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Infectious Potential of the Causative Agent of Sunflower Phomopsis and Its Influence on Disease Expansion in Russia and Neighboring Countries

Yakutkin Vladimir I.

All-Russian Research Institute of Plant Protection (VIZR), St-Petersburg, Russia

Email address:
vladimir_yakutkin@mail.ru

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Abstract: Phomopsis is a widespread sunflower disease in Russia and neighbouring countries. Phomopsis advanced infectious potential contributes to the disease expansion in the area of commercial sunflower cultivation in Eastern and South-eastern Europe. Phomopsis manifestation includes sunflower seed infection, pleomorphic sporulation of the pathogen in anamorphic stages and aerogenic inoculum of ascospores in the teleomorphic stage of its development. Infection of the seeds promotes the spread of the disease up to 9.5%; α and β spores produced during the anamorphic stage of the pathogen live cycle can infect sunflower plants with effectiveness close to 45.5%. Ascospores drive disease expansion defeating over 70% of plants in the local area. Three phytosanitary zones with different manifestations of Phomopsis are identified in the area of sunflower cultivation in Moldova, Ukraine, Russia and Kazakhstan. A distinct area where the disease is not represented forms the fourth zone. The territorial distribution of the zones and their sizes are presented in the form of a cartographic model in GIS with substantiation of the long-term territorial forecast of Phomopsis. Limitation of the sunflower Phomopsis expansion is possible only under the widespread application of the integrated protection system. Defining role in this disease protection system must belong to the sunflower assortment resistant to Phomopsis.

Keywords: Sunflower Phomopsis, The Sourses of the Infection, Phytosanitary Zones of the Disease, Territorial Forecast of Phomopsis

1. Introduction

Phomopsis is currently a widespread and harmful sunflower disease in the world. For the first time, sunflower Phomopsis became known in 1932 in the USA, where the ascomycete *Diaporthe arctii* was identified as the causative agent of the disease [1]. Unexpectedly, in Yugoslavia, the sunflower Phomopsis appeared in 1960, causing up to 100% in yield drop [2]. In this country, another ascomycete *Diaporthe (Phomopsis) helianthi) Munt.-Cvet., Mihaljc. & Petrov* was identified as the causative agent of the disease [3], although there was no particular reason for this. In USA in 1983 Phomopsis was recorded on extensive crops of sunflower, the causative agent of which was identified by the already known ascomycete *D. helianthi* [4]. Some Yugoslavian researchers pointed out that the causative agent of Phomopsis on sunflower is a complex of species *Diaporthe sp*. [5]. Several reports suggested that other pathogens may also be the causative agents of the disease: *Diaporthe gulyae Shivas, Thompsonand Young [6], Diaporthe longicolla (Hobbs) Santos Vrandečić and Phillips [7], Diaporthe stewartii Harrison [8]*.

It should be noted that a number of fungal pathogens of sunflower diseases have numerous synonyms. Thus, the causative agent of sunflower white rot (*Sclerotinia sclerotiorum*), identified in 1884, currently has 8 synonyms. It is possible that pathogens causing Phomopsis will eventually find themselves in a similar status. According to the latest taxonomic revision, the causative agent of sunflower Phomopsis is presented in the international database as *Phomopsis helianthi Munt.-Cvet., Mihaljc. & Petrov*, and his ascus stage *Diaporthe helianthi Munt.-Cvet.,* *Mihaljc. & Petrov* is its synonym [9].

In the former Soviet Union (USSR) Phomopsis of sunflower first appeared in 1985 in Moldova and Ukraine [10]. In Russia, Phomopsis was registered on sunflower in 1989 in the Central Black Earth Zone, and again in 1990 in the Stavropol region [11]. The causative agent of the disease was identified as ascus fungus *Diaporthe helianthi Munt.-Cvet., Mihaljc. & Petrov*, previously described in Yugoslavia as *Phomopsis helianthi*. Several studies have shown that in Russia and neighbouring countries, Phomopsis disease is caused by anamorphic and teleomorphic stages of fungus. In the anamorphic stage, the pathogen (*Ph. helianthi*) has pleomorphic sporulation and produces α and β spores. In the teleomorphic stage, also known as *Diaporthe helianthi*, it forms an aerogenic inoculum abundant in ascospores.

2. Material and Method

The presented materials are cumulative results of the long-term studies of sunflower Phomopsis from 1989 to 2020. The infectious potential of the causative agent of the disease was studied in the field and laboratory settings: infection of the sunflower seeds, infectious ability of α and β spores in the anamorphic stage of the pathogen, and properties of the aerogenic inoculum of teleomorphic ascospores. Infection of seed with the Phomopsis causative agent was studied in field experiments at the Weidelevsky Institute of Sunflower (WIS), Belgorod Region, Russia on 15 samples of sunflower seeds of domestic and foreign reproduction. At least 30 plants represented each variant, all experiments were conducted in triplicates. Infected seeds were planted in 15 m² beds in triplicates. Special care was taken to ensure the protection of the experimental plants from the aerogenic inoculum of the pathogen.

The pleomorphism of the geographic populations of the pathogen was investigated by microscopy of the affected stems, followed by isolation of the pathogen in pure culture on nutrient media. The concentration of α and β spores in the pycnidia of the fungus *Ph. helianthi* was calculated as percentage. The pleomorphic sporulation of each geographic population was studied on 40 infected sunflower plant sections with a large representation of pycnids of *Ph. helianthi* in triplicate, according to the published method [11]. The infectious ability of monosporous isolates of α and β spores was studied at a concentration of 10^6 spores per 1 ml by inoculating 30 plants in the budding phase in three replicates. For this, pieces of pure agar medium were placed into the stems incisions following by injection of 0.5 ml of a spore suspension at the indicated concentrations.

To study ascospores formation at the teleomorphic stage of the fungus *D. helianthin* and their aerogenic emission from the perithecia, numerous samples of affected stems after overwintering were distributed in the sunflower fields. Aerogenic inoculum of ascospores was revealed in the environmental sediment collected on glass slides, distributed in sunflower fields during different periods of vegetation. The dynamics and infectious potential of ascospores were studied on 50 sunflower plants in 4 replicates in a controlled experimental environment free from other infections pathogens.

The distribution of Phomopsis in the area of sunflower propagation in Russia, Moldova and Ukraine was identified by the result of twenty years of disease monitoring carried out during 1989-2019. That monitoring accounted for the percentage of infected plants and intensity of the disease manifestation at the affected sites [11]. At least 15% of sunflower crops were surveyed, in line with the criteria for a reliable estimate of the disease prevalence in these countries. To assess the manifestation of the disease on sunflower in Kazakhstan, we used published materials and personal communications from the local agricultural authorities. The effect of weather conditions on Sunflower Phomopsis manifestation and development has been studied using the integrated GTC indicator [12]. A cartographic model of Phomopsis distribution in the general sunflower area in Russia and the neighbouring countries was created in GIS-based on our and partially published materials using software MapInfo Professional 9.5 USER GUIDE, 2008 [13], Idrisi 32.11 [14].

Phytosanitary Disease Zones with possible crop losses were established by agricultural authorities based on our adopted gradations (Table 1). The materials presented in the integrated system for sunflower protection from Phomopsis were obtained in the results of many years of research and data analysis for multiple regions in Russia and neighbouring countries.

Table 1. *Criteria for the Phomopsis diseases manifestation in the phytosanitary zones of sunflower cultivation in Russia and neighboring countries.*

Zone and level sunflower affected by Phomopsis	Sunflower affected by Phomopsis, in %	Estimated yield loss, in %
Zone 1, strong	up to 50 and more	up to 35 and more
Zone 2, middle	up to 30	to 10
Zone 3, weak	up to 15	up to 5
Zone 4, no disease detected	0.0	0.0

Field and laboratory studies of sunflower Phomopsis were carried out according to the commonly accepted method of experiment planning [15]. For statistical evaluation of the results, the average indicators (M) and its standard error (± SEM) were calculated using Statistica 6.0 software package [16].

3. Result and Discussion

For a long time in Russa were cultivated only local breeding varieties and populations of sunflower for commercial production. After developing sunflower hybrids by heterotic selection in other countries, they were intensively introduced into many USSR regions, including Russia. Phomopsis, previously unknown in the USSR sunflower disease, was initially detected on the foreign hybrid sunflower plants in Moldova and Ukraine in 1985 [10]. In 1989, Phomopsis was found in the Central Black Earth Zone, Russia and also affecting foreign sunflower hybrids. A year later, the disease was identified in the Stavropol region, Russia, affecting the first domestic hybrid Pervenets. The causative agent of the disease was identified as fungus *Phomopsis (Diaporthe) helianthi*, previously isolated in Yugoslavia and Moldova. Soon, populations of the traditional Russian sunflower varieties were also affected by Phomopsis.

Several studies have shown that the pathogen caused Phomosiss in Russia and neighbouring countries at the various life stages: anamorphic and teleomorphic, both accompanied by the stage-specific spores.

During the sunflower growing season, the pathogen Ph. helianthi is represented by the anamorphic stage and pleomorphic α and β spores developed in the pycnidia. At the end of the vegetation season affected plants carries the teleomorphic stage of the pathogen. The fungus completes its development after overwintering on plant stems in the fields. In a result, the perithecia of *Diaporthe helianthi* containing ascospores develops on the same plant material.

It was found that primary source of Phomopsis infection on sunflower in Russia and the neighbouring countries are infected seeds. The disease development from the infected seeds may lead to 1.5% to 9.5% damaged plants (Table 2).

Table 2. *Manifestation of Phomopsis from infected sunflower seeds.*

Sample ID	Variety, hybrid	Country of reproduction	Affected plants, in %
1.	Leader (v.)	Russia	1.5 ± 0.6
2.	Improved leader (v.)	Russia	2.5 ± 0.7
3.	Pervenets (h.)	Russia	3.4 ± 0.5
4.	Rzhaksinsky (v.)	Russia	5.7 ± 1.5
5.	MPK-8607 (h.)	Moldova	7.8 ± 2.0
6.	Sunbred (h.)	Moldova	3.4 ± 0.5
7.	Soldor (h.)	Ukraine	5.3 ± 1.2
8.	Kharkiv 46 (h.)	Hungary	4.1 ± 0.9
9.	Hybrid No. 6 (h.)	Hungary	3.1 ± 0.4
10.	B.306 (h.)	Yugoslavia	8.6 ± 2.1
11.	NSH-15 (h.)	France	8.7 ± 0.8
12.	Astrasol (h.)	Argentina	5.6 ± 1.5
13.	ACA 887 (h.)	USA	3.5 ± 0.5
14.	NX 17 (h.)	USA	6.8 ± 1.9
15.	Kargel (h.)	USA	9.5 ± 3.7

Note: here and further: (v.) - variety-population; (h.) - heterotic hybrid.

In the experimental conditions, minimal damage by sunflower Phomopsis – 1,5% was observed on the Russian variety population Leader when the disease was initiated from the infected seeds. Maximum damage to the plants by the disease developed from the infected seeds was observed on the hybrid Kargel grown from the seeds imported from USA, up to 9.5% of plants were affected. Manifestation of Phomopsis was detected on 3.4% - 8.7% plants propagated in Russia from the infected seeds obtained from the other countries. In laboratory experiments, when seeds were infected with the pure cultures of the pathogen, frequencies of Phomopsis occurrence were similar to the field experiments.

The initial appearance of Phomopsis contracted from the infected sees is detected in the form of small, infrequent pink or dark brown necrotic lesions on the basal parts of the stems. In the budding and further into the flowering season, the symptoms of Phomopsis contracted from the infected seeds develop on the stems in the form of the light or dark brown necrotic spots (Figure 1). Later, in these necrotic spots, the pathogen develops anamorphic stage pycnidia with pleomorphic conidial sporulation of α and β spores.

Figure 1. *Phomopsis on the stem of a growing sunflower.*

It should be noted that Phomopsis expansion in Russia and neighbouring countries was driven by the uncontrolled import of heterotic hybrids from the USA, Canada, Argentina, and Europe by the growers denning the possibility of seeds contamination. A similar situation was documented in USSR in 1947-1948 when sunflower seed material contaminated by downy mildew (*Plasmopara halstedii*) was introduced from the United States. This disease has now spread everywhere in Russia and neighbouring countries, causing significant damage sunflower industry.

The study of pleomorphic sporulation of the fungus *Ph. helianthi* showed that β-spores are predominant in the geographical populations, with the frequency of occurrence from 92% to 95.1% (Table 3) Slightly elevated β - spores proportion, over 95.1%, was detected in the Moldovan geographic population. The frequency of α-spores detections in the pathogen population usually ranges from 3% to 8%, with a slightly higher count detected in the pycnidia of the causative agent in the Russian population (8%). Presence of mixed sporulation: $\alpha + \beta$ – spores, in the geographical populations of the pathogen was minimal and ranged from 2% to 5%, with slightly elevated content found in the Ukrainian pathogen population (5%).

Table 3. *The content of α and β spores in pycnidia of geographic populations of pleomorphic sporulation of the fungus Ph. helianthi.*

Population Number	Population Geographic location	Concentration of spores in pycnidia fungus *Ph. helianthi*, in %		
		α	β	$\alpha + \beta$
1.	Russian	8.0 ± 1.1	90.0 ± 3.1	2.0 ± 0.3
2.	Moldavian	2.0 ± 0.5	95.1 ± 4.7	2.9 ± 0.5
3.	Ukrainian	3.0 ± 0.6	92.0 ± 3.8	5.0 ± 0.9

Considering the identified ratios of spores of the pleomorphic sporulation in different geographic populations of the pathogen, studies with limited samples of pycnidia usually describes only overrepresented β-spores. In contrast, other variants of sporulation of the fungus *Ph. helianthi* are not found. Therefore the presence of Ph. helianthi various pleomorphic spores promotes to the famous discussion about the taxonomic position of the causative agent of sunflower Phomopsis.

Pleomorphic sporulation with α and β spores in the pycnidia of the fungus Ph. helianth, as was established in our studies, is an additional source of Phomopsis infection. During the sunflower growing this source of infection noticeable enhances the distribution of the disease. It has been shown that if sunflower inoculation with pleomorphic α and β was carried out at the beginning of the flowering, then Phomopsis manifestation varied from 10% to 45.5% of affected plants (Table 4). Differences in sunflower infection with pycnospores of the pathogen is probably related to the level of the plant resistance to the disease. When sunflower was infected exclusively with α-spores, the detection rate of Phomopsis infections ranged from 10% to 26.7%. The β-spore inoculum caused more severe damage to sunflower by Phomopsis, resulting in 13.3% to 45.5% of affected plants. Some researchers indicated that α-spores of the fungus Ph. helianthi cannot be considered as a significant infection thread for sunflower. However, it is known that α-spores of other pathogens from the genus Phomopsis sp. can cause Phomopsis on the appropriate host plants. Therefore, the α-spores of the fungus *Ph. helianthi* potentially can infect the sunflower and lead to Phomopsis development.

Table 4. *Phomopsis manifestation on sunflower infected with α and β pycnospores of the fungus Ph. helianthi.*

Sample number	Sunflower variety	Plant affected / the development of the disease, in % / in points	
		α – spores	β – spores
1.	Pervenets (h.)	10.0 / 2	13.3 / 2
2.	NSH-15 (h.)	15.0 / 1	25.0 / 1
3.	Leader (v.)	10.0 / 1	13.2 / 2
4.	Caucasian (v.)	10.3 / 2	13.3 / 3
5.	Berezansky (v.)	10.0 / 1	23.5 / 2
6.	USP (v.)	26.7 / 2	43.3 / 3
7.	Enisey (v/)	27.7 / 3	45.5 / 4

Note: 1 point - necrosis on stems occupies 5% of their surfaces; 2 points – necrosis occupies 15% of the surface of the stems; 3 points - necrosis takes 30% stem surfaces; 4 points – plant death.

Among other sources of the causative agents for sunflower Phomopsis, the most important is the aerogenic inoculum of ascospores of the pathogen. Such inoculum is generated by the teleomorphic form of the fungus developed on the infected plant debris after overwintering in the field. In the sunflower propagation area in Russia and neighbouring countries, the emission of ascospores of the pathogen, as have been shown in several studies, occurs at different times. In a single case, the first signs of the pathogen ascospores emission were detected as early as April in Belgorod region in Russia. The more intense ascospores emission began in May and proceeded further through the sunflower cultivation season (Table 5).

Table 5. *Dynamics of the ascospores emission from the perithecia of the fungus D. helianthi during the growing season of sunflower (WIS, Belgorod region, Russia).*

Period number	Sunflower growing season	Average number of ascospores in crops sunflower on slides, in units
1.	May	10 ± 4
2.	June	45 ± 5
3.	July	65 ± 7
4.	August	20 ± 6

The pathogen ascospores emission in the Belgorod region in May was recorded with an average concentration of up to 10 ascospores per one glass slide, when the slides were placed in sunflower beds. In June and further in July, the emission intensity sharply increased and up to 45 and 65 ascospores per glass. In August, during the period of sunflower ripening, the ascospore emission intensity decreased, with an average of 20 ascospores per glass slide. The wave-like nature of the ascospores emission from the apothecia of the fungus *D. helianthi* is associated with the periods of perithecia maturation, and it is affected by the humidity and temperature in the local agrocenose territory. The most intense emission of ascospores occurs at an average air temperature of 22°C to 24°C with humidity at 50% - 60%, or at the generalised integrated index (GTC) value in the range of 1.0 -1.2 [17].

In the experimental condition, the initial signs of infection by Phomopsis aerogenic inoculum was registered as punctate necrosis on the cotyledon leaves of sunflower seedlings. More pronounced symptoms of the disease appeared on the young true leaves in the form of dark marginal angular necrosis, which subsequently dried out. In the phase of four true leaves, up to 5.8% of plants were affected by Phomopsis (Table 6). During the budding, flowering, and ripening phases, the disease intensified not only on the leaves but also on the stems of the plants (Figure 1), leading up to 25.6%, 65.9%, and 78.3%, respectively. During the period of sunflower ripening, Phomopsis from an aerogenic inoculum manifested itself on up to 82.5% of plants, with complete plant death up to 28.7%. Altogether that corresponds to the total yield losses of up to 25%. At the end of the sunflower growing season, Phomopsis manifested itself on goats with limited spots and on the stems in the form of grey necrosis (Figure 2).

Figure 2. *Phomopsis on a sunflower stalk at the end of its growing season.*

Table 6. *Infection of sunflower with the Phomopsis pathogen aerogenic inoculum at the different plant growth phases (WIS, Belgorod Region, Russia).*

Number phase	Development phase sunflower	Affected plants, in %	Complete death of the plants, in %
1.	Four pairs of true leaves	5.8 ± 1.2	0.0
2.	Budding	25.8 ± 2.4	0.0
3.	Bloom	65.9 ± 4.3	5 ± 0.3
4.	The beginning of maturation	78.3 ± 6.7	15.1 ± 4.2
5.	Full ripeness	82.5 ± 7.8	27.8 ± 6.3

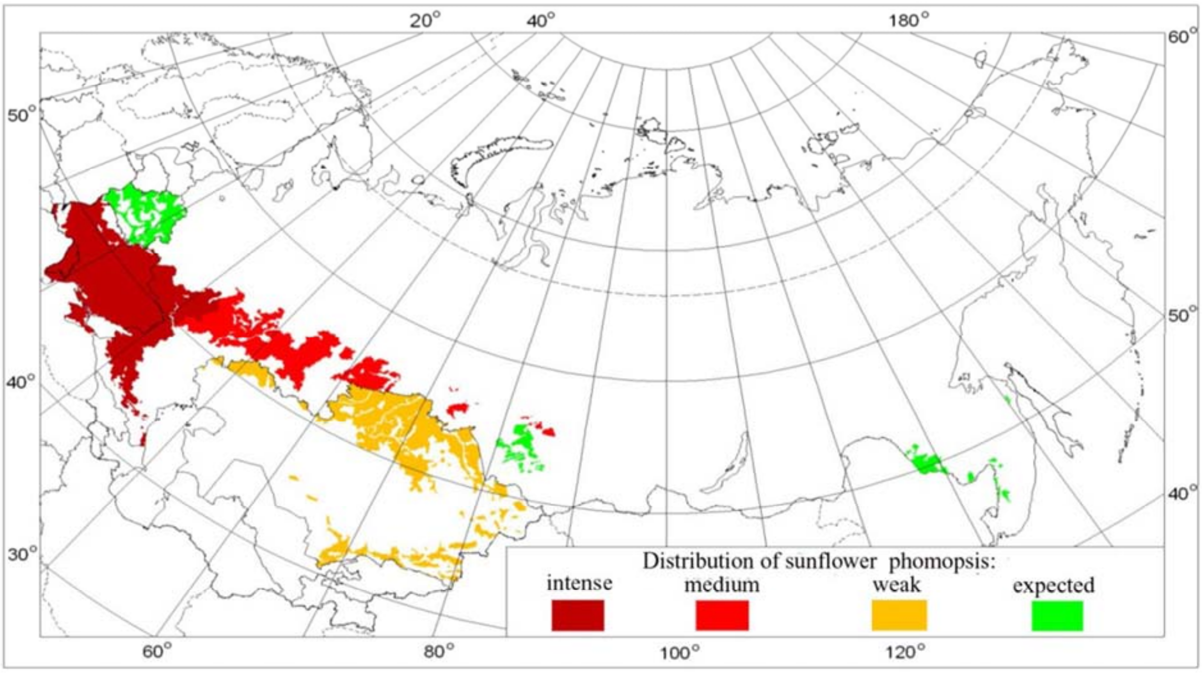

Figure 3. *Phomopsis manifestation phytosanitary zones of Moldova, Ukraine, Russia, Kazakhstan and Belarus.*

Grades of Phomopsis manifestation:
zone 1, intensely affected to plants up to 50% or more;
zone 2, moderately affected to plants up to 30%;
zone 3, weakly affected plants up to 15%;
zone 4, under observation (expected), the disease has not been identified but may appear.

After the appearance of Phomopsis in 1985 in Moldova and Ukraine [10] a specific infectious potential of the causative agent of the disease was formed on sunflower crops, which contributed to its further expansion. Four years later, in this region, the prevalence of the disease was registered in 70% of sunflower crops [19]. In 1988-1989, Phomopsis in Ukraine spread at a speed of up to 80-100 km per year [20]. Route surveys of sunflower crops carried out by us in 1995-2010 showed that Phomopsis is manifested in all regions of Moldova and Ukraine, with damage to plants up to 55% or more, and their complete death up to 15%. In Russia, after the detection of sunflower Phomopsis in 1989 in the Central Black Earth Zone, its intensive growth also took place. Three years later, in this zone, the prevalence of the disease reached 40%, with the complete death of plants up to 10% to 60% of the sown area of sunflower. In the Stavropol region, where the disease was discovered in 1990, by 2015 [18], Phomopsis appeared in 65% of the sown area of sunflower, including the surrounding regions. In 2007, Phomopsis was registered in the Volga region of Russia, with a prevalence of up to 15%. In the Volgograd area within Volga region, the prevalence of the disease reached 70% over 50 hectares of sunflower fields repeatedly sown with seeds supplied from Moldova. Phomopsis appeared in the southern Urals of Russia with a prevalence of 1.5% to 40% or more on American crops, European, domestic hybrids and varieties - populations. Currently, the disease is spreading in the Asian part of Russia and neighbouring Kazakhstan. Currently, four Phomopsis phytosanitary zones, differing in the intensity of the disease manifestation, have been recognised within the general sunflower cultivation area in Russia and neighbouring countries (Figure 3).

Phytosanitary zone 1, where the manifestation of Phomopsis exceeds 50%, includes Moldova, Ukraine and several regions in Russia - the Central Black Earth Zone, the North Caucasus and Crimea. Zone 1 covers 42% of the sunflower cultivation area in Russia and neighbouring countries (Figure 4). The infection by the disease causative agent is not a limiting factor for its formation on sunflower in these places. Within this zone, weather conditions during the growing season contribute to the epiphytotic disease: when GTC reaches 1.0-1.2, the sunflower yield losses of up to 35% or even more are possible. Considering all that information, the phytosanitary zone 1 represents of a high-risk Phomopsis area.

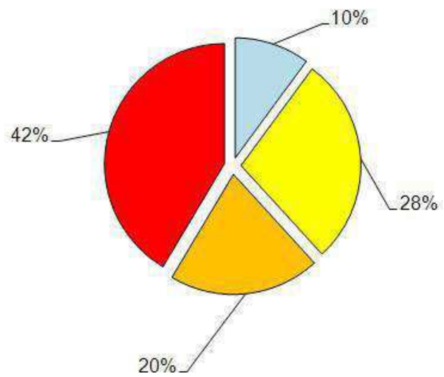

Figure 4. *The size of Phomopsis phytosanitary zones in the general area of sunflower cultivation in Russia, Moldova, Ukraine, Kazakhstan and Belarus.*

Note: 42% - zone 1, an intense manifestation of Phomopsis with plant damage more than 50%; 28% - zone 2, a moderate manifestation of Phomopsis with plant damage up to 30%; 20% - zone 3, weak manifestation of Phomopsis with plant damage up to 15%; 10% - zone 4, where Phomopsis was not detected, but the disease can manifest itself.

Phytosanitary zone 2, with the disease prevalence up to 30% of affected plants and the average risk of its manifestation, includes Middle Volga, Ural and Western Siberia regions, which 2 covers 20% of the sunflower cultivation area in Russia. In this zone, under the indicated weather conditions during the growing season, possible yield losses can reach up to 10%. A phytosanitary zone 3 includes Kazakhstan, with 15% affected by Phomopsis plants and a low risk of significant damage. In this country, the disease on sunflower appeared in recent years and is still not spread up. Zone 3 occupies 28% of the total area used for crops production in Kazakhstan. Under favourable weather conditions during the sunflower growing season in this zone, possible yield losses can reach 6%. The fourth zone, where Phomopsis has not yet been detected, but its appearance is possible, includes Altai region with more than 300,000 hectares covered by sunflower plantation, Amur, Khabarovsk and Primorsky regions of Russia, as well as Belarus, where commercial sunflower farming exceeds 30 thousand hectares and constantly expanding. Currently, this zone still occupies 10% of the total area of sunflower in these countries. Areas with the limited manifestation of Phomopsis - zones 2 and 3, and the disease-free zone 4, are under threat of the disease aggravation caused by the transmission of aerogenic inoculum from phytosanitary zone 1, affected by the high infectious potential of the causative agent.

Currently, the expansion of Phomopsis can be controlled only by implementing everywhere Integrated Sunflower Protection System (ISPS) or Integral Pest Management (IPM). One of the elements of this system is the optimal rotation of sunflower plants in the crop rotations cycles not exceeding 9% of the total capacity. An assortment of sunflower that is resistant to Phomopsis can significantly limit disease harmfulness. However, several studies showed that high-yielding hybrids and varieties-populations of domestic and foreign selection actively used in the commercial production of sunflower in Russia and neighbouring countries can be affected by Phomopsis over 35% in case of the increased level of infection in the area.

Safe and effective fungicides implemented as a part of IPM can control Phomopsis expansion. However, our long-term studies have shown that fungicides used for seed dressing and protection of growing sunflower have insufficient biological effectiveness against the disease. Fungicide formulations like TKS, Scarlet, Klad, Protravitel, Pioneer, Fludimaks, and others certified in Russia for to treatment of Phomopsis have limited biological effectiveness not exceeding 40% - 45%. The fungicides Thanos, Famax, Ulis, Propulse and others have been proposed against aerogenic fungal infections in Russia and neighbouring countries. Under conditions of an average level of aerogenic inoculum, when the affected sunflower in control reaches 30%, their biological effectiveness against the disease did not exceed 25%.

The use of chemical protection in the sunflower agrocenoses is regulated by several factors, and the most important of those are environmental and consumer safety.

Studies had shown that the most effective and profitable effect in Russia is achieved when fungicides with not less than 75% effectiveness are applied twice at the end of budding and during the sunflower flowering on the fields with an expected yield of at least 20 centners per hectare.

Optimisation of the chemical protection against Phomopsis is possible only in combination with the disease monitoring and prognosis in the critical period for sunflower infection. The prognostic factors for the use of fungicides against the disease are increased emission of the aerogenic inoculum under conditions of sunflower moistening at GTC from 1 to 1.2, and expected threshold of disease harmfulness at least 6% of the affected plants are in the budding/beginning of flowering leaving possibility for the plants further growth.

Investigations of biological methods for sunflower Phomopsis control showed their poor effectiveness. In the field experiments in WIS (Belgorod region, Russia), the effectiveness of the biological product Sternifag, a destructor of Phomopsis infection in plant debris in the soil and on its surface, did not exceed 25%. The effectiveness of Russian biological products Alirin, Imidor, Aquamix, Vitaplan, Trichocin, Sternifag and others used for seed treatment against the disease turned out to be no more than 20%. When Alirin was used twice on sunflower against aerogenic infection of Phomopsis, the biological efficiency was within 17%. At present, intensive research is being carried out in Russia to further increase the complex effectiveness of biological protection methods effective against Phomopsis and other sunflower diseases.

4. Summary and Conclusion

Different sources of Phomopsis contamination on sunflower have different effects on its expansion. The diseases contracted from the Sunflower seeds infected with Phomopsis causes the disease manifestation in up to 9.5% of the infected plants. Pleomorphic sporulation of the fungus *Ph. helianthi* with the formation of inoculum of α and β spores during the sunflower growing season can increase the number of plants affected by Phomopsis up to 45.5%. The infectious potential of the ascospores of the fungus *D. helianthi* in the teleomorphic stage of its development is the most decisive in infecting growing sunflower resulting in over 70% of plants affected by Phomopsis. Infectious ascospores also are the main factor of the disease expansion on crops.

In the vast area of sunflower in Russia and the neighbouring countries, in the conditions of the existing infectious potential of Phomopsis, three phytosanitary zones with different disease intensity manifestations have been formed. The disease has not yet been detected in the fourth zone of the general area of sunflower. Currently, the control of Phomopsis expansion in Russia and neighbouring countries is only possible under prevalent compliance with the integrated protection system of sunflower. The central role in this system should be played by the sunflower varieties resistant to Phomopsis. Other additional integrated protection measures can significantly enhance sunflower protection against this dangerous disease.

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References

[1] Wehmeyer L. E. The genus *Diaporthe Nitschke* and its segregates, 1933. Ann Arbor, University of Michigan Press, pp. 23-33.

[2] Mihaljcevic M., Petrov M., Cvetcovic M. M., 1980. *Phomopsis sp.* is a new parasite of sunflower in Yugoslavia. Modern ariculture., 28, pp. 531-539.

[3] Muntanola-Cvetkovic M., Mihaljcevic M., Petrov M., 1981. On the identity of causative agent of a serious - *Diaporthe* disease in sunflower plants. Nova Hedwigia, 34, pp. 417-435.

[4] Herr L. J., Lipps P. E., Watters B. L., 1983. Diaporthe stem canker of sunflower. Plant Disese, 67, pp. 911-913.

[5] Aćimović, M., Štraser, N., 1982. *Phomopsis sp.* is a new parasite of sunflower. Plant protection, 33 (2), pp. 117—158.

[6] Thompson, S. M., Tan, Y. P., Young, A. J., Neate, S. M., Aitken, E. A. B. and Shivas, R. G., 2011. Stem cankers on sunflower (*Helianthus annuus*) in Australia reveal a complex of pathogenic *Diaporthe (Phomopsis*) species. Persoonia, 27, pp. 80-89.

[7] Mathew F. M., Alananbeh, K. M., Balbyshev N., Jordahl J. D. E., Meyer S. M., Castlebury L., Gulya T. J. and Markell S. G., 2017. Phomopsis stem canker: A reemerging threat to sunflower (*Helianthtus annus*) in the United States. Phytopathology, 105, pp. 900-907.

[8] Olson, T. R., Kontz, B., Gulya, T. J., Markell, S. G. and Mathew F. M., 2017. First report of *Diaporthe stewartii* causing Phomopsis stem canker of sunflower (*Helianthus annuus*) in Minnesota. Plant Dis., Vol. 101, Number 2, pp. 382.

[9] Catalog of Life: 2020-04 Beta, 2020. Annual Checklist http://www.catalogueoflife.org/annual-checklist/2020/

[10] Bogdanova V. N., Karadzhova L. V., Steyberg M. E., 1986. On time detect Phomopsis. Agriculture of Moldova, 12, pp. 24-25.

[11] Yakutkin V. I., 1991. Identification of the causative agent of Phomopsis sunflower and methods of its accounting (Methodical instructions). VASKHNIL, VIZR. Leningrad, 23 p.

[12] Selyaninov G. T., 1928. On agricultural climate assessment. Proceedings on agricultural meteorology. Issue 20, VIR. L., pp. 169-178.

[13] MapInfo Professional 9.5 USER GUIDE, 2008.150 p. http://www.mapinfo.ru/product/mapinfo-professional

[14] Eastman J. R.. Idrisi 32 Tutorial. Idrisi Production 1987-1999, 1999. Clark University, 298 p.

[15] Dospekhov B. A, 1985. Field experiment technique (with the basics statistical processing of research results). Agropromizdat, 351p.

[16] Statistica 6.0. Statsoft, Inc., USA. http://softwaretopic.informer.com/use-statsoft-statistica-6-windows-7/

[17] Yakutkin V. I., 1998. Gray stem spot is a new disease of sunflower in Russia. 7th International Congress of Plant Pathology. Abstracts, p. 6.

[18] Yakutkin V. I., 2017. Diagnosis and regular accounting of Phomopsis are the conditions for timely detection on organization of protective measures against the disease on sunflower crops in Russia. Materials of the 4th Congress of Mycologists of Russia, Moscow, April 12-14, 2017. Moscow, Vol. 7, pp. 134-136.

[19] Skripka O. V. 1989. Phomopsis is a dangerous disease of sunflower. Moscow, Agroproizdat, 4 p.

[20] Shinkarev V. P., Terekhov V. I., Sokolov Yu. G., 1991. Gray spot [the causative agent *Phomopsis (Diaporthe) helianthi Munt.-Cvet*.] – dangerous sunflower disease. Plant protection problems in North Caucasus: materials of the 80th anniversary meeting of the Scientist Council of SKNIIF, dedicated to the 30th anniversary of the establishment of the institute. Krasnodar, pp. 54-65.