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Reaction of winter wheat (*Triticum aestivum* L.) cultivars to infection with *Fusarium* spp. - mycotoxin contamination in grain and chaff

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Abstract

The aim of this study was to compare susceptibility of winter wheat (*Triticum aestivum* L.) cultivars to *Fusarium* Head blight - FHB and accumulation of mycotoxins in kernels and chaff, in different climate conditions in two locations Cerekwica near Poznan (Central West Poland) and Sitaniec, near Zamosc, Lublin region (South East Poland). Very high variation was found in the concentrations of mycotoxins (zearalenone-ZEA, nivalenol-NIV, deoxynivalenol-DON and moniliformin-MON) in examined fractions (*Fusarium*-damaged kernels-FDK and healthy looking kernels-HLK) and in chaff for individual cultivars in both locations. Moreover, in most cases significantly higher concentrations of investigated toxins were recorded in wheat coming from the area of Lublin than in that from the area of Poznan ($p < 0.05$). The highest *Fusarium* infection rate as well as mycotoxin biosynthesis level were observed in the Lublin location with percentage of the FDK fraction in the range from 8.1 to 81.6. In this region ZEA concentration ($\mu\text{g g}^{-1}$) after inoculation with *F. culmorum* and *F. graminearum* ranged from 0.02 to 0.48 and 0.32–1.04, respectively. In the Poznan area the toxin concentrations were considerably lower, ranging from 0.01 to 0.10 and from 0.03 to 0.13 for both isolates, respectively. The concentration of DON was significantly higher when compared to ZEA and NIV levels. The levels of MON accumulation ($\mu\text{g g}^{-1}$) in the FDK fraction were between 0.14 and 1.73 (Poznan area) and ND - 2.51 (Lublin area). *F.*

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3 *avenaceum* infection rate ranged between 7 and 35% in the samples where the toxin was
4 detected.
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8 **Keywords:** *Fusarium culmorum*, *F. graminearum*, *F. avenaceum*, *Fusarium* head blight,
9 wheat, zearalenone, deoxynivalenol, nivalenol, moniliformin, HPLC
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14 **Introduction**

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16 *Fusarium* species are common necrotrophic pathogens of small grain cereals in most
17 European countries. Three species *F. culmorum* (W.G. Smith) Sacc., *F. avenaceum* (Corda ex
18 Fries) Sacc., and *F. graminearum* Schwabe, have been considered as the most important in
19 Poland and other central European countries, while several other species as less important
20 (Bottalico and Perrone 2002). *F. culmorum* and *F. graminearum* have been shown to be
21 frequent and most aggressive to cereals in countries of moderate and colder climates. FHB
22 severity depends on several genetic, agronomic and climatic factors. The disease can result in
23 *Fusarium*-damaged kernels (FDK), which are smaller, shriveled and discoloured (Kiecana et
24 al. 2004). FHB can also cause economical losses because of reduced kernel weight and size,
25 low grain quality, and accumulation of several mycotoxins (mostly deoxynivalenol - DON
26 and zearalenone - ZEA) in infected kernels, chaff and rachises (Jones and Mirocha 1999). In
27 some regions disease epidemics have been observed, with high yield losses particularly in
28 wheat and other cereals. Observations of disease occurrence showed a lower susceptibility of
29 selected cultivars and breeding lines to most fungal pathogens (Mielniczuk et al. 2004,
30 Wisniewska et al. 2004). Profiles of mycotoxins produced by the above mentioned two
31 species (*F. graminearum* and *F. culmorum*) were found to be similar both under laboratory
32 and field conditions, with DON, nivalenol (NIV) and ZEA being the most important (Quarta
33 et al. 2005). The mycotoxin content in infected grains is also genotype-dependent
34 (Chelkowski et al. 2000, Wisniewska et al. 2004).
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50 The major *Fusarium* toxin found in the climatic conditions of Poland is zearalenone,
51 detected in cereals during plant growth and vegetation, as a secondary metabolite of fungi of
52 genus *Fusarium* (Golinski et al. 2002). The amounts of ZEA accumulated in cereals depend
53 on many factors such as temperature, duration of *Fusarium* infection, substrate and strain of
54 fungal species (Bennett and Klich 2003, Nuryono et al. 2005). This toxin is recognized as a
55 phytoestrogen with reported cytotoxic and genotoxic activity. Toxic properties of ZEA are
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3 related to the metabolite binding to estrogen receptors and disrupting the endocrine regulation
4 of the reproductive functions in females (Zinedine et al. 2007).
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7 An important toxin of the group of trichothecenes is deoxynivalenol (DON), being the
8 product of metabolism of such fungi as *F. graminearum* and *F. culmorum*. DON was
9 detected in such cereals as wheat, oat, barley, rye, rice, corn, as well as cereal-based products,
10 e.g. flour, bread or muesli. Accumulation of DON and its derivatives, including NIV, in
11 spring wheat accessions was on average $3.1 \mu\text{g g}^{-1}$ ($0.7\text{-}9.0 \mu\text{g g}^{-1}$) and it was lower than in
12 winter wheat accessions, with an average of $6.7 \mu\text{g g}^{-1}$ ($1.6\text{-}38.5 \mu\text{g g}^{-1}$) (Goral et al. 1995).
13 DON, similarly to other trichothecenes, has a significant effect on biochemical processes,
14 blocking e.g. protein biosynthesis or elongation of the polypeptide chain. It is assumed that
15 DON, being a highly toxic compound, does not exhibit carcinogenic properties. The most
16 frequently observed DON toxicosis symptoms in animals include vomiting and body weight
17 loss with successive numerous physiological changes in internal tissues (Wisniewska et al.
18 2002, 2004). Pigs were found to be the most susceptible animals to DON, despite the reported
19 potential detoxication by the intestinal microflora. Intake of feed containing DON may also
20 have a significant effect on reproduction of animals, causing in most cases fatal toxicoses.
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23 *Fusarium avenaceum* is reported as a very potent producer of moniliformin (MON), a
24 metabolite in the form of sodium or potassium salt of 3-hydroxycyclobut-3-ene-1,2-dione, is
25 toxic to plant and animal species (Kiecana et al. 2002, Jestoi et al. 2004). MON also is
26 suspected to cause the Keshan disease, a human myocardial impairment reported in rural
27 areas of China and South Africa (Pineda-Valdes and Bullerman 2000). Inhibition of pyruvate
28 dehydrogenase, i.e. the blockage of entry of pyruvate into the Krebs's cycle, and a decrease in
29 mitochondrial respiration are probably responsible for the acute toxicity of the compound
30 (Reams et al. 1996).
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33 The aim of this study was to compare susceptibility of winter wheat (*Triticum*
34 *aestivum* L.) cultivars to FHB and accumulation of mycotoxins in kernels and chaff, in
35 different climate conditions at two locations in Poland.
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38 **Materials and methods**

39 *Wheat samples*

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41 Material for the study comprised 10 winter wheat cultivars most common in East Europe,
42 differing in their reaction to *Fusarium* pathogens (6 quality cultivars - group A: cv. Tonacja,
43 Zyta, Sukces, Finezja, Ludwig, Rywalka; 3 bread cultivars - group B: cv. Mewa, Nutka,
44 Soraja; 1 forage cultivar - group C: cv. Symfonia) (Table 1). The experiment was performed
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3 in 2008, in a randomized complete block design in triplicate, at two different locations of
4 Poland: Cerekwica (82 m a.s.l.), Central West Poland - 30 km northwest of Poznan, and
5 Sitaniec (210 m a.s.l.), South East Poland - 90 km southeast of Lublin. Weather conditions for
6 both locations received from Institute of Meteorology and Water Management.
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10 11 12 *Inoculation procedure*

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14 At mid-anthesis (zadoks scale 65) 30 wheat heads of each replication were inoculated
15 individually (by brushing) with the conidial suspension ($100\ 000\ \text{spores ml}^{-1}$) isolates of three
16 *Fusarium* species: *F. graminearum* (KF 2870), *F. culmorum* (KF 846) and *F. avenaceum* (NN
17 1337), with plot size $1\text{m} \times 1\text{m}$. During two days after inoculation micro-irrigation was used.
18 Non-inoculated plots of the same genotypes were used as a control. Two weeks after
19 inoculation, disease progress was visually evaluated as the disease score of head (Fi) on a
20 scale of 0-5, where 0 means no infection and 5 denotes the highest infection of the head.
21 Inoculated and control heads were harvested and threshed manually, then kernels were
22 separated into two fractions: *Fusarium*-damaged kernels (FDK) and in healthy looking
23 kernels (HLK). The percentage of *Fusarium*-damaged kernels (%FDK) was calculated as a
24 percentage by weight.
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35 36 *Chemicals and reagents*

37 Mycotoxin standards (ZEA, DON, NIV, MON) were supplied by Sigma-Aldrich
38 (Steinheim, Germany). Acetonitrile and methanol (HPLC grade) were also purchased from
39 Sigma-Aldrich (Steinheim, Germany). Potassium chloride, di-potassium phosphate, *n*-hexane
40 and *t*-butyl-ammonium hydroxide were purchased from POCh (Gliwice, Poland) and water
41 (HPLC grade) was from our own Millipore water purification system.
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49 50 51 *Mycotoxin analysis*

52 Mycotoxins (ZEA, DON, NIV and MON) were analyzed as well in the two fractions
53 of wheat kernels described above - FDK and HLK, as in the fraction of chaff.
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55 56 57 *Deoxynivalenol, nivalenol and moniliformin analysis*

58 Finely ground material was extracted with acetonitrile-methanol-water (16:3:1, v/v/v)
59 using 5 ml of solvent per 1 g of sample. Extracts were defatted with *n*-hexane ($3 \times 50\ \text{ml}$) and
60 then concentrated. Half of the extract was used for MON analysis, while the remaining part
was used for DON and NIV determination. The extract of MON was purified on a Florisil

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3 column according to the method described by Kostecki et al. (1999). To analyze the
4 trichothecenes (DON, NIV), extracts were purified by filtration on a column according to the
5 method described by Tomczak et al. (2002).
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9 DON, NIV and MON were quantified by HPLC using a Waters 501 apparatus (Waters
10 Division of Millipore, Milford, MA, USA) with a C-18 Nova Pak column (3.9 × 300 mm) and
11 a Waters 486 UV detector ($\lambda_{\max} = 224$ nm for DON and NIV, while $\lambda_{\max} = 229$ nm for MON).
12 DON and NIV were eluted from the column with a 25% water solution of methanol (flow rate
13 0.7 ml min⁻¹) with retention times of 11.72 and 7.46 min, respectively. Regarding MON, the
14 acetonitrile:water solvent (15:85, v/v) buffered with 10 ml of 0.1 M K₂HPO₄ in 40% *t*-butyl-
15 ammonium hydroxide in 1 L of solvent (Sharman et al. 1991) was used as a mobile phase
16 (flow rate 0.6 ml min⁻¹). Retention time of MON was 11.5 min. Detection limits for DON,
17 NIV and MON were 0.01 µg g⁻¹. Positive results (on the basis of retention time) were
18 confirmed by HPLC analysis and by comparison with the relevant calibration curve
19 (correlation coefficients for NIV, DON and MON were 0.9994, 0.9997 and 0.9990,
20 respectively). Recoveries for NIV, DON and MON: 75, 87 and 90%, respectively, were
21 estimated in triplicates by extracting mycotoxins from blank samples spiked with 0.01–0.10
22 µg g⁻¹ of the compounds. The relative standard deviation (R.S.D.) value was below 5% for
23 DON and NIV, and below 7% for MON.
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37 *Zearalenone analysis*

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39 ZEA content was determined by HPLC with a fluorescence detector according to the
40 method described by Visconti and Pascale (1998). The chromatographic system was a Waters
41 2695 HPLC, with a Waters 2475 Multi λ Fluorescence Detector and a Waters 2996 Array
42 Detector. The excitation and emission wavelengths were 274 and 440 nm, respectively. The
43 reverse-phase column was a C-18 Nova Pak column (3.9 × 150 mm), while the mobile phase
44 was acetonitrile-water-methanol (46:46:8, v/v/v), at a flow rate of 0.5 ml min⁻¹. Quantification
45 of ZEA was performed by measuring the peak areas at the ZEA retention time according to
46 the relevant calibration curve (correlation coefficient $r=0.9998$). The limit of zearalenone
47 detection was 0.003 µg g⁻¹. The recovery of the compound was measured in triplicates by
48 extracting ZEA from blank samples spiked with 0.005–0.10 µg g⁻¹ of compound. The results
49 of experiments confirmed literatures data and contained in the range from 97 to 99%. The
50 relative standard deviation (R.S.D.) value was below 1%. In order to confirm the presence of
51 ZEA the Photodiode Array Detector was used.
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Statistical analysis

The two-way analysis of variance was carried out to determine the effects of locations, cultivars and locations \times cultivars interactions on the variability of disease score of head (Fi), the percentage of *Fusarium*-damaged kernels (%FDK), ZEA and DON concentrations in FDK as well as in HLK fractions and in chaff (ZEA in FDK, ZEA in HLK, ZEA in chaff, DON in FDK, DON in HLK, DON in chaff), HLK kernels per spike, FDK kernels per spike, HLK weight per spike, FDK weight per spike and thousand kernels weight (TKW).

The least significant differences (LSD) for each trait were calculated, and on these basis homogeneous groups for the analyzed traits were determined. The relationship between ZEA and DON for different traits (mycotoxin concentration in FDK and HLK fraction and in chaff) as well as Fi, HLK kernels per spike, FDK kernels per spike, HLK weight per spike, FDK weight per spike and TKW were estimated on the basis of correlation coefficients.

Results and discussion

Susceptibility of tested wheat cultivars to the *Fusarium* spp. and mycotoxin biosynthesis depends on pathogen virulence and weather conditions.

Analysis of variance indicated that the main effects of locations (Poznan and Lublin area) were significant for all the traits in the study (Tables 2-4), except for FDK kernels per spike for *F. culmorum* (Table 2), FDK weight per spike for *F. graminearum* (Table 3) and moniliformin concentration in the HLK fraction (MON in HLK) (Table 4); the main effects of cultivars were significant for all the traits, except for TKW for *F. culmorum* (Table 2). The locations \times cultivars (L \times C) interactions were not significant only for number of as well HLK and FDK kernels per spike, FDK kernels per spike and TKW for *F. culmorum* (Table 2), and for MON in FDK number of HLK and FDK kernels per spike and HLK weight per spike for *F. avenaceum* (Table 4).

Very high variation was found in concentrations of mycotoxins (ZEA, DON, MON) in fractions (HLK and FDK) and in chaff for individual cultivars in both locations (Tables 5-9). Moreover, in the most cases significantly higher concentrations of toxins were found in wheat of Lublin area origin than area of Poznan ($p < 0.05$) (Tables 5-9), what confirms earlier findings (Golinski et al. 1999, 2002).

The highest *Fusarium* infection rate as well as mycotoxin biosynthesis level were observed in the Lublin location with percentage of the FDK fraction in the range from 8.1 to

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3 81.6. In this region the ZEA concentration ($\mu\text{g g}^{-1}$) after inoculation with *F. culmorum* and *F.*
4 *graminearum* ranged from 0.02 to 0.48 and 0.32–1.04, respectively (Tables 5 and 6). In the
5 Poznan area the toxin concentrations were considerably lower, ranging from 0.01 to 0.10 and
6 from 0.03 to 0.13 for both isolates, respectively (Tables 5 and 6).
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10 The differences in climate conditions are in our opinion the reason of differences in
11 ZEA concentrations in both locations (Tables 5 and 6). Inoculation in Cerekwica was
12 performed May 30 and June 5 for all *Fusarium* pathogens isolates with few days of average
13 temperature increase with peaks of the highest temperature May 31, June 6 and 10. At the
14 same time rainfalls level was lower than it was before inoculation. In contrast, inoculation in
15 Lublin area was few days later (June 10) than in Cerekwica which is the reason because of
16 differences in climate and vegetation (cereals flowering). After inoculation - in Lublin area –
17 there were a few days with lower temperature and higher air relative humidity than previously
18 and during inoculation (weather reports for Lublin and Cerekwica). Such a situation explains
19 that lower temperature in Lublin area during disease development induced ZEA
20 contamination of kernels. Such observation was also reported by others (Klix et al. 2008).
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30 NIV was reported only in trace amounts in the FDK fraction of two cultivars after
31 inoculation with *F. culmorum* in the Lublin region. The concentration of DON was
32 significantly higher when compared to ZEA and NIV levels. In the Poznan region
33 contamination with DON did not exceed $80.8 \mu\text{g g}^{-1}$ in FDK fraction (Tables 7 and 8). It was
34 also noticed that the infection was higher after inoculation with *F. culmorum* both in the
35 Poznan and Lublin area, where the DON concentration in FDK fraction was in the range from
36 21.6 up to $114.6 \mu\text{g g}^{-1}$ (Table 7).
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43 It is worth noting that in several samples especially in Lublin area, but also in
44 Cerekwica, the level of DON was higher in kernels of FDK fraction than in chaff (Table 8).
45 We assume that dry summer in both locations was responsible for the fungus penetration to
46 inner parts of kernels (where humidity and water content is higher), followed by the disease
47 development and higher yield of the mycotoxins biosynthesis and/or their transport with
48 nutrients into the kernels centre, what effected in higher the metabolites concentration level
49 than it was in outer parts - in chaff temperature had to be higher (sun operation) in a contrary
50 to low moisture. To some extend this concept is similar not only to the results indicating
51 penetration of DON into kernels of cereals with FHB symptoms and pathogen development
52 but also in asparagus spears without fusariosis symptoms but more often MON and
53 fumonisins positive than diseased ones. This phenomenon was elucidated as follows:
54 mycotoxins accumulated in overgrown with pathogenic fungus and/or fungi crowns are
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3 transported with nutrients to developing spears. In fact the mycotoxins presence is definitely
4 related to abundance of pathogen(s) in crown and not in situ of chemical analysis (spears)
5 (Waskiewicz et al. 2010). It is necessary to point out the differences in the structure of kernels
6 and spears, differences resulting in only limited penetration of mycotoxins in hard tissue.
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10 Moreover, a significant positive correlation for *F. culmorum* were observed between
11 FDK weight per spike and FDK kernels per spike in both locations as well as between HLK
12 weight per spike and TKW in Lublin (Table 9). The negative significant correlation was
13 observed only between HLK weight per spike and Fi (Table 9). As mentioned above
14 metabolite penetration into the kernels might be limited when humidity is high, mycotoxins
15 accumulate - in such situation - mostly on the kernels surface. The literature and our earlier
16 findings (Young and Miller 1985, Perkowski et al. 1990) indicate that usually the outer parts
17 chaff, husk are higher in the mycotoxin contamination levels, which is an interesting finding
18 with practical implications. During kernel threshing, hulling, dry and wet cleaning (washing),
19 grinding and milling significantly reduce the concentration levels of the mycotoxins not only
20 in kernels but also in such final products as flour, groats and flakes. In turn, for *F.*
21 *graminearum* a significant relationship was observed between FDK weight and kernels per
22 spike and HLK weight and kernels per spike in both locations as well as between DON in
23 HLK and ZEA in HLK, HLK weight per spike and TKW in Poznan (Table 10). In Lublin,
24 HLK kernels per spike was correlated with FDK kernels per spike and FDK kernels per spike
25 (Table 10). Edwards (2009) observed that the relationship between DON and ZEA
26 concentrations was not stable between years. The ZEA distribution was a similar pattern to
27 DON which is to be expected as they are produced by the same *Fusarium* species.
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42 In studies conducted in Austria, kernel samples of durum wheat predominantly
43 infected by *F. graminearum* and with a lower incidence of *F. culmorum* contained high
44 amounts of DON (up to 8.2 $\mu\text{g g}^{-1}$) together with low levels of ZEA (up to 0.33 $\mu\text{g g}^{-1}$) (Adler
45 et al. 1995), while in other studies DON was found in all tested wheat samples, ranging from
46 0.2 to 4.1 $\mu\text{g g}^{-1}$ (Berthiller et al. 2009). In Germany DON, together with ZEA and NIV, was
47 found in 87% of wheat samples at very high levels, mean being 3.96 $\mu\text{g g}^{-1}$ and the highest
48 43.4 $\mu\text{g g}^{-1}$ (Lepschy von Gleissenthal et al. 1989). The occurrence of DON (up to 1.18 $\mu\text{g g}^{-1}$)
49 was reported in Finland (Hietaniemi and Kumpulainen 1991) and in the Netherlands (up to
50 0.5 $\mu\text{g g}^{-1}$) together with ZEA (De Nijis et al. 1996). In France, Bakan et al. (2001) analyzed
51 strains of *F. culmorum* isolated from wheat grain, which produced ZEA (1700 $\mu\text{g g}^{-1}$), DON
52 (up to 51.9 $\mu\text{g g}^{-1}$) and NIV (up to 12.0 $\mu\text{g g}^{-1}$), whereas in Italy isolates of *F. culmorum*
53 produced DON up to 1700 $\mu\text{g g}^{-1}$ (Quarta et al. 2005). In Poland high amounts of DON (2.30-
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3 15.32 $\mu\text{g g}^{-1}$) related with a high incidence of *F. culmorum* and *F. graminearum* were
4 observed, whereas DON concentration was in most samples higher than those of NIV (0.01-
5 0.74 $\mu\text{g g}^{-1}$) (Chelkowski et al. 2002). Analysis of mycotoxins of six winter wheat genotypes
6 inoculated with *F. graminearum* revealed DON content ranging from 0.89 up to 1.53 $\mu\text{g g}^{-1}$
7 and a very low level of NIV (Ittu et al. 2000). In other studies the highest contamination with
8 DON of inoculated wheat was observed in Polish cultivars, at 38.5 and 35.7 $\mu\text{g g}^{-1}$ for cv.
9 Olimpia and Henika, respectively (Wisniewska et al. 2004).

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12 In Cerekwica the levels of MON accumulation ($\mu\text{g g}^{-1}$) in HLK were between not
13 detectable level (ND) and 0.13, while in the FDK fraction from 0.14 and 1.73, and in chaff at
14 levels between ND and 1.07 (Table 11). *F. avenaceum* infection rate ranged between 7 and
15 35% in the samples where the toxin was detected. In the Lublin region the MON content (μg
16 g^{-1}) in the HLK fraction ranged between ND and 0.11, in FDK in the range of ND-2.51, while
17 in chaff between 0.03 (cv. Rywalka) and 0.48 (cv. Sukces) (Table 11). In this area the
18 infection rate with *F. avenaceum*, in the analyzed cultivars varied, from 3 to 41%. For *F.*
19 *avenaceum* we observed positive correlation between number and weight of HLK and FDK
20 kernels per spike, FDK kernels and weight per spike, MON in FDK and MON in HLK in both
21 locations (Table 12). Additionally, MON in chaff was correlated with MON in HLK and
22 MON in FDK as well as HLK weight per spike with TKW in Lublin (Table 12).

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25 The achieved results indicate that MON content depends on the susceptibility of
26 particular genotype to infection with *F. avenaceum*, what is confirmed as well by studies in
27 Norway, where moniliformin was found in 76% tested wheat samples (with the highest toxin
28 concentration 0.95 $\mu\text{g g}^{-1}$) (Uhligh et al. 2004) as studies conducted in Finland by Jestoi et al.
29 (2004), where significant correlation between *F. avenaceum* contamination level and the level
30 of MON (0.03-0.10 $\mu\text{g g}^{-1}$) was observed. In Poland, wheat samples with *F. avenaceum*
31 inoculum contained the toxin in the range from 0.01 to 0.35 $\mu\text{g g}^{-1}$ (Chelkowski et al. 2002)
32 and 1.72 $\mu\text{g g}^{-1}$ (Tomczak et al. 2002).

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35 In cereals four types of plant resistance mechanisms to fusariosis have been suggested:
36 resistance of the host plant to infection with pathogenic fungi (mechanism I); resistance of the
37 host to pathogen spread in the tissue (II); ability of the plant to degrade mycotoxins (III) and
38 tolerance of the host tissue to a high concentration of toxic metabolites (Kiecana et al. 2002).
39 In the district of Lublin, with suggestion to the other parts of Poland two cultivars Sukces and
40 Tonacja are recommended for general purpose kernels while cv. Symfonia as a feed -
41 component. In our present studies cultivars Ludwig and Finezja were of the lowest
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3 susceptibility to *F. avenaceum* inoculation and MON accumulation (Mewa, Ludwig and
4 Finezja in Lublin; Rywalka, Ludwig and Finezja in Poznan) while cv. Sukces exhibited the
5 lowest susceptibility in both locations. After inoculation with *F. culmorum* the lowest
6 susceptibility and the mycotoxin formation were observed for cv. Nutka, Zyta and Rywalka
7 for both localities (Finezja and Soraja in Lublin; Rywalka in Poznan), while the highest for
8 cv. Symfonia and Sukces (Soraja in Poznan and Mewa and Symfonia in Lublin). Cultivars
9 Tonacja and Nutka (Finezja and Ludwig in Lublin and Symfonia and Zyta in Poznan) were
10 the lowest susceptibility to *F. graminearum* inoculation and with the lowest toxic metabolite
11 biosynthesis while cv. Mewa (Soraja in Lublin and Mewa in Poznan) of the highest.

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Recorded results indicates on winter wheat cultivars with low susceptibility to
infection under different climate conditions, therefore experiments described in this paper
should be continued to select winter wheat cultivars of the lowest susceptibility to FHB,
mycotoxin formation and the most suitable for different climate and cultivation conditions in
Poland.

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References

- Adler A, Lew H, Brodacz W, Edinger W, Oberforster M. 1995. Occurrence of moniliformin,
deoxynivalenol, and zearalenone in durum wheat (*Triticum durum* Desf.). *Mycotoxin Res.*
11: 9-15.
- Bakan B, Pinson L, Cahagner B, Melcion D, Semon E, Richard-Molard D. 2001. Toxigenic
potential of *Fusarium culmorum* strains isolated from French wheat. *Food Add Contam.*
18: 998-1003.
- Bennett JW, Klich M. 2003. *Mycotoxins*. *Clin Microbiol Rev.* 16: 497–516.
- Berthiller F, Dall'asta C, Corradini R, Marchelli R, Sulyok M, Krska R, Adam G,
Schuhmacher R. 2009. Occurrence of deoxynivalenol and 3- β -D-glucoside in wheat and
maize. *Food Add Contam.* 26(4): 507-511.
- Bottalico A, Perrone G. 2002. Toxigenic *Fusarium* species and mycotoxins associated with
head blight in small-grain in Europe. *Eur J Plant Pathol.* 108: 611 – 624.

- 1
2
3 Chelkowski J, Stepien L, Tomczak M, Wisniewska H. 2002. Identification of toxigenic
4 *Fusarium* species in wheat ears using PCR assay and their mycotoxins in kernels.
5 *Phytopathol Pol.* 25: 47-57.
6
7
8
9 Chelkowski J, Wisniewska H, Adamski T, Golinski P, Kaczmarek Z, Kostecki M, Perkowski
10 J, Surma M. 2000. Effects of *Fusarium culmorum* head blight on mycotoxin accumulation
11 and yield traits in barley doubled haploids. *J Phytopathol.* 148: 541-545.
12
13
14 De Nijis M, Soentoro P, Delfgou-Van Asch E, Kamphuis H, Rombouts FM, Notermans
15 SHW. 1996. Fungal infection and presence of deoxynivalenol and zearalenone in cereals
16 grown in The Netherlands. *J Food Protect.* 59: 772-777.
17
18
19 Edwards SG. 2009. *Fusarium* mycotoxin content of UK organic and conventional wheat.
20 *Food Add Contam.* 26(4): 496-506.
21
22
23 Golinski P, Kiecana I, Kaczmarek Z, Kostecki M, Kapturek P, Wisniewska H, Chelkowski J.
24 1999. Scab response of selected winter wheat cultivars after inoculation with *Fusarium*
25 *avenaceum* (Fr.) sacc. *J. Phytopath.* 147: 717-723.
26
27
28 Golinski P, Kaczmarek A, Kiecana I, Wisniewska H, Kapturek P, Kostecki M, Chelkowski J.
29 2002. *Fusarium* head blight of common Polish winter wheat cultivars – comparison of
30 effects *Fusarium avenaceum* and *F. culmorum* on yield components. *J. Phytopath.* 150:
31 135-141.
32
33
34
35 Goral T, Foremska E, Chelkowski J, Arseniuk E. 1995. Characteristic of triticale, wheat and
36 rye varieties on their resistance and tolerance to head infection by *Fusarium* spp. *Bulletin*
37 *PBCI* 195/196: 251-259.
38
39
40
41 Hietaniemi V, Kumpulainen J. 1991. Contents of *Fusarium* toxins in Finnish and imported
42 grains and feeds. *Food Add Contam.* 8: 171-182.
43
44
45 Ittu M, Grabarkiewicz-Szczesna J, Kostecki M, Golinski P. 2000. Deoxynivalenol
46 accumulation and other scab symptoms in six Romanian wheat genotypes inoculated with
47 *Fusarium graminearum*. *Mycotoxin Res.* 16: 15-22.
48
49
50
51 Jestoi M, Rokka M, Yli-Mattila T, Parikka P, Rizzo A, Peltonen K. 2004. Presence and
52 concentrations of the *Fusarium*-related mycotoxins beauvericin, eniaticins and
53 moniliformin in Finnish grain samples. *Food Add Contam.* 21(8): 794-802.
54
55
56
57 Jones RK, Mirocha CJ. 1999. Quality parameters in small grains from Minnesota affected by
58 *Fusarium* head blight. *Plant Dis.* 83: 506-511.
59
60

- 1
2
3 Kiecana I, Mielniczuk E, Kaczmarek Z, Kostecki M, Golinski P. 2002. Scab response and
4 moniliformin accumulation in kernels of oat genotypes inoculated with *Fusarium*
5 *avenaceum* in Poland. *Eur J Plant Pathol.* 108: 245-251.
6
7
8 Kiecana I, Mielniczuk E, Cegiello M. 2004. Reaction of oats genotypes to *Fusarium*
9 *avenaceum* (Fr.) Sacc., *Fusarium culmorum* (W.G.Sm.) Sacc. and *Fusarium graminearum*
10 (Schwabe.) infection. *Agronomijas Vestis. Latvian Journal of Agronomy*, 7: 165-169.
11
12
13 Klix MB, Beyer M, Verreet J-A. 2008. Effects of cultivars, agronomic practices, geographic
14 location, and meteorological conditions on the composition of selected *Fusarium* species
15 on wheat heads. *Can J plant Pathol.* 30: 46-57.
16
17
18 Kostecki M, Wisniewska H, Perrone G, Ritieni A, Golinski P, Chelkowski J, Logrieco A.
19 1999. The effects of cereal substrate and temperature on production of beauvericin,
20 moniliformin and fusaproliferin by *Fusarium subglutinans* ITEM – 1434. *Food Add Contam.*
21 16(9): 361-365.
22
23
24 Lepschy von Gleissenthal J, Dietrich R, Martlbauer E, Schuster M, Suss A, Terplan G. 1989.
25
26 A survey on the occurrence of *Fusarium* mycotoxins in Bavarian cereals from the 1987
27 harvest. *Zeitschrift fur Lebensmittel-Untersuchung und Forschung* 188: 521-526.
28
29
30 Mielniczuk E, Kiecana I, Perkowski J, 2004. Susceptibility of oat genotypes to *Fusarium*
31 *crookwellense* Burgess, Nelson and Toussoun infection and mycotoxin accumulation in
32 kernels. *Biologia, Bratislava*, 59/6: 809-816.
33
34
35 Nuryono N, Noviandi CT, Böhm J, Razzazi-Fazeli E. 2005. A limited survey of zearalenone
36 in Indonesian maize-based food and feed by ELISA and high performance liquid
37 chromatography. *Food Control* 16: 65–71.
38
39
40 Perkowski J, Chelkowski J, Wakulinski W. 1990. Mycotoxins in cereal grain Part 13.
41 Deoxynivalenol and 3-acetyl-deoxynivalenol in wheat kernels and chaff with head
42 fusariosis symptoms. *Nahrung* 34(4): 325-328.
43
44
45 Pineda-Valdes G, Bullerman LB. 2000. Thermal stability of moniliformin at varying
46 temperature, pH, and time in an aqueous environment. *J Food Protect.* 63(11): 1598-1601.
47
48
49 Quarta A, Mita G, Haidukowski M, Santino A, Mule G, Visconti A. 2005. Assessment of
50 trichothecene chemotypes of *Fusarium culmorum* occurring in Europe. *Food Add Contam.*
51 22(4): 309-315.
52
53
54 Reams R, Thacker HL, Novilla M, Laska D, Horn J, Harrington D, Greenlee W, Vesonder R.
55 1996. Development of an L6 myoblast *in vitro* model of moniliformin toxicosis.
56 *Mycopathologia* 133: 105-114.
57
58
59
60

- 1
2
3 Sharman M, Gilbert J, Chelkowski J. 1991. A survey of the occurrence of the mycotoxin
4 moniliformin in cereal samples from sources worldwide. *Food Add Contam.* 4: 459-466.
5
6 Tomczak M, Wisniewska H, Stepień L, Kostecki M, Chelkowski J, Golinski P. 2002.
7 Deoxynivalenol, nivalenol and moniliformin in wheat samples with head blight (scab)
8 symptoms in Poland (1998-2000). *Eur J Plant Pathol.* 108: 625-630.
9
10 Uhlig S, Torp M, Jarp J, Parich A, Gutleb AC, Krska R. 2004. Moniliformin in Norwegian
11 grain. *Food Add Contam.* 21(6): 598-606.
12
13 Visconti A, Pascale M. 1998. Determination of zearalenone in corn by means of
14 immunoaffinity clean-up and high-performance liquid chromatography with fluorescence
15 detector. *J. Chromatogr A* 815: 133-140.
16
17 Waskiewicz A, Irzykowska L, Bocianowski J, Karolewski Z, Kostecki M, Weber Z, Golinski
18 P. 2010. Occurrence of *Fusarium* fungi and mycotoxins in marketable asparagus spears.
19 *Polish J Environ Stud.* 19(1): 219-225.
20
21 Wisniewska H, Chelkowski J, Perkowski J, Busko M, Bocianowski J. 2002. Components of
22 resistance against *Fusarium culmorum* in spring wheat. *J Appl Genet.* 43A: 345-354.
23
24 Wisniewska H, Perkowski J, Kaczmarek Z. 2004. Scab response and deoxynivalenol
25 accumulation in spring wheat kernels of different geographical origins following
26 inoculation with *Fusarium culmorum*. *J Phytopathol.* 152: 613-621.
27
28 Young JC, Miller JD. 1985. Appearance of fungus, ergosterol and *Fusarium* mycotoxins in
29 the husk, axial stem, and stalk after inoculation of field corn. *Can J Plant Sci* 65: 47-53.
30
31 Zinedine A, Soriano JM, Moltó JC, Mañes J. 2007. Review on the toxicity, occurrence,
32 metabolism, detoxification, regulations and intake of zearalenone: An oestrogenic
33 mycotoxin. *Food Chem Toxicol.* 45: 1-18.
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Table 1. Characteristics of the cultivars used in the experiment (date from Research Centre for Cultivar Testing)

Cultivar	Technological value/group	Frost resistance	Lodging resistance	Soil acidity tolerance	Protein and gluten contents
Finezja	quality/A	medium	medium	medium	high
Ludwig	quality/A	low/medium	low	medium	high
Mewa	bread/B	high	low	medium	high
Nutka	bread/B	low	high	medium	low/medium
Rywalka	quality/A	medium	low	medium	high
Soraja	bread/B	medium	medium	medium	medium
Sukces	quality/A	low	high	high	high
Symfonia	forage/C	high	medium	medium	medium
Tonacja	quality/A	high	high	medium	high
Zyta	quality/A	low	medium	medium	high

Table 2. Mean squares from analysis of variance for *F. culmorum*

Trait	Mean squares			
	Cultivars	Locations	Cultivars × Locations interaction	Residual
Degrees of freedom	9	1	9	38
Fi	0.873***	85.049***	0.786***	0.161
ZEA in HLK	0.149***	1.830***	0.150***	0.002
ZEA in FDK	0.051***	0.537***	0.518***	0.001
ZEA in chaff	268.058***	1258.871***	266.055***	2.456
DON in HLK	1.065***	3.353***	1.304***	0.253
DON in FDK	780.700*	24265.900***	797.100*	359.800
DON in chaff	2037.300***	2575.300**	3122.700***	211.700
HLK kernels per spike	77.570**	4005.480***	33.600	22.610
FDK kernels per spike	19.878*	16.537	12.642	7.495
HLK weight per spike	0.112**	10.660***	0.080*	0.035
FDK weight per spike	0.019**	0.071***	0.014*	0.005
TKW	185.000	3721.200***	163.500	172.600

* - significant at 0.05 level

** - significant at 0.01 level

*** - significant at 0.001 level

Table 3. Mean squares from analysis of variance for *F. graminearum*

Trait	Mean squares			
	Cultivars	Locations	Cultivars × Locations interaction	Residual
Degrees of freedom	9	1	9	38
Fi	0.741***	5.424***	0.546***	0.104
ZEA in HLK	0.099***	0.554***	0.100***	0.001
ZEA in FDK	2.583***	12.520***	2.524***	0.027
ZEA in chaff	47.739***	1801.983***	60.470***	5.131
DON in HLK	0.932***	2.212***	1.510***	0.081
DON in FDK	460.800*	13320.600***	481.800**	160.500
DON in chaff	1801.360***	867.540**	1843.910***	89.610
HLK kernels per spike	48.620	2856.140***	61.190*	26.760
FDK kernels per spike	18.583*	49.625*	20.061*	7.581
HLK weight per spike	0.111*	10.394***	0.185**	0.051
FDK weight per spike	0.026*	0.027	0.030*	0.012
TKW	60.710***	1516.270***	39.220**	11.630

* - significant at 0.05 level

** - significant at 0.01 level

*** - significant at 0.001 level

Table 4. Mean squares from analysis of variance for *F. avenaceum*

Trait	Mean squares			
	Cultivars	Locations	Cultivars × Locations interaction	Residual
Degrees of freedom	9	1	9	38
Fi	1.050***	9.025***	0.657***	0.045
MON in HLK	0.006***	0.000	0.004*	0.001
MON in FDK	2.167***	1.580**	0.407	0.192
MON in chaff	0.596***	1.908***	0.285***	0.042
HLK kernels per spike	20.092**	110.433***	7.378	5.310
FDK kernels per spike	3.806**	26.268***	2.268	1.284
HLK weight per spike	0.132*	17.997***	0.087	0.051
FDK weight per spike	0.044***	1.311***	0.030**	0.009
TKW	65.590**	506.630***	43.380*	20.210

* - significant at 0.05 level

** - significant at 0.01 level

*** - significant at 0.001 level

Table 5. The average values for ZEA in FDK, ZEA in HLK and ZEA in chaff ($\mu\text{g g}^{-1}$) for *F. culmorum*

Cultivar	ZEA in HLK			ZEA in FDK			ZEA in chaff		
	Lublin	Poznan	Means	Lublin	Poznan	Means	Lublin	Poznan	Means
Finezja	0.085	0.000	0.043g	0.415	0.009	0.212c	5.862	0.022	2.942bcd
Ludwig	0.528	0.002	0.265d	0.188	0.036	0.113e	4.279	0.002	2.141cd
Mewa	0.863	0.000	0.432a	0.036	0.072	0.054f	46.810	0.097	23.454a
Nutka	0.095	0.000	0.048fg	0.439	0.035	0.237bc	4.016	0.016	2.016cd
Rywalka	0.067	0.005	0.036g	0.217	0.029	0.123de	4.343	0.008	2.175cd
Soraja	0.259	0.017	0.138e	0.480	0.103	0.292a	6.247	0.014	3.130bc
Sukces	0.605	0.007	0.306c	0.424	0.068	0.246b	5.004	0.056	2.530cd
Symfonia	0.791	0.002	0.397b	0.196	0.101	0.148d	9.124	0.045	4.585b
Tonacja	0.188	0.006	0.097ef	0.023	0.047	0.035f	3.926	0.018	1.972cd
Zyta	0.045	0.000	0.023g	0.034	0.061	0.047f	2.286	0.005	1.145d
Means	0.353A	0.004B		0.245A	0.056B		9.190A	0.028B	
LSD _{0.05}	C: 0.050, L: 0.023, C×L: 0.071			C: 0.031, L: 0.014, C×L: 0.043			C: 1.831, L: 0.819.1, C×L: 2.590		

Means with the same letter are not significantly different

Table 6. The average values for ZEA in FDK, ZEA in HLK and ZEA in chaff ($\mu\text{g g}^{-1}$) for *F. graminearum*

Cultivar	ZEA in HLK			ZEA in FDK			ZEA in chaff		
	Lublin	Poznan	Means	Lublin	Poznan	Means	Lublin	Poznan	Means
Finezja	0.091	0.0000	0.046cd	0.315	0.032	0.173c	14.925	0.130	7.527b
Ludwig	0.119	0.0001	0.060c	0.598	0.003	0.300c	22.455	0.020	11.238a
Mewa	0.115	0.0002	0.057c	1.037	0.025	0.531b	10.994	0.040	5.517b
Nutka	0.189	0.0000	0.094b	0.563	0.026	0.295c	4.015	0.044	2.029d
Rywalka	0.040	0.0022	0.021d	0.468	0.007	0.237c	4.152	0.014	2.083d
Soraja	0.912	0.0003	0.456a	4.617	0.065	2.341a	10.990	0.037	5.514b
Sukces	0.068	0.0101	0.039cd	0.442	0.032	0.237c	10.609	0.084	5.347bc
Symfonia	0.205	0.0009	0.103b	0.387	0.126	0.257c	14.321	0.173	7.247b
Tonacja	0.130	0.0004	0.065c	0.687	0.018	0.352bc	5.591	0.002	2.797cd
Zyta	0.068	0.0000	0.034cd	0.401	0.043	0.222c	12.240	0.172	6.206b
Means	0.194A	0.0014B		0.951A	0.038B		11.029A	0.072B	
LSD _{0.05}	C: 0.026, L: 0.011, C×L: 0.036			C: 0.194, L: 0.087, C×L: 0.274			C: 2.658, L: 1.189, C×L: 3.759		

Means with the same letter are not significantly different

Table 7. The average values for DON in FDK, DON in HLK and DON in chaff ($\mu\text{g g}^{-1}$) for *F. culmorum*

Cultivar	DON in HLK			DON in FDK			DON in chaff		
	Lublin	Poznan	Means	Lublin	Poznan	Means	Lublin	Poznan	Means
Finezja	0.47	0.54	0.505cd	84.8	43.5	64.14abc	67.5	41.4	54.45b
Ludwig	1.36	0.21	0.785bcd	114.6	41.3	77.94ab	9.4	33.0	21.20d
Mewa	0.91	1.11	1.010abc	68.7	44.1	56.38bc	7.1	62.2	34.68cd
Nutka	1.37	1.26	1.315ab	101.1	54.2	77.66ab	13.3	37.2	25.25d
Rywalka	1.22	1.92	1.570a	90.3	21.6	55.96bc	43.9	21.7	32.79cd
Soraja	0.85	0.38	0.615cd	88.4	80.8	84.62a	14.6	97.6	56.09b
Sukces	2.63	0.29	1.460a	78.6	28.3	53.45c	115.9	45.6	80.75a
Symfonia	2.10	0.55	1.325ab	60.0	51.8	55.92bc	14.2	71.2	42.73bc
Tonacja	0.27	0.44	0.355d	84.0	29.1	56.53bc	33.2	37.6	35.44cd
Zyta	1.15	0.90	1.026abc	82.0	55.5	68.77abc	22.8	25.4	24.07d
Means	1.23A	0.76B		85.2A	45.0B		34.2B	47.3A	
LSD _{0.05}	C: 0.59, L: 0.26, C×L: 0.83			C: 22.17, L: 9.91, C×L: 31.35			C: 17.01, L: 7.61, C×L: 24.05		

Means with the same letter are not significantly different

Table 8. The average values for DON in FDK, DON in HLK and DON in chaff ($\mu\text{g g}^{-1}$) for *F. graminearum*

Cultivar	DON in HLK			DON in FDK			DON in chaff		
	Lublin	Poznan	Means	Lublin	Poznan	Means	Lublin	Poznan	Means
Finezja	0.21	0.69	0.45bcde	71.2	36.3	53.76ab	12.5	41.9	27.19cd
Ludwig	0.24	0.13	0.19e	43.5	18.2	30.86e	45.2	13.3	29.27cd
Mewa	0.08	0.95	0.52bcde	58.7	42.6	50.62abc	60.0	102.3	81.16a
Nutka	0.22	1.27	0.75b	54.2	27.1	40.62bcde	19.7	35.7	27.70cd
Rywalka	0.30	0.22	0.26de	77.4	21.4	49.40abcd	35.9	19.0	27.44cd
Soraja	0.32	0.31	0.32cde	62.7	56.6	59.65a	68.9	16.9	42.90b
Sukces	0.15	2.97	1.56a	52.6	29.1	40.84bcde	31.8	55.2	43.50b
Symfonia	0.76	0.29	0.53bcd	41.8	33.6	37.67cde	18.4	22.5	20.45d
Tonacja	0.77	0.44	0.61bc	60.2	14.2	37.23de	60.5	9.7	35.12bc
Zyta	0.51	0.13	0.32cde	71.2	16.4	43.84bcde	48.6	8.8	28.72cd
Means	0.36B	0.74A		59.3A	29.5B		40.1A	32.5B	
LSD _{0.05}	C: 0.33, L: 0.15, C×L: 0.47			C: 14.81, L: 6.62, C×L: 20.94			C: 11.06, L: 4.95, C×L: 15.65		

Means with the same letter are not significantly different

Table 9. The correlation matrix for the traits studied in Poznan (above diagonal) and Lublin (below diagonal) for *F. culmorum*

	Fi	ZEA in HLK	ZEA in FDK	DON in HLK	DON in FDK	HLK kernels per spike	FDK kernels per spike	HLK weight per spike	FDK weight per spike	TKW
Fi	1.00	0.30	-0.26	0.22	0.05	-0.25	0.04	-0.66*	-0.16	-0.38
ZEA in HLK	0.34	1.00	0.45	-0.16	0.05	-0.24	0.15	-0.39	-0.09	-0.21
ZEA in FDK	-0.38	-0.18	1.00	-0.24	0.43	-0.38	0.25	-0.27	0.12	-0.11
DON in HLK	-0.16	0.46	0.27	1.00	-0.11	-0.24	-0.03	-0.09	-0.02	0.11
DON in FDK	0.09	-0.26	0.20	0.10	1.00	-0.18	0.24	-0.09	0.10	0.13
HLK kernels per spike	-0.42	-0.11	0.15	-0.20	0.14	1.00	-0.10	0.54	-0.14	-0.33
FDK kernels per spike	0.49	0.42	-0.17	0.35	0.32	-0.16	1.00	-0.12	0.84**	-0.02
HLK weight per spike	-0.05	0.29	-0.12	0.05	-0.03	0.58	0.19	1.00	0.16	0.55
FDK weight per spike	0.23	0.29	-0.11	0.34	0.54	0.09	0.77**	0.14	1.00	0.29
TKW	0.09	0.37	-0.29	0.30	0.05	-0.03	0.26	0.63*	0.37	1.00

* significant at 0.05 level, ** significant at 0.01 level

Table 10. The correlation matrix for the traits studied in Poznan (above diagonal) and Lublin (below diagonal) for *F. graminearum*

	Fi	ZEA in HLK	ZEA in FDK	DON in HLK	DON in FDK	HLK kernels per spike	FDK kernels per spike	HLK weight per spike	FDK weight per spike	TKW
Fi	1.00	-0.23	0.20	-0.14	0.56	-0.42	0.34	-0.61	0.12	-0.45
ZEA in HLK	0.40	1.00	-0.02	0.72*	-0.02	-0.12	0.15	-0.09	0.28	-0.01
ZEA in FDK	-0.01	0.20	1.00	-0.09	0.47	-0.29	0.19	-0.28	0.33	-0.09
DON in HLK	0.16	0.39	0.30	1.00	0.09	-0.44	0.43	-0.33	0.47	-0.19
DON in FDK	0.09	-0.38	0.04	0.14	1.00	-0.52	0.50	-0.58	0.42	-0.39
HLK kernels per spike	-0.31	-0.28	-0.06	0.11	-0.12	1.00	-0.59	0.81**	-0.54	0.39
FDK kernels per spike	0.20	0.03	0.27	-0.10	0.21	-0.72*	1.00	-0.51	0.82**	-0.33
HLK weight per spike	-0.20	-0.16	0.09	0.20	-0.16	0.93***	-0.62	1.00	-0.24	0.71*
FDK weight per spike	0.19	-0.06	0.32	-0.11	0.25	-0.63*	0.93***	-0.53	1.00	0.02
TKW	0.16	0.09	0.48	0.16	0.00	-0.04	0.25	0.27	0.45	1.00

* significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level

Table 11. The average values for MON in FDK, MON in HLK, and MON in chaff for ($\mu\text{g g}^{-1}$) *F. avenaceum*

Cultivar	MON in HLK			MON in FDK			MON in chaff		
	Lublin	Poznan	Means	Lublin	Poznan	Means	Lublin	Poznan	Means
Finezja	0.000	0.017	0.008d	0.023	0.216	0.120de	–	0.019	0.019b
Ludwig	0.000	0.000	0.000d	0.037	0.142	0.090e	–	0.147	0.147b
Mewa	0.000	0.132	0.066b	0.000	1.245	0.623bcd	–	0.000	0.000b
Nutka	0.076	0.050	0.063b	0.392	1.155	0.774bc	0.097	0.017	0.057b
Rywalka	0.038	0.000	0.019cd	0.119	0.445	0.282cde	0.035	0.144	0.090b
Soraja	0.038	0.020	0.029bcd	0.060	0.476	0.268cde	0.037	1.069	0.553a
Sukces	0.110	0.108	0.109a	2.510	1.728	2.119a	0.481	0.825	0.653a
Symfonia	0.050	0.022	0.036bcd	0.799	0.874	0.837b	0.176	1.066	0.621a
Tonacja	0.050	0.058	0.054bc	0.122	0.506	0.314cde	0.074	0.079	0.077b
Zyta	0.061	0.050	0.056bc	0.626	1.146	0.886b	0.226	0.428	0.327ab
Means	0.042A	0.046A		0.469A	0.793B		0.161B	0.379A	
LSD _{0.05}	C: 0.04, L: 0.02, C×L: 0.06			C: 0.51, L: 0.23, C×L: 0.72			C: 0.19, L: 0.17, C×L: 0.34		

Means with the same letter are not significantly different

Table 12. The correlation matrix for the traits studied in Poznan (above diagonal) and Lublin (below diagonal) for *F. avenaceum*

	Fi	MON_HLK	MON_FDK	HLK kernels per spike	FDK kernels per spike	HLK weight per spike	FDK weight per spike	TKW
Fi	1.00	0.03	0.14	-0.29	0.06	-0.34	0.11	-0.12
MON_HLK	-0.29	1.00	0.78**	-0.32	0.40	-0.31	0.29	0.09
MON_FDK	-0.34	0.71*	1.00	-0.58	0.70*	-0.55	0.62	0.19
HLK kernels per spike	-0.29	-0.16	0.04	1.00	-0.51	0.81**	-0.54	-0.13
FDK kernels per spike	0.26	0.15	-0.08	-0.54	1.00	-0.51	0.95***	0.12
HLK weight per spike	-0.32	-0.08	0.10	0.93***	-0.50	1.00	-0.48	0.18
FDK weight per spike	0.20	0.22	-0.02	-0.44	0.97***	-0.39	1.00	0.11
TKW	-0.35	0.22	0.28	0.33	-0.24	0.63*	-0.11	1.00

* significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level