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MICROORGANISMS AND GLOBAL CLIMATE CHANGE

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Abstract

Today, a global climate change is speeding up (Intergovernmental Panel on Climate Change — IPCC, Switzerland) that limits leaving organisms' adaptation to the environment. As a result, the distribution of phytopathogenic fungi may obviously change. Particularly, in 1985 a new disease of wheat yellow leaf spot appeared in the European south of Russia (Krasnodar Region) (E.F. Granina et al., 1989). In 2005-2007 the causal agent of yellow leaf spot *Pyrenophora tritici-repentis* was found on wheat in North-Western Region of Russia. On some cultivars the disease severity reached 70 %, and pathogens become more virulent and viable. Despite the North Caucasus and the Far East were specific areas for *Fusarium graminearum* in Russia, since 2003 *F. graminearum* appeared on the territory of the Russian North-West. The average disease severity on cereals was 93.3 % in 2007 and 87.3 % in 2008. Recently *F. graminearum* predominates on cereals in the Netherlands (J. Arts et al., 2003), GB (P. Jennings et al., 2004), North Germany (T. Miedaner et al., 2008) and Finland (T. Yli-Mattila et al., 2010). In the south of Russia, *Septoria tritici* predominates among species causing wheat glum blotch, and in the North-West it is *Stagonospora nodorum.* In 2003-2005, *S. tritici* became the main wheat pathogen in the North-Western Russia. On susceptible spring wheat cultivars the disease was found in 51 to 100 % plants, with a severity of 8 to 30 %. These observations suggest that global warming of climate leads to an expansion of thermophilic fungi species, and pathogens begin to spread from the south to the north. *Pythium, Rhizoctonia, Sclerotinia* soil fungi are influenced by climatic factors. They form the overwintering structures that protect them from external influences. Increasing the temperature can lead to a decrease of the latent period and to increase of pathogens aggressiveness. Temperature can influence the function of the parasites virulence genes and resistance genes in plants. Thus, it is necessary to control the emergence of new plant diseases, improve protective measures, and develop cultivars with high adaptability.

Keywords: climate change, phytopathogenic fungi, soil microorganisms, bioecology of microorganisms, environment conditions.

Various aspects of the problem of global climate change, including its possible catastrophic impact on agriculture are discussed at all levels in recent years. According to experts, Russia not get over 40 million tons of the full amount of crop production in grain equivalent annually. Climate change can result in the extinction of 30-40 % of plant and animal species, degradation of key ecosystems, reduced agricultural productivity and thus to the aggravation of the problem of food safety [1].

The climate change will undoubtedly affect the abundance of harmful and beneficial organisms, their biological and ecological characteristics, relationships with plants. Information about these changes will be critical for creating science-based systems of integrated plant protection and improvement of soil fertility.

The spread of plant diseases under global warming. In 1985, a new disease of wheat yellow leaf spot caused by the *Pyrenophora tritici-repentis* (Died.) Drechsler fungus was identified in the Krasnodar Territory [2]. In 1992-1993 the disease was identified in the Stavropol Territory, though it did not occur in the northern latitudes. But in 2005-2007, yellow leaf spot was found on wheat in Leningrad, Pskov, and Novgorod regions [3]. On some varieties of spring and winter wheat, the disease severity reached 70 % [4]. Population analysis demonstrated that «southern» populations are more diverse in their racial composition than «northern» ones, but the latter are more virulent to differentiator varieties [5]. The age of a population is known to affects its structure. Apparently, the *P. tritici-repentis* pathogen in the new environmental conditions has not yet accumulated enough mutations to ensure the intraspecies diversity, and is fixed in the new niche by increasing its virulent and aggressive properties. In addition, the life cycle of the parasite includes a sexual and an asexual stages. The presence of a sexual stage creates additional opportunities for the preservation of the fungus in the new environmental conditions and for the increase in genetic diversity, which allows the fungus to remain in non-standard conditions in the uncharacteristic assortment of wheat.

Fusariosis of cereals is among the most dangerous diseases of plants. In the late 1980s and early 1990s, the strongest epiphytotic of wheat head blight outbreak occurred in the North Caucasus. The main causative agent of the disease was the fungus *Fusarium graminearum* Schwabe. Historically, its main habitat in Russia is the North Caucasus and the Far East. This fungus was found in the cereal crops in the Central Chernozem region and central Russia with a low frequency. However, since 2003, *F. graminearum* appeared in complex of pathogens that cause fusariosis of cereal crops cultivated in the North-West Russia [6]. It was originally identified in Leningrad Region, but in 2007 it appeared in Vologda, Novgorod, and Kirov regions, and in 2008 in Kaliningrad and Pskov regions. The average disease severity on cereals was 93.3 % in 2007 and 87.3 % in 2008. The number of samples with *Fusarium* infection in the north of chernozem Soil Zone averaged 93.3 % in 2007 and 87.3 % in 2008 [7], which can be explained by the global warming and the changes observed in the composition of the atmosphere. This is proved by the publication of our colleagues from the Nordic countries. In the recent years, *F. graminearum* predominates on cereals in the Netherlands [8], Great Britain [9], North Germany [10], and Finland [11].

With the ambient temperature changes, changes in species dominance can occur. The situation described for the North of Italy can be an example [12]. In this area, fungus *Fusarium verticillioides* (Sacc.) Nirenberg was predominant on corn. The optimum for the growth of the above species is 25-30 °C. The summer of 2003-2004 was dry and hot. Fungus *Aspergillus flavus* Link ex Gray tolerant to the temperature of 35 °C became predominant. Temperature above 30 °C enhanced the production of aflatoxins. As for the production of tricothene mycotoxins, their accumulation in wheat grains was shown to increase at the temperature above 32 °C [12].

Septoriosis is another harmful disease of wheat. There are two main causative agents. These are *Stagonospora nodorum* (Berk.) Castell. et Germano [teleomorph *Phaeosphaeria nodorum* (E. Mull.) Hedjiar.] which causes wheat leave and ear septoriosis, and *Septoria tritici* Roberge ex Desm. [teleomorph *Mycosphaerella graminicola* (Fuckel) J. Schroet.], wheat leave septoriosis pathogen. The *Stagonospora nodorum* species is widespread, but it is predominant and most harmful in the North-West and Volga-Vyatka region, as well as in the Baltic countries. The *Septoria tritici* species is predominant and causes great harm in the southern regions, such as the North Caucasus, the Lower Volga, in the south-east of Ukraine, and in Moldova [13]. Since 2007, the south species of *S. tritici* became the pathogen in the North-West [14]. Infestation of spring wheat in the phase of milky-wax ripeness was 51-100 % depending on the variety, and the severity of the disease was from 8 to 30 %.

A new pathogen of *Ramularia collo-cygni* was described on barley in 2011 in the Krasnodar Territory [15]. This thermophilic species is distributed mainly in the southern countries, but in 2013 it was found in the north of Russia in Arkhangelsk Region in the vicinity of Kotlas.

All these observations suggest that global warming results in the expansion of the area of thermophilic fungi species, and southern diseases begin to spread to the north.

Climate and soil organisms. Extreme weather events such as long periods of drought and heavy rainfalls have a strong impact on the metabolic activity of microbes. This can lead to a change in the balance of soil nutrients and even increase the nitrogen oxide emissions. Global climate change may affect the structure of the soil microbiota, directly or indirectly. The direct effect is manifested, for example, by an increase in the soil temperature which usually stimulates the activity of soil microorganisms. Hot and dry spring and summer weather is favorable for the development of soil fungi such as root rot pathogens. The warming of the soil is known to increases the frequency of horizontal gene transfer among bacteria. An increase in temperature from 20 to 30 °C has been experimentally shown [16] to increase 10-fold the frequency of conjugation and gene transfer between *Escherichia coli* и *Rhizobium meliloti*. Indirect effects of climate change on microorganisms are manifested through the effect on the physiological and biochemical processes in plants. For example, it is known that an increase in CO_2 concentration decreases the concentration of nitrates in the soil and at the same time increases mycorrhiza saturation by 47 %, and the number of nitrogen-fixing bacteria increases as well [17].

Impact of climate change on the bio-ecology of microorganisms. Each organism has its optimum temperature for growth and development. Typically, in the majority of fungi, this optimum is in the range of 24-28 °C with a minimum of 4-8 °C and the maximum allowable temperature of 30-35 °C. In some species, the maximum exceeds 40 °C, e.g., for the spores of *Ustilago avenae* Pers. it is 50-53 °C [18]. Apparently, heat-resistant species should be paid particular attention when predicting phytosanitary situation due to climate warming.

Fluctuations of temperature sensitivity may occur within the same genus. For example, wheat rust pathogens differ in their requirements for temperature. In particular, yellow rust develops at the temperature of 2-15 °C, brown rust needs 10-30 °C and for stem rust it is 15-35 °C [19]. The spores of *Tilletia asperifolioides* G.W. Fisch., *T. bromi-tectorum* J. Urries, *T. caries* (DC) Tul., *T. contraversa* Kuehn, *T. elymi* Diet et Holw., *T. fusca* Eliss et Everh., *T. guyotiana* Hariot, *T. holci* (West.) DeToni, *T. scrobiculata* G.W. Fisch. germinate at 5 °C, whereas it is 10 °C for *T. asperifola* Eliss et Everh. spores and 15 °C for *T. pallida* G.W. Fisch. Spores [20]. It should also be considered that in different stages (conidia sporulation, mycelial growth, formation of overwintering structures) fungi may have different requirements for temperature. Fungus *Cronartium fusiforme* Hedgc. et N.R. Hunt is an example, with its ascospores germinating at the minimum temperature of 11 °C, optimum of 21 °C and maximum of 29 °C, urediniospores germinating at the minimum temperature of 8 °C and maximum of 29 °C, and teliospores germinating at 15 °C and 26 °C, respectively [21].

Obviously, for the prediction of the potential development of a disease in the new environmental conditions, particular attention should be paid to the detailed study of the temperature requirements in each pathogen stage. This is also important because different scenarios for climate warming are expected. Some experts believe that winters will be warmer, while others suggest that it will be summers, and the warming will affect the northern latitudes greater [22]. Moderately warm winters may contribute to the survival of the fungal genera *Alternaria*, *Cercospora*, *Colletotrichum*, *Phomopsis*, *Septoria*, *Venturia.* Higher winter temperature contributes to the preservation of the stem rust pathogen *Puccinia graminis* Pers. and enhances the further development of the disease on *Festuca arundinaceae* and *Lolium perenne* [23]. Soil fungi belonging to the *Pythium, Rhizoctonia, Sclerotinia* genera, etc. will be affected by climatic factors to a lesser extent, as they form the overwintering structures that protect them from external influences. According to researchers, the warmer summer contributes to the development of the *Podosphaera*, *Sphaerotheca*, *Uncinula* and *Ustilago* species [24].

Temperature increases may result in a decrease of the latent period such as in a wheat septoriosis pathogen *S. tritici* [25]. When this pathogen was cultured in different temperature conditions, a dependency of the pycnidia formation frequency on the incubation temperature was found [26]. Thus, pycnidia were formed on the varieties of Katepwa, Kyle, and AC Melita at day 11 after inoculation and incubation at 22 °C during the day and at 15 °C at night and at incubation day 19 at 15 °C during the day and at 11 °C at night. Observations of the potato late blight in Finland have shown that while at the beginning of the 1990s it appeared in 80-90 days after planting, starting from 1998 it appeared on the day 40 to 50 after planting [27]. With increasing temperature, the leaf infestation increases concurrently which indicates the growing pathogen aggressiveness. Rust fungi behave similarly, i.e., temperature increase often results in an increase of aggressiveness [28].

Climate and interrelations of microorganisms with plants. Undoubtedly, climate change will affect the host and parasite interrelations. Under the impact of high temperatures, plants habit can change, tissues are destroyed, and organs die. At higher temperatures, the changes in the RNA metabolism and protein synthesis, as well as enzyme activity are possible [29]. Plants are known to be more susceptible to diseases after stress [30]. This will undoubtedly affect their resistance against parasites and pathogens. Research shows that, for example, wheat and oats become more susceptible to pathogens with an increase in temperature, but some types of cereal become more resistant with increasing temperature [31]. The temperature can seriously affect the effectiveness of resistance genes. Thus, the temperature above 20 °C may cause the loss of resistance to stem rust in oat varieties with genes *Pg3* and *Pg4* [32]. Conversely, the lignification of cell walls is enhanced at higher temperatures, thereby the resistance against fungal pathogens increases. Rape resistance to stem cancer is observed at a temperature of 15 °C and is not manifested at 25 °C [33]. The varieties with durable resistance to pathogens are less dependent on the environmental factors [34]. The temperature also affects the functioning of virulence genes in parasites [35].

Some protective measures in the conditions of climate warming. First of all, constant monitoring of the emergence of new plant diseases is required. Particular attention should be paid to pathogen species that may be found in the more northern regions. To control the soil microbial communities, metagenomic studies are necessary. To predict the species preservation in the new environmental conditions and the development of diseases, a detailed study of the biological and ecological characteristics of pathogens is required. As noted above, even the fungi belonging to the same genus differ in their requirements to the temperature. Based on the biological and ecological features of pathogens, their development due to climate warming can be predicted. However, it should be kept in mind that climate change may be different in different areas of the same country. The result of protective measures, of course, depends on the effects of climatic factors. Extreme temperature, winds, rainfall, etc. may affect the phytotoxicity of the fungicides, the dynamics of their content in the soil, precipitation on the leaves, leaf uptake and degradation of the drug. Our study in several areas of the country has proven that climate and weather conditions had a significant impact on the effectiveness of pesticides. Long experience in the North Ossetia showed that treatment with pesticides in the years with normal weather conditions increased the yield of Partizanka variety wheat by 4.3-5.0 %. The yield was reduced by 8.5-13.7 % in the year with excessive moisture after treatment with pesticides [36]. These findings suggest the need to consider not only the degree of development of pests, but also climatic features. In breeding programs, more attention should be paid to the unification of small resistance genes and genes controlling race nonspecific resistance in varieties, which will provide long-term disease resistance in the changing environmental conditions. New approaches to the breeding of resistant varieties, including marker (marker-assisted selection) and transgenic selection should be used more comprehensively [37, 38].

Thus, humanity has entered the era of global climate change. The challenges of agro-ecosystems conservation in the new environmental conditions are on the agenda. Special attention should be paid to the breeding of resistant varieties, in particular to the creation of varieties with a broader ability to adapt to the changing environmental conditions. One of the factors of maintaining agro-ecosystem stability is the science-based system of integrated plant protection. Climate change on the planet is of international importance, so it would be timely to establish an international network of observing the spread of plant diseases, the microorganisms in the soil environment and to ensure the continuous exchange of information between countries.

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