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Crop cultivation measures to reduce mycotoxin contamination in cereals*

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Summary

In cereal farming, *Fusarium* head blight is of great significance since in the case of an infestation not only yield and quality is affected, but also mycotoxin contamination of harvest products must be expected. Since mycotoxins produced in grain during cereal cultivation can only be partially removed by cleansing or processing, preventative measures against *Fusarium* infection on the field are of particular importance. Crop cultivation measures provide good possibilities for limiting the risk of infection if suitable crop rotation, type of soil tillage, choice of variety and plant protection are combined with each other in terms of situation and location.

Introduction

Moulds are part of the natural soil micro-flora and are active in the decomposition of organic plant residues. Among these fungi is the genus *Fusarium* with some phytopathogenic varieties that are able to actively penetrate growing plants.

Cereals, particularly wheat and maize, are frequently infected by the species *Fusarium graminearum* and *F. culmorum* resulting in "head blight" disease. *Fusarium* head blight is accompanied with the destruction of valuable components in the kernels through to quality and yield losses in the harvest products (ARGYRIS et al., 2003). Also, many *Fusarium* species develop special mycotoxins in the course of their growth that may have detrimental effects on the health of humans and animals when exposed through contaminated food and feed, respectively (HUSSEIN and BRASEL, 2001).

The most frequently appearing mycotoxins in cereals and maize produced by *Fusarium* under central European climate conditions are deoxynivalenol and zearalenone (CHELKOWSKI, 1998; ELLNER, 2000; BOTTALICO, PERRONE, 2002). Both substances differ from each other in their chemical structure and affect vital functions of mammals, such as farm animals. Deoxynivalenol inhibits protein biosynthesis, has an irritating effect on skin and mucous membranes, and also harms the immune system (UENO, 1977; ROTTER et al., 1996). Zearalenone has an estrogen-like effect that can lead to changes in female reproductive organs and to reproductive problems (KUIPER-GOODMAN et al., 1987).

Since February 2004, limit values for the *Fusarium* toxins deoxynivalenol, zearalenone and fumonisins in certain cereal and maize products, or rather dietetic foodstuffs, have been enacted in Germany (see Bundesgesetzblatt Jahrgang 2004, Part 1, Nr. 5). It is therefore important to prevent the *Fusarium* infection in cereals and maize as far as possible under field conditions in order to minimize mycotoxin contamination of harvest products.

In the following, weather induced infection risks and possibilities for control of *Fusarium* head blight and mycotoxin contamination through preventive crop cultivation measures will be discussed.

Climatical conditions promoting *Fusarium* infection

The intensity and frequency of *Fusarium* head blight is particularly promoted through rainfall, humidity and local temperatures of above 17 C° at the time of flowering (OBST et al., 2000; ROSSI et al., 2001). The total precipitation level (at least 2 mm) is in this case of less relevance as is the actual rainfall before and during flowering (SUTTON, 1982; DOOHAN et al., 2003).

Massive ear infections are mostly caused by *Fusarium graminearum* and *Fusarium culmorum* in the period from the middle of the ear/panicle emergence through to the end flowering (Fig. 1). *F. graminearum* develop ascospores (sexual reproduction organs) on plant residues on or near the soil surface which can reach the ears directly through air movement. Another method, promoted by continuous leaf moisture, is via conidiospores (asexual reproductive organs) that reach the ears mainly through splashing rain from the soil or plant residues over the leaves (OBST and BECHTEL, 2000).

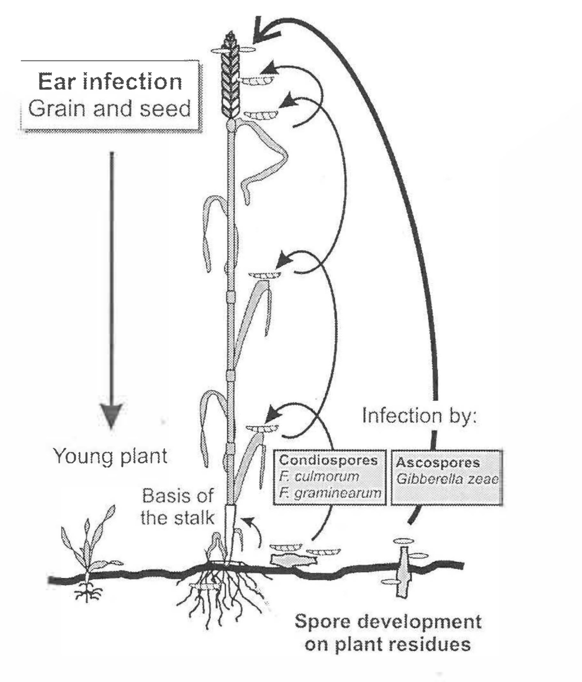

Fig. 1: Life cycle of *Fusarium graminearum* (*Gibberella zeae*) and *F. culmorum*
(Source: J. Weinert, G.A. Wolf, Institut für Pflanzenpathologie und Pflanzenschutz, Universität Göttingen)

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The infection of ears first leads to contamination of the individual spikelets which lighten prematurely in colour and to a clearly visible "head blight". In the course of the pathogenesis (Fig. 2), the fungus can proceed from an infected spikelet to the rhachis, expand into the corn layers below (KANG, BUCHENAUER, 2000) and by disturbing the nutritional supply in the upper corn layers causing shrunk grain which do not contain mycotoxins. Kernels below the primary infection can contain *Fusarium* mycotoxins even if they are fully developed.

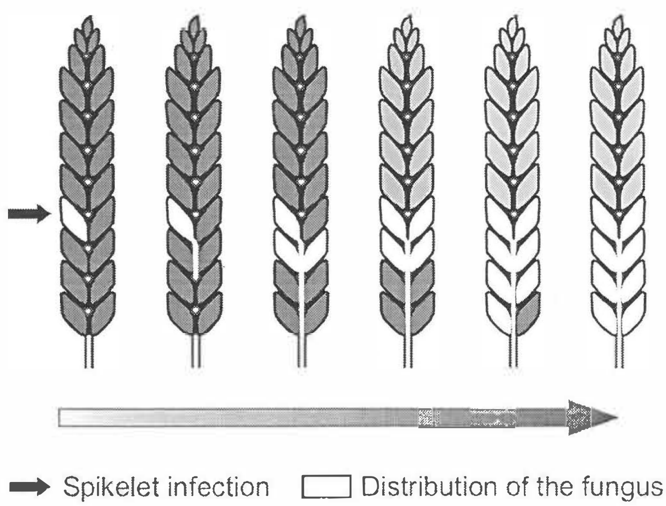

Fig. 2: Ear infection by *Fusarium graminearum* and *Fusarium culmorum* (Source: J. Weinert, G.A. Wolf, Institut für Pflanzenpathologie und Pflanzenschutz, Universität Göttingen)

Since the climatical conditions at the growth location, particularly at the time of flowering, is not predictable in the long-term, prophylactic crop cultivation measures must be made to reduce the infection potential at the soil surface and thus to limit the danger of infection.

Prevention and control of *Fusarium* infection in cereals

Crop rotation

The crop rotation plays an important role with regard to infection of cereals with *Fusarium*. In narrow crop rotation systems with a high share of grains, particularly if maize is planted before grains, crop species preferably infected by *Fusarium* follow one another directly thus leading to a higher risk of mycotoxin contamination (OBST et al., 2000; ELLNER, 2000).

If cereal share is reduced within a wider crop rotation system, the fungus does not find enough suitable plants or plant residues to grow, multiply and survive. To reduce the danger of infection, it is recommended to avoid maize as pre-crop and to rotate cereals with non-host crops like legumes or catch crops (BOTTALICO, PERRONE, 2002; KRUPINSKI et al., 2002).

Soil Tillage

Fusarium species survive on dead but not rotted plant residues (stalks, straw, stubble).

The elimination of host debris from the soil surface effectively reduces the *Fusarium* infection pressure (OBST et al., 2000; DILL-MACKY, JONES, 2000), which can best be achieved by ploughing. But through deep ploughing of plant residues, rotting is delayed, so that old debris that is again ploughed to the surface in the next year still has inoculum potential that could infect the following crop.

Through conserving soil tillage (i.e., mulched drilling) different amounts of plant residues remain on the soil surface depending on the type of tillage practices implemented. Particularly maize stubble and straw are infected by *Fusarium*, these residues are difficult to rot and seem to be well suited to the ascospore development of *Gibberella zeae*, the teleomorph of *Fusarium graminearum* (RINTELEN, 2000).

In order to speed up the rotting processes, plant residues should be chopped as finely as possible and distributed evenly over the whole area before incorporated into the soil, regardless of whether ploughing or conservational soil tillage processes are applied. Whether this measure eliminates efficiently *Fusarium* spore development on plant residues remaining on soil surface when mulching techniques are applied should be further researched.

Direct drilling is the process with the highest potential risk with regard to development of *Fusarium* and production of toxins (OLDENBURG, BRUNOTTE, 2002), since the residues remain completely on the soil surface and no working into the soil occurs. Direct drilling therefore should be avoided if maize is the preceding crop for cereals and if a narrow cereal crop rotation is planned.

Choice of Variety

Within Europe the range of resistance to *Fusarium* head blight available in commercial varieties differs between countries (HOLLINS et al., 2003). Due to intensified further development in breeding, increasing wheat varieties with good resistance characteristics to head blight (Varieties of infection classes 2-3, see Beschreibende Sortenliste, 2004, List of the German Variety Agency) are registered in Germany.

Certain morphological and phenological characteristics of the cereal reduce the susceptibility to ear infection by *Fusarium* (ZIMMERMANN, 2000). In long straw varieties, the distance between the soil and the ears is greater so that the fungus spores must overcome a longer distance to reach the ears. A short flowering period reduces the time in which the fungus can infect the ears (MESTERHAZY, 1995). Other resistance components are genotypical differences in the penetration or distribution resistance in the ears, resistance against seedborne infection and tolerance against *Fusarium* mycotoxins (GILCHRIST et al., 1997; MESTERHAZY et al., 1999; MIEDANER, 1997).

By planting less susceptible varieties, significantly reduced ear infection as well as significantly lower mycotoxin content in the kernels can be expected in comparison to susceptible varieties. However, in the case of strong *Fusarium* infection pressure combined with further unfavorable factors, such as long-term rainfall, the resistance abilities of even good resistant varieties can break down (see Tab. 1, variety Petrus, artificially infected). The planting of highly susceptible varieties should generally be avoided and good resistant varieties should be planted in areas that tend to have high precipitation at the time of flowering, when soil conserving tillage is applied, maize is a preceding crop to cereals and in case of a narrow cereal crop rotation.

Seed quality

Infected seed can lead to an early infection of sprouts or young plants and as a consequence, emergence damage or development difficulties may occur (ARGYRIS et al., 2003). With the use of certified seed this problem can be avoided. In the case of replanting farm-produced cereal seed, it is essential to pay attention that the seed is free of *Fusarium* infection.

Fertilization/Plant Nutrition

The growth and development of a plant are decisively determined by its nutrition. Susceptibility to infection and the course of disease may be influenced by the nutritional condition of the plant. However, the effect of a nutrient cannot be regarded in an isolated manner. It can vary at different concentration levels and can depend on the absence or presence of other essential nutrients.

In general, overfertilization with nitrogen appears to promote *Fusarium* infection of cereals as well as malnutrition (COOK, 1980; OBST, 1988; YI et al., 2002; MA et al., 2004).
However, little is known on the effect of type, composition, dosage and termination of the fertilizer inputs in agricultural practice on the contamination of cereals with *Fusarium* mycotoxins. Studies on the influence of nitrogen fertilization on mycotoxin contents in wheat kernels showed that a nitrogen deficit (< 80 kg N/ha) resulted in significantly reduced DON contents in the kernels, but not in fertilizer inputs usual in practice (LEMMENS et al., 2004). As a result of other experiments, no definite effect of nitrogen input on mycotoxin contamination of winter wheat could be concluded (AUFHAMMER et al., 2000).

Tab. 1: Influence of nitrogen fertilization on deoxynivalenol content in grain of winter wheat (harvest year: 2002)

N-fertilization	Deoxynivalenol concentration (mg/kg dry matter)							
kg N/ha	**Complet,** a.i.		**Petrus,** a.i.		**Complet,** n.i.		**Petrus,** n.i.	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0	**11.28**	0.85	**6.55**	0.58	**0.38**	0.06	**0.21**	0.03
60	**9.20**	0.24	**11.39**	0.81	**0.35**	0.11	**0.18**	0.04
120	**11.10**	1.51	**11.38**	1.17	**0.59**	0.25	**0.16**	0.05
180	**10.53**	1.18	**12.24**	2.50	**0.53**	0.13	**0.14**	0.03
240	**11.76**	0.82	**11.06**	1.03	**0.51**	0.05	**0.20**	0.05

Complet: Variety susceptible to *Fusarium* head blight
Petrus: Variety with good resistance against *Fusarium* head blight
a.i. = artificially infected with *Fusarium culmorum*
n.i. = naturally infected
SE = Standard error of 4 replicates

In own field studies, no direct influence of the N fertilization on the deoxynivalenol content by inputs of 0 to 240 kg N/ha were found in winter wheat (Tab. 1), which is contradictory to the results of LEMMENS et al. (2004). However, from both examinations it can be concluded that manipulation of N dosage relevant in practice is not an effective tool in controlling *Fusarium* head blight and toxin contamination.

Plant Protection Measures

Sufficiently effective fungicides against *Fusarium* head blight are not yet available. Chemical plant protection substances with azole agents can reduce infection rates and deoxynivalenol contents with an effectiveness of 50 to 70 percent in contrast to untreated cereals (OLDENBURG et al., 1999; CHALA et al., 2003), but cannot prevent it entirely. In order to target the optimal level of effectiveness, the exact timing of the application within a time slot of one week after the start of flowering, when the infection of the ears mainly takes place, is of decisive significance. The closer the time point of fungicide application is to the actual time point of ear infection the better the success of treatment (CHALA et al., 2003).

Fungicides containing strobilurine agents (kresoxym-methyl or azoxystrobin) can in contrast cause increased deoxynivalenol levels in grains (OBST et al., 2000; OLDENBURG et al., 2001; MAGAN et al., 2002), when not combined with azole fungicides (DARDIS, WALSH, 2000). In comparison to untreated cereals, the application of strobilurines between the end of shooting to the end of the ear emergence can lead to a doubling in the mycotoxin content in grain (OLDENBURG et al., 2001). This effect can be eliminated through the subsequent application of an azole fungicide at the time of flowering (OLDENBURG et al., 2001; CHALA et al., 2003).

An application of azole fungicides at the point of flowering is not in general recommended in cereal cultivation, but should be taken into consideration when risky agricultural practices (e.g. narrow maize-cereal crop rotation, planting of susceptible varieties, application of strobilurine fungicides) occur with infection-promoting weather conditions at the time of flowering.

Growth Regulators

Whether the growth regulators used in cereal crop cultivation to avoid risk of lodging affect the frequency and extent of *Fusarium* infection and mycotoxin contamination in practice can at this time not be judged with certainty due to limited investigations available. In some field examinations the use of growth regulators in combination with leaf fungicides led to increased head blight and DON contents in wheat (OERKE et al., 2002). To what extent the stalk shortening reduces the higher resistance ability of long straw varieties to *Fusarium* has not been sufficiently clarified. It is thus recommended to use growth regulators moderately and not to dose them above the level required for the lodging resistance of the plants.

Harvest conditions

As larger amounts of *Fusarium* toxins develop mainly within the last weeks before the harvest (MATTHÄUS et al., 2004), a delayed harvest carries an increased toxin risk. Also the harvest should take place under favorable weather conditions in order to avoid quality reducing risks for the subsequent storage, such as kernel moisture above 14 percent promoting the development of storage moulds (BECK, 2000; HOMDORK et al., 2000), or soiled harvest products. A prompt post-harvest drying is necessary in the case of unfavorable humid weather conditions at harvest to maintain both grain product and seed quality.

Conclusions

The total avoidance of the development of *Fusarium* toxins in cultivated plants and plant raw materials for food and feed production is not possible, even with the application of all risk-reducing crop cultivation measures. Through a suitable combination of good agricultural production techniques based on situation and location, the risk of mycotoxin contamination can be significantly reduced and the probability to exceed highest levels permissible in food stuffs can be minimized. High quality plant harvest products in combination with optimal storage and processing practices are important factors to assure the preventative consumer protection and a high level of food safety.

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