Can Bt Maize Reduce Exposure to the Mycotoxin Fumonisin in South Africa?

Carl Pray[a], John Rheeder[b], Marnus Gouse[c], Yvette Volkwyn[b], Liana van der Westhuizen[b] and Gordon S. Shephard[b]

[a] Department of Agricultural, Food and Resource Economics, School of Environmental and Biological Sciences, Rutgers, State University of New Jersey, New Brunswick, USA. pray@aesop.rutgers.edu

[b] PROMEC Unit, Medical Research Council, TYGERBERG, South Africa. john.rheeder@mrc.ac.za

[c] Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, Pretoria, South Africa. marnus.gouse@up.ac.za

Contributed Paper prepared for presentation at the International Association of Agricultural Economists' 2009 Conference, Beijing, China, August 16-22, 2009.

Can Bt Maize Reduce Exposure to the Mycotoxin Fumonisin in South Africa?

ABSTRACT

The mycotoxin fumonisin is associated with oesophageal cancer and birth defects. The Eastern Cape province of South Africa has high levels of fumonisin in maize and oesophageal cancer. This study measures the amounts of the mycotoxin fumonisin in the grain of Bt maize, commercial hybrids, and farmer-saved, local mixtures of seed that were produced and stored by small holders in South Africa. We find that adoption of Bt maize can reduce poor rural consumers exposure to fumonisin. Greater consumption of maize meal milled in modern mills could have a similar impact.

KEY WORDS

Bt maize, mycotoxins, fumonisin, South Africa

Acknowledgements. We would like to thanks Rockefeller Foundation for their financial support of this project and Felicia Wu for her comments on earlier versions of this paper.

1. Introduction

Starting in the late 1940s, there was a dramatic rise in oesophageal cancer (OC) deaths in rural areas of the Transkei regions of South Africa, which is part of the Eastern Cape Province (Rose and Fellingham 1981). In the period 1996-2000, the OC incidence in this region was 31.2/100,000 for males and 21.8/100,000 females. This was far higher than the next highest cancer incidences in these regions during that time which were lung cancer in men (6.2/100,000) and cervical cancer in women (19/100,000). In South Africa as a whole, the OC rate is 14.3/100,000. Globally, the OC rate is about 4/100,000 for women and 9/100,000 for men (Somdyala et al 2003). There is also evidence that fumonisin exposure causes neural tube defects (NTDs) in human babies by disrupting the uptake of folate in cell lines (Missmer et al. 2006, Marasas et al. 2004).

Transgenic Bt maize emerged as a potential solution to controlling fumonisin contamination. Bt maize contains a gene from the soil bacterium *Bacillus thuringiensis*, which encodes for formation of a crystal (Cry) protein that is toxic to maize stalk borer. Insect damage is one factor that predisposes maize to mycotoxin contamination, because insects create kernel wounds that encourage fungal colonization, and insects themselves serve as vectors of fungal spores (Sinha 1994, Wicklow 1994, Munkvold et al. 1999). If Bt maize reduces insect damage, if may also reduce the risks of fungal contamination and fumonisins (Wu 2006).

The objective of this study was to examine the extent to which Bt hybrids could reduce the amount of fumonisins in maize at the village level. A second objective of this study was to find out whether adoption of the Bt maize could reduce rural consumers' exposure to mycotoxins to levels considered safe by the international health community.

2. Background

Fumonisins are produced primarily by the fungi *Fusarium verticillioides* and *F. proliferatum*. The disease in maize caused by these fungi is called *Fusarium* kernel rot. The first report implicating fumonisins in human disease was in connection with high human oesophageal cancer (OC) rates in Transkei, South Africa in 1988. Fumonisin has since been shown to be positively associated with OC (Rheeder et al 1992). The Joint

FAO/WHO Expert Committee on Food Additives (JECFA) evaluated the fumonisins and allocated a group provisional maximum tolerable daily intake (PMTDI) of 2 µg/kg body weight to FB_1, FB_2 and FB_3, alone or in combination (WHO 2002).

Maize flour makes up the basic starch in South Africa and large part of all the food consumed by the poor. A recent survey of consumption patterns in Bizana and Centane in the Eastern Cape Province by PROMEC (Table 1) found that adults consumed from 335 to 483 g of maize per person per day.

Table 1. Maize Consumption and fumonisin exposure (probable daily intake)

Demographic Group	Regions of Transkei (Eastern Cape)	Consumption of maize (g per person per day)	Fumonisin exposure village maize (µg kg^{-1}bw day^{-1})	Fumonisin exposure commercial maize flour (µg kg^{-1}bw day^{-1})
Maize consumption				
Children 1- 9	Bizana	244	6.60	2.46
	Centane	248	14.14	1.92
Adolescents 10-17	Bizana	370	4.05	1.51
	Centane	365	8.33	1.13
Adults 18-65	Bizana females	335	3.03	1.13
	Bizana males	423	3.82	1.43
	Centana Females	428	8.15	1.11
	Centane Males	483	9.19	1.25

Sources : Maize consumption columns 1 through 4 from Shephard et al 2007. Last column calculated using data from Shephard et al 1996 data with assumption that Bizana maize contained 670 μg kg^{-1} of fumonisins, Centane maize contained 1,840 ug kg^{-1} and that commercial flour has 250 μg kg^{-1} fumonisins.

The amount of fumonisin in the grain in these regions is very high (Shephard et al 1996). Fumonisin contamination does not vary much between grain large commercial farmer and good quality grain of small semi-subsistence farmers in low OC areas.. However, fumonisin is much higher in maize meal that is milled in local mills than it is in the maize meal or maize grits that have been milled in commercial mills. Fumonisins are much lower in flour from commercial mills because the commercial milling process takes off the outer shelf of the grain which contains most of the fumonisins.

The last two columns in Table 1 show approximately how much fumonisin rural consumers eat. The next to the last column assumes that the levels of fumonisins are the levels that existed on home grown and milled maize in the two regions and that all of the maize eaten is home grown. However, in recent years due to lack of rainfall and other factors in some regions of Eastern Cape there has been almost no local production. Rural consumers must now eat some combination of local and commercially milled. If consumers ate only commercially milled maize from local stores, then the amounts consumed would be dramatically reduced to the amount shown in the last column of Table 1.

Using the village milled maize fumonisin concentrations, the average exposure in all groups is far above 2 μg kg^{-1}bw day^{-1} which JECFA recommended as the safe upper limit of daily consumption. If all maize flour comes from the commercial mills, the mean consumption of children in Bizama is still 50 percent higher than the JECFA limit and most other groups (last column Table 1) consume fumonisin at about the JECFA limit, which implies that about half the people still get more than recommended amount.

Hybrid Bt maize seeds have spread widely to commercial farmers and some small farmers in recent years. Bt hybrids currently cover about 43 percent of the white maize produced in South Africa (Gouse, Kirsten & Van Der Walt 2009). Studies by PROMEC and the Agricultural Research Council have found that in experiment station Bt maize has about 60% less fumonisins than identical non-Bt varieties (Vismer et al 2005). Could the spread of Bt maize into the Eastern Cape reduce fumonisin exposure of the poor?

3. Results of the village study

Samples of maize were collected in villages in KwaZulu Natal annually 2004 through 2007. We had also selected villages in Eastern Cape Province, but they did not receive the Bt maize seed in time to plant it the first year and then drought prevented them from growing maize in the second and third years of the project. After harvest we collected approximately 50 samples of farmer-stored cobs from farmers who we knew were growing Bt maize because they were part of economic studies that were already underway. These samples were sent to the PROMEC research facilities for analysis of levels of fungus and fumonisin on and in the grain using standard procedures which PROMEC has developed and published over the years.

The results of the village surveys are in Table 2. There is a clear advantage of BT maize over the conventional hybrids. In nine of the ten village/year comparisons non Bt commercial maize had higher levels of fumonisin than Bt maize. If we compare the means of the non Bt commercial maize and the Bt maize across all villages and years (last line of Table 2) the Bt maize had 28 % less fumonisin than the non Bt maize.

Table 2. Comparison of total fumonisin levels (ng/g or ppb) in maize in rural KwaZulu-Natal during 2004-2006

Year & Location	Traditional Maize	Commercial Maize	Bt Maize
2004			
Simdlangentsha	753	623	239
Hlabisa	159	450	1147
2005			
Simdlangentsha	271	815	396
Hlabisa	250	472	22
2006			
Simdlangentsha	996	1200	152
Hlabisa	2065	1380	804
Dumbe	426	2595	1280
2007			
Simdlangentsha	-	1812	51
Hlabisa	-	348	129
Dumbe	3391	848	500
Average of the entire sample	1233	886	474

Source: Survey

The Bt had less fumonisins than local mixtures in five of the eight village/years when there was a direct comparison. Comparing the mean of the traditional maize and the Bt maize, the Bt maize had 62 % less fumonisin than the traditional maize. These differences in fumonisin levels are similar to the differences between commercial non-Bt hybrids and Bt hybrids on the ARC experiment stations which was about 60% described above (Vismer et al 2005).

4. How much could Bt maize reduce mycotoxin exposure?

In order to test the impact of shifting from local landraces to Bt maize, we have done a simulation of what the impact of that shift would be using the information from Table 1.

Table 3 Potential Fumonisin Exposure Reductions

Group	Region	Fumonisin exposure village maize	Sim 1 All village maize is Bt - 62% fumonisin reduction
Maize consumption			($\mu g\ kg^{-1} bw\ day^{-1}$)
Children 1- 9	Bizana	6.60	2.51
	Centane	14.14	5.37
Adolescents	Bizana	4.05	1.54
	Centane	8.33	3.17
Adults 18-65	Bizana females	3.03	1.15
	Bizana males	3.82	1.45
	Centane Females	8.15	3.10
	Centane Males	9.19	3.49
Beer consumption	Centane/Bizana Per capital	0.2	0.2
	Drinkers only	6.5	6.5

Source: First three columns Shephard et al 2007. Sim 1 calculated by the authors.

If the Bt maize could be introduced into this area and adopted by 100% of farmers and if the reduction in fumonisin exposure due to Bt is what was found in KZN (sim 1 column 4), then there would be a dramatic reduction in fumonisin exposure. In Bizana most groups of people except children would have lower exposure than the JECFA maximum level. In Centane all groups would remain above the JECFA maximum levels.

5. Conclusions and policy implications

The spread of Bt maize to small farmers in the Eastern Cape Province could greatly reduce human exposure to fumonisins but not solve the problem of fumonisin in human and animal diets. However, getting small farmers to grow Bt maize in the Eastern Cape would be a major undertaking. Farmers are not using hybrids in these areas, rather they are using relatively well adapted OPVs and they save their own seed. Even with the good will of a major seed company we were not able to get seed of existing Bt hybrids out to farmers so that they could test it. In order to get widespread acceptance of Bt cultivars, some organization would have to either breed and distribute OPVs which are well adapted to this area or the government will have to provide well adapted hybrids every year or two.

Changes in the consumption patterns toward more commercially milled grain have probably already helped reduce exposure to fumonisins. These changes seem to be due to a combination of higher welfare payments may have allowed some families to buy grain and bad weather that has lowered production of local maize. None of these changes in consumption were policies to improve diets, but policies could be constructed to encourage more farmers to switch to maize meal that has been milled by commercial mills.

The next step needed is a thorough evaluation of what policy options are available, what the costs of the different types of interventions would be and how much these options could reduce risk of OC and NTDs.

References

Bakan, B., Melcion, D., Richard-Molard, D., Cahagnier, B. "Fungal growth and Fusarium mycotoxin content in isogenic traditional maize and genetically modified maize grown in France and Spain." Journal of Agricultural and Food Chemistry, **2002**, *50*(4), 728-731.

Dowd, P.F. "Biotic and Abiotic Factors Limiting Efficacy of Bt Corn in Indirectly Reducing Mycotoxin Levels in Commercial Fields." *Journal of Economic Entomology* **2001**, *94*(5), 1067-1074.

Gouse, M., Kirsten, J.F. & Van Der Walt, W.J. (2008). Bt Cotton and Bt Maize: An Evaluation of Direct and Indirect Impact on the Cotton and Maize Farming Sectors in South Africa. Report commissioned by the South African Department of Agriculture. Directorate Biosafety. Harvest House, Pretoria, South Africa

Hammond, B., Campbell, K., Pilcher, C., Robinson, A., Melcion, D., Cahagnier, B., Richard, J., Sequeira, J., Cea, J., Tatli, F., Grogna, R., Pietri, A., Piva, G. Rice, L. "Reduction of fumonisin mycotoxins in Bt corn." *The Toxicologist,* **2003**, *72*(S-1), abstract 1217.

Marasas, W.F.O., T.S. Kellerman, W.C.A. Gelderblom, J.A.W. Coetzer, P.G. Thiel, and J.J. van der Lugt. 1988. Leukoencephalomalacia in a horse induced by fumonisin B_1, isolated from *Fusarium moniliforme*. *Onderstepoort J Vet Res* 55:197-203.

Munkvold, G.P., Hellmich, R.L., Rice, L.G. "Comparison of Fumonisin Concentrations in Kernels of Transgenic Bt Maize Hybrids and Nontransgenic Hybrids." *Plant Disease* **1999**, *83(*2), 130-138.

Rose, E.F. and S.A. Fellingham. (1981) Cancer Patterns in Transkei, South African Journal of Science Vol. 77, pp 555-561.

Shephard GS, Marasas WFO, Burger H-M, Somdyala NIM, Rheeder JP, Van der Westhuizen L, Gatyeni P, Van Schalkwyk DJ. Exposure assessment for fumonisins in them former Transkei region of South Africa. Food Addit Contam 2007; 24: 621-629.

Shephard, G.S., Thiel, P.G., Stockenstrom, S., & Sydenham, E.W. (1996). Worldwide survey of Fumonisin contamination of corn and corn-based products. *Journal of AOAC International* Vol. 79 (3), pp 671-687.

Sinha, A.K. “The impact of insect pests on aflatoxin contamination of stored wheat and maize” in *Stored Product Protection: Proceedings of the 6th International Working Conference on Stored-product Protection*, E. Highley, E.J. Wright, H.J. Banks & B.R. Champ, eds., Wallingford, UK, CAB International, 1994; 1059-1063.

Wicklow, D.T. “Preharvest origins of toxigenic fungi in stored grain” in *Stored Product Protection: Proceedings of the 6th International Working Conference on Stored-product Protection*, E. Highley, E.J. Wright, H.J. Banks & B.R. Champ, eds., Wallingford, UK, CAB International, 1075-1081, 1994.

Wu, F. (2006). “Mycotoxin Reduction in Bt Corn: Potential Economic, Health and Regulatory Impacts.” *Transgenic Research* 15, 277-289.