Parasitic activity of plant pathogens at the underground organs of spring wheat in the West Siberia

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Abstract. The purpose of the research was to determine the factors of soil phytopathogens parasitic activity at the underground organs of spring wheat varieties, to clarify the etiology of root rot during the growing season. The studies were carried out in 2020-2021 in the northern forest-steppe of the Ob region (West Siberia) using generally accepted methods. A high parasitic activity of soil phytopathogens was established during the entire growing season of spring wheat: the zonal threshold of harmfulness was exceeded at seedlings up to 2.8 times, at bloom stage to 5 times, and at ripeness stage up to 4 times. The host plants susceptibility to infection with phytopathogens increased during the growing season due to abiotic (drought) and biotic (cereal flies) stresses, which neutralized varietal differences. The main phytopathogens at the underground organs of 20 spring wheat varieties were Bipolaris sorokiniana Sacc. Shom. and Fusarium Link. fungi, the occurrence of which at all underground plant organs (primary roots, secondary roots, stem bases) during the growing season was 100%. The dominance of Fusarium fungi increased during the growing season of plants. The biological diversity of Fusarium fungi was maximal in the bloom phase (up to 7 species on secondary roots of one variety). The species composition of Fusarium fungi was represented by permanent species - F. poae (Peck.) Wollenw. and F. oxysporum Schltdl., additional species - F. sambucinum Fuck., F. graminearum Schwabe and F. equiseti (Corda) Sacc., rare - F. solani Koord., F. sporotrichioides Sherb., F. culmorum Sacc., F. heterosporum Nees., F. acuminatum Ellis & Verb. The succession of Fusarium fungi in the system of plant organs and in the phases of vegetation was revealed, and the parameters of realized ecological niches overlap of Fusarium fungi species were determined.

1. Introduction
The increase in the area of the conductive (favorable for phytopathogens) soils and their colonization, in particular, by root rot pathogens of the most important agricultural crops, including those from the genus Fusarium, has become a global problem. These phytopathogens on the territory of Russia almost everywhere (by ~ 80%) colonized the agricultural cenosis’ soil above the biological thresholds of harmfulness. According to FAO, the global areas of degraded and diseased (conductive) soils exceeded 1.2 billion hectares, and direct losses from soil fatigue and harmfulness of soil phytopathogens account for 25% of the world harvest [1-3]. Under these conditions, ensuring a favorable phytosanitary state of soils and limiting the expansion of root infecting pathogens is
achieved by purposeful induction and maintenance of soil suppression, that is, suppression of the development or elimination of economically significant phytopathogens [4, 5]. *Fusarium* fungi are the causative agents of many cultivated and wild plants diseases. The fungi of this genus cause root rot, *Fusarium* spike blight and plant wilt [6-8]. In addition to reducing the yield and quality of products, the main feature and *Fusarium* pathogens danger is their ability to accumulate mycotoxins in products. *Fusarium* fungi produce 148 toxic compounds that are extremely hazardous to human and animal health. Among them are zearalenone and trichothecene mycotoxins. The use of products contaminated with these mycotoxins causes serious diseases in humans and animals [9, 10].

In the process of evolution *Fusarium* fungi have formed with host plants two-membered (parasite-host) parasitic systems characterized by relative stability and long-term functioning in time and space [11, 12]. The details of the *Fusarium* fungi parasitic systems functioning have been insufficiently studied, given the exceptional practical significance of this fundamental problem. All fungi of the *Fusarium* genus are soil micromycetes, their main ecological niche is the underground organs of plants, where they carry out trophic functions and reproduce [13].

The details of the ecological niches implementation in the system of underground plant organs by individual types of phytopathogens have not been studied. The degree of ecological niches overlapping by *Fusarium* species has not been determined, as well as the influence of host plants on these processes. Varieties of cultivated plant species, differing in origin and having significant genomic differences, can influence the realization and size of certain phytopathogenic species ecological niches, but this aspect of the parasitic systems functioning studies are insufficient.

2. Methods and materials

Objective of the research: revealing the ability of spring wheat varieties to suppress the parasitic activity of *Fusarium* fungi by limiting their ecological niches.

To carry out research on an experimental field located in the northern forest-steppe of the Ob region 20 varieties were sown from the Institute of Cytology and Genetics SB RAS collection of spring wheat (laboratory of plant gene pool) from different regions: Novosibirskaya 15, Sibirskaya 17, Obskaya 2 (Novosibirsk region), LT-3 (Leningrad region), Voronezhskaya 18 (Voronezh region), Tulaykovskaya Nadezhda (Samara region), Zaurolochka (Kurgan region), Long Fu 13 (China), Stepnaya 53 (Kazakhstan), DL 803-2 (India), Mayon 1 (Syria), Remus (Germany), Manu (Finland), Quarna (Switzerland), Toma (Belarus), Evros (Greece), Calingiri (Australia), NIL Thatcher Lr35 (Canada), M83-1541 (USA), Karee (South Africa).

The area under each variety was 2 m² in triplicate. The predecessor was fallow. The soil was leached black soil. The hydrothermal conditions of the 2020 growing season were quite extreme and contributed to the development of *Fusarium* infection. May was very warm and humid. The excess of the average annual temperature data was 4.4 degrees. At the same time, 1.6 rainfall rates fell. In June, against the background of mean annual temperatures, only 45% of precipitation from long-term norm fell. The plants experienced water stress. In July, 1.35 rainfall rates fell, the temperature was close to the average annual values. August, like May, was warm and humid, the average monthly temperature exceeded the norm by 2.4 degrees, and precipitation fell 1.28 from the average annual norm.

To establish the varietal etiology of *Fusarium* root rot and the confinement degree of the individual *Fusarium* species ecological niches to plant organs and their varieties, 60 plants (20 plants from each replication) of each spring wheat variety were selected and their mycological analysis was carried out differentiated by organs - stem base, primary roots and secondary roots. Organ-differentiated analysis made it possible to clarify the confinement of fungi to individual plant organs and to reveal the size of ecological niches of certain species in the host organ system, as well as to study the degree of divergence of phytopathogens ecological niches. To study the dynamics and direction of the pathogenic mycocenosis succession, the selection of plants was carried out in dynamics according to the phases of vegetation (seedlings, bloom, ripeness). Mycological analysis of organs was carried out on Chapek agar (CA) in 5 replicates. Phytopathogens were isolated in a pure culture on potato dextrose agar (PDA) and identified to a species according to classical keys [14]. For each species, the
frequency (in %) of its occurrence on plant organs and by varieties, in dynamics by phases of vegetation, was determined. The confinement of each selected species to individual plant organs was established, the presence or absence of the influence of the variety was revealed. The *Fusarium* fungi succession in plant ontogeny was studied by changing the frequency of their occurrence, by the appearance or disappearance of species on organs as they mature. The degree of overlap or divergence of individual phytopathogens realized ecological niches was determined by the frequency of their joint occurrence on the same organs on the scale: 0% - complete divergence of ecological niches, no joint occurrence; 1-30% - weak overlap; 31-50% moderate overlap; 51-100% strong overlap.

3. Results and discussion

3.1 Parasitic activity of soil phytopathogens
The parasitic activity of soil phytopathogens was high throughout the growing season: the zonal threshold of harmfulness (TH) was exceeded by seedlings up to 2.8 times (TH = 5%), at bloom - up to 5 times (TH = 10%), and at ripeness - up to 4 times (TH = 15%) (table 1).

| Variety                  | Seedlings | Bloom | Ripeness |
|--------------------------|-----------|-------|----------|
| Novosibirskaya 15        | 6.6       | 43.3  | 46.4     |
| Sibirskaya 17            | 10.1      | 34.8  | 50.1     |
| Obskaya 2                | 11.1      | 37.0  | 46.4     |
| Average on Siberian      | 9.3       | 38.4  | 47.6     |
| LT-3                     | 9.1       | 42.3  | 43.1     |
| Tulaykovskaya Nadezhda   | 14.0      | 39.5  | 47.8     |
| Voronezhskaya            | 8.6       | 48.3  | 42.3     |
| Zauralochka              | 6.1       | 37.4  | 47.3     |
| Average on European part of the Russian Federation | 9.5       | 41.9  | 45.1     |
| Long Fu 13               | 9.2       | 46.5  | 50.3     |
| Stepnaya 53              | 10.9      | 33.2  | 43.9     |
| DL 803-2                 | 13.2      | 45.3  | 43.9     |
| Mayon 1                  | 10.7      | 48.3  | 52.3     |
| Average on Asia          | 11.0      | 43.3  | 47.6     |
| Remus                    | 6.6       | 49.5  | 52.8     |
| Manu                     | 12.4      | 36.3  | 55.0     |
| Quarna                   | 11.6      | 41.4  | 53.6     |
| Toma                     | 9.7       | 41.1  | 40.3     |
| Evros                    | 11.4      | 45.9  | 39.7     |
| Average on Western Europe| 10.3      | 42.8  | 48.3     |
| Calingiri                | 6.2       | 46.4  | 60.0     |
| NIL Thatcher Lr35        | 12.5      | 37.9  | 55.8     |
| M83-1541                 | 8.0       | 42.5  | 46.7     |
| Karee                    | 8.8       | 45.9  | 50.8     |
| Average on America, Africa, Australia | 8.9       | 43.2  | 53.3     |
| Smallest significant difference in average values, significance level - 0.05 | 1.18       | 5.12  | 5.63     |

The dynamics of the root rot epiphytotic process reflected the peculiarities of the growing season hydrothermal conditions. May contributed to the rapid growth of spring wheat plants and the active course of microbiological processes. This can explain the relatively low parasitic activity of phytopathogens at the seedlings phase. In June, against the background of average annual
temperatures, only 45% of precipitation fell out of the multiyear average. Plants underwent water stress, which intensified the development of the disease [15]. At the same time, they were severely (up to 100%) damaged by intra-stem pests (Oscinella pusilla Mg., Phorbia genitalis Schnalb., Mayetiola destructor Say.), which enhanced the root rot pathogenesis, regardless of the disease etiology [12]. The correlation coefficient between the root rot incidence and damage by intra-stem pests was R = 0.713 ± 0.092. In this regard, at the bloom phase, a strong symptoms manifestation caused by soil phytopathogens was noted. The root rot epiphytotic process activity increased 4-6 times. Then, the root rot epiphytotic process reached a plateau, which is typical for soil infections [2]. The difference in the infestation of varieties between the bloom and ripeness phases was 5-20%, that is, it was insignificant. Studies have not allowed to identify resistant to root rot varieties within the studied collection. Under conditions of massive damage by cereal flies, all varieties by the end of the growing season had a high, similar in level of infestation. The variation coefficient reflects the regularity of the varietal differences impact on the root rot epiphytotic process during the growing season. Thus, at the seedlings phase C_V was 24.1 ± 4.0, at the bloom phase it decreased 2.5 times and amounted to 10.9 ± 1.7, at the end of the growing season - 9.4 ± 1.5, that is, there was a leveling varieties by root rot infestation during the growing season. The strength of the varieties influence on the phytopathogens parasitic activity during the growing season was ultimately unreliable, but the strength of the growing season influence was very large and amounted to 96.5%, being reliable by 1%. A detailed analysis of the spatial arrangement of replicates influence of each variety showed that the power of the spatial arrangement influence on their damage by cereal flies was 30.9% and was reliable at the 1% level, while the influence of the variety itself on this indicator was almost 2 times lower (16.8%) and was significant at the 5% level. These data indicate the need for a systemic restructuring in varieties assessing for resistance to soil phytopathogens and can be used in practical breeding. It is necessary to exclude the damaging factor - cereal flies, which "open the gates" to all soil phytopathogens. Under such conditions, the varieties did not have the opportunity to show genetically determined immune properties, especially in the second half of the growing season, and effective selection of genotypes valuable in terms of resistance to soil phytopathogens is difficult.

3.2. Ecological niches of soil phytopathogens at underground organs of spring wheat varieties
The underground organs of spring wheat varieties are the main specific ecological niche for soil phytopathogens, where they carry out all 3 ecological tactics - reproduction, survival, and trophic connections [13]. In the year of research, the taxonomic composition of pathogenic micromycetes at varieties underground organs was generally typical for the zone [2]. During the growing season, the main phytopathogens were Bipolaris sorokiniana Sacc. Shom. and Fusarium Link. fungi, their occurrence on the underground organs of plants during the growing season was 94.5-100% with an insignificant occurrence on the primary roots of Alternaria Nees. fungi (table 2).

Table 2. Etiology of spring wheat varieties root rot by phases of vegetation, %

| Plant pathogen       | The portion in the pathogenic complex of root rot of varieties , lim | Occurrence frequency |
|----------------------|---------------------------------------------------------------------|----------------------|
| Bipolaris sorokiniana| 0-50.0 0-55.0 5.0-55.0                                               | 94.5 96.7 100        |
| Alternaria spp.      | 0-22.2 0-15.0 0-30.0                                                | 7.8 11.7 20.0        |
| Fusarium spp., totally, including: | 50.0-100 53.3-100 30.0-100                                           | 100 100 100          |
| F.poaae              | 0-100 0-66.6 10.0-83.0                                               | 97.5 96.7 100        |
| F.oxysporum          | 0-25.0 0-46.7 2.5-50.0                                               | 86.4 91.7 100        |
| F.solani             | 0-6.4 0-9.9 0-32.0                                                   | 2.5 20.0 40.0        |
| F. equiseti          | 0-20.0 0-39.5 0-21.0                                                 | 46.1 43.3 23.3       |


F. graminearum 0-46.0 0-60.0 0-20.0 20.0 53.3 18.3
F. sambucinum 0-53.6 0-53.6 0-22.0 35.0 53.3 35.0
F. sporotrichioides - 0-12.1 0-10.0 - 25.0 10.0
F. culmorum - 0-5.2 0-27.0 - 3.3 65.0
F. heterosporum - 0-40.2 - - 3.3 -
F. acuminatum - 0-6.9 - - 3.3 -

F. poae and F. oxysporum were most often represented in the pathogenic complex of varieties underground organs during the growing season, the occurrence of which was close to 100% on all underground organs of spring wheat during the entire growing season. The occurrence of F. equiseti was maximal (46.1%) at the seedlings phase; by the end of the growing season, it decreased on average for organs to 23.3%, always reaching the most significant value at the stem bases, which indicates that the species is confined to straw organs. The occurrence of F. graminearum and F. sambucinum had a maximum (53.3%) in the middle of the growing season, decreasing to 2.5 and 1.5 times, respectively, by species at the beginning and end, and the species were more confined to the root system than to the stem bases. The complete absence of F. graminearum was revealed on the underground organs of Siberian varieties (Novosibirskaya 15, Sibirskaya 17, Obskaya 2) during the entire growing season. The species F. sporotrichioides was recorded on the underground organs of spring wheat varieties starting from the bloom phase and was more confined to the root system of plants. The frequency of occurrence of F. solani increased 16 times during the growing season and was maximal at the base of the stems, and on the roots of plants, especially at the seedlings and bloom phases, it was little or absent. F. culmorum was absent at the seedlings phase and was insignificantly represented in the pathogenic complexes of root rot at the bloom phase; however, at the end of the growing season, its occurrence reached 65% on average for the underground organs of varieties. F. heterosporum and F. acuminatum were found in pathogenic complexes in insignificant quantities only at the stage of wheat bloom; they can be classified as rare species.

The ecological niches overlapping in terms of the co-occurrence frequency of species was maximal, up to 100%, for F. poae and F. oxysporum. The smallest ecological niches overlap at all plants underground organs during the growing season was observed for F. solani and F. equiseti on average 8%. For the rest of the species, the ecological niches overlapping was 20-60% and depended on the plant organs where they were implemented, as well as on the phases of the growing season. In a number of cases, complete divergence of Fusarium species ecological niches by organs and varieties was revealed.

4. Conclusion
The parasitic activity of soil phytopathogens was high throughout the growing season: the zonal threshold of harmfulness was exceeded by seedlings up to 2.8 times, at bloom stage - up to 5 times, and at ripeness - up to 4 times. The susceptibility of host plants to infection with phytopathogens increased during the growing season due to abiotic (drought) and biotic (cereal flies) stresses. The main phytopathogens on the underground organs of 20 spring wheat cultivars were Bipolaris sorokiniana Sacc. Shom. and Fusarium Link. fungi, the occurrence of which at all underground plant organs (primary roots, secondary roots, stem bases) during the growing season was 100%. The dominance of Fusarium fungi increased during the growing season of plants. The biological diversity of Fusarium fungi was maximal in the bloom phase (up to 7 species on secondary roots of one variety). The Fusarium species composition was represented by permanent species - F. poae and F. oxysporum, additional species - F. sambucinum, F. graminearum and F. equiseti, rare - F. solani, F. sporotrichioides, F. culmorum, F. heterosporum, F. acuminatum. The Fusarium fungi succession in the system of plant organs according to the phases of vegetation was revealed, and the realized ecological niches parameters as well as their overlap levels for every Fusarium species were determined.
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