

## Incidence of *Fusarium* spp. and Levels of Fumonisin B<sub>1</sub> in Maize in Western Kenya

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Maize kernel samples were collected in 1996 from smallholder farm storages in the districts of Bomet, Bungoma, Kakamega, Kericho, Kisii, Nandi, Siaya, Trans Nzoia, and Vihiga in the tropical highlands of western Kenya. Two-thirds of the samples were good-quality maize, and one-third were poor-quality maize with a high incidence of visibly diseased kernels. One hundred fifty-three maize samples were assessed for *Fusarium* infection by culturing kernels on a selective medium. The isolates obtained were identified to the species level based on morphology and on formation of the sexual stage in *Gibberella fujikuroi* mating population tests. *Fusarium moniliforme* (*G. fujikuroi* mating population A) was isolated most frequently, but *F. subglutinans* (*G. fujikuroi* mating population E), *F. graminearum*, *F. oxysporum*, *F. solani*, and other *Fusarium* species were also isolated. The high incidence of kernel infection with the fumonisin-producing species *F. moniliforme* indicated a potential for fumonisin contamination of Kenyan maize. However, analysis of 197 maize kernel samples by high-performance liquid chromatography found little fumonisin B<sub>1</sub> in most of the samples. Forty-seven percent of the samples contained fumonisin B<sub>1</sub> at levels above the detection limit (100 ng/g), but only 5% were above 1,000 ng/g, a proposed level of concern for human consumption. The four most-contaminated samples, with fumonisin B<sub>1</sub> levels ranging from 3,600 to 11,600 ng/g, were from poor-quality maize collected in the Kisii district. Many samples with a high incidence of visibly diseased kernels contained little or no fumonisin B<sub>1</sub>, despite the presence of *F. moniliforme*. This result may be attributable to the inability of *F. moniliforme* isolates present in Kenyan maize to produce fumonisins, to the presence of other ear rot fungi, and/or to environmental conditions unfavorable for fumonisin production.

Maize was introduced into East Africa more than 300 years ago and has adapted to diverse conditions of soil, climate, and altitude (15). Maize is the most important cereal crop in Kenya and is used primarily for direct human consumption. In Kenya, about 1.4 million hectares are planted, which yield an estimated 2.8 million tons of grain annually (1). Maize is typically produced by resource-poor smallholder farmers under low-input conditions. Productivity is limited by rainfall and low soil fertility. In addition, an estimated 20 to 40% of the grain is lost nationwide due to pests and diseases (1). Stalk and ear rots caused by a number of fungi not only decrease yields but also have the potential to contaminate grain with mycotoxins that can adversely affect human health (1, 12, 20).

The tropical highlands of western Kenya, bordered on the west by Lake Victoria and on the east by the Great Rift Valley, are a major maize-growing region. Two recent surveys of maize ear rot in western Kenya have found that *Fusarium* species are the most frequent contaminants (6, 7, 12). *Fusarium* species from Kenyan maize have been identified by a number of methods, including differences in morphological characters, randomly amplified polymorphic DNA analysis (12), and assignment to mating populations within the *Gibberella fujikuroi* species complex (6, 7, 12). Overall, the most frequently isolated species was *Fusarium moniliforme* (synonym, *F. verticillioides*; *G. fujikuroi* mating population A), followed by *F. graminearum*, *F. subglutinans* (*G. fujikuroi* mating population E), and other

*Fusarium* species (6, 7, 12). The predominance of *F. moniliforme* in Kenyan maize is cause for concern because most isolates of this species produce fumonisins, mycotoxins that can cause equine leucoencephalomalacia, porcine pulmonary edema, and experimental liver cancer in rats (13). Furthermore, some studies have associated consumption of maize containing high levels of *F. moniliforme* and fumonisins with the occurrence of high rates of human esophageal cancer in certain regions of South Africa and China (11, 16, 23, 27).

Fumonisin has been detected in maize and maize-based foods and feeds in North America, South America, Europe, Asia, and South Africa, where extensive survey results have been reported (2, 4, 5, 16, 23, 24, 25, 27). However, there is little information on the occurrence of fumonisins in maize in Kenya or in other countries of sub-Saharan Africa other than South Africa. Comparisons of data from worldwide surveys associate high levels of *F. moniliforme* infection and fumonisins with drier, warmer climates (27). The relatively warm tropical highlands of western Kenya thus appear to provide suitable conditions for the production of fumonisins in maize. A preliminary survey of good-quality maize from four districts of western Kenya found only low levels of fumonisins (<100 ng/g) in 27 of the 33 samples tested (8, 16). The objective of the present study was a larger and more representative survey of both good-quality and poor-quality maize kernels from smallholder farm storage facilities in nine districts of western Kenya for contamination with *Fusarium* species and fumonisins.

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### MATERIALS AND METHODS

**Media.** *Fusarium* species were isolated on peptone-pentachloronitrobenzene agar medium (17), and the isolates were routinely maintained on a modified

TABLE 1. *Fusarium* species isolated from Kenyan maize<sup>a</sup>

Fungal contamination	No. of samples from:									Total no. of samples contaminated or tested
	Bomet	Bungoma	Kakamega	Kericho	Kisii	Nandi	Siaya	Trans Nzoia	Vihiga	
<i>F. graminearum</i>	4	3	6	2	9	3	0	9	12	48
<i>F. solani</i>	5	4	3	3	0	4	0	3	6	28
<i>F. equiseti</i>	0	0	0	1	0	0	0	0	0	1
<i>F. moniliforme</i>	13	10	6	10	12	6	3	9	23	92
<i>F. subglutinans</i>	4	3	2	0	3	2	0	5	4	23
<i>F. oxysporum</i>	1	0	1	1	0	0	0	0	2	5
<i>Fusarium</i> spp.	1	0	1	0	2	2	0	1	1	8
None (clean samples)	6	2	4	2	1	5	0	2	0	22
Total <sup>b</sup>	23	14	10	18	17	16	3	20	32	153

<sup>a</sup> Five kernels were plated per sample. One sample from each storage facility was analyzed. The values shown are numbers of samples from which the given *Fusarium* species were isolated in the districts studied.

<sup>b</sup> Total number of samples tested from that district.

Czapek-Dox minimal or complete medium (3), while potato dextrose agar was used to culture strains for identification. Carrot agar was used for sexual crosses (9).

**Sample collection and isolation of *Fusarium* species.** Shelled maize kernel samples were collected from smallholder farm storage facilities in the districts of Bomet, Bungoma, Kakamega, Kericho, Kisii, Nandi, Siaya, Trans Nzoia, and Vihiga in western Kenya in 1996. The farms were selected randomly from those that had dry maize in their storage facilities (basket granary, cribs, gunny bags, etc.). One or two samples were taken from each of 148 storage facilities: 99 storages were sampled once, and 49 were sampled twice, for a total of 197 samples for fumonisin analysis. Samples from an additional five storage facilities in the Bomet district were analyzed for *Fusarium* infection but not for fumonisins. The samples comprised good-quality maize (125 samples), with a less-than-34% incidence of visibly diseased kernels, for human consumption and poor-quality maize (72 samples), with a more-than-34% incidence of visibly diseased kernels, for livestock feeding. Most samples were white maize. Sample sizes ranged from 500 g to 1 kg of grain. The proportion of visibly moldy, rotted, or discolored kernels in each of the 197 samples was determined by scoring all kernels in a representative sample of 100 kernels. One sample from each of 153 storage facilities was analyzed for *Fusarium* infection. Five kernels (each randomly picked from a container) from each sample were surface disinfected by immersion in 1% NaOCl for 30 s, rinsed in sterile distilled water for 20 s, and then transferred to peptone-pentachloronitrobenzene agar medium. These kernels were incubated at 25°C for 5 to 7 days, and one colony per kernel was transferred to potato dextrose agar for identification based on morphology by the system of Nelson et al. (18).

**Crossing procedure.** Macroconidial morphology, the trait most commonly used to key *Fusarium* species, is not useful for distinguishing species in section *Liseola* (teleomorph *G. fujikuroi*) (10, 18). Members of section *Liseola* appear to exist as reproductively isolated mating populations. Field isolates can thus be identified by the ability to form fertile perithecia with standard mating population testers. Crosses were made on carrot agar plates (60 by 15 mm) as described by Klittich and Leslie (9) by using standard tester strains (one each of the + and - mating types) of mating populations A (*F. moniliforme*), B (*F. sacchari*), C (*F. fujikuroi*), D (*F. proliferatum*), E (*F. subglutinans*), F (*F. thapsinum*), and G (*F. nygamai*). Tester strains were kindly supplied by J. F. Leslie, Kansas State University, Manhattan. All crosses were made by using a standard tester strain as the female and the uncharacterized field isolate as the male. Only 2 of the 563 isolates tested in the *Liseola* section were not fertile, and their identification was based on morphology.

**Fumonisin extraction, cleanup, and analysis.** Maize kernel samples, 250 to 300 g, were shipped by air express to the National Center for Agricultural Utilization Research, Peoria, Ill. The samples were scored for the presence of visibly moldy and discolored kernels and then stored at 4°C until analysis. The samples were analyzed for fumonisins by high-performance liquid chromatography (HPLC) using standard methods (22, 29). In brief, a 50-g subsample was finely ground in a laboratory mill and thoroughly mixed. Aliquots (5 g) of the ground subsample were extracted with 1:1 acetonitrile-water for 3 h with shaking every 15 min. The extracts were filtered through Whatman 2V filter paper and cleaned up by chromatography on a Bond-Elut strong anion-exchange resin cartridge previously conditioned by the successive passage of methanol (5 ml) and methanol-water (3:1, 5 ml). The cartridge was then washed with methanol-water (3:1, 8 ml), followed by methanol (3 ml), and fumonisins were eluted with 0.5% acetic acid in methanol (14 ml). The eluate was evaporated to dryness under nitrogen and stored at 4°C until analysis. The cleaned extracts were derivatized with *ortho*-phthalaldehyde immediately before analysis on a Spectra Physics 8700 liquid chromatograph.

## RESULTS

The incidence and geographical distribution of *Fusarium* species in Kenyan maize are reported in Table 1. *F. moniliforme* (*G. fujikuroi* mating population A) was recovered from 60% of the samples overall and was the dominant species in all nine of the districts surveyed. *F. graminearum* was recovered from 31% of the samples and from eight of the nine districts surveyed. *F. solani* and *F. subglutinans* (*G. fujikuroi* mating population E) were also widespread throughout most districts but were recovered at lower frequencies (18 and 15%, respectively). Other *Fusarium* species, including *F. equiseti* and *F. oxysporum*, were occasionally present.

Fumonisin B<sub>1</sub> levels were above the detection limit of 100 ng/g in 93 (47%) of the 197 maize samples tested (Table 2). The proportion of fumonisin B<sub>1</sub>-positive samples ranged from a low of 10% in the Bomet district to highs of 56% in the Vihiga district, 59% in the Kisii district, and 72% in the Bungoma district. The incidence of *F. moniliforme* in the maize samples from these three districts also was high (71 to 72%), suggesting a trend toward a higher proportion of fumonisin B<sub>1</sub>-positive samples in districts with a higher incidence of

TABLE 2. Fumonisin B<sub>1</sub> levels in Kenyan maize

District	No. of samples	% of samples positive	Fumonisin B <sub>1</sub> concn (ng/g) <sup>a</sup> of positive samples		% of <i>F. moniliforme</i> -infected samples <sup>b</sup>
			Mean	Range	
Bomet	20	10 a	340 a	130-540	57
Bungoma	25	72 c	450 a	120-2,000	71
Kakamega	22	41 bc	370 a	110-1,300	60
Kericho	18	22 ab	370 a	150-920	56
Kisii	17	59 c	3,000 b	160-12,000	71
Nandi	28	50 bc	310 a	130-1,200	38
Siaya	4	50 bc	1,000 ab	180-1,900	100
Trans Nzoia	31	52 bc	280 a	110-700	45
Vihiga	32	56 c	460 a	120-3,500	72
Total	197	47	670	110-12,000	60

<sup>a</sup> Fumonisin B<sub>1</sub> was determined by HPLC (26) of one or two samples from each storage facility tested. Differences between districts in the percentage of fumonisin B<sub>1</sub>-positive samples and the mean fumonisin B<sub>1</sub> concentration of positive samples were evaluated statistically. In each column, numbers followed by the same letter are not significantly different by the chi-square test ( $P < 0.002$ ).

<sup>b</sup> Samples were analyzed as described in Table 1, footnote a.

TABLE 3. Occurrence of fumonisin B<sub>1</sub> in maize kernel samples collected in Africa

Country	No. of samples	% of samples positive	Mean fumonisin B <sub>1</sub> concn (ng/g) <sup>a</sup> of positive samples	Detection limit (ng/g)	Yr of sample collection, source, quality (reference)
South Africa	24	62	1,400	50	1985, smallholder farms, good quality (23)
South Africa	23	100	16,000	50	1985, smallholder farms, moldy (23)
South Africa	14	79	1,200	50	1989, smallholder farms, good quality (23)
South Africa	13	100	27,000	50	1989, smallholder farms, moldy (23)
South Africa	249	75	450	50	1989 and 1990, commercial grade (24)
Benin	11	64	640	100	1992, commercial grade, good quality (4)
Zambia	20	35	410	100	1992, commercial grade, good quality (4)
Eastern and southern Africa	25	40	260	100	1994, retail outlets, sample lots, quality unknown (5)
Kenya	197	47	672	100	1996, smallholder farms, mixed good quality and diseased (this study)

<sup>a</sup> Fumonisin B<sub>1</sub> was determined as described in Table 2, footnote a.

*F. moniliforme*. There were several exceptions to this trend, however, including Bomet district samples, which had a relatively high percentage (57%) of *F. moniliforme*-positive samples but a low percentage (10%) of fumonisin B<sub>1</sub>-positive samples (Table 2). The mean fumonisin B<sub>1</sub> levels of the 97 positive samples ranged from 280 ng/g in the Trans Nzoia district to 3,000 ng/g in the Kisii district (Table 2). Fumonisin B<sub>1</sub> levels were above 1,000 ng/g in only 10 samples, 5 of which were collected from farms in the Kisii district. The Kisii samples included one sample (2,100-ng/g fumonisin B<sub>1</sub>) of high-quality maize being used for human consumption and four samples (3,600- to 12,000-ng/g fumonisin B<sub>1</sub>) of low-quality maize being used for animal feed.

All of the 197 maize samples in this survey were scored for diseased kernels by counting the number of visibly moldy, rotted, or discolored kernels in a representative sample of 100 kernels. To compare fumonisin levels, samples were assigned to four quality grades based on the percentages of diseased kernels. Forty-eight percent of the samples were grade 1 (0 to 25% diseased), 22% were grade 2 (26 to 50% diseased), 9% were grade 3 (51 to 75% diseased), and 21% were grade 4 (76 to 100% diseased). Half of the samples in quality grades 1, 2, and 3 contained fumonisin B<sub>1</sub> at levels above the detection limit of 100 ng/g, but only 3 of the 156 samples in these grades contained fumonisin B<sub>1</sub> at more than 1,000 ng/g. In samples of the poorest quality, grade 4, 17% contained fumonisin B<sub>1</sub> at more than 1,000 ng/g, but 65% contained no detectable fumonisin B<sub>1</sub>.

## DISCUSSION

The prevalence of *F. moniliforme* (*G. fujikuroi* mating population A) in this survey confirms this fumonisin-producing species as the predominant *Fusarium* species in Kenyan maize. A field survey for *Fusarium* in the major maize-growing areas of Kenya in 1993 also found *F. moniliforme* to be predominant (82% of isolates from maize), followed by *F. graminearum* (9% of isolates) and *F. subglutinans* (7% of isolates) (7). Furthermore, in a recent survey of maize grain purchased from market stalls and roadside traders in central and western Kenya, Macdonald and Chapman (12) also reported a high incidence of *F. graminearum* (9% of the kernels tested) and of "*F. moniliforme*" (14% of the kernels tested), defined in a broad sense that included several mating populations. In their study, mating population A accounted for 86% and mating population E accounted for 14% of the isolates of "*F. moniliforme*" from Kenyan maize.

Despite the prevalence of *F. moniliforme* in maize and the importance of maize as a food staple, there is little information available on the natural occurrence of fumonisins in maize

consumed by rural populations in sub-Saharan Africa, with the exception of South Africa. Table 3 compares fumonisin survey data from this study to data from previous surveys of fumonisin levels in African maize. Surveys of maize from rural smallholder farms in the Transkei region of South Africa were conducted in 1985 and 1989 (23). High incidences and levels of fumonisin B<sub>1</sub> were found in both good-quality and moldy maize. Surveys of South African maize grown commercially and for export from 1989 to 1993 found a high incidence of fumonisins but much lower levels than in the maize from smallholder farms in the Transkei region (24, 27). Limited surveys of good-quality maize from hybrids grown in Benin and Zambia in 1992 and from various countries in eastern and southern Africa in 1994 (including one sample from Kenya) also found a high incidence, but low levels, of fumonisins (4, 5). Data from these surveys can be directly compared to data from the present study because all of the fumonisin analyses used the HPLC method of Sydenham et al. (29), and the fumonisin detection limits were similar, either 50 or 100 ng/g.

An overview of the limited data available indicates that fumonisin B<sub>1</sub> levels in maize from smallholder farms in Kenya, with the possible exception of the Kisii district, are generally lower than expected based on the high incidence of *F. moniliforme* and visibly diseased kernels. These data confirm prior observations of a generally poor correlation between the incidence of *F. moniliforme* and fumonisin levels in maize collected from smallholder farms in South Africa (16, 23, 24, 27). Another reason for these results is that the maize samples tested are infected with multiple species of *Fusarium*, all of which cause similar ear and kernel rot symptoms. Thus, kernels exhibiting disease symptoms could be infected with *F. moniliforme* or *F. proliferatum*, which do produce fumonisins, with *F. subglutinans*, which produces little or no fumonisins, or with *F. graminearum*, *F. solani*, *F. oxysporum*, *F. equiseti*, and other *Fusarium* species, or with other fungi that do not produce fumonisins (11, 19, 30).

Some studies of fumonisin contamination of maize have indicated that environmental conditions in the area of cultivation play a role in the production of fumonisins in maize (4, 16, 21, 26, 28). It has been observed in the United States that commercial hybrids differ in the tendency to accumulate fumonisins and that hybrids grown outside their adapted range tend to accumulate higher concentrations (26). In the present study, agroecological conditions in the various districts where the maize was cultivated were not determined. The maize genotypes grown in all of the districts except Siaya were primarily of the Hybrid 600 series (Kenya Seed Company, Nairobi) with an identical genetic base. Future studies should investigate the influence of environmental conditions and plant genotypes on fumonisin production in Kenyan maize, and the

ability of isolates of *F. moniliforme* from Kenyan maize to produce fumonisins under controlled conditions in the laboratory and in the field. Furthermore, although the relatively low level of fumonisin contamination of Kenyan maize from small-holder farms is a reassuring finding, some locations yielded maize with unacceptable levels of fumonisins. Our survey data should be useful in estimating the actual exposure to fumonisins of Kenyan populations that depend on maize as their primary source of nutrition. In addition, the widespread presence of *F. graminearum* and *F. subglutinans* warrants further surveys for the presence of the mycotoxins, such as deoxynivalenol, zearalenone, moniliformin, and fusaproliferin, that can be produced by these *Fusarium* species in maize (1, 5, 14, 25).

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#### REFERENCES

1. Anonymous. 1992. Information bulletin no. 7. Kenya Agricultural Research Institute, Nairobi.
2. Beardall, J., and J. D. Miller. 1994. Natural occurrence of mycotoxins other than aflatoxin in Africa, Asia and South America. *Mycotoxin Res.* **10**:21–40.
3. Correll, J. C., C. J. R. Klittich, and J. F. Leslie. 1987. Nitrate non-utilizing mutants of *Fusarium oxysporum* and their use in vegetative compatibility tests. *Phytopathology* **77**:1640–1646.
4. Doko, M. B., S. Rapior, A. Visconti, and J. E. Schjoth. 1995. Incidence and levels of fumonisin contamination in maize genotypes grown in Europe and Africa. *J. Agric. Food Chem.* **43**:429–434.
5. Doko, M. B., C. Canet, N. Brown, E. W. Sydenham, S. Mpuchane, and B. A. Siame. 1996. Natural co-occurrence of fumonisin and zearalenone in cereals and cereal-based foods from eastern and southern Africa. *J. Agric. Food Chem.* **44**:3240–3243.
6. Kedera, C. J., T. E. O. Ochor, J. A. W. Ochieng, and R. E. Kamidi. 1994. Maize ear rot incidence in western Kenya. *Int. J. Pest Manag.* **40**:117–120.
7. Kedera, C. J. 1994. Tracking and identification of genetic diversity within populations of *Fusarium* section *Liseola* from maize. Ph.D. thesis. Kansas State University, Manhattan.
8. Kedera, C. J., and R. D. Plattner. Unpublished data.
9. Klittich, C. J. R., and J. F. Leslie. 1988. Nitrate reduction mutants of *Fusarium moniliforme* (*Gibberella fujikuroi*). *Genetics* **118**:417–423.
10. Leslie, J. F. 1995. *Gibberella fujikuroi*: available populations and variable traits. *Can. J. Bot.* **73**:S282–S291.
11. Leslie, J. F., R. D. Plattner, A. E. Desjardins, and C. J. R. Klittich. 1992. Fumonisin B<sub>1</sub> production by strains from different mating populations of *Gibberella fujikuroi* (*Fusarium* section *Liseola*). *Phytopathology* **82**:341–345.
12. Macdonald, M. V., and R. Chapman. 1997. The incidence of *Fusarium moniliforme* on maize from Central America, Africa and Asia during 1992–1995. *Plant Pathol.* **46**:112–125.
13. Marasas, W. F. O. 1995. Fumonisins: their implications for human and animal health. *Nat. Toxins* **3**:193–198.
14. Marasas, W. F. O., N. P. J. Kriek, S. J. van Rensburg, M. Steyn, and G. C. van Schalkwyk. 1977. Occurrence of zearalenone and deoxynivalenol, mycotoxins produced by *Fusarium graminearum* Schwabe, in maize in southern Africa. *South Afr. J. Sci.* **73**:346–349.
15. Miracle, M. P. 1966. Maize in tropical Africa. The University of Wisconsin Press, Madison.
16. Munkvold, G. P., and A. E. Desjardins. 1997. Fumonisins in maize: can we reduce their occurrence? *Plant Dis.* **81**:556–565.
17. Nash, S. M., and W. C. Snyder. 1962. Quantitative estimations by plate counts of propagules of the bean root rot *Fusarium* in field soils. *Phytopathology* **52**:567–572.
18. Nelson, P. E., T. A. Toussoun, and W. F. O. Marasas. 1983. *Fusarium* species: an illustrated manual for identification. Pennsylvania State University Press, University Park.
19. Nelson, P. E., R. D. Plattner, D. D. Shackelford, and A. E. Desjardins. 1992. Fumonisin B<sub>1</sub> production by *Fusarium* species other than *F. moniliforme* in section *Liseola* and by some related species. *Appl. Environ. Microbiol.* **58**:984–989.
20. Njuguna, J. G. M., C. J. Kedera, L. M. Muriithi, W. Songa, and B. O. Odhiambo. 1990. Overview of maize diseases in Kenya, p. 52–61. *In* Proceedings of a Workshop on Review of the National Maize Program. Kenya Agricultural Research Institute, Nairobi.
21. Pascale, M., A. Visconti, M. Pronczuk, H. Wisniewska, and J. Chelkowski. 1997. Accumulation of fumonisins in maize hybrids inoculated under field conditions with *Fusarium moniliforme* Sheldon. *J. Sci. Food Agric.* **74**:1–6.
22. Plattner, R. D. 1995. Detection of fumonisins produced in *Fusarium moniliforme* cultures by HPLC with electrospray MS and evaporate light scattering detectors. *Nat. Toxins* **3**:294–298.
23. Rheeder, J. P., W. F. O. Marasas, P. G. Thiel, E. W. Sydenham, G. S. Shephard, and D. J. van Schalkwyk. 1992. *Fusarium moniliforme* and fumonisins in corn in relation to human esophageal cancer in Transkei. *Phytopathology* **82**:353–357.
24. Rheeder, J. P., E. W. Sydenham, W. F. O. Marasas, P. G. Thiel, G. S. Shephard, M. Schlecter, S. Stockenstrom, D. W. Cronje, and J. H. Viljoen. 1995. Fungal infestation and mycotoxin contamination of South African commercial maize harvested in 1989 and 1990. *South Afr. J. Sci.* **91**:127–131.
25. Ritieni, A., A. Moretti, A. Logrieco, A. Bottalico, G. Randazzo, S. M. Monti, R. Ferracane, and V. Fogliano. 1997. Occurrence of fusaproliferin, fumonisin B<sub>1</sub>, and beavericin in maize from Italy. *J. Food Agric. Chem.* **45**:4011–4016.
26. Shelby, R. A. 1994. Differential fumonisin production in maize hybrids. *Plant Dis.* **78**:582–584.
27. Shephard, G. S., P. G. Thiel, S. Stockenstrom, and E. Sydenham. 1996. Worldwide survey of fumonisin contamination of corn and corn based products. *J. Assoc. Off. Anal. Chem. Int.* **79**:671–686.
28. Sniijders, C. H. A. 1994. Breeding for resistance to *Fusarium* in wheat and maize, p. 37–52. *In* J. D. Miller and H. L. Trenholm (ed.), *Mycotoxins in grain. Compounds other than aflatoxin*. Eagan Press, St. Paul, Minn.
29. Sydenham, E. W., G. S. Shephard, and P. G. Thiel. 1992. Liquid chromatographic determination of fumonisins B<sub>1</sub>, B<sub>2</sub>, and B<sub>3</sub> in foods and feeds. *J. Assoc. Off. Anal. Chem. Int.* **75**:313–318.
30. Thiel, P. G., W. F. O. Marasas, E. W. Sydenham, G. S. Shephard, W. C. A. Gelderbloem, and J. J. Nieuwenhuis. 1991. Survey of fumonisin production in *Fusarium* species. *Appl. Environ. Microbiol.* **57**:1089–1093.