selective surveys of sunflower crops to detect plant infections by the causal agents of powdery mildew (*Plasmopara halstedii* Berl. & de Toni), white mold (*Sclerotinia sclerotiorum* (Lib.) de Bary), phomopsis stem canker (*Diaporthe helianthi* M. Munt. et al.), and black stem (*Phoma macdonaldii* Boerema.), sampling of plant material for isolation of pathogens' isolates were conducted in a short crop rotation at the State Enterprise "Experimental farms "Reconstruction" of The Plant Breeding and Genetics Institute – National Center of Seed and Cultivar Investigation.

Diagnostic signs of powdery mildew, white mold, phomopsis stem canker, and black stem were studied on plant samples that were infected and collected under field research conditions. Laboratory diagnostics were carried out in The Problem Scientific-Research Laboratory of "Mycology and Phytopathology" of the Department of Phytopathology named after Academician V. F. Peresypkin of the National University of Life and Environmental Sciences of Ukraine using macroscopic, microscopic, and biological methods [27]. Morphological analysis of pathogens was conducted by preparing microscopic slides, which were analyzed using light microscopy (stereomicroscopes "SZM-45B" and "Olympus CX41"). In case of atypical diagnostic signs on affected plant organs, their fragments were placed in desiccators at 100 % air humidity and incubated in a thermostat at a temperature of 22–25 °C. Further analysis included examining the morphological features of mycelium and propagules formed by pathogens. The technical efficiency of fungicides was calculated according to Abbott's formula [28].

To determine yield losses from disease infections during harvesting, 20 model plants were selected in four replications [29] and subjected to biometric analysis using a measurement-weight method – to determine plant height, yield structure, and productivity. To assess the reliability of the obtained research results, a mathematical-statistical method (Agrostat) was used.

3. Results and Discussion

According to research results, without the use of fungicides, the incidence rate of white mold (*Sclerotinia sclerotiorum* (Lib.) de Bary) on sunflower crops at the micro-stage BBCH 17 was 6.5 % (Table 1). Later, the infection progressed and reached a level of 9.1 % at the micro-stage BBCH 50. Tested fungicides had different effects on the extent of plant infection with this disease. Alpha-standard SC (carbendazim 500, 0.5 l/ha) had the weakest fungicidal activity in the first round of use – the disease incidence rate ranged from 4.4 % to 8.0 % depending on the record date. The best inhibition of white mold (*S. sclerotiorum* (Lib.) de Bary) development was achieved with Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha). When used, the plant infection rate at the micro-stage BBCH 50 was 2.0 %.

Table 1

The extent of development of sunflower white mold depending on the fungicides used during the first round of application (A, BBCH 16), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Thanos, 50 WG
BBCH 17	6.5	4.4	1.5	1.0	1.1
BBCH 30	7.4	5.9	1.8	1.2	1.3
BBCH 40	8.5	6.2	2.0	1.5	1.5
BBCH 50	9.1	8.0	2.4	2.0	2.1

During the first round of fungicide application, the incidence rate of *Phoma macdonaldii* Boerema on the control plot (BBCH 17) was 1.0 %, which was the minimum value throughout the observation period. By the micro-stage BBCH 50, this figure increased to 3.2 % (Table 2). Fungicide protection of sunflower crops significantly inhibited the development of black stem (*Ph. macdonaldii* Boerema) throughout the vegetation period, with the lowest incidence rate at the micro-stage BBCH 50 observed when using Amistar Gold, 250 SC – 0.5 % (azoxystrobin 125+difenoconazole 125, 1.0 l/ha).

Table 2

The extent of development of sunflower black stem depending on the fungicidal treatment during the first round of application (A, BBCH 16), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Thanos, 50 WG
BBCH 17	1.0	0.5	0.4	0.3	0.3
BBCH 30	1.3	0.6	0.5	0.3	0.4
BBCH 40	2.7	0.8	0.7	0.4	0.5
BBCH 50	3.2	1.2	0.8	0.5	0.6

Development of sunflower stem canker (*Diaporthe helianthi Munt.-Cvet.* et al.) was observed starting from the micro-stage BBCH 30 (beginning of stem elongation). On the control plot, the incidence rate of stem canker doubled from BBCH 30 to BBCH 50, increasing from 1.5 % to 3.0 % (Table 3). The highest incidence rate among the fungicide treatment groups was observed when Alpha-standard SC (carbendazim 500, 0.5 l/ha) was applied – 0.5–1.5 % depending on the record date. The lowest level of disease development, 0.3–0.4 %, was observed when sunflower crops were treated with Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha).

Table 3

The extent of development of sunflower stem canker depending on the fungicidal treatment during the first round of application (A, BBCH 16), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Thanos, 50 WG
BBCH 17	0.0	0.0	0.0	0.0	0.0
BBCH 30	1.5	0.5	0.3	0.3	0.3
BBCH 40	2.8	1.1	0.5	0.4	0.4
BBCH 50	3.0	1.5	0.6	0.5	0.4

The dominant pathogen during the record period of the study was *Plasmopara halstedii* Berl. & de Toni. From the micro-stage BBCH 17 to BBCH 50, the incidence rate of downy mildew on the control plot increased from 4.5 % to 8.3 % (Table 4). The least effective fungicide for controlling downy mildew was Alpha-standard SC (carbendazim 500, 0.5 l/ha), with disease incidence rate ranging from 4.1–8.2 % depending on the record date. The development of the disease under this condition was practically identical to the control. Other tested fungicides significantly inhibited the development of downy mildew. The lowest incidence rates, 0.1–0.6 %, were observed when using Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha).

Table 4

The extent of development of sunflower downy mildew depending on the fungicidal treatment during the first round of application (A, BBCH 16), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Thanos, 50 WG
BBCH 17	4.5	4.1	0.5	0.8	0.1
BBCH 30	5.6	5.3	0.8	1.0	0.3
BBCH 40	7.3	7.6	1.1	1.2	0.5
BBCH 50	8.3	8.2	1.2	1.4	0.6

The incidence rate of sunflower plants infected with *Sclerotinia sclerotiorum* (Lib.) de Bary increased throughout the vegetation period on the control plot, reaching 17.5 % at the micro-stage BBCH 91. The minimum values were observed when fungicide Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha) was used, with disease development ranging from 2.1 % to 2.5 % depending on the record date. The highest incidence rate of white mold (*S. sclerotiorum* (Lib.) de Bary) among the fungicide treatment groups, 8.0–14.5 %, was observed when Alpha–standard SC (carbendazim 500, 0.5 l/ha) was used. Cymoxyl WP (cyamoxanil 300+flutriafol 210, 0.5 kg/ha) and Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) were also capable of inhibiting the development of *S. sclerotiorum*, with observed disease incidence rate at the micro-stage BBCH 91 being 4.2 % and 3.5 %, respectively (Table 5).

In the second half of sunflower vegetation period (BBCH 51 – BBCH 91), there were a significant positive dynamic in the development of black stem (*Ph. macdonaldii* Boerema). On the control plot, the incidence rates were 3.2 % and 15.3 % for the aforementioned micro-stages of development (Table 6). All tested fungicides proved to be effective at inhibiting the development of this disease, with the best results obtained when using Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha), with the incidence rate ranging from 0.5 % to 1.6 % depending on the record date.

Table 5

The extent of development of sunflower white mold depending on the fungicidal treatment during the second round of application (B, BBCH 51), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Acanto Plus SC
BBCH 51	9.1	8.0	2.4	2.0	2.1
BBCH 61	14.4	8.5	3.5	2.3	2.3
BBCH 71	15.5	10.3	3.9	2.8	2.4
BBCH 81	16.4	11.2	4.1	3.1	2.4
BBCH 91	17.5	14.5	4.2	3.5	2.5

Table 6

The extent of development of sunflower black stem depending on the fungicidal treatment during the second round of application (B, BBCH 51), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Acanto Plus SC
BBCH 51	3.2	1.2	0.8	0.5	0.6
BBCH 61	7.4	1.5	1.1	0.8	1.0
BBCH 71	8.5	2.2	1.4	1.1	1.2
BBCH 81	13.1	3.4	1.9	1.3	1.5
BBCH 91	15.3	3.9	2.3	1.6	1.7

The incidence rate of *Diaporthe helianthi Munt.-Cvet.* et al. on the control plot at the micro-stage, BBCH 51 was 3.0 %. Increasing throughout the sunflower vegetation period, this figure reached its maximum, 14.5 %, at the micro-stage BBCH 91 (Table 7). All tested fungicides exhibited relatively high activity against the stem canker. The lowest disease incidence rate at the micro-stage BBCH 91, 1.4 %, was observed when using Amistar Gold 250 SC (azoxystrobin 125 + difenoconazole 125, 1.0 l/ha).

Table 7

The extent of development of sunflower stem canker depending on the fungicidal treatment during the second term of application (B, BBCH 51), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Acanto Plus SC
BBCH 51	3.0	1.5	0.6	0.5	0.4
BBCH 61	9.3	1.8	0.7	0.5	0.6
BBCH 71	11.2	2.4	0.9	0.8	1.0
BBCH 81	12.8	2.9	1.5	1.1	1.3
BBCH 91	14.5	3.3	2.1	1.4	1.5

During the second half of the vegetation period, sunflower crops were most severely affected by the pathogen causing powdery mildew. On the control plot, during the seed ripening stage (BBCH 91), disease incidence rate was 28.9 % (Table 8). Alpha-standard SC (carbendazim 500, 0.5 l/ha) was found to be ineffective against downy mildew, with disease incidence rate on all record dates being practically at the same level as that of the control. Other tested fungicides exhibited higher activity levels against the disease, with the lowest incidence rate at the micro-stage BBCH 91, 3.2 %, observed when using Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha).

Table 8

The extent of development of sunflower downy mildew depending on the fungicidal treatment during the second round of application (B, BBCH 51), 2023, %

Micro-stages of plant development	Conditions				
	Control (water treatment)	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Acanto Plus SC
BBCH 51	8.3	8.2	1.2	1.4	0.6
BBCH 61	25.1	12.8	2.0	1.9	1.1
BBCH 71	26.5	24.3	3.5	2.8	2.7
BBCH 81	28.4	26.1	4.4	3.4	2.9
BBCH 91	28.9	29.2	5.1	4.5	3.2

During the first round of application, the biological efficacy of the tested fungicides against white rot varied from 12.0 % to 78.0 %, and against downy mildew – from 1.2 % to 92.7 % (Table 9). The minimum efficacy at controlling these sunflower diseases was observed when Alpha-standard SC (carbendazim 500, 0.5 l/ha) was used. All other fungicides had high biological efficacy. In this study, Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) was the most effective against white rot, while Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha) – against downy mildew.

According to the results of field tests of fungicides, their biological effectiveness against pathogens that were detected in the sunflower agrocenosis during two rounds of application was determined. During the first round of application, the biological efficacy of the tested fungicides against white mold (*S. sclerotiorum* (Lib.) de Bary) varied from 12.0 % to 78.0 %, and against downy mildew – from 1.2 % to 92.7 %. The minimum efficacy at controlling these sunflower diseases was observed when Alpha-standard SC (carbendazim 500, 0.5 l/ha) was used. All other fungicides had high biological efficacy. In this study, Amistar Gold 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) was the most effective against white rot, while Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha) – against downy mildew.

Table 9

Biological efficacy of fungicides at the micro-stage BBCH 50 after the first round of application (A, BBCH 16), 2023, %

Diseases	Conditions			
	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Thanos 50 WG
White mold	12.0	73.6	78.0	76.9
Black stem	62.5	75.0	84.3	81.2
Stem canker	50.0	80.0	83.3	86.6
Downy mildew	1.2	85.5	83.1	92.7

In terms of activity against black stem and stem canker, Alpha-standard SC (carbendazim 500, 0.5 l/ha) demonstrated some efficacy – 62.5 % and 50.0 % respectively, but it was significantly weaker compared to other tested fungicides. The best control of black stem in studied conditions was achieved with Amistar Gold 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) which had a biological efficacy of 84.3 %. The development *of Diaporthe helianthi* was best inhibited by the

Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha), which had a biological efficacy 92.7 %.

Alpha-standard SC (carbendazim 500, 0.5 l/ha) did not show activity against downy mildew during the second round of application (BBCH 51). Its biological efficacy against white rot was also relatively low, 17.1 %. However, this fungicide demonstrated significantly higher efficacy at controlling black stem and stem canker – 74.5 % and 77.2 %, respectively. Nonetheless, Alpha-standard SC (carbendazim 500, 0.5 l/ha) still lagged behind other fungicides. In this study, the highest efficacy against white rot and downy mildew was achieved with the Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha) – 85.7 % and 88.9 %, respectively (Table 10). The highest efficacy against black stem and stem canker was achieved with Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) – 89.5 % and 90.3 %, respectively. Against all sunflower diseases, Cymoxyl WP (cymoxanil 300+flutriafol 210, 0.5 l/ha) had slightly lower biological efficacy than Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha) and Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha).

Table 10

Biological efficiency of fungicides after the second round of application (B, BBCH 51), 2023, %

Diseases	Conditions			
	Alpha-standard SC	Cymoxyl WP	Amistar Gold, 250 SC	Acanto Plus SC
White mold	17.1	76.0	80.0	85.7
Black stem	74.5	84.9	89.5	88.8
Stem canker	77.2	85.5	90.3	89.6
Downy mildew	0.0	82.3	84.4	88.9

Fungicide protection of sunflower crops positively influenced plant growth processes. The height of the plants from fungicide treatment plots ranged from 160.4 cm to 171.4 cm, while it was 134.5 cm for plants from the control plot (Table 11). In other words, the height difference in plants between treatment and control plots ranged from 25.9 cm to 36.9 cm. The tallest plants were observed when Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) and Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha)/Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha) were used.

The smallest basket diameter, 17.2 cm, was observed in plants from the control plot. Fungicide protection of the crops was associated with basket diameters that were 1.3–7.4 cm larger, with maximum values observed when Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) and Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha)/Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha) were used. These fungicides also contributed to forming of the maximum weight of 1000 seeds in the experiment – 61.5–62.0 g, which was 11.1–11.6 g heavier compared to the control.

Table 11

Effects of fungicidal treatment on sunflower crop productivity indicators, 2023

Conditions	Plant height		Basket diameter		Weight of 1000 seeds	
	cm	±compared to control	cm	±compared to control	g	±compared to control
Control (water treatment)	134.5	–	17.2	–	50.4	–
Alpha-standard SC	160.4	+25.9	18.5	+1.3	57.5	+7.1
Cymoxyl WP	168.4	+33.9	22.0	+4.8	59.3	+8.9
Amistar Gold 250 SC	170.5	+36.0	23.7	+6.5	61.5	+11.1
Thanos 50 WG/Acanto Plus SC	171.4	+36.9	24.6	+7.4	62.0	+11.6

The smallest values for plant height, basket diameter and weight of 1000 seeds were observed when Alpha-standard SC (carbendazim 500, 0.5 l/ha) was used. Its impact on yield was also the lowest, 2.54 t/ha, compared to other fungicide treatment groups (Table 12).

Table 12

Sunflower seed yield from control and fungicide-treated experimental plots, 2023

Conditions	Seed yield, t/ha		±compared to control	
	Mean	±SD (Standard deviation)	t/ha	%
Control (water treatment)	1.32	±0.07	–	–
Alpha–standard SC	2.54	±0.12	1.22	92.4
Cymoxyl WP	2.95	±0.15	1.63	123.5
Amistar Gold, 250 SC	3.24	±0.16	1.92	145.5
Thanos, 50 WG/Acanto Plus SC	3.31	±0.18	1.99	150.8
LSD (0.05)	0.24	–	–	–

For other tested fungicides, seed yield was significantly higher – 2.95–3.31 t/ha, which is 1.63–1.99 t/ha or 2.2–2.5 times greater than that of the control (Fig. 1). The maximum level of sunflower seed yield in the experiment was achieved when Amistar Gold, 250 SC (azoxystrobin 125+difenoconazole 125, 1.0 l/ha) and Thanos, 50 WG (cymoxanil 250+famoxadone 250, 0.6 kg/ha)/Acanto Plus SC (picoxystrobin 200+cyproconazole 80, 1.0 l/ha) were used. There were no statistically significant differences between the yields of the fungicide treatment groups, and they were within the LSD (0.05) range.

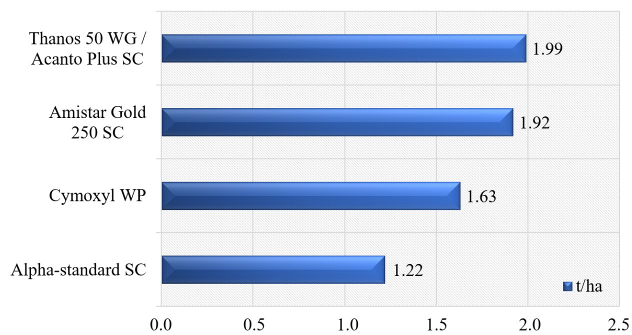

Fig. 1. Sunflower seed yield differences in fungicidal treatment groups compared to the control, 2023, t/ha (author's calculations)

The results of monitoring the phytosanitary condition of sunflower crops indicate an increase in the phytopathogenic pressure from the pathogens of white mold, black stem, stem canker and downy mildew in the sunflower agrocenosis, which confirms data from numerous researchers [18–21]. This is explained by the disruption of crop rotation structure, monoculture of sunflowers, and attempts to reduce the cost of cultivation through the use of a single fungicide treatment [20, 23]. Given the different taxonomic affiliations of fungal pathogens, it is impossible to rely on effective protection using products from only one class of chemical compounds. Therefore, the protection system for the crop against the most common phytopathogens should include fungicides from various chemical classes or multi-component preparations, as well as biologically justified timing for their application. The conducted research represents effective fungicide protection schemes that can be used in production in the presence of such pathogens as *Sclerotinia sclerotiorum* de Bary, *Plasmopara halstedii* Berl. de Toni, *Phoma macdonaldii* Boerema, *Diaporthe helianthi* M. Munt., et al. However, a significant limitation to achieving the results presented in the study remains the excessive saturation of sunflower crops in the southern region of Ukraine, which creates favorable conditions for early plant infection and the accumulation of a strong infectious background of the aforementioned phytopathogens. Considering the marginal profitability of sunflowers and their priority for agricultural producers, it is important to implement hybrids of the crop that possess horizontal resistance to diseases and to actively use biological agents (antagonists of disease pathogens) in the protection system.

4. Conclusions

According to the experimental results, it was determined that the main diseases of the sunflower crop in 2023 were white mold, downy mildew, black stem and stem canker lesion. White mold and downy mildew were the most prevalent, while black stem and stem canker – where the least prevalent. The disease incidence rate increased with each growth period. From BBCH 17 to BBCH 50, the incidence rate of white mold increased from 6.5 % to 9.1 %, of downy mildew – from 4.5 % to 8.3 %, and of black steam – from 1.0 % to 3.2 %. Stem canker lesion appeared at the micro-stage BBCH 30, in which the incidence rate was 1.5 %, and at micro-stage BBCH 50, it was twice as high.

The first fungicidal treatment of crops, conducted at the micro-stage BBCH 16, had a positive effect on their susceptibility to diseases – the extent of plant infection significantly decreased. Fungicide Alpha-standard SC was found to be ineffective against white mold and downy mildew, as the development of these diseases in sunflower crops was only slightly lower compared to the control, which was not treated with any fungicides. At the same time, Alpha-standard SC showed better efficacy at controlling black stem and stem canker lesion. Fungicides Cymoxyl WP, Amistar Gold, 250 SC, and Thanos, 50 WG showed high efficacy against all identified sunflower diseases. The best results against white mold and black stem were achieved when Amistar Gold, 250 SC was used, while Thanos, 50 WG was the most effective against downy mildew and stem canker lesion.

In further stages of organogenesis, the susceptibility of sunflower crops to diseases increased. On the control plot, from BBCH 51 to BBCH 91, the incidence rate of white mold increased from 9.1 % to 17.5 %, of downy mildew – from 8.3 % to 28.9 %, black steam – from 3.2 % to 15.3 %, and of stem canker lesion – from 3.0 % to 14.5 %. The second round of fungicide treatment (micro-stage BBCH 51) had a positive effect on the state of sunflower crops. Investigated plant protection products significantly inhibited the development of diseases. The exception was the fungicide Alpha-standard SC, which did not effectively control the development of white mold and downy mildew. In contrast, Acanto Plus SC had the most significant inhibitory effect on the development of white mold and downy mildew, whereas Amistar Gold, 250 SC was effective against black steam and stem canker lesion.

The maximum biological efficacy against white mold and black stem in the first round of fungicidal treatment (micro-stage BBCH 16) was achieved with Amistar Gold, 250 SC (78.0 % and 84.3 %), while Thanos, 50 WG was effective against stem canker lesion and downy mildew (86.6 % and 92.7 %). As for the second round of fungicidal treatment (micro-stage BBCH 51), the highest biological efficacy against white mold and downy mildew was achieved with Acanto Plus SC, while Amistar Gold, 250 was effective against black stem and stem canker lesion.

Fungicide protection of sunflower crops contributed to an increase in plant productivity indicators such as plant height, basket diameter, and 1000 seeds weight. The largest values were achieved when Amistar Gold, 250 SC and Thanos, 50 WG/Acanto Plus SC were used. Treatment with these fungicides led to the formation of the maximum level of seed yield – 3.24–3.31 t/ha, which was 1.63–1.99 tons per hectare or 2.2–2.5 times greater than that of the control sunflower crops.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

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