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PATHOGENIC COMPLEX AND RECOVERY OF CEREAL AGROCENOSES IN THE STEPPE OF UKRAINE

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Topicality. *Changes in weather and climatic conditions affect the formation of pathogenic complexes of grain agrocenoses and the species composition of pathogens, which are typical for the Steppe zone of Ukraine. At the same time, changes in cultivation technologies accompanying the transition to new forms of management also play a significant role in the formation of pathogenic complexes. It is necessary to find out the features of the pathogenic mycoflora formation and plant immunity in order to scientifically substantiate measures to stabilize the phytosanitary state of agrocenosis at the current stage of grain production.* ***Purpose****. To divide into appropriate groups of grain crop diseases in the Steppe zone in terms of the nature of development, harmfulness and hydrothermal dependence of their pathogens.* ***Materials and Methods.*** *In 1999–2019, we conducted surveys of wheat (winter and spring), rye, barley (winter and spring), oats and maize for disease infestation in the Northern Steppe of Ukraine according to generally accepted methods of phytopathological research.* ***Results.*** *Over the years of research, we identified 123 pathogens, which caused 135 diseases in grain crops. The most diverse composition of pathogens was observed on wheat and maize, 64 and 55 pathogens, and, 33 and 41 diseases, respectively. It should be noted a wide range for specialization of the widespread pathogens in the Northern Steppe of Ukraine. The pathogens of smut infects generally a certain type of grain crops, rusts are somewhat less specialized. Less specialized parasites, such as fungi from the genera Fusarium, Helminthosporium, Alternaria cause the same type of diseases in several plant species, and some of them affect different plant organs. Thus, among the pathogens of Fusarium root rot of wheat, rye, barley and maize, we identified the fungus Fusarium moniliforme Sheld. On the maize, in particular, this pathogen caused seedling mould, root and stem rot, cob rot, and grain mould.* ***Conclusions.*** *It was established that the hydrothermal regime can affect the development of diseases not only due to its compliance with the pathogen's requirements, but also affect the resistance of plants. The problem of agrocenosis recovery can be successfully solved by adapting modern intensive technologies of growing grain crops that aimed to optimally utilized ecological resources by plants in the Steppe of Ukraine, and prevent the spread of harmful organisms.*

Key words: *winter wheat, maize, pathogens, diseases, hydrothermal conditions, harmfulness*

Introduction. At least 120 species of pathogenic organisms are capable to develop on the cereal crops, in particular, about 200 pathogens – on wheat [1, 2]. Most of them are distributed globally, but the harmfulness of these pathogens, as well as the area of less widespread species, is determined by regional environmental conditions, cultivation practices and susceptibility of a particular crop.

Pathogenic complexes of grain agrocenosis have their own peculiarities in the Steppe zone of Ukraine. Unstable moistening with uneven precipitation and temperature conditions both in terms of years and availability of environmental resources during the growing season directly affect the species composition of pathogens. At the same time, new forms of management, accompanied by changes in cultivation technologies, play a significant role in the formation of pathogenic complexes. Often these changes have a negative impact.

Reducing the number of tillage and crop management operations and disrupting crop rotations has led to the recovery of a number of harmful species that were at sub-threshold levels until recently. The above circumstances require

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to clarify the peculiarities of the pathogenic mycoflora formation and plant health in order to scientifically substantiate methods for stabilisation of the phytosanitary state of agrocenosis at the current stage of grain production.

Purpose of the research is to group the diseases of cereals in the Steppe of Ukraine according to the nature of development, harmfulness and hydrothermal dependence of their pathogens.

Materials and Methods. During 1999–2019, we surveyed winter and spring wheat, rye, barley, oat and maize crops for disease infestation and determined the species composition of their pathogens in field crop rotations of the Experimental Farm and Synelnykove Breeding and Research Station at the Institute of Grain Crops of NAAS of Ukraine and in production crops of other farms located in the Dnipro region.

Diseases were accounted by the methods of the Institute of Plant Protection of the NAAS [3] and the All-Union Research Institute of Maize [4], the species composition of pathogenic organisms was identified according to the methods of M. K. Khokhriakov [5] and the Institute of Botany of the Academy of Sciences of the Ukrainian SSR [6].

Results. Over the years of research, 123 pathogens causing 135 diseases have been identified in grain crops. The most diverse species composition was observed in wheat and maize, with 33 and 41 diseases and 64 and 55 pathogens, respectively (Fig. 1).

We noted a wide range of pathogen specialisation common in the Steppe zone. Smut pathogens prevailed for certain grain crops, while rust pathogens were somewhat less common. Less specialised pathogens, such as fungi from the genera Fusarium, Helminthosporium, and Alternaria, could affect similar diseases of several plant species, and some of them were capable of affecting different organs. Therefore, we found that *Fusarium moniliforme Sheld*. was among the pathogens of fusarium root rot of wheat, rye, barley and maize; in the maize, in particular, it caused sprout mould, root and stem rot, ear rot and grain mould.

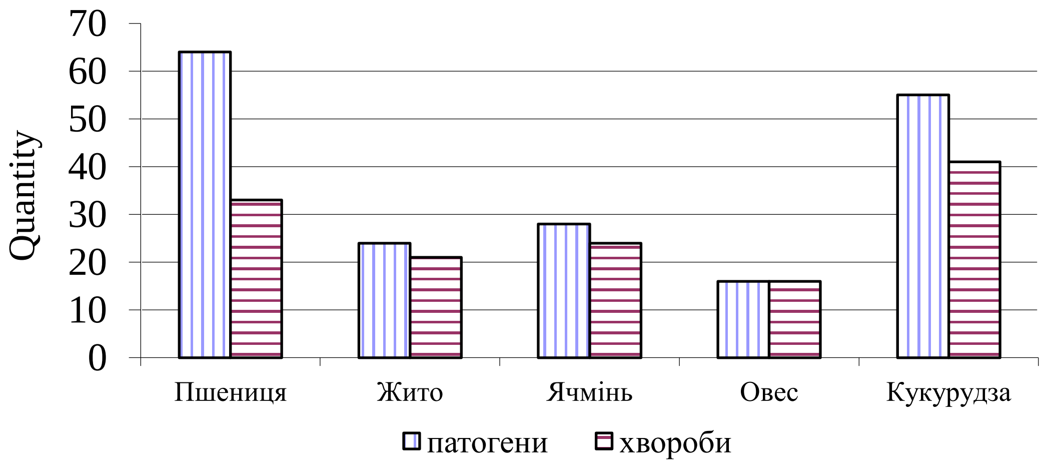

Fig. 1. Quantitative composition of pathogens and diseases of grain crops, for 2006–2019

Among the wheat pathogens, there were quite rare species, such as *Calonectria graminicola (Berk. et Br.) Wr.* and *Epichloe typhlina (Pers.) Tul.* that caused rotting the sprouts and stems; *Septoria briosiana Mor., Mastigosporium album Riess, Ovularia pulchella (Ces.) Sacc., Scolecotrichum graminis Fuck.* – leaf blight, *Stemphylium botryosum Wallr.* – grain mould. It is observed on the maize leaves – *Epicoccum neglectum Desm.* and the maize roots – *Periconia macrospinosa Lef. et John.* and *Stachybotrys alternans Bon.*

Most of registered diseases were annually widespread; hydrothermal and economic factors determined the degree of their harmfulness. Special plant protection measures, including chemicals, were most often required against smut diseases, mould of maize sprouts, powdery mildew, rust and other leaf spots of cereals.

Depending on the weather conditions, the formation of the pathogenic complex in grain crops could be different. Under wet growing season, its species composition was dominated by obligate pathogens. For example, rainfall in the spring and summer of 2004, 2008, and 2012 contributed to the development of powdery mildew and brown rust, which resulted in the application with fungicides in grain crops, primarily winter wheat. In the dry years (1999, 2002, 2003, 2005, 2007, 2009, 2011, 2017, and 2019), there were a number of environmental and parasitic diseases: root rot, mycoses of maize sprouts and ears.

Significant development of diseases caused by both obligate and facultative parasites was often combined in one season (2000, 2001, 2006, 2013, 2014). Against the general background of extreme weather conditions, short periods with moderate air temperatures and humidity were observed during the disease-susceptible stages of plant development. In particular, under such conditions, the development of powdery mildew and brown rust on cereals resumed, while previous drought weakened the plants, making them susceptible to septoria. In arid years, maize blister smut acquired epiphytic development when small, insignificant rainfall at the end of intensive leaf formation or during flowering provided germination of the airborne infectious base and penetration into the meristem tissues of the disease agent *Ustilago maydis (DC.) Corda*.

When a wet period turns into a dry one, disease development can be inertial. The availability of moisture is one of the main conditions for the development of powdery mildew. However, the disease can often spread significantly during a long spring and summer period without rain. In a well-developed grass stand at high temperatures, due to the evaporation of soil water accumulated in the previous period, an above-ground layer of moist air contributed to the continued development of powdery mildew even for medium-resistant winter wheat varieties such as Fantsiia, Selianka, Tira, Zira, Smuhlianka, Zolotokolosa, Misiia Odeska, and Yuvileina 100. Under such conditions, plants remained susceptible to helminthosporium, septoria and other blight diseases for a long time, especially when plants were weakened by other factors, such as suppression of their development by some herbicides or other agrochemicals, nutrient deficiencies, and extreme day and night temperature fluctuations.

Our research allows us to group grain crop diseases in the Steppe of Ukraine by the nature of their development and harmfulness (Table 1).

The temperature regime of the growing season plays a significant role in the selection of certain types of phytopathogens. Thus, in the Steppe zone, there was an annual threat of thinning of maize seedlings due to germinating seeds infestation by mould fungi. The mould damage to sprouts depended on quality of pre-sowing seed treatment and the degree of mechanical injury in both warm and cool springs and reached 20–30 %, increasing with low-quality seedbed preparation and soil crust formation during maize germination. Significant disease development in a wide range of temperatures was ensured by changes in the species of pathogen composition. In the period of sowing – sprout emergence at soil temperatures above 18 °C, we found that pathogen *Fusarium moniliforme Scheld.* prevailed, while at lower temperatures of 10–15 °C, the proportion of species from the genera Penicillium and Cladosporium increased. This was also found in earlier studies [8].

The hydrothermal regime influenced both the disease development due to its compliance with the pathogen requirements and plant resistance. The effectiveness of the immunological method of pest control was from 20 to 100 %, depending on the pathogen (Table 2).

Adverse weather conditions during wintering weakened winter wheat plants, making them susceptible to root rot pathogens. On the other hand, the stressful reaction of plants to extreme weather conditions could sometimes be interpreted as a manifestation of fungal and viral infections. For example, the spring frost detrimentally affected the plants that were resuming growth. In May 2007, at the stage of stem elongation – the beginning of heading of winter wheat, due to damage by frosts (-4 ... -7 °C), the meristem tissues of internodes and head died and were colonized by necrotrophic microorganisms.

Such damage could be visually misdiagnosed as cercospora root rot due to the presence of eye spots in the root part of the stem and white heads, however, the presence of the pathogen, the fungus *Pseudocercosporella herpotrichoides (Fron.) Deighton*., was not detected by mycological analysis of necrotic areas of the

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Table 1. Grouping grain crop diseases by the nature of development and harmfulness in the Steppe zone

Trait of grouping diseases	Type or conditions of manifestation	Main diseases
Pathogen distribution	constantly high	root rot, powdery mildew, leaf septoria and brown rust of cereals, maize seedling mould, fusarium and ear bacteriosis
	foci in certain years	septoria and fusarium ear blight, oat crown rust, maize stem rot, barley yellow dwarf virus, smuts, nigrosporosis and grey ear rot
	sporadic	yellow rust of cereals, rust and helminthosporium of maize leaves, bacteriosis of leaves and heads
Harmfulness	constantly high	all types of smuts
	high actually	powdery mildew, wheat leaf septoria, maize seedling mould, root rots
	high in certain years	rust of cereals, septoria and fusarium of the head, fusarium rot and bacteriosis of ears
	low	grey ear rot, other sporadic diseases
Hydrothermal dependence	at wet conditions	powdery mildew, septoria, rust, wheat cercospora, blister smut, mould and rot of the head and ears
	in extreme weather conditions	common and fusarium root rot, fusarium stem rot of maize
	at low temperatures	mould of germinating seeds, rots and moulds of winter crops
	low	smuts of cereals
	through the impact on disease vectors	barley yellow dwarf virus and other viruses, ear bacteriosis
Cost-effective methods to manage pathogen development	cultivation of resistant varieties	diseases caused by obligate parasites (powdery mildew, rust, smut, etc.)
	fungicide application	smut diseases of cereals, maize head smut, powdery mildew, rust, leaf septoria
	compliance with agrotechnical, management and economic protection measures	root and stem rots, blister smut, mould of head (ears) and grain, ear rots

stem. In 2001 and 2007, low temperature damage of winter wheat plants was also accompanied by leaf yellowing and shoot development inhibition, which are signs characteristic of barley yellow dwarf virus or nutrient deficiency.

Grain producers are unable to influence both weather conditions and chemical-physical properties of the soil, and therefore the improving agrocenosis can be successfully solved by technologies aimed at the fullest utilization of the ecological resources by plants and controlling the spread of pests. Primarily, agrotechnical practices to improve the conditions of plant growth and development and minimize stressful situations during critical periods of development, which increases plant resistance to pathogens, largely solve the problem of protecting grain crops from environmental and parasitic diseases [7]. On the other hand, agrotechnical practices are an important factor in preventing the accumulation and elimination of the pathogenic basis for almost all grain crop diseases (Table 3).

However, in recent years, the application of various methods of integrated plant protection systems in our country, compared to the period of stable agricultural production (1986–1990), has seen a decrease in the share of agrotechnical practices from 40 % to 17 %, biological practices from 10 % to 3 %, while immunological and chemical practices have increased from 15 % to 20 % and from 35 % to 60 %, respectively [9]. Such changes require a theoretical revision of modern integrated systems and their greater biologisation.

Today, successful agricultural production is impossible without the application of such intensification tools as mineral fertilisers, plant protection products against diseases, pests and weeds, biologically active substances, growth regulators, etc., which can increase the level of agrocenosis productivity by 40–60 %. However, their unregulated application can lead to lower crop yield, deterioration in the quality of crops and negative environmental impact [10].

Three critical stages of plant development can be identified in the grain crop protection against diseases: sowing – sprout emergence, transition from the vegetative to the reproductive phase, and the final period of leaf-stem functioning.

The first stage of protection starts in the pre-sowing and sowing periods, with a number of critical measures that determine the phytosanitary state of the agrocenosis and the grain crop health throughout the growing season.

The field, variety, method of tillage and seed preparation, sowing date and methods, fertilization, etc. must be selected with consideration of the risk of disease losses. Seed treatment is a mandatory activity that ensures external and internal seed disinfection, protects germinating seeds and sprouts from infection in the soil, increases field germination and winter hardiness of plants, and as a result reduces or even eliminates the plant spraying during the growing season. The selection of disinfectants based on the results of phytotechnical examination of seeds and the disease development forecast in each specific condition.

Our research has shown that two critical periods of leaf disease harmfulness and the need for plant protection should be foreseen in the spring and summer. The manifestation of powdery mildew and other spot diseases in the early stages of crop development, even with the subsequent cessation of the disease, will affect the ability of plants to form the expected yield. The pathological process and the negative impact of diseases result in insufficient productive tillering or ear fullness. Grain crops are treated at the end of tillering – beginning of the stem elongation at the damage degree of the two upper leaves with powdery mildew and septoria of 1 % and above, which is approximately 3–4 spots per leaf of powdery mildew or 2–3 septoria spots. The appearance of the flag leaf is the optimal period for the second fungicide treatment of winter wheat crops and pest protection. During this period, the development of brown rust, Septoria, Pyrenophora and other leaf spots progresses. The flag leaf dies when 20 % of its area is affected by the disease, and the yield and quality of the crop are significantly reduced.

Conclusions. In the conditions of unstable moisture and extreme air temperature fluctuations in the Steppe of Ukraine, facultative pathogens are the most widespread among the pathogens of cereals. Agrotechnical practices that ensure high plant viability and prevent the accumulation of the infectious pathogen base play a key role in limiting the development of ecological and parasitic diseases of cereals. When there is a threat of epiphytotic development of

Table 2. Effectiveness of disease control by different methods according to the hydrothermal dependence of their pathogens

Parasites	Hydrothermal dependence	Diseases	Protective effect, %		
			immunological method	agrotechnical practices	chemicals
Obligate	high	powdery mildew, brown rust	100	20	90
	low	smut	80	20	100
Facultative	high	septoria, fusarium head blight, grain and head mould	40	20	80
	low	fusarium and common root rots	20	> 50	20
Viruses	through the impact on disease vectors	barley yellow dwarf virus, stripe mosaic	50	50	90

Table 3. Ecological principles of controlling the phytosanitary state of agrocenosis

Components of the pathological process	Factors controlling the disease development	Methods for control of the phytosanitary state of agrocenosis	Objects of control
Plant	Genetic resistance	Breeding and growing resistant varieties	Obligate parasites*, facultative** – partially
	Acquired resistance	Immunisation of plants with physical (heat treatment, electromagnetic field, etc.), chemical (internal therapy) and biological (pre-immunity) methods	Most of the parasites
	Viability	Agrotechnical methods for increasing plant resistance and compensatory capacity	Facultative parasites
Pathogen (causative agent disease)	Virulence	Select a plant variety with appropriate resistance genes	Obligate parasites
	Infectious load	Crop rotation. Elimination of the infectious basis by chemical (seed dressing, plant spraying), biological (biofungicides), agrotechnical (tillage) or physico-mechanical (manual, heat treatment, irradiation) methods and others. Elimination of the residues of affected plants, weeds, vectors and intermediate hosts of pathogens. Sowing with certified seeds. Quarantine measures.	All obligate and facultative parasites
External environment	Hydrothermal	Setting the right time for sowing, tillage methods, harvesting and yield storage. Irrigation and other measures to avoid plant stress	Same ones
	Edaphic	Tillage, fertilisation and soil improvement, conservation of soil fertility	Same ones
	Biotic	Choosing a predecessor, preventing the spread of competing organisms, maintaining the beneficial organisms	Same ones
	Lighting	Grass stand formation (sowing methods and rates, plant density). Weed control	Pathogens of environmental and parasitic diseases
	Anthropic	Phytohygiene (to avoid plant injuries and poisoning caused by human activity)	Same and wound pathogens

* – *Erysiphe graminis DC, genera Puccinia, Tilletia, Ustilago, Sorosporium reilianum Mc Alp. and others.*

** – *Bipolaris sorokiniana Shoem., genera Fusarium, Drechslera, Septoria, Penicillium, Alternaria and others.*

diseases caused by obligate parasites, in particular leaf spot and smut pathogens, chemical protection of cereals is required.

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Актуальність. Зміни погодно-кліматичних умов вносить свої корективи в формування патогенних комплексів зернових агроценозів, характерних для степової зони України і безпосередньо відбиваються на видовому складі збудників хвороб. Водночас, істотну роль у формотворчих процесах патогенних комплексів відіграють й зміни у технологіях вирощування, що супроводжують перехід до нових форм господарювання. Ці обставини вимагають з'ясування особливостей формування патогенної мікофлори та імунітету рослин з метою наукового обґрунтування заходів стабілізації фітосанітарного стану агроценозів на сучасному етапі зерновиробництва. **Метою досліджень** було проведення розподілу у відповідні групи хвороб зернових культур в зоні Степу за характером розвитку, шкідливості і гідротермічної залежності їх збудників. **Матеріали і методи.** У 1999–2019 рр. нами проведені обстеження посівів пшениці (озимої і ярої), жита, ячменю (озимого і ярого), вівса і кукурудзи на ураженість хворобами в Північному Степу України за загальноприйнятими методиками фітопатологічних досліджень. **Результати.** За роки досліджень у посівах зернових культур було ідентифіковано 123 патогени, що викликали 135 хвороб. Найбільш різноманітний їх склад спостерігався на пшениці та кукурудзі, відповідно 33 і 41 хвороб та 64 і 55 їхніх збудників. Слід відзначити широкий спектр ступеню спеціалізації збудників хвороб, поширених в зоні. Найбільш пристосованими до певного виду зернової культури були збудники сажок, дещо менше – іржі. Менш спеціалізовані паразити, як-от гриби з родів Fusarium, Helminthosporium, Alternaria могли викликати однотипні хвороби кількох видів рослин, а деякі з них були здатні уражувати їх різні органи. Так, гриб Fusarium moniliforme Sheld ми виявляли серед збудників фузаріозних кореневих гнилей пшениці, жита, ячменю і кукурудзи; на останній, зокрема, він виступав збудником пліснявіння сходів, кореневої і стеблової гнилі, гнилі качанів та пліснявіння зерна. **Висновки.** Встановлено, що гідротермічний режим впливає не лише на розвиток патогену, але й відбитися на стійкості рослин. Проблема оздоровлення агроценозів може успішно вирішуватись застосуванням сучасних інтенсивних технологій вирощування зернових культур, що сприяють найповнішому використанню рослинами екологічних ресурсів зони та запобігають поширенню шкідливих організмів.

***Ключові слова**: пшениця озима, кукурудза, патогени, хвороби, гідротермічні умови, шкодочинність*