Mycotoxin contamination of maize (Zea mays L.) samples in Hungary, 2012–2017

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Abstract
Mycotoxin contamination of maize often raises risks for human and animal health. The most frequently detected mycotoxins in maize are trichothecenes, fumonisins, and aflatoxin. A total number of 17,011 maize samples were tested by SGS for their mycotoxin content between 2012 and 2017. The toxin results clearly show that the southern areas of the country had higher levels of toxin contamination than the average. According to the dataset, aflatoxin contamination has become regular but the appearance of fumonisins was also more frequent. Deoxynivalenol toxin accumulation in crops can also reach dangerous levels under favorable ecological conditions. The fluctuation between years and regions is decisively shaped by the weather conditions. However, the two pathogens with less virulence (Fusarium verticillioides and Aspergillus flavus) must be taken into account and the contribution of insect pests. 72.63% of the total fumonisin concentration was defined as fumonisin B1, 20.34% as fumonisin B2, and 7.03% as fumonisin B3. The correlations between the three fumonisins analogs were highly significant (P = 0.001), and correlation coefficient varied between 0.961 and 0.998 across the six years of evaluation. This is the first complex evaluation of deoxynivalenol, fumonisin, and aflatoxin contamination of maize samples in Hungary.

Keywords Mycotoxin · Maize · Hungary · Deoxynivalenol · Fumonisin · Aflatoxin

Introduction
Maize (Zea mays L.) is the most important ingredient of feeds and one of the most important agricultural export products of Hungary. Food and feed safety problems have increasing significance in maize production. Species of genus Fusarium and Aspergillus cause important animal and human health concerns worldwide, but their damage and danger vary in different parts of the world (Munkvold and White 2016). In the last decades, no such data were published from Hungary. As many years were with high temperatures and drought in the Mediterranean area, it was clear that fumonisins and aflatoxins might have a higher incidence than found in the past (Battilani et al. 2016; Cotty and Jaime-Garcia 2007; Miedaner and Juroszek 2021).

Ni et al. (2011) showed a positive correlation between the degree of insect damage on the ear and aflatoxin contamination. Folcher et al. (2010) tested the fumonisin B1 + B2 (FB1 + FB2), deoxynivalenol (DON), and zearalenon (ZEA) content of the MON 810 Bt transgenic maize hybrid and its non-GMO isogenic pair. The Bt genotype presented reduced fumonisin concentrations by more than 90% and ZEA content by 50% confirming the earlier results (Munkvold et al. 1997).

After examination of maize samples from different maize growing areas of Hungary, nearly two thirds of the maize samples tested were found to be contaminated by Aspergillus flavus, and about one fifth of these were also able to produce aflatoxin (Dobolyi et al. 2013). These results were confirmed with the report of high incidence of aflatoxin in Serbia (Kos et al. 2013). In maize, many Fusarium spp. were identified from grains (Mesterházy and Vojtovics 1977, Goertz et al. 2010, Dorn et al. 2009, Ivić et al. 2009, Scauflaire et al. 2011).

In Hungary, the predominance of F. verticillioides was revealed, while the presence of Fusarium graminearum, F.}

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proliferatum, F. Sporotrichioides, and F. subglutinans was rare. In warmer years, Penicillium and Aspergillus isolates also appeared in increasing proportion (Tóth et al. 2012).

Aflatoxin data are published from Serbia (Jakic-Dimic et al. 2009), fumonisin, DON, and ZEA data from Poland (Czembor et al. 2015). In Romania aflatoxin, DON, zearalenone, and fumonisin contamination were reported (Tabuc et al. 2009), while DON, ZEA, but no aflatoxin occurrence from maize samples were reported from Croatia (Pleadin et al. 2012). In data published in Italy, DON, ZEA, aflatoxins, and fumonisins occurred in a significant part of the samples (Leggieri et al. 2015). In Spain, mostly aflatoxin, fumonisins, and zearalenone were found in the samples examined (Tarazona et al. 2020). Multitoxin contamination of the samples is shown in early data of Borutova et al. (2012).

Aflatoxin production of A. flavus isolates was studied (Astoreca et al., 2012) at different water potential and temperature values, and their effect on mycotoxin concentration during storage was modeled by a predictive way. At a water potential value of 0.90, storage was only safe below 15 °C, while at 0.80, it was already 27 °C. With a water potential level of 0.77, storage was possible regardless of temperature.

To lower toxin contamination, the use of fungicides in maize is not widespread due to less effective technology. Among the various agrotechnical specifications, the advantage of early sowing and the precise timing of irrigation can be highlighted, but insecticide control and early harvesting are also of paramount importance. However, the most important factor is the resistance of the hybrid. The role of resistance breeding in prevention of mycotoxin contamination in maize is, therefore, particularly important (Munkvold, 2014).

The limit of total fumonisin concentration for unprocessed maize samples is 4000 µg/kg and 200–1000 µg/kg for processed foods. For DON, these values are 1750 µg/kg and 750 µg/kg, respectively. The prescribed limits for AFB1 vary from 0.1 to 8 µg/kg, depending on the type of food (EU Commission Regulation No 1126/2007/EK). The limits for samples intended for animal feed depend on the animals kept and their age.

As in the last decades, no wide evaluation of the mycotoxins was published in Hungary, our aim was to present a long-term dataset for the most important mycotoxins in maize.

**Materials and methods**

17,011 samples were analyzed in maize between 2012 and 2017. SGS Hungária Ltd. was helpful in providing the toxin test results. Their mycotoxin-testing laboratories operate according to strict guidelines and accreditation to ISO 17025, ISO 9001:2008, so both sampling and the analytical methods are validated (technical descriptions of the analysis of mycotoxins are available on the website of SGS).

The samples originated from farmers from all counties of Hungary who sent their grain samples for mycotoxin determination. Most of the samples were mixed, and a significant part of them were stored samples, so it is advisable to evaluate them in relation to the previous year. A significant part of the toxin concentration determinations of the grains harvested in September, October or later was performed next year when it was sold or used. There are no informations regarding the length of the storage period, and because of this, the preharvest or postharvest character of the toxin contamination is not specified. Higher degree of insect damage can also cause additional toxin contamination and this effect is included in the dataset.

Table 1 shows the number of samples tested in each year. Toxin concentrations for DON is indicated in mg/kg values, while in case of total aflatoxin (B1 + B2 + G1 + G2) µg/kg. In point of fumonisins, not only the sum of FB1 and FB2 concentrations was given but also FB3 contamination in mg/kg.

Toxin data were grouped by county. Averages were shown in the figures per type of toxin and per year. The sum of these toxins is highlighted in the figures and tables shown.

### Results

**Average toxin contamination of maize samples between 2012–2017**

The annual data are shown in Appendix 1–6.

Mean toxin data of the six years tested are shown in Table 2. In 2014 and 2015, DON was dominant toxin (The EU limit for adult pigs is 0.9 mg/kg, but for piglets only 0.2 mg/kg.). Higher concentrations of fumonisins and aflatoxins were found in 2013 and 2014. In other years, only sporadic occurrence was found. In the case of aflatoxin, positive values were observed every year except 2012, when no measurements for this toxin were performed. Many of the samples from harvest of 2012 were tested in 2013; therefore,

### Table 1  Number of maize samples tested in the laboratory of SGS, Hungary, 2012–2017

| Year | Number of samples |
|------|-------------------|
| 2012 | 429               |
| 2013 | 2009              |
| 2014 | 4743              |
| 2015 | 5713              |
| 2016 | 2010              |
| 2017 | 2107              |
| Total| 17,011            |
higher concentrations were present. Aflatoxin concentrations were significantly lower in 2015 and 2016 but significantly higher in 2017. Total fumonisin contents of the samples in 2013 and 2014 were significantly higher than from other years. Toxin composition and maximum values differ significantly throughout the years and cannot be forecasted precisely. Climate change does not mean a continuous increase of toxin contamination, but higher differences can occur from year to year. Our conclusion is that resistance against all major pathogens is necessary to control one or more diseases effectively.

The two-way ANOVA (Table 3) shows highly significant differences between years and the year × toxin interactions indicating the influence of the yearly weather conditions on the toxin contamination.

Based on the results of two-way ANOVA (Table 4) regarding toxin concentrations, geographical location had a highly significant effect on distribution of all three toxins, while the effect of years was significant for DON and fumonisin, while the incidence of aflatoxin was much more unpredictable, further increasing the concern of aflatoxin. Based on the results of the three-way ANOVA, there are highly significant differences for all three main factors (LSD 5% for factor A is 0.85) similarly to the County × Toxin and Toxin × Year interactions (Table 5).

The maximum values (Table 6) of DON surpassed the EU limits each year. Two years showed higher than 100 µg/kg aflatoxin concentrations, while the EU limit for feeds is 20 µg/kg. We should also consider that the limit for human consumption is only 4 µg/kg which poses a threat also in years without Aspergillus epidemic. The distribution of

| Table 2 | Average toxin concentrations of the tested maize samples, 2012–2017 |
| Years | DON (mg/kg) | Total aflatoxin (µg/kg) | Total fumonisin (mg/kg) |
| 2012 | 0.10 | n. d. | 0.31 |
| 2013 | 0.14 | 1.20 | 1.00 |
| 2014 | 1.34 | 1.10 | 2.01 |
| 2015 | 1.20 | 0.39 | 0.75 |
| 2016 | 0.39 | 0.34 | 0.53 |
| 2017 | 0.25 | 1.20 | 0.30 |
| Mean | 0.57 | 0.71 | 0.82 |
| LSD 5% | 0.26 | 0.26 | 0.26 |

*a Aflatoxin determination was not performed in 2012

| Table 3 | Two-way ANOVA of the tested maize samples (Years and Toxins), 2012–2017 |
| Source of variance | SS | df | MS | F | p-value | F crit |
| Years A | 59.21 | 5 | 11.84 | 10.97*** | 9.1E − 10 | 2.23 |
| Toxins B | 3.49 | 2 | 1.74 | 1.61 | 0.20058 | 2.23 |
| A × B | 35.38 | 10 | 3.54 | 3.28*** | 0.00047 | 1.52 |
| Within | 349.87 | 324 | 1.08 |
| Total | 447.95 | 341 |

***p = 0.001

| Table 4 | Two-way ANOVA of the tested maize samples (Counties and Years), 2012–2017 |
| Source of variance | SS | df | MS | F | p-value | F crit |
| Counties A | 51.99 | 17 | 3.06 | 2.59*** | 0.000769 | 1.67 |
| Year + Toxin B | 80.03 | 14 | 5.72 | 4.83*** | 7.77E−08 | 1.73 |
| Within | 281.46 | 238 | 1.18 |
| Total | 413.48 | 269 |

***p = 0.001
maximum values prove the fact that only one year is not suitable to judge the potential risk of a mycotoxin. The correlation between DON content and total aflatoxin concentration is not significant (Table 7). The correlation between DON and total fumonisin as well as total fumonisin and total aflatoxin is \( r = 0.45 \), just above the limit of LSD 5%.

### Regional differences in toxin contamination of maize in Hungary

Based on the DON toxin results, it can be concluded that the western part of the country is well separated from the eastern one, and the toxin concentrations were higher in that part of the country. This can be explained by the fact that in the vast majority of the years, the western part of the country has more precipitation and a lower average temperature, which favors the growth of *Fusarium graminearum* and the production of DON toxin (Table 8).

In regard of aflatoxin, we only examined the period between 2013 and 2017, as no data were available from 2012. The spread of *Aspergillus flavus*, the main producer of aflatoxin, is controlled by hot and dry weather conditions. We generally obtained exceptionally high values

### Table 6 Maximum toxin concentrations of maize samples in Hungary, 2012–2017

| Years | DON (mg/kg) | Total aflatoxin (µg/kg) | Total fumonisin (mg/kg) |
|-------|-------------|-------------------------|-------------------------|
| 2012  | 1.61        | n. d                    | 1.71                    |
| 2013  | 2.79        | 115.88                  | 6.31                    |
| 2014  | 5.36        | 109.40                  | 11.89                   |
| 2015  | 9.40        | 61.95                   | 5.36                    |
| 2016  | 4.83        | 18.31                   | 5.59                    |
| 2017  | 2.30        | 64.94                   | 2.27                    |

### Table 7 Correlation between toxin concentrations of maize samples in Hungary, 2013–2017

|          | DON | Total aflatoxin | Total fumonisin |
|----------|-----|-----------------|-----------------|
| Total aflatoxin | 0.0933 |                  |                 |
| Total fumonisin   | 0.4573*| 0.4595*         |

\*p=0.05

### Table 8 Regional differences in toxin contamination of maize in Hungary, means for 2012–2017

| Counties          | Regions | DON (mg/kg) | Total aflatoxin (µg/kg) | Total fumonisin (mg/kg) |
|-------------------|---------|-------------|-------------------------|-------------------------|
| Veszprém          | NW      | 0.87        | 2.17                    | 0.63                    |
| Fejér             | NW      | 0.71        | 0.43                    | 1.06                    |
| Komárom-Esztergom | NW      | 0.90        | 0.12                    | 0.72                    |
| Győr-Moson-Sopron | NW      | 0.62        | 0.36                    | 0.75                    |
| Vas               | NW      | 0.71        | 0.07                    | 0.41                    |
| Mean              |         | 0.76*       | 0.63                    | 0.71                    |
| Baranya           | SW      | 0.86        | 1.15                    | 1.82                    |
| Tolna             | SW      | 1.17        | 0.63                    | 1.44                    |
| Somogy            | SW      | 0.97        | 0.75                    | 1.11                    |
| Zala              | SW      | 1.21        | 0.10                    | 0.57                    |
| Mean              |         | 1.05*       | 0.66*                   | 1.24*                   |
| Bács-Kiskun       | SE      | 0.61        | 2.60                    | 1.51                    |
| Csongrád-Csanád  | SE      | 0.17        | 1.63                    | 0.85                    |
| Békés             | SE      | 0.17        | 1.38                    | 0.91                    |
| Jász-Nagykun-Szolnok | SE | 0.42        | 0.21                    | 1.40                    |
| Mean              |         | 0.34        | 1.46*                   | 1.17*                   |
| Pest              | NE      | 0.57        | 1.16                    | 0.72                    |
| Szabolcs-Szatmár-Bereg | NE | 0.32        | 0.30                    | 0.53                    |
| Borsod-Abáuj-Zemplén | NE | 0.33        | 0.07                    | 0.50                    |
| Hajdú-Bihar       | NE      | 0.13        | 0.12                    | 0.58                    |
| Heves             | NE      | 0.10        | 0.17                    | 0.04                    |
| Mean              |         | 0.29        | 0.36                    | 0.47                    |
| LSD 5%            |         |              |                          | 0.85                    |

\*Italic values Means of regions with the highest toxin contamination
in the Southern Great Plain region, but Southern Trans-
danubia had also outstanding concentrations, which was
joined by Pest county, presumably due to samples from
the southern regions of the county (Table 8).

In case of fumonisins, the higher value range of the
southern counties was common, but the regions of the
Great Plain and Transdanubia were mixed. This was per-
haps due to the general occurrence of fumonisins and
the fact that *Fusarium verticillioides* is the most char-
acteristic pathogenic species of maize and that warmer,
drier climate favors its growth and mycotoxin production
(Table 8).

**Occurrence of fumonisin analogs in maize samples
between 2012 and 2017**

Among the 105 fumonisin data of different counties 31
(29.5%) have no detectable FB content. The highest FB1
value was 3.54 mg/kg. The average concentrations of
the examined FB derivatives were 0.63 mg/kg for FB1,
0.17 mg/kg for FB2, and 0.06 mg/kg for FB3 (Fig. 1).
FB2 or FB3 was never detected alone. The correlations
between the three fumonisins analogs were highly sig-
nificant (*p* = 0.001), and correlation coefficient varied
between 0.961 and 0.998 across the 6 years of evaluation.
72.63% of the total fumonisin concentration was defined
as FB1, 20.34% as FB2, and 7.03% as FB3. Isolates of *F.
verticillioides* can produce fumonisin analogs in different
composition. This means that the toxin composition in
different isolates can be regulated differently.

**Discussion**

The aim of this study was a complex evaluation of natural
DON, total fumonisin, and total aflatoxin contamination of
maize samples derived from different geographical regions
of Hungary. The six years of national dataset clearly show
that all major mycotoxins occur in maize. The southern
counties of the country, near the Romanian (Tabuc et al.
2009), Serbian (Jaksic et al. 2019), and Croatian border
(Pleadin et al. 2012) show significantly higher toxin con-
tamination than counties in the northern part of Hungary.
In the case of countries, the north of Hungary fumonisin
was present in all samples examined, while DON was pre-
sent in 66.67% of the samples in Poland (Czembor et al.,
2015). Regarding the results of countries to the south of
Hungary, the concentration of DON and ZEA was extremely
low each year in Italy (Leggieri et al., 2015). In contrast, the
incidence of aflatoxins was 75%, while fumonisins occurred
in all samples (field samples). Tarazona et al. (2020) have
tested high number of stored maize samples for mycotoxin
concentrations in Spain. 20.4%, 5.1%, 3%, and 3% of these
maize samples had mycotoxin concentration exceeding the
European Union permissible limits for total fumonisin, ZEA,
AFB1, and total aflatoxins. There were samples in which
co-occurrence of more than one mycotoxins was present.
Quantifiable levels were observed in 33.5% of samples being
the association of FB1, FB2, and DON, followed by the pres-
ence of FB1, FB2, ZEA, and DON. In accordance with these
results, global climate change is increasing the incidence of
*A. flavus* isolates as well as changes in the composition of
mycobiota (Cotty et Jaime-García 2007). Our data support
that the production of aflatoxin can also be of field origin,

![Occurrence of fumonisin B analogs and the total fumonisin concentrations between 2012 and 2017](image-url)
and its occurrence is becoming more pronounced as a result of climate change. The epidemic refers to one, two, or all three major toxins. The fluctuation between years is decisively shaped by the weather conditions, and this is true for the warmer and drier southern counties, where aflatoxin was also present. A part of the aflatoxin contamination could be of preharvest origin, but publications with clear data were not published yet. The correlation between DON and total fumonisin as well as total fumonisin and total aflatoxin concentration (2013–2017) is $r = 0.45$, just above the limit of LSD 5%. There were some references previously supporting these data (Mesterhazy et al. 2012), but the significance of the correlations were not high enough to draw reliable conclusions. We should consider that the toxin content of the most contaminated lots is not tested by farmers, so the real toxin contamination data are most likely worse. As higher toxin contamination can occur across the whole country, higher plant resistance level is necessary to prevent larger ecological damages. Blaney et al. (2008) suggested also the same in Australia. Prevention is the cheapest way to avoid epidemics and raise food and feed safety. F. verticillioides isolates which may cause natural infection of maize belonged to the dominant FB chemotype, with higher amounts of FB1 and FB2 in the samples (Szécsi et al. 2010). Based on the evaluated data the mean ratios of FB1:FB2, FB1:FB3 and total fumonisins were 3.7:1; 10.5:1; and 0.7:1, respectively. The overall ratio of FB2 was higher and the concentration of FB3 was lower than previously reported from Iran (Ghiasian et al., 2005).

### Appendix 1 Toxin concentrations of maize samples in 2017, means for counties

| County                | DON   | Total aflatoxin | FB1 | FB2 | FB3 | Total fumonisin |
|-----------------------|-------|-----------------|-----|-----|-----|-----------------|
| Bács-Kiskun           | 0.24  | 7.11            | 0.53| 0.21| 0.05| 0.79            |
| Baranya               | 0.33  | 1.21            | 1.05| 0.31| 0.09| 1.45            |
| Békés                 | 0.03  | 2.36            | 0.00| 0.00| 0.00| 0.00            |
| Borsod-Abaúj-Zemplén  | 0.42  | 0.00            | 0.00| 0.00| 0.00| 0.00            |
| Csongrád-Csanád      | 0.03  | 0.13            | 0.00| 0.00| 0.00| 0.00            |
| Fejér                 | 0.07  | 0.00            | 0.14| 0.06| 0.00| 0.20            |
| Győr-Moson-Sopron     | 0.59  | 0.00            | 0.63| 0.21| 0.06| 0.90            |
| Hajdú-Bihar           | 0.04  | 0.04            | 0.42| 0.13| 0.03| 0.58            |
| Heves                 | 0.10  | 0.00            | 0.00| 0.00| 0.00| 0.00            |
| Jász-Nagy kun-Szolnok | 0.03  | 0.00            | 0.00| 0.00| 0.00| 0.00            |

### Appendix 2 Toxin concentrations of maize samples in 2016, means for counties

| County                | DON   | Total aflatoxin | FB1 | FB2 | FB3 | Total fumonisin |
|-----------------------|-------|-----------------|-----|-----|-----|-----------------|
| Bács-Kiskun           | 0.51  | 0.13            | 1.74| 0.63| 0.16| 2.53            |
| Baranya               | 0.97  | 0.04            | 0.40| 0.14| 0.04| 0.58            |
| Békés                 | 0.05  | 1.16            | 0.00| 0.00| 0.00| 0.00            |
| Borsod-Abaúj-Zemplén  | 0.19  | 0.00            | 0.72| 0.20| 0.06| 0.98            |
| Csongrád-Csanád      | 0.13  | 2.88            | 0.00| 0.00| 0.00| 0.00            |
| Fejér                 | 0.46  | 0.00            | 0.40| 0.13| 0.04| 0.57            |
| Győr-Moson-Sopron     | 0.27  | 0.05            | 0.00| 0.00| 0.00| 0.00            |
| Hajdú-Bihar           | 0.09  | 0.00            | 0.43| 0.10| 0.05| 0.58            |
| Jász-Nagy kun-Szolnok | 0.79  | 0.11            | 0.00| 0.00| 0.00| 0.00            |
| Komárom-Esztergom     | 0.41  | 0.10            | 0.71| 0.20| 0.07| 0.98            |
| Pest                  | 0.23  | 0.92            | 0.18| 0.09| 0.02| 0.29            |
| Somogy                | 0.46  | 0.31            | 0.49| 0.16| 0.05| 0.70            |
| Szabolcs-Szatmár-Bereg| 0.10  | 0.56            | 0.37| 0.08| 0.04| 0.49            |
| Tolna                 | 1.32  | 0.15            | 1.34| 0.53| 0.13| 2.00            |
| Vas                   | 0.33  | 0.00            | 0.10| 0.06| 0.00| 0.16            |
| Veszprém              | 0.60  | 0.01            | 0.00| 0.00| 0.00| 0.00            |
| Zala                  | 0.49  | 0.00            | 0.10| 0.02| 0.01| 0.13            |
| Mean                  | 0.44  | 0.38            | 0.41| 0.14| 0.04| 0.59            |
### Appendix 3 Toxin concentrations of maize samples in 2015, means for counties

| County             | DON  | Total aflatoxin | FB1 | FB2 | FB3 | Total fumonisin |
|--------------------|------|-----------------|-----|-----|-----|-----------------|
| Bács-Kiskun        | 1.26 | 0.83            | 0.00| 0.00| 0.00| 0.00            |
| Baranya            | 1.72 | 0.03            | 1.97| 0.54| 0.21| 2.72            |
| Békés              | 0.30 | 1.04            | 1.58| 0.39| 0.16| 2.13            |
| Borsod-Abáuj-Zemplén| 0.13 | 0.13            | 0.09| 0.03| 0.00| 0.12            |
| Csongrád-Csanád    | 0.09 | 3.22            | 0.00| 0.00| 0.00| 0.00            |
| Fejér              | 1.67 | 0.08            | 0.51| 0.12| 0.07| 0.70            |
| Győr-Moson-Sopron  | 1.14 | 0.20            | 0.31| 0.07| 0.01| 0.39            |
| Hajdú-Bihar        | 0.31 | 0.07            | 0.56| 0.14| 0.05| 0.75            |
| Heves              | 0.04 | 0.00            | 0.00| 0.00| 0.00| 0.00            |
| Jász-Nagykun-Szolnok| 1.01 | 0.12            | 2.10| 0.50| 0.16| 2.76            |
| Komárom-Esztergom  | 1.76 | 0.03            | 0.49| 0.14| 0.04| 0.67            |
| Nógrád             | 0.03 | 0.00            | 0.00| 0.00| 0.00| 0.00            |
| Pest               | 1.56 | 0.08            | 1.23| 0.24| 0.10| 1.57            |
| Somogy             | 2.29 | 1.00            | 1.12| 0.30| 0.12| 1.54            |
| Szabolcs-Szatmár-Bereg| 0.66 | 0.11            | 0.74| 0.17| 0.07| 0.98            |
| Tolna              | 3.03 | 0.14            | 0.00| 0.00| 0.00| 0.00            |
| Vas                | 1.38 | 0.01            | 0.00| 0.00| 0.00| 0.00            |
| Veszprém           | 2.00 | 0.32            | 0.00| 0.00| 0.00| 0.00            |
| Zala               | 2.38 | 0.06            | 0.00| 0.00| 0.00| 0.00            |
| Mean               | 1.20 | 0.39            | 0.56| 0.14| 0.05| 0.75            |

### Appendix 4 Toxin concentrations of maize samples in 2014, means for counties

| County             | DON  | Total aflatoxin | FB1 | FB2 | FB3 | Total fumonisin |
|--------------------|------|-----------------|-----|-----|-----|-----------------|
| Bács-Kiskun        | 1.52 | 3.42            | 2.56| 0.75| 0.29| 3.60            |
| Baranya            | 1.94 | 1.72            | 2.66| 0.80| 0.30| 3.76            |
| Békés              | 0.47 | 2.03            | 1.27| 0.34| 0.14| 1.75            |
| Borsod-Abáuj-Zemplén| 0.97 | 0.07            | 1.09| 0.22| 0.10| 1.41            |
| Csongrád-Csanád    | 0.72 | 3.56            | 3.54| 1.06| 0.49| 5.09            |
| Fejér              | 1.97 | 0.62            | 2.45| 0.71| 0.29| 3.45            |

### Appendix 5 Toxin concentrations of maize samples in 2013, means for counties

| County             | DON  | Total aflatoxin | FB1 | FB2 | FB3 | Total fumonisin |
|--------------------|------|-----------------|-----|-----|-----|-----------------|
| Bács-Kiskun        | 0.02 | 4.09            | 1.13| 0.31| 0.12| 1.56            |
| Baranya            | 0.07 | 3.87            | 1.27| 0.39| 0.16| 1.82            |
| Békés              | 0.05 | 1.67            | 0.67| 0.18| 0.07| 0.92            |
| Borsod-Abáuj-Zemplén| 0.13 | 0.22            | 0.30| 0.06| 0.02| 0.38            |
| Fejér              | 0.02 | 1.86            | 0.56| 0.14| 0.06| 0.76            |
| Győr-Moson-Sopron  | 0.08 | 0.76            | 0.57| 0.17| 0.06| 0.8             |
| Hajdú-Bihar        | 0.07 | 0.35            | 0.14| 0.03| 0.01| 0.18            |
| Heves              | 0.07 | 0.00            | 0.17| 0.04| 0.01| 0.22            |
| Jász-Nagykun-Szolnok| 0.13 | 0.88            | 1.82| 0.45| 0.18| 2.45            |
| Komárom-Esztergom  | 0.22 | 0.50            | 1.54| 0.23| 0.15| 1.92            |
| Pest               | 0.06 | 2.54            | 0.95| 0.30| 0.10| 1.35            |
| Somogy             | 0.22 | 1.78            | 0.00| 0.00| 0.00| 0.00            |
| Szabolcs-Szatmár-Bereg| 0.46 | 0.55            | 0.41| 0.10| 0.05| 0.56            |
| Tolna              | 0.11 | 1.98            | 1.40| 0.43| 0.18| 2.01            |
Appendix 6 Toxin concentrations of maize samples in 2012, means for counties

| County          | DON | Total aflatoxin | FB1 | FB2 | FB3 | Total fumonisin |
|-----------------|-----|-----------------|-----|-----|-----|----------------|
| Bacs-Kiskun     | 0.09| n.d             | 0.41| 0.12| 0.05| 0.58           |
| Baranya         | 0.11| n.d             | 0.43| 0.09| 0.06| 0.58           |
| Bekes           | 0.11| n.d             | 0.52| 0.09| 0.04| 0.65           |
| Borsod-Abatúj-Zemplén | 0.12| n.d             | 0.09| 0.02| 0.00| 0.11           |
| Csongrád-Csanád | 0.06| n.d             | 0.00| 0.00| 0.00| 0.00           |
| Fejér           | 0.06| n.d             | 0.53| 0.11| 0.04| 0.68           |
| Győr-Moson-Sopron | 0.15| n.d             | 0.00| 0.00| 0.00| 0.00           |
| Hajdu-Bihar     | 0.07| n.d             | 0.08| 0.02| 0.01| 0.11           |
| Heves           | 0.24| n.d             | 0.00| 0.00| 0.00| 0.00           |
| Jász-Nagykun-Szolnok | 0.12| n.d             | 0.00| 0.00| 0.00| 0.00           |
| Komárom-Esztergom | 0.35| n.d             | 0.59| 0.12| 0.04| 0.75           |
| Somogy          | 0.08| n.d             | 0.38| 0.10| 0.03| 0.51           |
| Szabolcs-Szatmár-Bereg | 0.08| n.d             | 0.08| 0.02| 0.00| 0.10           |
| Tolna           | 0.08| n.d             | 0.35| 0.06| 0.02| 0.43           |
| Vas             | 0.04| n.d             | 0.00| 0.00| 0.00| 0.00           |
| Veszprem        | 0.16| n.d             | 0.60| 0.24| 0.07| 0.91           |
| Zala            | 0.06| n.d             | 0.36| 0.10| 0.03| 0.49           |
| Mean            | 0.12| n.d             | 0.26| 0.06| 0.02| 0.35           |

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Goertz A, Zuehlke S, Speiteller M, Steiner U, Dehne HW, Waalwijk C, Oerke EC (2010) Fusarium species and mycotoxin profiles on commercial maize hybrids in Germany. Eur J Plant Pathol 128(1):101–111. https://doi.org/10.1007/s10658-010-9634-9

Ivic D, Domijan AM, Peraica M, Milicevic T, Cvjetkovic B (2009) Fusarium spp. contamination of wheat, maize, soybean, and pea in Croatia. Arh Hig Rada Toksiko 60(4):435

Jakić-Dimić D, Nešić K, Petrović M (2009) Contamination of cereals with aflatoxins, metabolites of fungi Aspergillus flavus. Biotechnol Anim Husb 25(3):1203–1208

Jakić S, Živkov-Baloš M, Jajić I, Abramović B (2019) Fumonisins in Serbian corn: long-time assessment under actual climate change conditions. Cereal Res Commun 47(4):714–723

Kos I, Mastilović J, Hajnal EJ, Šarić B (2013) Natural occurrence of aflatoxins in maize harvested in Serbia during 2009–2012. Food Control 34(1):31–34. https://doi.org/10.1016/j.foodcont.2013.04.004

Leggieri MC, Bertuzzi T, Pietri A, Battilani P (2015) Mycotoxin occurrence in maize produced in Northern Italy over the years 2009–2011: focus on the role of crop related factors. Phytopathol Mediterr 54(2):212–221

Mesterházy Á, Vojtovics M (1977) Survey of Fusarium spp. diseases of maize in 1972–1975. Novenytermeles 26(5):367–378

Mesterházy Á, Lemmens M, Reid LM (2012) Breeding for resistance to ear rots caused by Fusarium spp. in maize—a review. Plant Breed 131(1):1–19

Miedaner T, Juroszek P (2021) Global warming and increasing maize cultivation demand comprehensive efforts in disease and insect resistance breeding in north-western Europe. Plant Pathol 70(5):1032–1046

Munkvold GP (2014) Crop management practices to minimize the risk of mycotoxins contamination in temperate-zone maize. In: Logrieco A (ed) Mycotoxin reduction in grain chains. Wiley, Hoboken, pp 59–75

Munkvold GP, White DG (2016) Compendium of corn diseases, vol 165. APS Press, St Paul

Munkvold GP, Hellmich RL, Showers WB (1997) Reduced Fusarium ear rot and symptomless infection in kernels of maize genetically engineered for European Corn Borer Resistance. Phytopathology 87(10):1071–1077. https://doi.org/10.1094/phyto.1997.807.10.1071

Ni X, Wilson JP, Buntin GD, Guo B, Krakowsky MD, Lee RD, Schmizel EA (2011) Spatial patterns of aflatoxin levels in relation to earfeeding insect damage in pre-harvest corn. Toxins 3(7):920–931. https://doi.org/10.3390/toxins3070920

Pleadin J, Sokolović M, Perši N, Zadražek M, Jakić V, Vulić A (2012) Contamination of maize with deoxynivalenol and zearalenone in Croatia. Food Control 28(1):94–98

Scauflaire J, Mahieu O, Louvieaux J, Foucart G, Renard F, Munaut F (2011) Biodiversity of Fusarium species in ears and stalks of maize plants in Belgium. Eur J Plant Pathol 131(1):59–66. https://doi.org/10.1007/s10658-011-9787-1

Szécsi Á, Szekeres A, Bartók T, Oros G, Bartók M, Mesterházy Á (2010) Fumonisin B1–4-producing capacity of Hungarian Fusarium verticillioides isolates. World Mycotoxin J 3(1):67–76

Tabuc C, Marín D, Guerre P, Sesan T, Bailly JD (2009) Molds and mycotoxin content of cereals in southeastern Romania. J Food Protect 72(3):662–665

Tarazona A, Gómez JV, Mateo F, Jiménez M, Romero D, Mateo EM (2020) Study on mycotoxin contamination of maize kernels in Spain. Food Control 118(2020):107370

Tóth B, Tóth É, Kótai É, Varga M, Toldiné Tóth É, Pálfi X, Háfra E, Varga I, Téren I, Mesterházy Á (2012) Role of Aspergilli and Penicillia in mycotoxin contamination of maize in Hungary. Acta Agron Hung 60(2):143–149