The Most Important Fungal Diseases of Cereals—Problems and Possible Solutions

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Abstract: The level of cereal yields and the quality of these yields depend, to a large extent, on a crop management system, the genetic potential of a given cultivar, but also on factors that may cause damage to plants or a reduction in yield. Such factors include fungal diseases of cereals, which may cause a reduction in yield by 15–20%, and in extreme cases even by 60%. The main factors determining the occurrence of these pathogens are the weather conditions during the growing season of plants, crop rotation, the previous crop, the soil tillage system, and nitrogen fertilisation. Fungal diseases of cereals limit plant growth and development, as well as reduce grain yield and quality. This paper reviews the literature on fungal diseases of cereals.

Keywords: cereal diseases; fungal diseases; mycotoxins; plant protection; disease resistance

1. Introduction

Fungal diseases are an important yield-limiting factor in cereals with estimated yield losses of 15–20%; when they occur to a large extent, losses may reach as high as 50% [1–3]. Economically important cereal diseases include Blumeria graminis, Puccina recondita, Puccinia graminis, Puccina striiformis, Septoria tritici and Septoria nodorum, as well as Fusarium. Cereals are often cultivated in succession, which increases the risk of pathogens from plants accumulating and living in the soil [4]. To some extent, this occurrence can be reduced by using proper crop rotation and by using cultivars with high resistance to pathogens [5–7]. Crop rotation is the most rational crop management factor to limit the occurrence of such diseases [8]. One factor that largely determines the occurrence of fungal diseases is the weather conditions, which are beyond human control. Fungal diseases contribute both to a decrease in yields and to a deterioration of crop quality [9].

In recent years, cereal fungal diseases have occurred in many parts of the world and are considered to be one of the main factors affecting yield and yield quality. Cereal plants are attacked by many pathogens throughout the growing season. Limited crop rotation is considered to be the primary cause of fungal diseases [10–12].

The occurrence of fungal diseases is also influenced by simplified tillage [13], high nitrogen fertilisation and cultivation of a monoculture [14]. Many authors [15,16] indicate that no-till systems lead to an increase in cereal stem base and root diseases. Crop residues left in the field favour the moisture and higher temperatures left in the 10–15 cm soil layer, where pathogens are most active [17]. One of the most important factors that influence the occurrence of fungal diseases is the course of weather conditions during the growing season [18].

The aim of this paper is to present the causes and consequences of fungal diseases in cereals based on a literature review.

2. Genesis and Evolution of Fungal Diseases

Among the numerous fungal species that inhabit the soil, about 8000 species of fungi and oomycetes are associated with crop diseases [19], reducing crop yields, and threatening
food security worldwide [20]. There is a constant process of coevolution between pathogens and the organisms that they attack. This involves the mutual adaptation of pathogens to changes in plant populations that result in higher levels of resistance. Targeted selection for pathogen resistance is used in cereal breeding. Therefore, fungal pathogens also need to adapt to plant changes in order to survive. This process therefore relies on the mutual adaptation of different pathogen species to the plant host population. An additional factor favoring the spread of cereal pathogens is the international trade of grains and seeds, as well as climate change, which contributes to an increase in the geographical range of individual pathogenic species [21]. Certain diseases, despite their currently limited range, could be a major problem in cereal crops worldwide in the future. One of these is wheat blast, which is currently a problem for wheat crops in South America and Bangladesh [22]. Projections associated with a warming climate could significantly increase the spread of fungal diseases [23]. Climate change and associated extreme weather conditions favour the transmission of new variants of pathogens by air [24]. In recent years, scientific advances have significantly contributed to the knowledge of pathogen biology, genomics and evolution, host–pathogen interactions, epidemiology and disease management [25].

The most commonly used method in the fight against cereal pathogens is fungicide protection. However, it has been noted that individual species are developing resistance to the active substances contained in plant protection products [26]. The use of chemical plant protection is also associated with environmental contamination by leaving residues of active substances in soil and grains [27]. Therefore, alternative biological methods are being sought to control fungal pathogens. As indicated by scientific research, certain bacterial strains may be as effective in reducing fungal diseases as active substances contained in fungicides. Research by Wachowska et al. [28] showed that bacteria of the genus *Sphingomonas* inhibited the growth of fungi of the genus *Fusarium* as effectively as a triazole fungicide.

### 3. Characteristics of the Most Common Fungal Diseases

*Blumeria graminis* is a common fungal disease that affects all cereal species, including grasses. The pathogen overwinters in the form of chasmothecia which, when they burst in the spring, release spores that cause infection. Rapid disease development occurs in late spring and summer. A white or greyish-white coating appears on the leaves, leaf sheaths, and sometimes also on the ears. Over time, the ear darkens and numerous black spots—the chasmothecia of the fungus—appear on the surface. The disease affects the new leaves, as the lower old leaves had already developed resistance against it and the infected leaves dry out prematurely; with strong pathogen pressure, whole plants may die [12]. The spread of the disease favours high humidity. As a result of infection by the disease, the quality of grains and the 1000-grain weight decrease [29]. Grain yield reduction, which results from plant infection by pathogens, can reach 15–20%, and in the case of severe infection, can reach 50% or more [1,2]. Czembor and Czembor [29,30], found that the infection of *Blumeria graminis* in barley crops led to a 10% reduction in grain yields.

Diverse isolates of different forms of *B. graminis*, exhibit varying pathogenicity towards multiple cereal species. In a study by Czembor et al. [31], isolates from wheat and rye, showed low virulence against triticale. Research by Czajkowski and Czembor [32] showed that there is variability in susceptibility to powdery mildew isolates from wheat relative to triticale of different cereal species. The above authors found that triticale and wheat showed different susceptibility to this pathogen depending on both species and cultivar. These studies indicate the possibility of targeted selection and breeding of cultivars resistant to this pathogen. Of great importance for powdery mildew resistance in wheat is the Pm2 gene [33]. Different variants of this gene influence whether a given cultivar is resistant to infestation. Markers useful for resistance in wheat breeding for this gene are Xgwm205 and Xcfd81 [34]. Moreover, the need to search for new, highly specific markers coupled to powdery mildew resistance genes seems justified [35]. A good solution to reduce powdery
mildew infestation is to sow varietal mixtures. Applied sowing of a mixture of winter wheat varieties reduces up to 73% of plant infestation with a simultaneous increase in yield [36].

Another method to minimise the exposure of cereal plants to *Blumeria graminis* is biological protection. Spraying plants with *Aureobasidium pullulans* cell suspension has contributed to reducing the intensity of powdery mildew symptoms on subflag and flag leaves of cereals and grasses, but the effectiveness of applying biocontrol agents was significantly lower than that of fungicides. Repeated treatment of plants with a high concentration of *Aureobasidium pullulans* cell suspension generally resulted in better plant development and a significant increase in the abundance of endophytic bacteria of the genus *Azotobacter* and epiphytic bacteria of the *Pseudomonas* group [37].

Fusarium head blight is the most widespread disease in wheat cultivation; it is caused by fungi belonging to the genus *Fusarium*, namely *F. culmorum* and *F. graminearum* [38]. It occurs on all cereals in the Polish climatic zone (wheat, rye, triticale, oats, barley, maize). Fusarium head blight is the most important disease affecting wheat cultivation. Fungi of the genus *Fusarium*, besides fusarium head blight can also cause a number of other diseases: seedling wilt, root rot, or take-all disease. Ear infestation by *Fusarium* spp. leads to a reduction in yield and a deterioration of grain quality due to contamination by harmful mycotoxins [39,40]. Fungi reduce the commercial and consumption value of the crop and have the ability to produce mycotoxins, resulting in the accumulation of toxins in the grain even before harvest. The species that produce the most mycotoxin are *F. graminearum* and *F. culmorum*. Mycotoxins are not only harmful to humans and animals, but also have phytotoxic effects. The negative effects on plants can result in cell death, stunted growth, chlorosis, disrupted mitosis and changes to their protein metabolism. The cereal plants’ defence against the phytotoxic effects of mycotoxins is the transformation of the parent forms of mycotoxins into modified forms. These are free mycotoxins bound to proteins or sugars. These forms are more difficult to detect than the free mycotoxins, making it significantly more difficult to detect and determine the final mycotoxin level in grains [41].

Trichothecenes and zearalenone have been identified as the most important fusarium mycotoxins. Zearalenone (ZEA) is formed mainly by *F. culmorum* and *F. graminearum*. Trichothecenes have been divided, in terms of structure, into four groups: A, B, C and D. The most common trichothecenes belong to groups A (T-2 toxin, HT-2 toxin) and B (deoxynivalenol, nivalenol, 3-acetyl-DON, 15-acetyl DON, fuzarenone, trichothecin).

One of the most important methods of prevention is fungicide protection, whose effectiveness depends not only on the type of active substance of the preparation, but also on the correct execution of the spraying procedure. As reported by Vučajnk et al. [42], nozzle pressure has a major impact on the effectiveness of the treatment performed. In their results, the authors found that the 1000-grain weight was higher at a spraying pressure of 6 bar than at 2 or 4 bar.

The occurrence of fusarium head blight in cereal crops is most often identified by characteristic symptoms. At the earing stage, an early blanching of the husks and a light pink colouring of the ears can be observed. These are the first symptoms of infection by *Fusarium*. Visual assessment and determination of the ear infestation index have so far been the only methods for evaluating the infestation and degree of resistance of individual cereal cultivars to *Fusarium*. Currently, attempts are being made to implement modern, more reliable and objective assessments. One of these is remote sensing. The method is based on comparing photographs of healthy plants with patterns of infested plants and of infested plants with patterns of healthy plants. The resulting images of plant patches are then used as a basis for the analysis of wavelength histograms, as well as for the calculation of indicators enabling the assessment of crop health [43]. Remote sensing can be used to create health maps of cereals infested by *Fusarium*, as well as by other diseases, such as: *Puccinia recondita*, *Puccinia striiformis*, *Blumeria graminis*, *Septoria tritici*, *Septoria nodorum* or *Oculimacula acuformis* [44]. According to Doohan et al. [45], the degree of ear infestation by *Fusarium* highly depends on weather conditions (temperature and humidity). The fungi multiply and this results in a significant loss of yields, as well as deterioration in their
The development of this pathogen is also affected by crop management techniques used, including field preparation, crop rotation, fertilisation and plant protection products [47,49–53]. The study results obtained by Czaban et al. [54] confirm that the spread of fusarium head blight and the infestation of winter wheat grains by fungi of the genus *Fusarium* depend mainly on weather factors. Fusarium head blight risk assessment and models to predict the occurrence of this disease are based on weather conditions affecting the crop from flowering to early milk maturity. Wheat cultivation technology has also had an impact on the colonisation of ears by *Fusarium*. In a study by Czaban et al. [54], ears and grains of wheat from treatments where intensive cultivation technology was applied were most severely infected. The infection of spelt wheat grains [55] and spring barley grains [56] by fungi of the genus *Fusarium* were lower in the organic system compared to the integrated and conventional systems. The search for genes responsible for resistance to *Fusarium* is ongoing. Góral et al. [57] distinguished *Fusarium*-resistant and -susceptible triticale lines. Moreno-Amores et al. [58] also point to the possibility of targeted selection of wheat cultivars for resistance to *Fusarium*.

*Pseudocercosporella herpotrichoides* is one of the most important pathogens of wheat (*Triticum aestivum* L.) caused by two pathogenic fungi, *Oculimacula yallundae* and *Oculimacula acuformis*. In the early stages of the disease, small, elongated, brown spots can be observed on leaf scapes. At the earing stage, and especially a few weeks before the harvest, easily identifiable symptoms appear on the lower internode of the blade in the form of spots. Very often several spots merge and take on an irregular shape. The spots can also have darker edges. If the infestation is severe, white and lighter greyish mycelium develop inside the stem [59,60]. The basic protective treatment is the use of fungicides, which show varying rates of effectiveness [61]. The use of fungicide treatments also increases the cost of cultivation, so sources of genetic resistance to this pathogen are being sought. It is considered that the two genes, Pch1 and Pch2, determine high resistance of common wheat to *Oculimacula yallundae* and *Oculimacula acuformis*. Targeted breeding selection can be effective in reducing the harmfulness of these pathogens in wheat. The importance of the Pch1 and Pch2 genes in common wheat resistance to eyespot has been confirmed by Majka et al. [62]. There were no symptoms of stem base infestation in winter wheat lines/cultivars where both Pch1 and Pch2 genes were present in the genotype. In addition to resistance breeding, an important element in the prevention of stem base eyespot is also the use of correct crop rotation and the introduction of intercrops. The results of the study by Majchrzak et al. [8] confirm the influence of forecrops on the occurrence of fungal stem base diseases. The most frequent disease found among cereals was Fusarium crown rot of the stem base and roots. This occurred at the highest intensity in wheat grown after white mustard (30.3%), and at the lowest intensity after oilseed rape (25.9%) and Abyssinian catan (26.4). The occurrence of this disease is mainly determined by weather. Majchrzak et al. [8], found a higher severity of stem base diseases in 2001, which saw a wet growing season.

This is also confirmed by the results of the study by Kozdój et al. [63], where a significant decrease in grain yield in spring barley of the Pallas cultivar resulted from a decrease in the number of grains per plant and ear by 30–34%. The degree of reduction in the number of grains per ear as a result of powdery mildew infection depends, among other things, on the severity of the disease, the susceptibility of cultivars to infection, and the course of weather conditions during the growing season [64].

Lematczycyk et al. [65] showed that the cultivation of stubble intercrops improves the phytosanitary status of a site with a high proportion of cereals in the crop rotation and reduces the severity of fungal diseases, including stem base eyespot. Simplified tillage also contributes to a reduction in stem base diseases compared to conventional tillage [66].

*Gaeumannomyces graminis* var. *tritici* is one of the most important pathogens of wheat and occurs quite frequently. In the field, the disease occurs in patches and plants in these areas are often smaller and paler. Disease symptoms can be seen particularly in spring or before earing. Infected plants have bleached ears with very small grains or no grains at all. In case of high humidity, black balls, which are the fruiting bodies of the pathogen,
are observed on the bases of the infected stalks. Lateral roots, as a result of infection with the disease, gradually die. One possible solution is the use of biological plant protection solutions. Zhang et al. [67] used 272 *Bacillus* isolates, which they tested for antifungal activity against *Gaeumannomyces graminis*. Out of the 128 strains tested that showed antagonistic activity, 24 of them exhibited at least three of the four plant growth-promoting parameters (i.e., indoleacetic acid and siderophore production, inorganic phosphorus solubilisation and organic phosphorus solubilisation) towards wheat. The results of this study showed that the most effective strain was *Bacillus subtilis* Pnf-12. The effect of using these bacteria was to reduce the incidence of stem base rot by 69%. The Pnf-12 strain also caused a significant improvement (*p* < 0.05) in root and shoot weight of wheat plants, although their root length and height were similar to the control group. The mechanism of this disease control may be related to the production of antifungal lipopeptides such as surfactin, iturin and phengycin. As effective as the inoculant itself was, the extract obtained from the filtrate of the culture of *Bacillus subtilis* was also productive and when applied to wheat seedlings, reduced the severity of the disease infestation on the roots by 91.3% [68]. The soil and its microbiological activity also have an important role in suppression (reduction of pathogenicity). It is also important to use correct agronomic practices, which, in combination with appropriate sulphur fertilisation, have a positive effect on the reduction of pathogenicity of *Gaeumannomyces graminis* in wheat [69]. Fertilisation with iron sulphate in wheat crops where stem base rot is a problem reduces the wheat infestation significantly [70]. Durán et al. [71] showed that soil micro-organisms play an important role in controlling and limiting the occurrence of *Gaeumannomyces graminis*. The traditional way to combat *Gaeumannomyces graminis* is by using fungicides. The studies of Wang et al. [72] indicate the high efficacy of the active ingredient thiosemicarbazide 4-chlorocinnamate for the control of stem base rot. In field trials, thiosemicarbazide 4-chlorocinnamate showed good control efficacy with a mechanism based on a laccase inhibitor. Furthermore, synthetic plant protection products, natural plant extracts with fungitoxic activity can also be used. Paz et al. [73] demonstrated the effective action of sesquiterpenoid drimans extracted from *Drimys winteri*, a natural antifungal agent against *Gaeumannomyces graminis*. Their action is based on the cell walls of the hyphae and consequently on their destruction. Proper crop rotation is also a desirable method to reduce the occurrence of stem base rot in wheat crops. As shown by Van Toor et al. [74], a break in wheat cultivation of a minimum of one growing season is required to ensure that the inoculum in crop residues in the soil has been eliminated to such an extent as to maximally reduce the incidence of infestation by *Gaeumannomyces graminis*.

*Puccinia recondite* causes rusty brown spore clusters that occur mainly on the upper side of leaves (less frequently on the lower side). The leaf rust primarily affects winter and spring wheat, but also winter and spring triticale. The source of infection is often crop residues left in the field. Under favourable conditions, the infection develops very quickly and the rust covers the leaves completely. The higher the temperature and moisture, the faster the infection develops, as stated by Wojtowicz [75]. Each increase in air temperature shortens the incubation period of the fungus and accelerates the development of infection. The shortest incubation period of five days is observed at an average temperature of 24.3 °C, while its decrease by 3 °C slows down infection by 1–2 days [76]. Climate change, and in particular, warming of the climate, could further increase the pressure from this disease on wheat, and thus cause significant yield losses [77].

The fast development of the disease accelerates the appearance of disease symptoms such as yellowing of the leaves and their death. This results in significant yield reductions, which can be as high as 50%. By applying beneficial endophytes, the damage of this disease on the final wheat yield can be reduced. This is supported by the study of Anwaar et al. [78], who observed reduced disease severity in wheat plants that were inoculated with endophytes, such as *T. viride*, *A. lolii* and *C. lindemuthianum*. Breeding wheat varieties that are resistant to rust disease is also a promising method to prevent yield losses due to brown rust, as well as being the most economical and environmentally friendly way to control
As shown by Anwar et al. [78], there is a large variation in resistance to brown rust in common wheat, so that resistant lines can be isolated and used for further resistance breeding. In particular, the Lr19 gene, which has a significant effect on resistance in wheat, should be considered, with GB and Xwmc221 as good markers [79]. Fungicide protection in rust prevention can include synthetic fungicide applications as well as plant extracts. As shown by Shabana et al. [80], spraying with a plant extract composed of *Azadirachta indica*, cloves, and *Cinchona L.* four days after leaf rust inoculation, completely prevented the development of the disease in wheat (100% disease control) and its effectiveness was comparable to that of the synthetic fungicide Sumi-8.

*Puccinia striiformis* is highly dependent on weather conditions. Stripe rust, caused by *Puccinia striiformis*, has high moisture requirements and is sensitive to temperature fluctuations (especially during the long incubation period). Until now, yellow rust appeared in Poland sporadically and was not a major problem. However, in recent years there has been a greater incidence of yellow rust on wheat and some forms of triticale, which is influenced by climate [81].

*Septoria tritici* is a pathogen, which manifests itself by yellow, red and brown spots on the leaves, which can occur at any stage of growth. It affects mostly cereals, but is most frequently observed on wheat, triticale and rye (rarely). The pathogen persists for quite a long time in a latent form, which the farmer is unable to notice. Later, spots appear on the seedlings and the leaves die off prematurely, not giving the plant a chance for proper growth and development. A study by Horoszkiewicz-Janki et al. [14] showed the influence of the forecrop and tillage method on the incidence of chaff septoria in wheat monoculture. Simplified tillage contributed to a higher intensity of chaff septoriais. An important direction in the prevention of septoriais in crops is resistance breeding. As shown by Arraiano and Brown [82], the gene responsible for increased resistance to this disease in wheat is located on chromosome 6 of 6AL and is associated with a reduction in leaf area. A genotypic selection strategy should be associated with a simultaneously confirmed phenotypic plant resistance to septoriais at all stages of plant development to confirm the true degree of resistance [83].

*Pyrenophora tritici-repentis* initially appears on leaves in the form of black spots, which gradually enlarge. The development of the disease causes a merging of spots and the formation of extensive necroses, which leads to the death of the entire leaf blade. Necrosis also appears on infected stems. The disease appears on the ears, leading to blanching and dying, and the infected kernels are yellow or brown. Forecrop has an influence on the incidence of cereal diseases [10,84]. This is also confirmed in the study by Marks et al. [85], in which the intensity of diseases was significantly modified by the stand on which winter wheat was grown. The diseases, which manifest themselves in the leaves (apart from stripe leaf septoria), occurred most strongly in the control treatment where wheat was grown after spring rapeseed. The infection index ranged from 5.5% (brown rust) to 11.8% (brown leaf spot). The severity of cereal diseases depends largely on weather conditions [17], forecrop [86], nitrogen fertilization (Table 1), or weed control [87]. Tables 2–4 show differing severities of particular pathogens through different years. Kurowski et al. [88] indicate that the infection of winter triticale by *Pyrenophora tritici-repentis* and *Puccinia recondita* depended on the method of weed control and nitrogen fertilisation. The authors found lower plant infestation on treatments where a herbicide was applied compared to unprotected sowings. Additionally, the method of application of the nitrogen fertiliser influenced the occurrence of these diseases. The lower plant infection of *Pyrenophora tritici-repentis* and *Puccinia recondita* occurred on treatments without nitrogen fertilisation. The strongest symptoms of the diseases were observed after an application of nitrogen fertilisation at three dates.
Table 1. Occurrence of brown rust in 2004 and 2006 and *Pyrenophora tritici-repentis* in 2005 (%) depending on nitrogen fertilisation and weed control. Reprinted from reference [88].

| Specification | Disease and Year of the Study | 2004 | 2006 | 2005 |
|---------------|--------------------------------|------|------|------|
|               | *Puccinia recondita*            |      |      |      |
|               |                                | 1.6  | 2.5  | 2.6  |
| Method of weed control | 2 | 3.6 | 2.6 | 2.5 |
|               |                                | 1    | 1.8  | 2.2  |
|               |                                | 1.4  | 1.9  | 2.8  |
|               | **NIR**<sub>0.05</sub>         | 0.34 | 0.34 | 0.32 |
|               | *Pyrenophora tritici-repentis*  |      |      |      |
| Method of nitrogen fertilization (kg·ha<sup>-1</sup>) | A | 0.2 | 0.5 | 0.7 |
|               |                                | 2.4  | 1.6  | 2.3  |
|               |                                | 3.2  | 3.9  | 4.1  |
|               | **NIR**<sub>0.05</sub>         | 0.34 | 0.34 | 0.32 |

Explanations: 1—control (without weed control), 2—harrowing, 3—herbicide, 4—harrowing + herbicide, A—control (without nitrogen fertilization), B—70 + 65, C—70 + 25 + 40, D—70 + 25 (foliar application) + 40.

* Lowest significant difference.

Table 2. Disease severity in winter wheat (infection index in %)—average for 2003–2005. Reprinted from reference [85].

| Disease                          | Plant Succession |
|---------------------------------|------------------|
|                                 | A                | B                | C    | D    | E    | F    |
| *Zymoseptoria tritici*          | 42               | 44.1             | 29.2 | 31.2 | 29.5 | 35   |
| *Puccinia Recondita*            | 4.9              | 1.4              | 2.2  | 0.8  | 1.6  | 3.2  |
| *Pyrenophora tritici-repentis*  | 4.6              | 3.7              | 4.4  | 3.3  | 5.3  | 4.4  |
| *Blumeria graminis*             | 4.8              | 0.9              | 3    | 0.5  | 3.8  | 4.3  |
| *Septoria nodorum*              | 8.9              | 8.1              | 5.9  | 6.8  | 9.9  | 7.3  |
| *Fusarium*                      | 58.7             | 66.8             | 60.7 | 61.2 | 51.3 | 52.5 |
| *Oculimacula acuformis*         | 11               | 17.5             | 14.2 | 12.8 | 16.2 | 21.3 |
| *Gaumannomyces graminis var. tritici* | 1.5             | 3.5              | 1.5  | 0.5  | 0    | 0    |

Explanations: A—winter wheat—spring rapeseed—winter wheat (control); B—winter wheat—black fallow—winter wheat; C—winter wheat—herbicide fallow—winter wheat; D—winter wheat—white mustard fallow—winter wheat; E—winter wheat—fallow with Westerwold ryegrass—winter wheat; F—winter wheat—fallow with Persian clover—winter wheat.

Table 3. Percentage of flag leaf area infected by *Pyrenophora tritici-repentis*. Reprinted from reference [14].

| Factor             | Mean from Study Years |
|--------------------|-----------------------|
| Cultivation        | Simplified 1.1         |
|                    | Traditional 1.3        |
| Forecrop           | Wheat 2.3              |
|                    | Maize 0.5              |
|                    | Rapeseed 0.9           |
Table 4. Percentage of ear area infected by *Septoria nodorum*. Reprinted from reference [14].

|         | Factor     | 2009/2010 |
|---------|------------|-----------|
| Cultivation | Simplified | 3.5       |
|         | Traditional| 3.2       |
| Forecrop | Wheat      | 6.2       |
|         | Maize      | 2.1       |
|         | Rapeseed   | 1.8       |

4. Conclusions

Research conducted so far has shown that both the tillage method, cultivation technology, fertilisation rate and the choice of cultivar have an effect on the incidence of fungal diseases of cereals. However, to a large extent the occurrence of these pathogens depends on weather conditions during plant growth and development. Fungal diseases cause high yield losses as they reduce the assimilative area of leaves and ears, resulting in poor grain formation and a decrease in the number of grains per ear. They also contribute to grain quality deterioration by contaminating it with health-hazardous mycotoxins. The main disease control strategy is targeted resistance breeding of new cereal cultivars, which has its advantages and disadvantages. The advantage is a significant reduction in plant protection products, which has a positive economic effect for farmers, but also an environmental one. On the other hand, the disadvantage of resistance breeding is the possibility of interaction between different genes responsible for resistance to different diseases. An additional problem is the one-sided selection associated with increasing grain yield of cereals, which significantly reduces the genetic pool of plants, eliminating potential resistance genes.

As cereals are one of the most important cultivated crops, international scientific cooperation is also needed to improve cereal resistance to fungal diseases and the grain yield losses they cause.

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