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# The influence of catch crops on fungal diversity in the soil and health of oat

*Elżbieta Mielniczuk*, Elżbieta Patkowska, Agnieszka Jamiołkowska*

*Department of Plant Protection, University of Life Sciences in Lublin, Lublin, Poland*
**Corresponding author: elzbieta.mielniczuk@up.lublin.pl*

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**Abstract:** The aim of the research was to determine the quantitative and qualitative composition of soil-borne fungi in the cultivation of oat, as well as to assess the healthiness of this cereal. The experiment considered spring barley and potato as forecrops, and white mustard or lacy phacelia cultivated after spring barley as catch crops before oat. The population of fungi showing antagonistic effect towards selected fungi pathogenic to cereal was determined. The most fungi (pathogenic and antagonistic) were found in the soil under oat cultivation after spring barley, while the least after potato. The cultivation of oat after spring barley with the use of catch crops significantly influenced a reduction in the number of fungi obtained from the soil. On the other hand, catch crop cultivation increased the share of antagonists in the soil fungus population. Among the species recognised as antagonistic, *Clonostachys rosea*, *Trichoderma viride*, *T. koningii*, and *T. harzianum* predominated. The introduction of catch crops, especially white mustard, also positively influenced the healthiness of oat. The average disease index for the tested oat cultivars grown after potato and after spring barley with white mustard and lacy phacelia as catch crops was 11.02, 12.78 and 15.90, respectively, whereas after spring barley it was 21.75.

**Keywords**: *Avena sativa* L.; infection; phytosanitary condition; microorganisms; crop rotation

It is well-known from the literature that oat has a positive effect on the soil environment in addition to improving the healthiness and yielding of consecutive plants. It is also tolerant of the choice of forecrops and a large proportion of cereals in the sowing structure (Weber and Kita 2010, Wesołowski and Cierpiała 2013). Nevertheless, oat – like other cereals – is infected by plant pathogens, especially by *Fusarium* spp. Particularly big quantities of *Fusarium* spp. were found on the roots, seedlings and the lower internodes of oat stems (Lemańczyk 2010, Kiecana et al. 2014, Hofgaard et al. 2016). The development of fusarium blight of the base of the stems creates a danger of the accumulation of those infection factors in the soil after oat cultivation and the infection of consecutive plants by fungi from the genus *Fusarium*. That is why to make oat perform its function of a good forecrop, its infection by pathogens needs to be limited. To improve the phytosanitary condition of the soil, the cultivation of catch crops is used and a special role is ascribed to stubble catch crops. The best catch crops include white mustard and lacy phacelia (Kraska and Mielniczuk 2012, Wesołowski and Cierpiała 2013). Introducing stubble catch crops to cereal crop rotations is a factor mitigating the unfavourable effects of an excessive share of cereals in the sowing structure. It improves the soil structure, limits water losses and prevents migration of nutrients into the deeper parts of the soil in addition to supporting the development of useful microorganisms limiting the development of plant pathogens (Askegard and Eriksen 2008, Wanic et al. 2013, 2018). A very important role of stubble catch crops is that when they are plowed, they introduce biomass to the soil which decreases ecological threats and improves the supply of nutrients and the phytosanitary conditions of consecutive plants. The cultivation of stubble catch crops usually contributes

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to a significant increase of grain yield or its improved quality (Macdonald et al. 2005, Wojciechowski 2008). There is a need for agronomic improvements capable of increasing crop yields while alleviating environmental impacts. One such approach is the use of optimised crop rotations (Dias et al. 2015). Therefore, the purpose of the present study was to establish the species and quantitative composition of fungi in the rhizosphere of oat cultivated after forecrops of spring barley and potatoes, as well and after spring barley with catch crops of white mustard and lacy phacelia, and their influence on the healthiness of stem bases of four oat cultivars.

## MATERIAL AND METHODS

The investigations were conducted in the years 2016–2018 in the South-Eastern part of Poland (Lublin region) (50°56'02''N, 23°21'04''E, World Reference Base for Soil Resources (WRB): Dystric Cambisols). The experiment included the cultivation of four oat cultivars (Arden, Bingo, Kozak, Romulus) immediately after spring barley (forecrop) (the option I), after potato (IV) and after spring barley with stubble catch crops in the form of white mustard or lacy phacelia (II and III). The experiment was carried out in the system of random blocks in four repetitions. The area of each plot was 20 $m^2$. The soil cultivation preparing the field for oat started with skimming and harrowing after the harvest of forecrops. Before winter, ploughing was performed to a medium depth. In spring, harrowing was performed, and before sowing cultivating and harrowing were performed. In the options with catch crops, white mustard (*Sinapis alba* L.) cv. Borowska (15 kg/ha) and lacy phacelia (*Phacelia tanacetifolia* Benth.) cv. Anabela (15 kg/ha) were seeded following the harvest of spring barley and after the post-harvest treatments in the second 10 days' period of August. Catch crops were cultivated for green manure. They were plowed with pre-winter plowing to a medium depth. Oat was sown at the rate of 550 kernels per $m^2$. Oat kernels were dressed with the seed dressing Maxim Star.

The object of the studies was also to obtain soil samples each year from a depth of 5–6 cm of the plough layer of the plots where the analysed oat cultivars were grown. The mycological analysis was conducted according to the method described by Czaban et al. (2007). The soil was sampled from each experimental combination. Martin's medium was used to establish the fungi number – CFU of soil DW (colony forming units/g dry weight of soil). The population of fungi having an antagonistic effect towards selected fungi pathogenic to cereal was determined according to the method described by Mańka and Mańka (1992). The antagonistic effect of all isolates *Trichoderma* spp., *Clonostachys rosea*, and *Talaromyces flavus* obtained from the soil, was determined in relation to *Fusarium avenaceum*, *F. culmorum*, *F. equiseti*, *F. graminearum* and *Bipolaris sorokiniana* strains, whose pathogenicity to cereals has been confirmed in previous studies (Kiecana et al. 2014, Cegiełko et al. 2019, Mielniczuk 2018).

The health of oat was evaluated at the milk stage (BBCH 73–77) in each year of studies. Fifty stems were randomly selected from each plot. The level of infection was determined according to a six score rating scale (where 0 – no disease symptoms, and 5° – over 75% of the stem base area infected). The disease index was calculated according to McKinney's formula (Mielniczuk 2018):

$$\text{disease index} = \frac{\sum(a_i \times b_i)}{n \times c} \times 100$$

where: $a_i$ – score of rating scale (from 0° to 5°), $b_i$ – number of stems in a given score of the rating scale; $n$ – total number of stems observed; c – highest score of the rating scale.

The results were statistically analysed by the analysis of variance using statistical program ARStat (developed at the Faculty of Applied Mathematics and Information Technology of the University of Life Sciences, Lublin). The means were compared to the use of the least significant differences based on the Tukey's test ($P \leq 0.05$).

## RESULTS AND DISCUSSION

After three years of studies, the mean total population of fungi in the soil environment ranged from 48.75 × $10^3$ CFU/g to 94.92 × $10^3$ CFU/g (Table 1). The largest population of fungi was found in the cultivation of particular oat cultivars after spring barley (the option I), while the smallest after potato (IV). The cultivation of oat after spring barley using catch crops significantly affected a decrease of the fungi population obtained from the soil in particular years of studies. Besides, differences were found in the fungi populations from under oat cultivation after white mustard (II) and after lacy phacelia (III). In the case of each cultivar, fewer fungi isolates were isolated after white mustard (Table 1). The obtained results confirmed other authors' studies on the ef-

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Table 1. Number of fungi isolated from soil in individual experimental treatments in 2016–2018

| Forecrop | Catch crop | Total CFU of fungi ($10^3$/g DW of soil) | | | | | | | | | | | | Average CFU of fungi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cv. Arden | | | | cv. Bingo | | | | cv. Kozak | | | | |
| | | 2016 | 2017 | 2018 | mean | 2016 | 2017 | 2018 | mean | 2016 | 2017 | 2018 | mean | |
| Spring barley | – | 94.63$^{c}$ | 90.15$^{c}$ | 94.62$^{c}$ | 93.13$^{c}$ | 89.26$^{c}$ | 90.89$^{d}$ | 91.26$^{d}$ | 90.47$^{c}$ | 95.49$^{c}$ | 91.17$^{a}$ | 98.11$^{c}$ | 94.92$^{c}$ | 91.73$^{c}$ |
| | white mustard | 58.72$^{a}$ | 62.55$^{a}$ | 66.34$^{b}$ | 62.54$^{a}$ | 55.64$^{a}$ | 60.19$^{b}$ | 59.18$^{b}$ | 58.34$^{a}$ | 59.62$^{b}$ | 61.72$^{b}$ | 64.24$^{ab}$ | 61.86$^{b}$ | 60.495$^{a}$ |
| | lacy phacelia | 78.89$^{b}$ | 76.00$^{b}$ | 70.32$^{b}$ | 75.07$^{b}$ | 69.51$^{b}$ | 70.18$^{c}$ | 69.46$^{c}$ | 69.72$^{b}$ | 62.27$^{b}$ | 63.48$^{b}$ | 69.72$^{b}$ | 65.16$^{b}$ | 67.905$^{b}$ |
| Potato | – | 62.72$^{a}$ | 58.55$^{a}$ | 57.33$^{a}$ | 59.53$^{a}$ | 54.36$^{a}$ | 49.19$^{a}$ | 52.72$^{a}$ | 52.09$^{a}$ | 56.11$^{a}$ | 52.72$^{a}$ | 58.36$^{a}$ | 55.73$^{a}$ | 54.025$^{a}$ |
| | | cv. Romulus | | | | | | | | | | | | |
| | | 2016 | 2017 | 2018 | mean | | | | | | | | | |
| Spring barley | – | 86.39$^{c}$ | 90.10$^{c}$ | 88.72$^{c}$ | 88.40$^{c}$ | | | | | | | | | |
| | white mustard | 60.21$^{b}$ | 58.29$^{b}$ | 59.21$^{b}$ | 59.24$^{b}$ | | | | | | | | | |
| | lacy phacelia | 62.36$^{b}$ | 60.20$^{b}$ | 62.46$^{b}$ | 61.67$^{b}$ | | | | | | | | | |
| Potato | – | 48.17$^{a}$ | 50.92$^{a}$ | 47.16$^{a}$ | 48.75$^{a}$ | | | | | | | | | |

Values in columns differ significantly ($P \leq 0.05$) if they are not marked with the same letter. CFU – colony forming units; DW – dry weight

fect of catch crops on microorganism communities in the soil from under the cultivation of different plant species (Pięta and Kęsik 2005, Patkowska et al. 2016). The cultivar of oat also affected the population of soil fungi and the largest population of fungi was obtained from the soil from under cv. Arden, while the smallest from under cv. Romulus. In the studied vegetation seasons, 3 682 fungi isolates belonging to 24 species were isolated from the soil (Table 2). Among the species recognised as pathogenic towards cereals the predominant ones comprised *Fusarium* spp., including *F. culmorum* and *F. equiseti.* Also, *B. sorokiniana* and *Rhizoctonia solani* were obtained. Within saprotrophic species, *Clonostachys rosea*, *Trichoderma viride*, *T. koningii*, *T. harzianum* and *T. aureoviride*, *Epicoccum nigrum* and *Penicillium* spp. were represented most numerously (Table 2). The studies showed that the best effect on the quantitative and qualitative composition of fungi in the soil was exerted by the use of potato as a forecrop for oat. In addition, a positive influence of catch crops was observed on the species composition of fungi. Laboratory tests showed differences in the number of antagonistic fungal isolates between experimental combinations (Figure 1). It was found that the introduction of catch crops effectively increased the proportion of antagonists in the soil fungi population. In particular, the use of white mustard stimulated the development of antagonists, mainly *Trichoderma* spp., which was like in the studies by Kraska and Mielniczuk (2012) and Patkowska et al. (2016). The activity and effects of beneficial rhizosphere microorganisms on plant health are well documented for fungi from genus *Trichoderma*, *Gliocladium* and non-pathogenic *Fusarium* (Dias et al. 2015). In addition to the ability of *Trichoderma* spp. to attack or inhibit the growth of plant pathogens directly, they can also induce systemic and localised resistance to a cultivar of plant pathogens (Harman et al. 2004).

In the present studies, the disease index determined for oat in the objects where stubble catch crops of white mustard (av. 12.78) and lacy phacelia (15.9) were sown was significantly lower than in the object without catch crops (21.75) (Table 2). The disease index calculated for oat cultivated with the catch crop of white mustard was not significantly different from the value obtained in the object where the potato was the forecrop for oat (11.02). Significantly the lowest disease index value was found for cv. Romulus (11.25), while the highest for cv. Kozak (20.22). Considering the results presented in other

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Table 2. Fungi frequently isolated from the soil in individual experimental treatments (sum from 2016–2018)

| Fungus species | Number of isolates/experimental combination | | | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | spring barley (forecrop) | | | | spring barley (forecrop) + white mustard (catch crop) | | | | spring barley + lacy phacelia | | | | potato | | | | |
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | |
| *Alternaria alternata* (Fr.) Keissl. | 33 | 26 | 28 | 20 | 12 | 8 | 10 | 13 | 25 | 16 | 14 | 19 | 12 | 13 | 14 | 12 | 275 |
| *Bipolaris sorokiniana* Shoemaker | 9 | 14 | 17 | 11 | 1 | – | – | – | 2 | – | 3 | – | – | – | – | – | 57 |
| *Chaetomium piluliferum* J. Daniels | – | 3 | – | 4 | – | 2 | – | 1 | 3 | 12 | 4 | 15 | – | 1 | 5 | 1 | 51 |
| *Clonostachys rosea* (Link) Schroers. Samuels. Seifert & W. Gams | 3 | 8 | 6 | 11 | 36 | 30 | 21 | 29 | 24 | 19 | 27 | 25 | 11 | 19 | 10 | 9 | 288 |
| *Epicoccum nigrum* Link | 11 | 4 | 9 | 5 | 12 | 9 | 17 | 12 | 6 | – | 7 | 11 | 5 | 19 | 14 | 8 | 149 |
| *Fusarium avenaceum* (Fr.) Sacc. | 16 | 21 | 9 | 8 | 4 | – | – | 9 | 11 | 12 | 6 | 4 | – | – | – | – | 100 |
| *F. culmorum* (Wm. G. Sm.) Sacc. | 85 | 62 | 58 | 29 | 14 | 9 | 8 | 10 | 12 | 19 | 24 | 31 | 1 | 8 | 1 | 6 | 377 |
| *F. equiseti* (Corda) Sacc. | 32 | 11 | 14 | 15 | 2 | – | – | 4 | 8 | 6 | 1 | 12 | – | 2 | – | 1 | 108 |
| *F. graminearum* Schwabe | – | 8 | 2 | 4 | – | – | – | – | – | 8 | – | – | – | – | – | – | 22 |
| *F. oxysporum* Schltdl. | 101 | 92 | 124 | 95 | 11 | 6 | 1 | 1 | 2 | 18 | 6 | 1 | 8 | 2 | 5 | 5 | 478 |
| *Humicola fuscoatra* Traaen | 6 | – | – | – | – | – | – | 12 | 5 | – | – | – | – | – | 1 | – | 24 |
| *Mucor hiemalis* Wehmer | 6 | 2 | 8 | 11 | 9 | 5 | 14 | 22 | 6 | 7 | 18 | 6 | 4 | 8 | 11 | 5 | 142 |
| *Neocosmospora solani* (Mart.) L. Lombard & Crous. | 6 | 7 | – | 5 | – | 1 | – | – | – | 2 | – | – | 3 | 17 | 4 | – | 45 |
| *Penicillium aurantiogriseum* Dierckx | 9 | 5 | 11 | 6 | 12 | 4 | 8 | 6 | 5 | 4 | 6 | 7 | 9 | 9 | 11 | 9 | 121 |
| *P. chrysogenum* Thom | – | 2 | 9 | – | 11 | 8 | 9 | 14 | 9 | 11 | 19 | 9 | 7 | 14 | 9 | 8 | 139 |
| *P. thomi* Maire | 2 | – | 5 | – | 5 | 2 | 1 | 6 | – | 8 | 9 | 10 | 9 | 2 | 9 | 5 | 55 |
| *Talaromyces flavus* (Klocker) Stolk & Samson | 4 | 2 | – | 1 | 5 | 8 | 9 | 2 | 2 | 1 | 5 | – | 5 | 7 | 2 | 8 | 61 |
| *Rhizoctonia solani* J. G. Kühn | 9 | 6 | 1 | 1 | 1 | 3 | – | – | 8 | – | – | 5 | 9 | 14 | 5 | 2 | 64 |
| *Rhizopus stolonifer* (Ehrenb.) Vuill. | 2 | 4 | 8 | – | – | – | – | – | – | 2 | – | – | 1 | 4 | – | – | 21 |
| *Stemphylium botryosum* Wallr. | 6 | 5 | 11 | 9 | – | – | 2 | 1 | | – | – | – | – | – | – | | 34 |
| *Trichoderma aureoviride* Rifai | – | 2 | – | 2 | 21 | 12 | 13 | 24 | 15 | 21 | 13 | 12 | 11 | 12 | 31 | 24 | 213 |
| *T. harzianum* Rifai | 10 | 9 | 5 | 2 | 45 | 28 | 19 | 23 | 11 | 15 | 20 | 9 | 12 | 18 | 28 | 22 | 276 |
| *T. koningii* Oudem. | 19 | 13 | 11 | 9 | 32 | 22 | 28 | 27 | 17 | 19 | 20 | 11 | 24 | 30 | 25 | 29 | 336 |
| *T. viride* Pers. | 22 | 15 | 11 | 8 | 35 | 29 | 38 | 34 | 25 | 21 | 16 | 29 | 33 | 38 | 40 | 19 | 413 |
| Total | 391 | 321 | 347 | 256 | 268 | 186 | 198 | 250 | 196 | 221 | 200 | 216 | 164 | 237 | 225 | 173 | 3 849 |

1 – cv. Arden; 2 – cv. Bingo; 3 – cv. Kozak; 4 – cv. Romulus

publications, the obtained disease index values for oat grown after potato and after spring barley with catch crops should be considered relatively low (Kraska and Mielniczuk 2012, Mielniczuk 2018). Plowing stubble catch crops, and especially introducing the biomass of white mustard to the soil, improved the healthiness of spring and winter wheat (Wojciechowski 2008, Kraska and Mielniczuk 2012). Majchrzak et al. (2004) observed improvement in phytosanitary conditions in monoculture cultivation of spring and winter wheat as a result of the introduction of catch crop of the Brassicaceae family. In the case of oat cultivated after other cereals, a positive influence of white mustard and lacy phacelia, as catch crops, on the yield size of grain was observed (Wesołowski and Cierpiała 2013). In conclusion, the introduction of catch crops, especially white mustard, as well as the selection of the right cultivar for cultivation, have a positive effect on main plant health status and allow to reduce the use of plant protection products in cereal crops. Such activities are particularly important in the case of the elimination of proper crop

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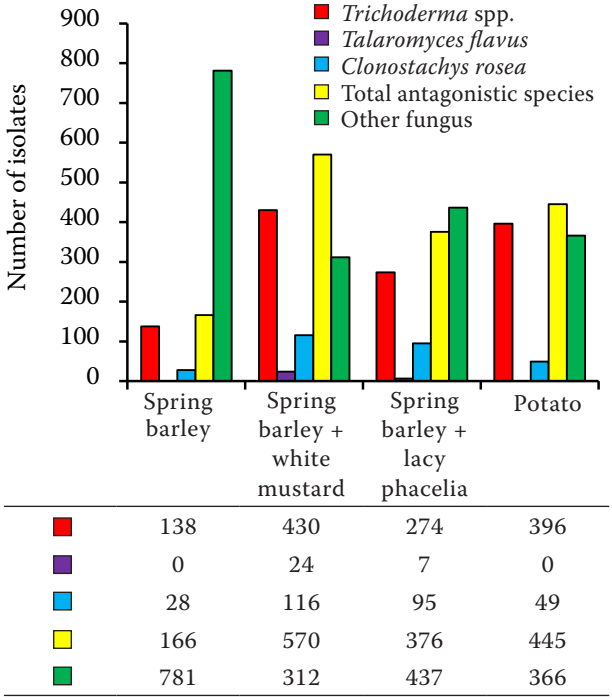
Table 3. Values of the disease index of oat stem bases in 2016–2018

| Forecrop | Catch crop | Cv. Arden | | | | Cv. Bingo | | | | Cv. Kozak | | | | Cv. Romulus | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2016 | 2017 | 2018 | mean | 2016 | 2017 | 2018 | mean | 2016 | 2017 | 2018 | mean | 2016 | 2017 | 2018 | mean | |
| Spring barley | – | 21.0$^{c}$ | 19.8$^{c}$ | 18.7$^{b}$ | 19.83$^{c}$ | 19.9$^{b}$ | 20.9$^{c}$ | 13.7$^{b}$ | 18.17$^{c}$ | 29.2$^{c}$ | 31.3$^{c}$ | 25.8$^{c}$ | 28.77$^{c}$ | 19.8$^{c}$ | 25.8$^{c}$ | 15.1$^{b}$ | 20.23$^{c}$ | 21.75$^{c}$ |
| | white mustard | 15.6$^{a}$ | 17.2$^{b}$ | 14.0$^{a}$ | 15.60$^{b}$ | 11.3$^{a}$ | 12.8$^{a}$ | 9.8$^{a}$ | 11.30$^{a}$ | 16.2$^{b}$ | 14.1$^{a}$ | 17.6$^{ab}$ | 15.97$^{a}$ | 7.9$^{a}$ | 10.2$^{b}$ | 6.6$^{a}$ | 8.23$^{ab}$ | 12.78$^{a}$ |
| | lacy phacelia | 16.8$^{b}$ | 18.0b$^{c}$ | 17.1$^{b}$ | 17.30$^{bc}$ | 17.4$^{b}$ | 17.8$^{b}$ | 10.4$^{a}$ | 15.20$^{b}$ | 18.1$^{b}$ | 26.6$^{b}$ | 20.6$^{b}$ | 21.77$^{b}$ | 11.2$^{b}$ | 9.7$^{b}$ | 7.1$^{a}$ | 9.33$^{a}$ | 15.90$^{b}$ |
| Potato | – | 13.6$^{a}$ | 12.1$^{a}$ | 12.8$^{a}$ | 12.83$^{a}$ | 9.9$^{a}$ | 10.2$^{a}$ | 8.9$^{a}$ | 9.67$^{a}$ | 13.2$^{a}$ | 14.0$^{a}$ | 15.9$^{a}$ | 14.37$^{a}$ | 8.6$^{a}$ | 7.2$^{a}$ | 5.8$^{a}$ | 7.20$^{a}$ | 11.02$^{a}$ |
| Average | | 16.75 | 16.78 | 15.65 | 16.39$^{B}$ | 14.63 | 15.43 | 10.70 | 13.58$^{AB}$ | 19.18 | 21.50 | 19.98 | 20.22$^{C}$ | 11.88 | 13.23 | 8.65 | 11.25$^{A}$ | 15.36 |

Values in columns differ significantly ($P \leq 0.05$) if they are not marked with the same small letter. Values in lines differ significantly ($P \leq 0.05$) if they are not marked with the same capital letter




| | Spring barley | Spring barley + white mustard | Spring barley + lacy phacelia | Potato |
|---|---|---|---|---|
| *Trichoderma* spp. | 138 | 430 | 274 | 396 |
| *Talaromyces flavus* | 0 | 24 | 7 | 0 |
| *Clonostachys rosea* | 28 | 116 | 95 | 49 |
| Total antagonistic species | 166 | 570 | 376 | 445 |
| Other fungus | 781 | 312 | 437 | 366 |

Figure 1. Number of antagonistic fungi towards pathogens in individual treatments, after three years of studies

rotation with increased monocrop farming as well as low resistance of cultivars for pathogens.

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