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Systems to reduce mycotoxin contamination of cereals in the agricultural region of Poland and Kazakhstan

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ABSTRACT

Field trials were conducted at two different geographical locations to study the effect of pesticide protection and its consequence on the mycotoxin level, ergosterol and quality parameters of wheat. The treatments involved the application of: herbicide (aryloxyalcanoic and benzoic acid), a set of two (benzimidazole and strobilurin) or three (triazole and morpholine) fungicides and a mix of herbicide and fungicides. Polish and Kazakh varieties of wheat were monitored in a three-year study. Weed populations were controlled by MCPA and dicamba, and a reduction of mycotoxin in wheat grain was observed at both geographical locations. The most significant reduction of the mycotoxin (trichothecenes, fumonisins and zearalenone) levels resulted from the application of combined MCPA/dicamba (BBCH 19–28) and thiophanate methyl/azoxytrobin (BBCH 44–58) and propiconazole/cyproconazole/tebuconazole/triadimenol/spiroxamine (BBCH 68–77). The highest concentrations of zearalenone and deoxynivalenol were detected in the control plots (571.0 and 151.0 μg/kg). The relationships between the fungal biomarker ergosterol and mycotoxins, were observed. The highest levels of ergosterol and contamination with mycotoxin were obtained for the Kazakh and Polish cereals in 2016.

1. Introduction

Fusarium species are plant pathogens which occur worldwide and produce over a hundred secondary metabolites, mainly associated with cereal crops (Osborne and Stein, 2007; Häggblom and Nordkvist, 2015; Dweba et al., 2017). The most important metabolites are mycotoxins (MYC). Among them, fumonisins, zearalenone (ZEN) and trichothecenes (deoxynivalenol (DON), nivalenol (NIV) and T-2 toxin) occur in biologically significant concentrations in cereals (Pleadin et al., 2013; Nordkvist and Häggblom, 2014; Jaillais et al., 2015).

The mycotoxin occurrence is unpredictable and difficult to estimate and may pose a problem for food and feed safety. Health risks associated with the consumption of cereal products containing *Fusarium* MYC are recognized worldwide and depend on the amount of food or feed and the composition of the diet (Juan et al., 2013). These compounds have been contributing to many diseases of animals and humans (Vanheule et al., 2014). Further, risk assessment and regulatory efforts should be established in order to ensure that the *Fusarium* MYC levels are kept below the established thresholds. In the near future, one should critically evaluate the existing thresholds for MYC in foods and feeds to ensure that such thresholds are at the safe level for consumers, i.e. lower than levels that can pose a potential hazard to human and animal health (Darwish et al., 2014; Luzardo et al., 2016).

A tolerable daily intake (TDI) has been established in the European legislation for many MYC (EC, 2002, 2006a, 2006b). Specifying the maximum limits for DON and ZEN in unprocessed wheat intended for human consumption (1′250 and 100 μg/kg) as well as limits for unprocessed durum wheat and oats (1′750 and 100 μg/kg), there is only a guideline for fodder grain (8′000 and 2′000 μg/kg). The lowest safety concentration has been set for pigs due to their higher sensitivity to *Fusarium* MYC (DON and zearalenone limits in feedstuffs is 900 and 250 μg/kg, respectively). There are no official limits for T-2 and HT-2. However, in 2013, the European Commission published a Recommendation for the combined concentration (1000 μg/kg for unprocessed oats and for wheat 100 μg/kg) for T-2 and HT-2 (EC, 2013).

Production of cereals constitutes one of the main activities of

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agricultural production in many countries. Kazakhstan is an important producer and exporter (mainly to destinations in Europe, including Russia and Ukraine, northern Africa, and Central Asia) of high-quality wheat (FAOSTAT, 2016). Poland has the second most important cereal cultivation area in the European Union (after France), and third in the harvest of cereals (after France and Germany) (FAOSTAT, 2016). In 2009–2012, cereal grains export fluctuated between 1.5 and 3.1 million tonnes. In both Poland and Kazakhstan, production of cereals is highly dependent on climate and soil conditions as well as on cereal varieties and chemical protection.

Fusarium MYC contamination of cereals can cause agro-economic losses at all levels of food and feed production, including crop and animal production, crop distribution and processing technology (Udomkun et al., 2017). Practical strategies to reduce or eliminate these mycotoxins from food and feed are required (Terzi et al., 2014; Tibola et al., 2015, 2016; Alberts et al., 2016). Wheat production is characterized by many challenges, among them a significant occurrence and spread of diseases and pests, which have a crucial influence on the economy. Further challenges include weed infestations and abiotic factors such as drought, frost and salinity, which affect the production of grain (Sommer et al., 2013). Chemical protection is a primary way for obtaining healthy crops and constant, high quality yields (Łozowicka et al., 2012). It is a basic component of an integrated crop management, and its effectiveness must be sustained as long as possible (Matyjaszczyk, 2013). The current trends of implementation of organic farming without chemical fungicides can increase the occurrence of fungal diseases and their development, and, in consequence, it may lead to the entry of toxic MYC in the food chain (Juan et al., 2013; Lazzaro et al., 2015). On the other hand, resistance to several fungicides has been confirmed recently, mainly to the older triazole fungicides such as tebuconazole, flutriafol and triadimenol (Tucker et al., 2013; Hysing et al., 2012; Wang et al., 2016).

In the literature, several studies have examined the effect of fungicide application in controlling fungal diseases and mycotoxin accumulation in cereal grains (Ioos et al., 2005; Giraud et al., 2011; Schmidt-Heydt et al., 2013). The majority of these studies have described the application of fungicides at or near the flowering stage of the host (Blandino and Reyneri, 2009; De Curtis et al., 2011; Rensburg et al., 2016). To our knowledge, there has been no published study investigating the effect of fungicide combined with herbicide.

The main aim of this study was to develop plant protection systems based on fungicides differing in mode of action and applied at different growth stages to prevent fungal development in cereals in Poland and Kazakhstan. Since *Fusarium* can be found on a range of broad-leaf and grass weeds, herbicides were included (Edwards, 2004; Landschoot et al., 2011; Degraeve et al., 2016). Thus, we hypothesized that fungicide application supported by herbicides during different stages can effectively reduce the mycotoxin contamination level in matured wheat grain collected from the two different geographic locations.

The contribution of the study is to propose strategies to reduce the risk of *Fusarium* mycotoxin contamination of cereals in agricultural areas and to obtain products which are safe for human and animal consumption. The collateral goals were: 1) evaluation of the effectiveness of pesticide application in reducing fungal diseases of cereals in Poland and Kazakhstan 2) determination of the impact of fungal diseases on the quality and amount of yield, and 3) study of the relationship between the fungal biomarker ergosterol (ERG) and mycotoxin content in cereal grain from two different geographic locations.

2. Materials and methods

2.1. Field experiment

During 2014–2016 at the Plant Protection Institute – National Research Institute in Bialystok, located in Northeastern Poland (Podlasie, 50°46′N, 17°51′E) (Location 1, L1) and Baitursynov Kostanay State University, located in Northern Kazakhstan (Kostanay, 53°10′N, 63°35′E) (Location 2, L2), field trials were conducted under natural infection conditions. The experiments were established in a randomized block design with 4 replications of spring wheat at L1 for Kandela, (Ka) and at L2 for Omskaya 29 (O29). Certified seed was sown on plots with an area of 16 m^2 (2 × 8 m) for each combination and control plots. All plots were cultivated according to good agriculture practices.

Sowing was carried out on the 1st, 8th and 5 th of April (L1) and 27th of March, the 8th and 11th of April (L2) in 2014, 2015 and 2016, respectively. Nitrogen (N) fertilization was applied twice: before seeding - 50 kg N/ha and during shooting phase - 40 kg N/ha. The fertilization with potassium (60% potassium salt - 60 kg K ha) and phosphorus (granulated triple superphosphate 48%–21 kg P/ha) in all the experimental treatments was the same. Harvest was conducted at the stage of full maturity: in 2014–26th and 30th of July 2015 – 5th and 1st of August, and in 2016–14th and 3rd of August, at L1 and L2, respectively.

The physico-chemical parameters of the soil showed that pH of soil at location L1 has basic soil (pH – 7.4), at location L2 pH is acidic (pH – 5.5). The content of macroelements in soil was as follows: at L1 – 18.9 mg/100 g K_2O, 19.3 mg/100 g P_2O_5 and 7.6 mg/100 g Mg and at L2 – 15.5 mg/100 g K_2O, 27.5 mg/100 g P_2O_5 and 6.8 mg/100 g Mg. The content of organic carbon reached the value of 1.2% (L1) and 2.2% (L2). The analysis of the granulometric composition showed that the L1 plots were cultivated on brown soil (loamy sand) and the L2 ones on chernozem.

2.2. Chemical treatments

Prior to the pesticide treatments, the soil was prepared for sowing, and phosphorus and potassium fertilization was applied in the same amounts for both experiments: 80 kg P_2O_5/ha and 150 kg K_2O/ha. Chemical protection was applied by using a knapsack compressed air sprayer, with four nozzles (XR 110 02 Tee Jet VP) at a liquid flow of 300 L/ha. The same fungicides and herbicide treatments were performed at L1 and L2 (Table 1). The chemical structures of the target pesticides are presented in Table 1. Herbicide (H) containing a carboxylic acid group (MCPA) and benzoic acid derivatives (dicamba) were applied at the tillering stage (scale BBCH 19–28) (Lancashire et al., 1991; Meier, 2001). Fungicide treatments were repeated twice at an interval of two weeks. At the wheat booting or heading stages (BBCH 44–58), protective treatment (F1) was performed using compounds from the group of benzimidazoles (thiophanate-methyl) and the active substances of triazole (propiconazole and cyproconazole). Fungicide application (F2) was performed with active substances from the strobilurin group (azoxystrobin) and with a plant protection product consisting of spiroxamine, tebuconazole and triadimenol at the late flowering stage or during the development of fruits (BBCH 68–77).

2.3. Climatic conditions

In the Köppen's climate classification, the Podlasie region (L1) and the Kostanay region (L2) are characterized by a humid continental climate (Dfb) (Peel et al., 2007).

In L1, the mean annual air temperature is 7.8 °C, the warmest month is July (average 19.3 °C) while the coldest one is January (−3.4 °C), and the mean annual precipitation is 544 mm. In L2, the mean annual air temperature is 3.0 °C, the warmest month is July (average 19.0 °C), whereas the coldest ones are January and February (−17.0 °C), and the mean annual precipitation is 336 mm. In both locations, the months from May to August are characterized by the highest rainfall, with the maximum value in July (own data from years 2002–2016). The detailed weather conditions in Poland and Kazakhstan are presented in Table 2.