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STRATEGIES OF DECREASING HARMFULNESS OF FUSARIOSIS AGENTS IN AGROPHYTOCENOSES

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Infections of cultivated plants, transmitted by fusariosis agents, are among the most harmful factors for humans in grain production. Thus, there is an obvious need for effective control over harmfulness of fusariosis agents in agrophytocenoses. Summarizing scientific data on the issues of forming the strategy of decreasing harmfulness of fusariosis agents in agrocenoses. The major factors of decreasing the level of infecting cereal crops with fusarioses are genetic improvement of plants via selection of species and hybrids, resistant to infections, agrotechnical means and chemical control using modern fungicides with a high level of inhibiting the development of the agent during the whole growing season. The main attention should be paid to controlling the presence and prevalence of infections of plants by such species as *F. graminearum*, *F. pseudograminearum*, *F. sporotrichioides*, *F. langsethiae*, *F. poae*, *F. avenaceum* and *F. verticillioides*, producing deoxynivalenol, nivalenol, T2- and HT2-toxins, moniliformin, and fumonisins, dangerous for vertebrates. Effective control over fusariosis agents in agrophytocenoses may be achieved via the introduction of resistant varieties and hybrids, restoration of crop rotations, required agrotechnical means and application of efficient fungicides. Summarizing the works in investigating fundamental and applied problems of fusarioses of cultivated crops is important for the organization of the effective system of mycotoxicological monitoring of cereals in Ukraine.

Keywords: fusariosis, *Fusarium*, mycotoxins, fungicides, agrophytocenoses.

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In recent years the problems of excessive field infections due to fusariosis agents have risen to a dangerously high level. Every 2–4 years, up to 5–15 % of winter cereal fields perish due to root rot infections, primarily, fusarioses. Practically each year a considerable share of Ukrainian grain is ranked lower since the fields are infected with fusariosis and cereals are damaged by mycotoxins.

Agrophytocenoses with *Fusarium* inoculum are contaminated at a global level. Rather low levels of controlling the disease using current agrotechnical and chemical protection means urge geneticists and breeders to create varieties and hybrids of cultivated plants, resistant to *Fusarium* species. However, the results of industrial experiments in all soil-climatic regions of Ukraine have demonstrated that novel genetic and biotechnological achievements and introduction of varieties/hybrids of cereals, resistant to fusariosis, cannot ensure a proper level of controlling the disease and a possibility of obtaining high quality grain.

Thus, it is important to pay attention to all the constituents of the technologies of cultivating plants while elaborating the means of effective control over fusarioses in cereals, which has also been noted by prominent phytopathologists in their works – from classic (Bilay) to modern ones (Gagkaeva, Retman, McMullen) [1–12]. Some means of controlling fusarioses are not efficient enough and thus cannot ensure a proper level of controlling the disease. Therefore, it is possible to achieve high and quality yields of cereals via complex application of different strategies of disease control: breeding resistant species/hybrids, agrotechnical means, first and foremost, returning the plant production of the country to biologically substantiated crop rotations and applying highly efficient fungicides, ensuring a better way of maintaining crop productivity, decreasing the risk of mycotoxin accumulation, ensuring high quality of grain and economic viability of grain production.

Fusarium head blight of cereals and kernel rot are highly harmful diseases, annually decreasing the level of productivity of cereals in Ukraine and causing the contamination of yield with mycotoxins, dangerous for humans and animals. Root rot, caused by the agents of *Fusarium* species, is highly harmful in Ukraine. Taking into consideration economic losses due to diseases and danger for health of the warm-blooded, most countries regulate the set levels of mycotoxins in grain at rather a low level, ppb and less.

It is often believed that plant diseases are caused by one species of the agent or even a specific strain. However, in nature microbes primarily exist in the composition of complex groups, which was noted as far as in the times of van Leeuwenhoek in the 16th century. It is noteworthy that most laboratory studies are based on specific strains of microorganisms, grown in a pure culture. Therefore, at present little is actually known about possible interspecies interactions and/or interactions between different taxons of pathogenic microbes in nature. Numerous infections and many diseases of humans and animals are results of multispecies synergetic interactions. It complicates the disease and should be considered while elaborating efficient control measures. On the other hand, there are scarce data about synergetic pathogen-pathogen interactions in case of diseases of plants, and the mechanisms of interactions are yet unknown. For instance, severe infections of root rot of wheat are caused by *F. graminearum*, *F. culmorum*, *F. poae* and *F. sporotrichioides*, and head blight – by a complex of *Fusarium graminearum* species. Root rot of corn is caused by *F. meridionale* and *F. boothii*, and both root rot and kernel rot – by *Trichoderma* sp., *Penicillium* sp., *Pyrenochaeta indica*, *F. moniliforme*, *F. graminearum* and *oxysporum*. These examples of synergetic interactions between the agents of plant diseases, causing the diseases of whole complexes, may be found to have achieved higher prevalence than expected, and the understanding of the main mechanisms may have important consequences in the field of plant disease epidemiology and fighting diseases [13].

SPECIFICITIES OF GENETIC DETERMINATION OF THE RESISTANCE OF CEREALS TO FUSARIOSES

Resistance to fusarioses is a multigenic feature of cereal crops. The differences between varieties and hybrids in terms of resistance may vary among different countries according to the changes in soil-climatic conditions and specificities of farming. The distinguished types of resistance are as follows: type I – resistance to the primary infection, type II – resistance to the spreading of a disease agent along the plant, type III – resistance to head damage, and type IV – resistance to head blight and trichothecenes. Type V is defined as resistance to the accumulation of trichothecenes. Type V resistance may be formed both via blocking of the accumulation of trichothecenes by inducing the metabolism of toxicants and via inhibiting the biosynthesis of mycotoxins.

250 QTL, present in all 21 chromosomes, have been identified so far. There is a known multigenic resistance: Fhb1 from Sumai 3 = 3B; Fhb2 from Chinese wheat = 6B. Others are QTLs from all the chromosomes of wheat, except for 7D. The most stable ones are on: 1B, 1D, 2B, 2D, 3A, 3B, 5A, 6B. DON resistance is related to 2D, 3B and 5A. The decrease in the damage levels is related to 2D, 3A and 5A [14].

THE ROLE OF CROP ROTATIONS IN INFECTING CEREAL CROP PLANTS WITH FUSARIOSES

Taking into consideration the role of harvest residues, infected with fusariosis agents, in ensuring a high level of inoculum harmfulness in agrophytocenosis, many authors note an important role of crop rotations in decreasing the damage of corn and grain crops by fusarioses [15–20].

Fusariosis agent, *Fusarium graminearum,* usually over-winters on plant residues. Some part of the agent may over-winter on seeds [20, 21]. The degree of the agent over-wintering is higher on plant residues, not infected with rot, for instance, on internodes of grain cereals [22, 23].

Corn fields are dangerous as they promote the development of fusarioses agents, therefore, the recommendations of scientific literature state the need to ensure at least a one-year-period between cereal crops or two years – between crops, sensitive to fusarioses, to decrease harmfulness of the agent [24]. After sowing corn and wheat for three years during the experiments in determining harmfulness of fusariosis agents in the crop rotations, E.B. Khonga and J.C. Sutton found perithecia and ascospores of *Gibberella zeae* – ascigerous stage of the agent of *F. graminearum* in the field, which was mostly found in the course of the first and second year.

S. Inch and J. Gilbert established that *F. graminearum* may be preserved on the infected seed for up to two years, regardless of the location of the seeds – on the soil surface or at the depth of 10 cm in soil [25]. These studies focus the attention on increasing harmfulness of fusarioses in recent years, which is obviously caused by enlarging the area of corn fields in Ukraine. It should be noted that corn fields are enlarged in some regions, first and foremost, in the "grain belt" of Ukraine and mostly in the fields of agroholdings. Due to economic reasons within the recent decade agroholdings and farms have introduced shorter crop rotations, where a high degree of damaging cultivated crops with fusarioses is observed. The agroholdings with large land banks proper define a great export potential of Ukraine in grain production.

A situation, similar to the current one for Ukraine, was observed almost 115 years ago in the eastern and central districts of the "corn belt" in the USA. For instance, D.E. Mathre reported the results of the profitability analysis of cultivating barley and the increase in the level of head blight infection spreading in early 1900s after the corresponding enlargement in the area of corn fields. Fusariosis damage to barley was so extensive that the production of this crop was almost terminated [18].

THE TURNOVER OF A SOIL LAYER: TILLAGE, STUBBLE PLOUGHING – THE FIRST ELEMENT IN CONTROLLING *FUSARIUM* AGENTS

Each methodological recommendation, issued since 1960s up till now to lay out the fundamentals of control fusariosis agents, starts with the thesis about the need of immediate processing of residues (stubble ploughing/tillage) after gathering the harvest. Scientific literature on the depth of tillage after gathering the harvest, deep soil tillage at the depth of 20–30 cm or the surface layer from 10 to 20 cm does not distinguish the impact on the decrease of the development of fusariosis agents, but the predominant majority of decades-long data about the efficiency of *no-till* demonstrate the danger of increased grain damage by mycotoxins. For instance, it was shown that, compared to ploughing, minimal tillage on corn fields resulted in the increase in the level of DON accumulation in the subsequent crop in the crop rotation – wheat – dozens of times [26].

Ploughing/turnover of the soil layer is the first constituent in the strategy of fighting fusarioses of cultivated plants. It should be noted that there is a preserving element of ploughing in terms of keeping harmfulness of fusariosis agents in soil. As a rule, the preservation of fusariosis agents in soil requires plant residues. Here, in case of deficient free oxygen for aerobic processes, the turnover of a heavy soil layer poses a threat of preserving plant residues and keeping harmfulness of the agent in soil. Despite a considerable amount of data about controlling fusariosis in the world literature, starting with Andersen [27] and finishing with modern publications, this specificity of decreasing the efficiency of controlling the disease is almost not considered in the publications. This problem is considered only in the works of D.W. Parry et al., M. McMullen et al., and R.W. Stack [10, 17, 28]. The system of soil tillage affects the prevalence of head blight in the field and the accumulation of mycotoxins [29].

Plant residues, parts of vegetative and generative organs, are the main sources of inoculum in case of infecting with *Fusarium* species [22]. According to the data of different authors, the distances, onto which ascospores are transferred, are in the range from several centimeters to dozens and even hundreds of kilometers. Recent publications have demonstrated that up to 90 % of inoculum comes from rather short distances – up to 6 m [30, 31]. The transfer of ascospores on long distances – dozens or hundreds of kilometers – decreases their harmfulness considerably because of UV-radiation [32–34].

It is noteworthy that economic conditions of grain production form a constant tendency of reducing the elements of cultivation technologies in soil tillage which requires efficient decisions in controlling fusarioses via the introduction of resistant species and application of effective agrochemicals.

THE IMPACT OF NUTRITIOUS BACKGROUND ON THE LEVEL OF CONTROLLING THE AGENTS OF *FUSARIUM* SPECIES

As early as in 1969, P.E. Onuorah demonstrated that the differences in the reaction of wheat varieties to the agents of *Fusarium* depend on the balance of nutrients and the phase of plant development. According to the mentioned author, manual treatment using high doses of nitrogen and potassium on the background of a low level of phosphorus in vegetative experiments decreased the damage of wheat plants by the fusariosis agent [35].

Numerous classic studies of the second half of the previous century demonstrated the efficiency of the main introduction of phosphorus (in the form of orthophosphate), potassium, sulfur, magnesium in terms of decreasing the prevalence of field infection by fusariosis agents.

Also, the introduction of microelements, which are components of redox-systems of plants, may promote the increase in plant resistance to damage from disease agents. Copper, iron, manganese and zinc are relevant elements in this regard. Within recent 10 years, during the experiments in achieving high productivity of winter wheat, the authors studied this dependence and it was not each year that they received statistically reliable yield gains in case of specific application of microelements. It is reasonable to conduct industrial trials of the application of modern complex fertilizers, containing the components of redox-systems of plants along with fungicides.

As for the role of nitrogen nutrition in the level of infecting plants with fusariosis agents, there is no agreement between our own information and the literature data. It is known that cereal crops evidently prefer nitrogen and neither medium nor high productivity level may be achieved without the nitrogen fertilizers. On the other hand, the main nitrogen nutrition for wheat, if introduced within the vegetation period, promotes powerful development of plant mass which may create conditions for increased risk of field damage with the agents of head blight. Also, foliar introduction of nitrogen in different forms, ammonium first and foremost, may cause the damage of a leaf apparatus and stalks of plants with subsequent infecting by disease agents.

Noteworthy is the fact that foliar introduction of both complex and monoform fertilizers containing organic acids, for instance, citrate, etc., cause the dissolution of cuticular waxes and the increased damage of plants with diseases. Further prevalence of diseases among plants also occurs in case of foliar introduction of complex and monoform fertilizers with a high level of ashen index (in particular, ammonium sulfate) or in high physiologically unsubstantiated doses (for instance, 20–25 kg/ha carbamide in the spraying solution with fungicides in the form of emulsion concentrate, *etc.*). In the experiments of 2004–2006, M. Yoshida et al. established that the application of nitrogen in the phase of blossoming increased the content of wheat protein considerably and did not promote the increased damage of plants with head blight and the accumulation of DON (deoxynivalenol) and NIV (nivalenol). These results demonstrate that nitrogen nutrition for wheat may be conducted closer to the phase of blossoming without any limitations in terms of increasing the accumulation of mycotoxins in grain in case of head blight [36]. It was demonstrated [37] that the increase in the background of nitrogen nutrition from 0 to 160 kg/ha caused the relevant increase in the level of infecting wheat heads with head blight – from 2.2 % at 0 N to 6.6 % at the introduction of 160 kg N per hectare. The form of the introduced nitrogen had no reliable impact on the prevalence of fusariosis. In the second series of experiments, after artificial inoculation with strains of *F. graminearum* and *F. culmorum*, the increase in DON accumulation was observed in case of higher nitrogen nutrition from 0 to 80 kg/ha. The level of DON accumulation remained unchanged with further increase in the nitrogen dose. It was also established [38] that the additional introduction of nitrogen and growth regulator Etefon promoted the increase in infecting wheat and triticale with *Fusarium* agents. It was determined [39] that the genotype and the level of zinc supply are factors, affecting the tolerance of wheat to root rot. Zinc deficiency mostly decreased the accumulation of dry substance mass of wheat seedlings. Infecting by *F. solani* decreased the mass of the seedling considerably only in one variety out of the investigated ones. However, infecting with the agent caused the decrease in the level of SH-groups in the roots. The processing with zinc prior to infecting with *Fusarium* increased the resistance of wheat plants to the agent [39–43].

THE IMPACT OF NANOCOMPOUNDS ON THE LEVEL OF CONTROLLING *FUSARIUM* AGENTS

A noteworthy recent work was the search for antifungal preparations among silver compounds. For instance, silver nanoparticles were investigated with the purpose of decreasing the prevalence of infecting rice *Oryza sativa* with the agent *Gibberella fujikuroi* (conidial stage of *Fusarium moniliforme*). It was established that silver nanoparticles decreased the level of harmfulness of *Gibberella fujikuroi* and did not affect seed germination and the development of seedlings [44]. Both silver nanoparticles and, probably, nanoparticles of microelements as components of redox-systems of plants may be promising constituents of the compositions of known fungicides.

THE BIOLOGICAL CONTROL OF DAMAGING CULTIVATED PLANTS BY *FUSARIUM* AGENTS

Constant increase in the application of chemical means to control diseases triggers the occurrence of resistant strains which, along with the increased contamination of agrophytocenoses with xenobiotics, promotes the search for the means of controlling diseases among biological agents. Large-scale studies identified a great number of species which have fine potential in terms of controlling phytopathogenic organisms. About 150 species of plants from 30 families and about 50 compounds were found to have potential antifungal activity. These substances may be used to control the species of *Fusarium* [45, 46]. Numerous means of biological control of fusariosis agents are available at the Ukrainian market of agrochemicals. The authors do not have any statistically reliable confirmations of the efficiency of these means in industrial trials. There were no positive reproducible results, obtained in industrial conditions for the administration of preparations of biological control of *Fusarium* species. This problem is discussed in the works of M. McMullen et al. [11, 12].

The drawback of suggestions on the application of some preparations for biological control is separating them from specific agrophytocenoses, wherefrom they have been isolated. In our opinion, a promising way of decreasing the harmfulness of *Fusarium* species is not just restoring crop rotations in the understanding of "classic" specialists but also introducing/forming biologically substantiated complex agrophytocenoses with a proper number of crops. It is known that the highest current result in the productivity of winter wheat – 15.015 t/ha (2003), 15.636 t/ha (2010), 16.791 t/ha (2017) was obtained by the scientists from New Zealand at simultaneous cultivation of two technical crops. It is evident that both different layering of crops and differences in quality indices can form the cenosis with high productivity. It would be reasonable to consider the possibility of simultaneous cultivation of species/hybrids, different in their level of resistance to diseases. For instance, the drawbacks of species with highly productive plasma in terms of the level of resistance to many diseases may be compensated with an underlaying crop (esparcet for wheat, vetch-oats, etc.). This approach may serve as a factor of decreasing the total level of damaging agrophytocenoses by the agents of *Fusarium* species and stable and commercially viable plant cultivation.

It should be noted that in recent years the margin between the chemical and biological methods has been vanishing quickly. For instance, a well-known fludioxonil is a synthetic analogue of pyrrolnitrine, which is a natural antifungal antibiotic of *Pseudomonas pyrrocinia.*

THE DECREASE IN THE LEVEL OF WEEDINESS OF FIELDS IN CONTROLLING THE AGENTS OF *FUSARIUM* SPECIES

A high level of field weediness is related to a relevant increased level of infecting with head blight [47]. The agents of fusarioses of cultivated plants were found on many grass weeds [48, 49] as well as on dicotyledon weeds [50].

There are scarce data in the scientific literature about the impact of herbicides on the level of infecting cereal crops with fusariosis agents. Perennial studies demonstrated the increase in the level of infecting spring wheat plants with fusariosis agents via spring application of glyphosate [51–53]. C.A. Levesque et al. [54–56] demonstrated that the application of glyphosate increased the level of colonization of six weed species with *Fusarium* species and led to a higher level of inoculum/mycelium density in the arable layer of soil. After the introduction of glyphosate and lactophyte, there was a decrease in the germination of conidia, the growth of mycelium and sporulation of *Fusarium solani* f. sp. *glycines* [57].

Outside of immediate control over weeds, herbicides may change the course of development of diseases which usually occurs via direct impact on the agent or indirect effect via the response of the plant to a phytotoxicant. In laboratory experiments herbicides MCPA and flumetsulam did not affect the growth of fungi. 2.4-DB inhibited the growth of fungus by 16–35 %. Such a herbicide as bentazon had a strong inhibiting effect on the development of *F. oxysporum*. Haloxyfop-methyl stimulated the growth of fungus by 29 %. Therefore, the application of some herbicides may affect the development of soil pathogens such as *Fusarium oxysporum*, stimulating or inhibiting their development [58]. The review of D. Sanyal et al. [59] states that the program of complex fighting with pests, pathogens and weeds requires deep studies on the interaction of agrophytocenosis constituents. Vegetative pathogenic organisms get infected from other pests and systems of applying agrochemicals.

The dependence between the manifestation of phytotoxicity of herbicides and changes in soil microflora was first described in 1945 [60, cit. in 59]. For instance, trifluraline may induce the overgrowth and shatter of soy hypocotyl, which creates conditions for the penetration of *Fusarium oxysporum* and complicates the course of foot rot [61]. The literature decribes numerous facts of inhibiting the development of pathogenic microorganisms, for instance, *Fusarium solani* f. sp. *pisi* with glyphosate on field pea *Pisum sativum* L. [62]. S. Sanofo et al. established that glyphosate decreased the level of germination for conidia, the growth of mycelium and sporulation of *Fusarium solani* [63]. Kidney bean plants (*Phaseolus vulgaris* L.) are exposed to more infecting with *Fusarium* according to the increase in glyphosate concentration [63].

THE IMPACT OF DAMAGE FROM INSECTS ON THE LEVEL OF INFECTING PLANTS WITH *FUSARIUM* SPECIES

Effective control of harmfulness of insects in the fields decreases the level of damage to seedlings and adult plants, and thus the level of field damage by root rot and head blight/kernel rot.

As for direct impact of transferring the agents of *Fusarium* species to plants by insects, it may be foreseen but hard to determine correctly in field and industrial conditions. It should be noted that the presence of many *Fusarium* species in the organisms of numerous species of insects is well-known. As for references, it was written in the review of G.H. Teetor-Barsch and D.W. Roberts in 1983 for 50 years of studies [64].

The works of G.P. Munkvold et al. [65, 66] established that effective control over insects in corn fields with genetically modified insect-resistant corn lines decreased the level of infecting with root rot and the level of fumonisin accumulation in corn along with the decrease in the level of infecting the crop with insects. The differences in the main ways of infecting the plants may also determine the level of the effect of introducing the means of controlling pests on the decrease in infecting the cultivated plants by fusariosis agents. For instance, the level of controlling root rot from pathogen *F. verticillioides* due to the damage of plants by insects will be sufficiently high [67]. This effect of controlling the damage by insects will be considerably lower or will not be detected at all for *F. graminearum*, which infects plants via generative organs of plants [64].

THE IMPACT OF FUNGICIDES ON THE LEVEL OF CONTROLLING F*USARIUM* AGENTS

Modern strategies of controlling the disease involve the use of fungicides, introduction of resistant species/hybrids and ensuring the relevant crop rotation.

In their work M.P. McMullen et al. studied a wide range of active substances of fungicides and made the following conclusions [12]:

▪ *Fusarium* head blight is a severe disease of cultivated plants, which is hard to control.

▪ Simultaneous treatment with fungicides of the class of triazoles may lead to a considerable decrease in the content of mycotoxins (DON) and the increased yield.

▪ The highest efficiency was manifested by prothioconazole, metconazole, tebuconazole + prothioconazole at the anthesis. The application of fungicides at earlier stages decreased the level of controlling head blight.

▪ It is impossible to achieve the level of controlling head blight of 50–55% and to decrease DON content by 40–45% via the introduction of resistant species. The conclusion is – it is possible to control fusariosis via the introduction of complex systems of protection.

▪ The application of fungicides of the strobilurin class to control head blight should be avoided due to its inefficiency [12, 68–71].

The results of extensive studies of Folicur (tebuconazol, 38.7 %) in 1998–2003 demonstrated the decrease in head blight infection only by 39.4 % and the content of mycotoxin DON – by 27.4 % [72]. Other fungicides were considerably less effective in controlling the disease.

The studies in Asia also established that tebuconazol was the most efficient in controlling wheat and barley head blight and decreasing the content of DON. Repeated treatment with tebuconazol did not result in statistically reliable relevant decrease in DON content. The efficiency at the level of tebuconazol was ensured by the introduction of Captain (thiophanate-methyl) and copper in the form of Cu-8-quinolate [73]. The limitation of the number of active substances, efficient against head blight, may create a threat of resistance in the strains of agents. It was demonstrated on the isolates of *F. graminearum*, *F. culmorum*, *F. avenaceum* and *F. poae*, where the efficiency of tebuconazol decreased after many applications [74, 75].

However, it should be noted that large-scale application of fungicides in the plant cultivation of Ukraine does not take place due to economic reasons. Therefore, the problems regarding the occurrence of resistant species of head blight strains may be postponed for some time. The application of specific active substances of fungicides should be considered not as a factor of controlling a wide range of disease agents but rather as a factor of changing microflora balance in agrophytocenosis. Therefore, the efficient control of fusariosis agents should also be accompanied with proper control over the agents of other diseases, dangerous for the region, which may be achieved by the introduction of complexes of fungicides.

For instance, the specificities of sensitivity of *Fusarium* species and saprophytic fungi, which damage wheat head and are antagonists to *Fusarium* species, were investigated. The investigation was carried out on isolates from winter wheat heads of *Alternaria alternata*, *Arthrinium* sp., *Aspergillus niger*, *Epicoccum* spp., *Microdochium* spp., *Rhizopus oryzae* and *Trichoderma* spp. In a polycomponent culture, *A. niger*, *R. oryzae* and *Trichoderma hamatum* were more efficient in inhibiting the growth of mycelium of *Fusarium* species compared to *Microdochium majus*. The species *A. alternate* and *Epicoccum* spp. were less efficient due to slow growth of mycelium. Saprophytic species were sensitive to triazoles. Prothioconazole and tebuconazole inhibited the growth of *Fusarium* species. Due to differences in the sensitivity to fungicides, remarkable for *Fusarium* species and their antagonists – saprophytic species, colonizing winter wheat heads, the application of fungicides modifies the balance of microflora of wheat head, which may impact the contamination of grain with mycotoxins [76].

It was established that the decrease in the level of infecting plants with head blight after the application of fungicides did not necessarily cause a relevant decrease in the accumulation of mycotoxins in grain.

A considerable amount of fungicides in sublethal concentrations stimulates the accumulation of mycotoxins *in vitro* [77, 78]. This fact testifies to the inadmissibility of decreasing the set doses of fungicides and using preparations, non-selective to disease agents.

It is important to use modern fungicides, highly active to disease agents, from the class of inhibitors of succinate dehydrogenase of generation II, first and foremost. For instance, this is Adepidyn (active substance – pidiflumetofen), which enhances the efficiency of known triazoles in controlling *Fusarium* agents, for instance, tebuconazole, considerably. Pidiflumetofen in compositions with fungicides of the group of triazoles enhances the efficiency of the composition, prolonging the terms of effective controlling of the agents and efficiently fighting the formation of resistance in the agents of harmful diseases, including fusariosis, Septoria blight, mildew *etc*.

There was also an investigation of the impact of infecting with the agents of *Fusarium* spp. and *Microdochium nivale* on quality indices of the grain of winter wheat, spring wheat, and oats in Sweden after previous treatment with such fungicides as Celest Extra, Formula M (CEFM, difenoconazole + fludioxonil) and Celest, Formula M (CFM, fludioxonil). During field experiments, the treatment of spring wheat seeds with CEFM did not have a considerable impact on most agronomic indices, including harvest. The treatment of the grain of winter wheat and oats with CFM led to the increase in the yield by 7–11 % and the density of plant stand by 33 % without any considerable impact on other indices [78].

The estimation of the term of applying fungicides against the fusariosis agents established that the efficiency of preparations, used 7 days after infecting, was much lower in case of introducing fungicides one day prior to infecting [79].

In the studies of C. Rodriguez-Brljevich, when corn damage started immediately after sowing, the dominating species was *F. graminearum*, and during the vegetative season the colonies of *F. subglutinans* and *F. verticillioides* were the most frequent in the plants of the crop. *Fusarium graminearum* was the most competitive species among *Fusarium* spp. in the colonization of corn rhizosphere; this specificity may have ensured its domination in the cenosis up to the phase of the second corn leaf [80].

Therefore, infecting the cultivated plants with fusariosis agents is one of the main harmful factors for humans in grain production although the agents of *Fusarium* species are saprophytes for a greater part of their life. The active development of plant cultivation in Ukraine highlighted many problems which only get more complicated with time. These super-complicated issues involve the need of efficient control over harmfulness of fusariosis agents in agrophytocenoses. First, this approach is of exclusive relevance for the application, and grain damage by the agents of different *Fusarium* species and mycotoxins is regulated by Ukrainian legislation and normative documents of the leading countries. Therefore, the need to solve this issue has powerful economic substantiation.

The major factors of decreasing the level of infecting cereal crops and other relevant agricultural crops with fusarioses are genetic improvement of plants via selection of species and hybrids resistant to infections, and chemical control using modern fungicides with a high level of inhibiting the development of the agent for a long time, actually – the whole growing season of the crop. Due to the threat of grain contamination with mycotoxins, the main attention should be paid to controlling the presence and infection with the species of *F. graminearum*, *F. pseudograminearum*, *F. sporotrichioides*, *F. langsethiae*, *F. poae*, *F. avenaceum* and *F. verticillioides*. The main mycotoxins, forming the most widespread species of fungi of *Fusarium* species, – deoxynivalenol, nivalenol, T2- and HT2-toxins, moniliformin, fumonisins – are exclusively dangerous for vertebrates. Therefore, there is an urgent need of creating a reliable system of measures in preventing mycotoxicoses of humans and animals. The use of PCR and ELISA allows to rapid and inexpensive control the presence of pathogens and mycotoxins. This relevant task requires uniting the efforts of specialists, which would allow summarizing extensive studies of fundamental and applied problems of fusarioses of cultivated plants with the purpose of increasing the efficiency of controlling *Fusarium* agents in agrophytocenoses of Ukraine.

Стратегії зменшення шкодочинності збудників фузаріозу в агрофітоценозах

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Інфікування культурних рослин збудниками фузаріозів є одним із головних шкодочинних факторів для людини у зерновиробництві. Тому, очевидна необхідність ефективного контролю шкодочинності збудників фузаріозу в агрофітоценозах. Узагальнено наукові дані з питань формування стратегій зменшення шкодочинності збудників фузаріозу в агроценозах. Головними факторами зниження рівня інфікування зернових культур фузаріозами є генетичне поліпшення рослин шляхом створення резистентних до інфікування сортів і гібридів, агротехнічні заходи та хімічний контроль з використанням сучасних фунгіцидів з високим рівнем інгібування розвитку збудника протягом усього вегетаційного сезону. Основна увага повинна приділятися контролю присутності та інфікування рослин видами *F. graminearum*, *F. pseudograminearum*, *F. sporotrichioides*, *F. langsethiae*, *F. poae*, *F. avenaceum* та *F. verticillioides*, які продукують небезпечні для хребетних тварин дезоксиніваленол, ніваленол, Т2- і НТ2-токсини, моніліформін та фумонізини. Ефективний контроль збудників фузаріозів в агрофітоценозах може бути досягнуто за впровадження резистентних сортів та гібридів, відновлення сівозмін, необхідних агротехнічних заходів, а також застосування ефективних фунгіцидів. Узагальнення розробок з дослідження фундаментальних та прикладних проблем фузаріозів культурних рослин важливо для організації ефективної системи мікотоксикологічного моніторингу збіжжя по Україні.

Ключові слова: фузаріоз, *Fusarium*, мікотоксини, фунгіциди, агрофітоценози.

Стратегии снижения вредоносности возбудителей фузариоза в агрофитоценозах

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Инфицирование культурных растений возбудителями фузариоза является одним из главных вредоносных факторов для человека в зернопроизводстве. Поэтому очевидна необходимость эффективного контроля вредоносности возбудителей фузариоза в агрофитоценозах. Обобщены научные данные по вопросам формирования стратегий уменьшения вредоносности возбудителей фузариоза в агроценозах. Главными факторами снижения уровня инфицирования зерновых культур фузариозами являются генетическое улучшение растений путем создания резистентных к инфицированию сортов и гибридов, агротехнические мероприятия и химический контроль с использованием современных фунгицидов с высоким уровнем ингибирования развития возбудителя в течение всего вегетационного сезона. Основное внимание должно уделяться контролю присутствия и инфицирования растений видами *F. graminearum*, *F. pseudograminearum*, *F. sporotrichioides*, *F. langsethiae*, *F. poae*, *F. avenaceum* и *F. verticillioides*, продуцирующих опасные для позвоночных животных дезоксиниваленол, ниваленол, Т2- и НТ 2-токсины, монилиформин и фуминозин. Эффективный контроль возбудителей фузариоза в агрофитоценозах может быть достигнут при внедрении резистентных сортов и гибридов, восстановлении севооборотов, необходимых агротехнических мероприятий, а также применении эффективных фунгицидов. Обобщение разработок по исследованию фундаментальных и прикладных проблем фузариоза культурных растений важно для организации эффективной системы микотоксикологического мониторинга зерна в Украине.

Ключевые слова: фузариоз, *Fusarium*, микотоксины, фунгициды, агрофитоценозы.

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