Mycotox Res (2010) 26:141–145
DOI 10.1007/s12550-010-0056-5

REVIEW

A review on comparative data concerning *Fusarium* mycotoxins in Bt maize and non-Bt isogenic maize

Vladimir Ostry · Jaroslava Ovesna · Jarmila Skarkova · Vladimira Pouchova · Jiri Ruprich

Received: 8 March 2010 / Revised: 15 April 2010 / Accepted: 20 April 2010 / Published online: 13 May 2010

Abstract The European corn borer reportedly promotes the infection of maize by *Fusarium* spp. Stalk and ear rots caused by *Fusarium* spp. are often related to mycotoxin accumulation in maize kernels. As a result, food and animal feed from maize are more severely contaminated with *Fusarium* mycotoxins: e.g. fumonisins (FUM), deoxynivalenol (DON) and zearalenone (ZEA). Bt maize is primarily an important potential tool for insect pest protection, both in the European Union and in other countries. Bt maize carrying the Bt genes is highly resistant to European corn borer larval feeding due to Bt toxin (δ toxin) production. Effective measures to combat pests therefore often have a positive side-effect in that they also reduce mycotoxin levels. Comparative analysis was used to the evaluation of the studies dealing with the reduction of *Fusarium* mycotoxins in Bt maize. Nineteen out of 23 studies on Bt maize came to the conclusion that Bt maize is less contaminated with mycotoxins (FUM, DON, ZEA) than the conventional control variety in each case.

Keywords Bt-maize · *Fusarium* · Deoxynivalenol · Fumonisins · Zearalenone

Presented at the Mycotoxin Workshop, Münster, Germany, June 15-17, 2009

V. Ostry (✉) · J. Skarkova · J. Ruprich
Department for Food Safety and Nutrition,
National Institute of Public Health in Prague,
Palackeho 3a, 61242 Brno, Czech Republic
e-mail: ostry@chpr.szu.cz

J. Ovesna · V. Pouchova
Czech Scientific Committee on Genetically Modified Food and Feed,
Crop Research Institute,
Drnovska 507, 161 06 Prague 6, Czech Republic

Introduction

Maize (*Zea mays* L.) is one of the world's major cereal grains, with a world annual average production (2004-2006) of 678 million metric tons (Mt), representing 32% of the 2.15 billion Mt of world cereal grain production (Chung et al. 2007). Maize is cultivated on large areas world-wide and serves as a staple food for millions of inhabitants. Maize is, however, a particularly problematic commodity in the context of mycotoxins and looks to become more so given the nature of the predicted changes in climate. It has a relatively high water requirement and under drought stress conditions that could be predicted to occur more frequently in a climate change scenario, its *Fusarium* symbionts seem to produce more of their respective mycotoxins. Under these conditions a person's meal could contain significant quantities of all of fumonisins (FUM), deoxynivalenol (DON), other trichothecenes and zearalenone (ZEA). This combination of factors, which global climate change is predicted to make more commonplace, already occurs in the tropics and there is no doubt at all that many people are exposed to cocktails of mycotoxins from maize, with adverse health consequences that we probably underestimate (Strosnider et al. 2006).

Heavy pest infestation makes maize plants more susceptible to fungal infections. The European corn borer (*Ostrinia nubilalis* Hübner) and other stalk-boring pests reportedly promote the infection by *Fusarium* spp. Stalk and ear rots caused by *Fusarium* spp. are often related to mycotoxin accumulation in maize kernels. As a result, food and animal feed from maize are more severely contaminated with *Fusarium* mycotoxins: e.g. FUM, DON and ZEA (Munkvold et al. 1997; Munkvold and Desjardins 1997).

Bt maize is one of the most commonly grown genetically modified crops in the world today. It contains a gene from the soil bacterium *Bacillus thuringiensis* Berl., which encodes for the formation of a crystal (Cry) protein that is toxic to certain members of the orders *Lepidoptera* and/or *Coleoptera* (Table 1). It is one of the most commonly grown transgenic crops in the world today. Bt maize production (including Bt maize with herbicide tolerance) has expanded to more than 35 million hectares worldwide. Now, about 80% of the maize produced in the US is genetically modified. The share of insect-resistant varieties in the total acreage decreased from 21 to 17%. Even varieties were less sold. The trend moves clearly towards varieties with combined insect resistance and herbicide tolerance (stacked genes). Here the proportion has risen from 28 to 40% of the maize land. Meanwhile, there are varieties on the market which produce two different variants of the Bt protein: one resists the corn borer, the other resists the corn root worm. While overall maize cultivation has dropped, the area of GM maize remains almost the same (increase from 27.4 to 27.7 million hectares).

Many countries in North and South America, Africa, and Asia grow GM maize. Maize is the only GM crop that is grown commercially in the European Union (EU). It is planted in four countries: Spain, Portugal, the Czech Republic and Slovakia. For the most part, maize is used for feeding livestock and as raw material for the starch industry. Starch, however, forms the basis of many foods and food additives (GMO Compass 2009).

Bt maize MON810 is primarily an important potential tool for insect pest protection, both in the EU and in other countries. Bt maize carrying the Bt gene (CryIAb) is highly resistant to European corn borer larval feeding according to Bt toxin (δ toxin) production (Munkvold et al. 1997). The Cry1Ab protein controls lepidopteran insect pests such as the European corn borer, *Ostrinia nubilalis* Hübner, the most important stalk-boring and ear-damaging insect pest of corn in the United States and in the Europe too. It also controls southwestern corn borer (*Diatraea grandiosella* Dyar) and other related corn-boring insects. The CaMV 35S gene promoter enables constitutive expression of the Cry1Ab protein in hybrids during the growing season, thus providing season-long protection against corn borers. The *B. thuringiensis*-based microbial pesticides that contain Cry proteins such as Cry1Ab have been used commercially in agriculture for over 40 years to control larval insect pests (Hammond et al. 2004).

Effective measures to combat pests therefore often have a positive side-effect in that they also reduce mycotoxin levels. Munkvold et al. (1997, 1999) were the first to report that, in Iowa, maize hybrids protected with the Cry1Ab protein had significantly lower FUM levels in the grain than in the grain from control non-Bt hybrids. Potential economic, health and regulatory impacts, benefits and risks of Bt maize and *Fusarium* mycotoxin reduction have been described (Wu et al. 2004; Wu 2004, 2006a, 2006b, 2007). A review on the relationship between Bt maize and *Fusarium* mycotoxin levels in harvest produce have been published by Wu (2007). This review summarizes the currently available research on the link between Bt maize and the reduction of important agricultural mycotoxins. The present review will focus on current information about Bt maize and the reduction of important agricultural *Fusarium* mycotoxins (FUM, DON, ZEA).

Table 1 Current Bt maize strain developments

Bt maize	Inserted gene
MON810	*Cry1Ab*[a]
MON863	*Cry3Bb1*[b]
MON863xMON810	*Cry3Bb1*[b], *Cry1Ab*[a]
NK603xMON810	*Cry1Ab*[a]
1507x59122xNK603	*Cry1F*[a], *Cry34Ab1*[a]
MON88017	*Cry3Bb1*[b]
MIR162	*vip3Aa19*[a]
MIR604	*Cry3A(mcry3A)*[b]
Bt11xGA21	*Cry1Ab*[a]
Bt11xMIR604xGA21	*Cry1Ab*[a], *Cry3A(mcry3A)*[b]
Bt11xMIR162xMIR604xGA21	*Cry1Ab*[a], *vip3Aa19*[a], *Cry3A(mcry3A)*[b]
MON89034xNK603	*Cry2Ab2*[a], *Cry1A.105*[a]
MON89034xMON810	*Cry1A.105*[a], *Cry2Ab2*[a], *Cry1Ab*[a]

[a] Against the order *Lepidoptera*

[b] Against the order *Coleoptera*

Experimental procedures

A comparative analysis was used for the evaluation of the studies dealing with the reduction of *Fusarium* mycotoxins (FUM, DON, ZEA) in Bt maize (MON 810, Bt 176, Bt 11).

The comparative analysis can be used as a guide to answer the question, “Is there a reduction of *Fusarium* mycotoxin concentrations in Bt maize hybrids compared with the corresponding isogenic plants?”. Meta-analysis was used for the evaluation of the studies dealing with the reduction of *Fusarium* mycotoxins (FUM, DON, ZEA) in Bt maize (MON 810, Bt 176, Bt 11). A large collection of analysis results from individual studies was analysed by the given approach for the purpose of integrating the findings. The quality criteria for the comparative analysis of individual studies were field trial design, validation of analytical methods and quality of analytical results of *Fusarium* mycotoxins. Thirty-four studies about *Fusarium* mycotoxin contamination in Bt maize and non-Bt isogenic maize grown in Europe, USA, South America and Asia were collected.

Only 23 relevant studies met our requirements according to the quality criteria for comparative analysis.

Results and discussion

The currently available varieties of Bt maize hybrids are very effective against the European corn borer, stalk borer and southwestern corn borer, and they can reduce damage by armyworm and corn earworm. The currently available varieties of Bt maize (MON 810, Bt 176, Bt 11) hybrids have shown strong evidence in field conditions worldwide of having significantly lower FUM levels than non-Bt isolines. There is also limited evidence for lower levels of DON and ZEA in Bt maize, although there are fewer field studies on these relationships. The results of the comparative analysis from the international studies can be seen in Table 2. Nineteen out of 23 studies on Bt maize came to the conclusion that Bt maize is less contaminated with *Fusarium* mycotoxins (FUM, DON, ZEA) than the conventional control variety in each case. It stands to reason because insects also play an important role in infection of maize by *Fusarium* spp. They can act as wounding agents or as vectors spreading the fungus from origin of inoculum to plants. It is likely that the presence of *Fusarium* spp. promotes insect attacks and insect infestation favours fungal infection (Dowd 1998; Schulthess et al. 2002).

Although the results vary, depending on the site, variety, trial design and type of mycotoxin, the general trend is clear: there is a clear correlation between the severity of the corn borer infestation and the *Fusarium* mycotoxin level. Cultivation of the conventional maize variety without any measures to control the corn borer produced both the highest pest infestation and the highest *Fusarium* mycotoxin levels. This effect is more pronounced on sites with high corn borer infestation. Chemical and biological methods of controlling the corn borer, e.g. the use of insecticides or parasitic wasps (*Trichogramma*), can reduce both the number of corn borer larvae and the level of mycotoxin contamination. On all sites, the Bt maize varieties used showed the best results: only isolated corn borers were found in the crops.

Table 2 International studies demonstrating information on the link between Bt maize and the reduction of *Fusarium* mycotoxins (FUM. DON, ZEA) in field trials

Bt maize lower mycotoxins than non-Bt isolines	No. of studies (country)		
	FUM	DON	ZEA
YES	4 (USA)	4 (Germany)	1 (Germany)
	Munkvold et al. 1999	Aulrich et al. 2001	Aulrich et al. 2001
	Dowd 2001	Papst et al. 2005	
	Hammond et al. 2002	Valenta et al. 2001	
	Hammond et al. 2004	Magg et al. 2002	
	2 (Argentina)	1 (Canada)	1 (France)
	De la Campa et al. 2005	Schaafsma et al. 2002	Bakan et al. 2002
	Barros et al. 2009		
	1 (France)		1 (Spain)
	Bakan et al. 2002		Bakan et al. 2002
	1 (Spain)		
	Bakan et al. 2002		
	1 (Germany)		
	Papst et al. 2005		
	1 (Italy)	-	-
	Masoero et al. 1999		
	1 (Philippines)	-	-
	De la Campa et al. 2005		
NO	1 (USA)	1 (Germany)	-
	Clements et al. 2003	Magg et al. 2002	
		1 (Switzerland)	-
		Naef et al. 2006	
		1 (Argentina)	-
		Barros et al. 2009	

Conclusion

The Bt maize had the lowest *Fusarium* mycotoxin levels according to the comparative analysis results from the international studies. *Fusarium* mycotoxin reduction has already had significant economic impacts in the Europe at current levels of Bt crop planting. In less-developed countries, the *Fusarium* mycotoxin reduction that Bt crops can provide could have important economic as well as health impacts. Bt maize may prove to be a useful tool to lower dietary intake of FUM, particularly in regions of the world where chronically high exposures persist. It can also increase the percentage of maize that would be suitable for consumption.

There is no available information on the link between Bt maize (NK603xMON810, MON863, MON863xMON810, 1507x59122xNK603, MON88017, MIR162, MIR604, Bt11xGA2, Bt11xMIR604xGA21, Bt11xMIR162xMIR604xGA21, MON89034xNK603 and MON89034xMON810) and the reduction of important agricultural *Fusarium* mycotoxins. The new varieties of Bt maize that may be commercialized soon are likely to have a more significant impact on *Fusarium* mycotoxin levels. Therefore, Bt maize is an important potential tool for *Fusarium* mycotoxin control, both in Europe and in other countries.

Acknowledgements Financial support for this work was provided by the Czech Scientific Committee on Genetically modified Food and Feed.

References

Aulrich K, Bohme H, Daenicke R, Halle I, Flachowsky G (2001) Genetically modified feeds (GMO) in animal nutrition: Bacillus thuringiensis (Bt) corn in poultry, pig and ruminant nutrition. Arch Anim Nutr 54:183–195

Bakan B, Melcion D, Richard-Molard D, Cahagnier B (2002) Fungal growth and Fusarium mycotoxin content in isogenic traditional maize and genetically modified maize grown in France and Spain. J Agric Food Chem 50(4):728–731

Barros G, Magnoli C, Reynoso MM, Ramirez ML, Farnochi MC, Torres A, Dalcero M, Sequeira J, Rubinstein C, Chulze S (2009) Fungal and mycotoxin contamination in Bt maize and non-Bt maize grown in Argentina. World Mycotoxin J 2: 53–60

Chung OK, Park SH, Kim Y (2007) Concerted efforts in cereal grain quality improvement. ICC International Conference on cereals and cereal products quality and safety, Rosario, Argentina, 23-26 September 2007.

Clements MJ, Campbell KW, Maragos CM, Pilcher C, Headrick JM, Pataky JK, White DC (2003) Influence of Cry1Ab protein and hybrid genotype on fumonisin contamination and Fusarium ear rot of corn. Crop Sci 43:1283–1293

De la Campa R, Hooker DC, Miller JD, Schaafsma AW, Hammond BG (2005) Modeling effects of environment, insect damage, and Bt genotypes on fumonisin accumulation in maize in Argentina and the Philippines. Mycopathologia 159:539–552

Dowd PF (1998) Involvement of arthropods in the establishment of mycotoxigenic fungi under field conditions. In: Sinha KK, Bhatnagar D (eds) Mycotoxins in agriculture and food safety. Marcel Dekker, New York, pp 307–350

Dowd PF (2001) Biotic and abiotic factors limiting efficacy of Bt corn in indirectly reducing mycotoxin levels in commercial fields. J Econ Entomol 94:1067–1074

GMO Compass (2009) GM maize in the EU (http://www.gmo-compass.org/eng/grocery_shopping/crops/18.genetically_modified_maize_eu.html)

Hammond BK, Campbell C, Pilcher T, De Gooyer A, Robinson L, Rice A, Pietri G Piva, Melcion D, Cahagnier B (2002) Reduction of fungal and fumonisin levels in Bt corn. Mycopathologia 155:22

Hammond BG, Campbell KW, Pilcher CD, De Gooyer TA, Robinson AE, McMillen BL et al (2004) Lower fumonisin mycotoxin levels in the graint of Bt corn grown in the United States in 2000–2002. J Agric Food Chem 52:1390–1397

Magg T, Melchinger AE, Klein D, Bohn M (2002) Relationship between European corn borer resistance and concentration of mycotoxins produced by *Fusarium* spp. in grains of transgenic *Bt* maize hybrids, their isogenic counterparts, and commercial varieties. Plant Breed 121:146–154

Masoero F, Moschini M, Rossi F, Prandini A, Pietri A (1999) Nutritive value, mycotoxin contamination and in vitro rumen fermentation of normal and genetically modified corn (Cry 1A (B)) grown in northern Italy. Maydica 44:205–209

Munkvold GP, Desjardins AE (1997) Fumonisins in maize—can we reduce their occurrence. Plant Dis 81:556–565

Munkvold GP, Hellmich RL, Rice LG (1999) Comparison of fumonisin concentrations in kernels of transgenic *Bt* maize hybrids and nontransgenic hybrids. Plant Dis 83:130–138

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 87:1071–1077

Naef A, Zesiger T, Défago G (2006) Impact of transgenic Bt maize residues on the mycotoxigenic plant pathogen *Fusarium graminearum* and the biocontrol agent *Trichoderma atroviride*. J Environ Qual 35:1001–1009

Papst C, Utz HF, Melchinger AE, Eder J, Magg T, Klein D, Bohn M (2005) Mycotoxins produced by *Fusarium* spp. in isogenic Bt vs. non-Bt maize hybrids under European corn borer pressure. Agron J 97:219–224

Schaafsma AW, Hooker DC, Baute TS, Illincic-Tamburic L (2002) Effect of Bt-corn hybrids on deoxynivalenol content in grain at harvest. Plant Dis 86(10):1123–1126

Schulthess F, Cardwell KF, Gounou S (2002) The effect of endophytic *Fusarium verticillioides* on infestation of two maize varieties by lepidopterous stemborers and coleopteran grain feeders. Phytopathology 92:120–128

Strosnider H, Azziz-Baumgartner E, Banziger M, Bhat RV, Breiman R, Brune MN, DeCock K, Dilley A, Groopman J, Hell K et al (2006) Workgroup report: public health strategies for reducing aflatoxin exposure in developing countries. Environ Health Perspect 114:1898–1903

Valenta H, Dänicke S, Flachowsky G, Böhme T (2001) Comparative study on concentrations of deoxynivalenol and zearalenone in kernels of transgenic Bt maize hybrids and nontransgenic maize hybrids. Mycotoxin Res 17:15–18

Wu F (2004) Explaining consumer resistance to genetically modified corn: an analysis of the distribution of benefits and risks. Risk Anal 24:717–728

Wu F (2006a) Mycotoxin reduction in Bt corn: potential economic, health and regulatory impacts. Transgenic Res 15: 277–189

Wu F (2006b) An analysis of Bt corn's benefits and risks for national and regional policymakers considering Bt corn adoption. Inter J Technol Global 2:115–136

Wu F (2007) Bt corn and mycotoxin reduction. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2(060), CABI, Oxford

Wu F, Miller JD, Casman EA (2004) Bt corn and mycotoxin reduction: economic impacts in the United States and the developing world. J Toxicol Toxin Rev 23:397–424