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ORIGINAL ARTICLE

Root rots of spring barley, their harmfulness and the basic effective protection measures

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Root rots of spring barley are considered to be outwardly barely visible diseases, but they are very harmful. With a significant degree of the disease development the growth of crops are suppressed, which affects the final result, that is the qualitative and quantitative indices of the future harvest are becoming worse. Root rots of spring barley are represented by pathogens from the genera of *Fusarium spp*. and *Drechslera spp.* The harmfulness of helminthosporiosis root rot is manifested itself in the growth retardation of the sick plants, breaking of their physiological and biochemical processes, weakening of mineral nutrition, reducing of plant productivity, and the deterioration of the grain quality. The harmfulness of fusariosis root rot is manifested itself in the slowing down of the growth and development of seedlings, leanness of crops, atrophy of productive stalks, the formation of an underdeveloped ear with the frail seeds. The favourable conditions for the pathogen development facilitate the appearance of the hollow ears on the affected plants of spring barley. The crops preceding spring barley, spatial isolation between winter and spring cereals, high quality seeds, soil cultivation, application of fertilizers and seeds treatment significantly influence the prevalence, harmfulness and economic importance of the diseases. Seeds treatment is an obligatory economically and ecologically appropriate agrarian measure, which protects the seeds, sprouts, shoots and young plants from the seed and soil pathogenic infection and provides the opportunity to protect the young plant seedlings at early stages of organogenesis.

In order to reduce the negative effects arising from the use of the pesticides in the cultivation of plants along with the chemical agents the biological preparations are used to protect the crops from the harmful organisms and the pathogens of root rots. In comparison with chemical agents the biological preparations have considerable disadvantages. These disadvantages are the low technical efficiency, strong dependence on weather conditions, and short-term protective action during the lingering development of the disease and narrow specialization.
Keywords: Spring barley; root rots; pesticides; biological fungicides; efficiency

Introduction

Barley is one of the most common spring grain crops in Ukraine. The sowing area under this crop in 2017 occupied 1619.2 thousand hectares, which is by 319.8 thousand hectares less than in 2016 and by 142.7 thousand hectares less than in 2015 (Grain Crops Protection, 2016).

Spring barley is a valuable food, forage and industrial crop. Pearl-barley and fine-ground barley are made from the grains of glassy and coarse-grained distichous barley. Several years ago the scientists discovered such substances as triglyceride and tocotrienol in barley protein. These substances can significantly lower the level of cholesterol in the blood. Barley flour (10-15%) is added during baking of rye and wheat bread, because of the low quality of gluten the bread of pure barley flour is of little size, faintly porous, it is quickly getting dry and crumbled. This is due to the quality and quantity of gluten in barley grains. It is difficult to wash it out and it does not have the necessary elasticity (Lykhochvor et al., 2008). Coffee surrogate and malt extracts are produced from barley grains. Barley in a mix with spring vetch, peas, and vetchling is grown for green fodder and hay; and the high-quality yield often reaches 25-30 t ha^{-1}.

Most often barley is used for grain fodder purposes. One kilo of grain contains 1.2 feed units and 100 g of digestible protein. Grain of barley is a high-nutritional and high-energetic fodder for most animals. Barley grain contains a lot of protein (9-12%) and carbohydrates (70-75%). It contains 7-11% of pentagons, 1.7-2.0% of sucrose, 3.8-5.5% of gluten, 1.6-2.0% of fat, and 2-3% of ash. It also contains the enzymes and vitamins of groups B, D, E, and carotene. Barley protein is of a moderate solubility

and satisfactory amino-acid composition (1 kg of grain contains 5.5 g of lysine, 1.7 g of tryptophan, 2 g of methionine, and 1.9 g of cystine). The fodder properties of barley are much better than those of wheat. Barley protein is lacking in 20% of lysine for sufficient feeding of animals and at the same time wheat protein is lacking in 43% of lysine.
Barley is especially valuable and indispensible for the production of high quality beer. The most valuable varieties of barley in brewing are the distichous varieties with well-filled and even grains (the mass of 1000 grains is 40-45 g), which have a lower film (8-10%), high content of starch (not lower than 63-65%) and lower content of protein (no more than 9-10%). The quality of the protein but not its quantity is of great importance. If protein contains a lot of sulfur, then it does not have a bad affect on the quality of beer; and if a content of protein in the grain is low (7-8%), then the beer is badly foaming, which reduces its consumer quality. The most valuable varieties of brewing barley in Ukraine are grown in the Forest-Steppe, in Polissia, as well as in the foothills of the Carpathians (Ivano-Frankivsk, Lviv, and Zakarpattia regions). The waste products of brewing (distillery refuse and beer small shot grains), which are used for animals feeding are also of importance (Lykhochvor, 2008; Safianov, 1978).
Due to its biological characteristics barley is a good component in the set of crops in a field crop rotation. It quite economically consumes moisture, has a short vegetation period, ripens early, allows using the machinery more rationally and reduces the intensity of field works. It is also used as an insurance crop for re-sowing of winter crops. In addition barley yields more crops than wheat in arid areas.
Recently the phyto-pathological situation of cereal crops has become worse in Ukraine. This is due to the breaching of the crop growing technology (the choice of preceding crop, crop rotation, sowing terms, balance of mineral fertilizers, the presence of a transitional crop fund, the quality of seed disinfection, and the use of fungicides), as well as to the change in the hydrothermal conditions during the period of vegetation and due to the affection of the zoned varieties by the diseases The losses of barley from a complex of the diseases can make up about 40% of the harvest (Bilovus, 2004).
The infection of plants with root rots causes a substantial damage to the crops of spring barley. Root rots are considered to be the outwardly barely visible diseases of cereals. Their pathogens are hemiparasitic fungi which spend their active period of life on the living plants, and saprophytic pathogens that live on the dead organic substrates directly in the soil or on its surface (Benken & Hryshechkyna, 1998; Riabchykova, 1998; Khatskevych et al., 1990). Quite often the plants can be affected by two or three pathogens of the disease. Fusariosis and helminthosporiosis root rots are the most common in the zone of the Eastern Forest-Steppe of Ukraine, their pathogens are the fungi of the genera *Fusarium spp*. and *Drechslera spp*. The signs of manifestation of these types of rots are similar (Tkachenko, 2004; Kupriyanova, 1987; Titova, Rudakova, 1987).
Fungi of the genus *Fusarium spp*. develop on the weakened plants and affect the roots, nodes of bushing out and the bases of stalks. The affected parts of the plants are becoming brown, destroying, and sometimes dry rot is forming. In the wet weather a pink bloom is formed on the affected organs. The development of the disease is facilitated by relatively cool weather with high air humidity (Shypylova, Hachkayeva, 1992). Barley affected by fusariosis contains mycotoxins of *deoxynivalenol* type, also known as *vomitoxin*. *Deoxynivalenol* is one of the least toxic agents among mycotoxins for animals; however the animals may give up eating the affected fodder. This toxin is produced mainly by fungi *F. graminearum* and *F. culmorum* (Hudec, 2006; Josef Hysek – Milan Vach, 2006).
Fusariosis root rots thin out the crops, reduce the nature of the grain and a mass of 1000 grains, and cause hollow ears and sinking. The quality of grain deteriorates (Svetov & Yermakov, 1989).
The species of *Drechslera sorokiniana (Sacc.) Shoem.* (synonym *Bipolaris sorokiniana Subram*.) and *Drechslera graminea* from the genus *Drechslera spp.* are common for barley. The disease manifests itself on the shoots in the form of browning of a coleoptile, yellowing and deformation of leaves, and general suppression of the plants. The adult plants become rotted; their primary and secondary roots, the node of bushing out and the lower part of the stalk become brown and black; as s result the crops lag behind the growth; and white ears, hollow ears, frail grains in the ear and the death of the productive stalks are observed. Sometimes the grain in the ear becomes wrinkled and brown in the germ area (black germ). Fungi of the genus *Drechslera* develop under the conditions of warm and dry weather, in the places with high levels of solar radiation and in the soils close to neutral (Kolomiyets & Kovalenko, 1998; Nesterov, 1998).
For quite a long period of time it has been assumed to consider that the pathogens of *Bipolaris sorokiniana* and *Fusarium spp*. develop together in the tissues of the same plant, and in fact it was impossible to determine the limits of helminthosporiosis and fusariosis root rots. That is why to designate the complex helminthosporiosis and fusariosis infections the name “common root rot” began to be used (Akulov, 2007; Conner et al., 1996; Peresypkin et al., 1991).
In agriculture in most cases root rots are not distinguished according to the pathogens. Cultivating of the varieties resistant to both types of rots is reasonable. However to solve the scientific issues, in particular the peculiarities of the prevalence and development of the pathogens, it is necessary to demarcate them and determine the degree of each pathogen development by the differentiation way.
During the phase of waxy ripeness of grain of spring barley crops, a clear demarcation of the ecological niches occupied by the fungi *Bipolaris sorokiniana* and *Fusarium graminearum* is observed. The first species predominates on the underground and surface parts of the stalks; the second one prevails on the roots. With the death of barley crops there is an intensification of the development of both types of root rots pathogens. In this case *B. sorokiniana* gradually colonizes the roots, and *F. graminearum* colonizes the stalks. As a consequence during the phase of full ripeness of the grain the infection of the affected parts of the plants has a mixed character with the dominance of *F. graminearum* (Akulov, 2007).
Fusariosis and helminthosporiosis root rots of spring barley annually lead to losses of 7-15% and sometimes of 50% of the harvest; it is mainly due to a decrease in the number of productive stalks and grains in the ear (Shamrai, 1993).

Methods

The aim of the work is the establishing of the most effective measures for the protection of spring barley from root rots taking into account their significant harmfulness. We also aimed at searching the seed treatment agents of fungicidal action which can make an alternative to chemical preparations. In the course of this study we have analyzed various sources of scientific literature as well as conducted our own field research using the generally accepted methods. On the basis of the obtained data the measures which should be a counterpart of the system for protection the crops of spring barley from harmful organisms were indicated.

Results and discussion

According to the data of A.J. Ter-Hrygorian, the intensity of root rot development is substantiated by the hydrothermal conditions in the region. In the case of helminthosporiosis root rot the infection of the crops is increasing and the hydrothermal coefficient is decreasing; but in the case of fusariosis infection the hydrothermal coefficient is increasing.

The resistance to stress conditions is a genetically endowed sign. The resistance of spring barley to the root rots is genetically controlled, but does not provide full protection of the variety from the infection; it only reduces the rate of infection spreading. The degree of barley resistance to *Bipolaris sorokiniana* is manifested itself as a reaction of plants to the pathological process and toxins of the pathogen (Korobova et al., 2013; Odyntsova, 1994; Durynina, 1990). The pathogens of root rots produce the hydrolytic enzymes and toxins. In particular *B. Sorokiniana* produces helminthosporol, helminthosporal, viktoxin, and cytokinin (Vadams & Mandahar, 1981), and the species of the genus *Fusarium spp*. produce fusarium acid, isomarticyn and zearagenon (Bilai, 1977).

As a response to the infection of *B. Sorokiniana* the crops of the resistant variety begin to form the reactions of adaptation and the total content of macro- and microelements in the cells are increasing; thus the pathogen toxins are stirring up by the enzymes and binding into a complex compound. The non-resistant varieties change the basic vital processes (respiration and absorption of substances), which ultimately leads to a decrease in the crop productivity (Durynina, 1990; Korobova et al., 2013).

In addition to the resistance of the variety, the preceding crops, spatial isolation between winter and spring cereals, the seeds of high quality, soil tillage system and application of fertilizers, the date of sowing, seeding depth, destruction of windfall shoots and weeds as well as the harvesting in the optimum time significantly influence the prevalence, harmfulness and economic importance of the diseases.

Usually the following measures reduce the prevalence of most diseases by 60%. But the use of chemical plant protection measures is necessary in the case of many diseases. First of all it is the treatment of seeds in order to avoid the fungal diseases and root rots as well as the spraying of crops to protect them from a complex of the diseases that affect the leaves and ears (Fedorenko & Retman, 2009; Chulkina, 1979).

The most simple and effective way to improve the phyto-sanitary condition of crops is the crop rotation. This is due to the natural disappearance of the soil infection in the absence of the favourable plants. The permanent growth of spring crops, including barley, leads to the accumulation of the soil infection, which is accompanied by the increased development and harmfulness of root rots. The least development of the diseases will be in the fields where the preceding crops are not affected by the root rots pathogens of cereals, and the most development of root rots will be when sowing the affected crops in the same fields again.

The best preceding crops as for the phyto-sanitary situation are corn for grain and silage, soybean, beets, potatoes and buckwheat. Spring cereals should not be sown after spring grain crops and the repeated winter wheat crops due to the threat of significant infection of plants by root rots and leaf spots, in particular, by powdery mildew, fusariosis, rust, septoriosis and helminthosporiosis.

The accumulation of infection depends on the soil cultivation method. Deep plowing with a plough and a coulter greatly reduces the development of the diseases.

When plowing at a depth of 25-27 cm the development of root rots and bacteriosis was 7.5-23.7%, while plowing at the depth of 14-16 cm the development of the diseases was 11.5-29.7%; the grain yields were 2.35 t ha^{-1} and 2.27 t ha^{-1} respectively. In the case of blade cultivation the development of helminthosporiosis root rot of barley is increased by 1.1-1.5 times in comparison with plowing (Popov, 2006).

The application of mineral fertilizers directly affects the physical, chemical and biological properties of the soil, which can lead to its improving or vice versa to its disease.

If to take into account the natural fertility of the soil in a particular field, then the balanced fertilization of spring barley crops facilitates reducing of the infection by root rots and helminthosporiosis spotting of the leaves and increasing the yields (Rohozhnykova et al., 2016; Zakharenko, 2002).

In the soil with a little amount of nitrogen and phosphorus the death of the young plants from root rots increases and bacteriosis spreads more widely on the crops. Sowing of barley 7 days later the optimal time leads to an increase in the diseases development by 8-9% and to a shortage of grain by 0.17 t ha^{-1} (Safyanov, 1978).

According to the research results of N.A. Maksiutov (1996) sowing spring barley in the same field permanently (3 years in succession) results in the shortage of grain yield by 30% due to the crops affected by the root rots pathogens. When sowing barley after peas, the affection of barley crops with root rots is significantly reduced.

The treatment of sowing material is a necessary, purposeful, economically and ecologically advisable agrarian measure, which protects the seeds, sprouts, crops and young plants from the seed, soil, and in some cases, from aerogenic pathogenic infection and makes it possible to obtain the seeds without pathogenic microflora. In addition it provides the opportunity to

protect the young plant seedlings at the early stages of organogenesis (Babayants, 2005; Kovalyshyna, 2003; Koishybayev 1995; Hailene, 1983).
Dozens of seed treatment agents are recommended for Ukrainian agriculture, their application for the pre-sowing seeds treatment can give the possibility to get healthy crops even in the presence of a sufficiently high level of the seed infection. The necessary seed treatment agent is chosen depending on the presence of certain pathogens in the seeds and in the soil, which is determined by the laboratory analyses and phyto-sanitary inspection of the farm fields, taking into account the weather and climatic conditions and the resistance of the cultivated varieties to the diseases (Sekun et al., 2007).
Contact fungicides destroy a wide range of phyto-pathogens that are on the surface of the seed. They also act in the soil at a short distance from the seeds, expanding the scope of protective action against the soil pathogens. An even and complete covering of the seed surface is very important for the effective action of these preparations. On the cereals the contact fungicides are used in combination with the systemic ones.
Thiram belongs to the effective substances of contact (local) action. It is a fungicide of protective action that does not penetrate into a plant or a seed, suppresses the germination or spores or mycelium growth that is found on the surface; the active substance of tetramethylthiuram disulphate is transported into the pathogenic cells, inhibits the activity of enzymes containing copper atoms or sulfur-hydrate groups. Thiram-based preparations are used to treat seeds against the root rots pathogens, seed mould, as well as against other diseases that are developed on the surface of the seed. Their active substance is a part of such preparations as vitavaks 200 FF, vita-classik, vitaros, viking, guarant, granivite, raxil extra, and stiraks.
Fludioxonil belonging to the phenilpyrrole class is a contact fungicide with a prolonged protective and weak systemic action. It inhibits the phosphorylation of glucose in the process of cellular respiration. It also influences the growth of mycelium, reproduction of pathogenic and cell membranes formation. Fludioxinil effectively inhibits the development of pathogens from the genera *Alternaria, Ascochyta, Aspergillus, Fusarium, Helminthosporium, Rhizoctonia, Penicillium, Tilletia*.
Systemic fungicides are absorbed by the seeds tissues. They can destroy the internal infection and provide a protective effect, preventing the pathogens from affecting the tissues in which they are contained (Yavdošhchenko, 2007, 2006).
Thiabendazole is characterized by high chemical stability; it forms a protective layer on the surface that can be stored for a long time. It also has a protective effect as for the fungi from the genera *Aspergillus, Botrytis, Ceratocystis, Cercospora, Cladosporium, Colletotrichum, Corticium, Diaporthe, Diplodia, Fusarium, Gibberella, Gloeosporium, Oospora, Penicillium, Phoma, Rhizoctonia, Sclerotinia, Septoria*, and *Thielaviopsis, Verticillium.* Thiabendazole is a part of such preparations as vincyt SC 050, vial and vial TT.
The active substances belonging to sterol synthesis inhibitors are represented the most widely. The substances of this group are characterized by high biological activity, low rates of consumption, systemic, protective and eradicating action on the pathogens, and high selectivity as for the beneficial organisms. They have an active influence on powdery mildew, septoriosis, fungal and rusty diseases.
Azoles that belong to the class of the sterol synthesis inhibitors fungicides take the leading place. In Ukraine the preparations based on the following active substances are registered: imidazoles - imazalil (baitan universal); prochloraz (kinto duo); triazoles - diniconazole (vial, sumi-8 FLO); diphenoconazole (dividend star 036 FS); tebuconazole (bunker, veha, vial TT, dioxyl, classic, kolchuga, lamardor 400 FS, morion, raxil, raxil extra, raxil ultra FS, raxon, ranazole, rostok, tebusan, TERRAsil, chelmsil); tetraconazole (lospel); triadimenol (baitan universal, rostok); triticonazole (kinto duo, corriolis, premis 25); cyproconazole (dividend star 036 FS, maxim star 025 FS); and protioconazole (lamardor 400 FS).
Azoles belong to the inhibitors of sterol biosynthesis, in particular ergosterol. Since sterols are responsible for the strength of the cell membranes, azoles do not suppress the germination of spores, but they inhibit further prolongation of germ tubes, differentiation of cells and growth of mycelium.
When a large number of azoles penetrate into a plant they can disrupt the synthesis of gibberellins and act as growth regulators. The most typical example is the effect of inhibition of the internode extension process in grain crops (retarded action). There is also a reduction of crops transpiration due to a violation of the sterol synthesis.
Cyproconazole quickly penetrates into the plant and moves along it, maintaining the activity for up to 45 days. Diphenoconazole is especially active against the diseases, root rots and seeds mould. Diniconazole is highly effective against the diseases of cereals and it is transmitted by the seeds and through the soil. It protects the sprouts for several weeks. When treating the seeds with tebuconazole it has an effective influence on the bunt fungi, seed mould and root rots. Triticonazole has a wide spectrum of action, a long protective effect and a lower effect on the plants in comparison to triadimenol (Yevtushenko & Mariutin, 2004).
The researches of many years concerning the evaluations of fungicidal properties of seed treatment agents have shown that after treatment of seeds with raxil and baitan in the recommended doses with the subsequent application of the surface spore suspension *Fusarium graminearum, Fusarium nivale, Bipolaris sorokiniana,* raxil inhibited the development of pathogens by 85-100%, increased the seeds germination, facilitated an increase in the root length by 13-29%, and exceeded baitan by these indices. Both preparations showed a retarded effect, reduced the length of the stalk shoot and increased the intensity of the leaves colour (Krasylovets & Krupchenko, 2010; Krasylovets et al., 2008; Krasylovets et al., 2006; Pavlova et al., 1995).
The efficiency of the seed treatment agents depends on the soil and climatic zones and the meteorological conditions in which they are used to a large extent, and first of all, it depends on water availability. In spite of quite high technical efficiency against the pathogens of the diseases some systemic preparations have retarded properties and a toxic action on the plants shoots in the case when there is not enough moisture in the crop layer of the soil. This action is manifested itself in reducing the field germination of the treated seeds, which is aggravated during the years of a severe drought; it leads to the formation

of a small number of plants, shoots and productive stems per area unit and to a yield shortage. Such properties are characteristic for vincit 050 CS, suspension concentrate, dividend star 036 FS, liquid suspension concentrate, and raxil, liquid concentrate of suspension (Krasylovets et al., 2006).
As a result of the researches carried out in the permanent laboratory of plant growing and variety studies of the Plant Growing Institute named by V.Ya. Yuryev in 2007-2009 it was noted that kinto duo had shown better technical efficiency as for the limiting root rots development during the phase of spring bushing out against both backgrounds of mineral nutrition (with fertilizers $(NPK)_{60}$ and without them) in comparison with other seed treatment agents (vitavaks 200 FF and vincit). The technical efficiency was 66,0-72%. Before harvesting the efficiency of kinto duo decreased to 23.2% against the background without fertilizing and it decreased to 26,2% when applying $N_{60}P_{60}K_{60}$. In spite of a slightly lower efficiency during the phase of barley bushing out, the fungicidal action of vincit lasted longer compared to other preparations, and at the time of harvesting its technical efficiency as for the limiting the development of root rots was 30,4% when applying $N_{60}P_{60}K_{60}$, and it was higher than that of vitavaks (14.5-25.8%) and kinto duo (23.2-2.2%) (Krupchenko, 2011).
Seed treatment can provide high technical efficiency in controlling root rots of spring barley and can save up to 5-10% of the crops depending on the selected seed treatment agent (Romanenko, 2005).
According to the researches carried out at the Synelnikovsk breeding and research station of the Grain Farm Institute the high technical efficiency in controlling root rots was shown by vitavaks 200 FF, raxil extra and sumi-8 Flo. It should be noted that the seed treatment agents had a quite high efficiency in controlling root rots at an early stage of plant development. Further it has decreased, which is natural because the effect of the seed treatment agents is weakening over time. Even during the period of milky-wax ripening of grain, when the basic records of plant affected by root rots (that is after 3.0-3.5 months after the seeds treatment) were conducted, the effectiveness of the preparations was at the level of 26.2-42.1%, and the grain yield in the variants with the seeds treatment agents exceeded the control by 0.22-0.39 t ha^{-1} (Yavdoshchenko, 2007; 2006).
In order to reduce the negative effects arising from the use of the pesticides in the cultivation of plants along with the pesticides the biological preparations are used to protect the crops from the harmful organisms and the pathogens of root rots. At present the scientists are still discussing the advisability of their application. The considerable disadvantages of their application are lower technical efficiency in comparison with chemical preparations, strong dependence on weather conditions, short-term protective action with the lingering development of the disease and narrow specialization (Monastyrskyi & Pershakova, 2009; Lapina, 2014).
According to the researches of Babych L.V. and other scientists the fluorescent bacteria of the genus *Pseudomonas* are active antagonists of the fungus *Bipolaris sorokiniana,* the pathogen of spring barley root rot; and some strains are even capable of reducing the degree of affection of barley crops by root rots and increasing the yield of grain (Babych et al., 1993).
In her researches L.D. Hryshechkina notes that the biological preparations reduce the development of helminthosporiosis and fusariosis root rots and increase the yield of grain crops by 21% (Hryshechkina, 2010).
The high efficiency in protecting the crops of spring barley from root rots were shown by Bactophyte (67.7% from helminthosporiosis infection and 57.5% from fusariosis one), Trichodermin (62.9% and 60.0% respectively), Albit (60.7% and 62%, respectively) and Ahat-25 K (61.8% and 50.0% respectively). At a weak degree of seeds infection (up to 10%) the technical efficiency of Albit preparation was 85.4%; it didn’t yield to the fungicide. With an increase in the level of the infection up to 30% the fungicidal activity of the preparation was reduced, and the technical efficiency was 69.7%. When the seeds infection exceeded 30%, the technical efficiency of Albit was not higher than 31.2% (Lapina, 2014).

Conclusions

The intensive development of root rots can lead to a significant shortage of spring barley grain and deterioration of its qualitative indices. In order to prevent the unwanted consequences it is necessary to select a resistant variety; create a balanced phyto-sanitary crop rotation; provide plants with a balanced set of nutrients, based on the needs of the variety; and carry out a qualitative treatment of seeds by a fungicidal agent. The choice of a seed treatment agent should depend on the type of seed infection. The criterion that determines the necessity of using the biological preparations for seed treatment is the degree of its infection, which should not exceed 30% of the external infection. With a high degree of the seed infection the use of biological preparations becomes ineffective.

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