In: Advances in Environmental Research. Volume 39
Editor: Justin A. Daniels
ISBN: 978-1-63482-366-1

Chapter 4

FUMONISIN IN ZAMBIA AND NEIGHBORING COUNTRIES IN A CHANGING CLIMATE

Leif Sundheim*[*,1,2] and Hadush Tsehaye[2,3]

[1]Norwegian Institute for Agricultural and Environmental Research, Plant Health and Plant Protection, Norway
[2]Norwegian University of Life Sciences, Department of Plant Sciences, Norway
[3]Mekelle University, Department of Dryland Crop and Horticultural Sciences, Mekelle, Tigray, Ethiopia

ABSTRACT

Zambia is one of the major maize producing countries in Africa, and maize production in the country has doubled in the last decade. About 10% of the production was exported in recent years. Zambia has suitable climate for increased maize cultivation. Fumonisin is a mycotoxin produced by *Fusarium* spp., and maize is the only crop contaminated with high amounts of fumonisin. Health of humans and domestic animals may be adversely affected by intake of fumonisin contaminated products. There are limited data on the fumonisin situation in Zambia, but available results indicate that Zambian maize is moderately contaminated with fumonisin. There are uncertainties involved in predicting the future climate for Zambia and other South and East African countries. It is not possible to predict how climate change during this century will affect the risk for fumonisin contamination of maize in Zambia and neighboring countries.

1. INTRODUCTION

Fumonisin is a group of mycotoxins, which are secondary metabolites produced by fungi. Maize is frequently contaminated and the only crop that contains high amounts of fumonisin. Species in the anamorphic fungal genus *Fusarium* infecting maize kernels in the field are the main sources of fumonisin contamination of food and animal feed (Marasas, 1995).

[*] Correspondence to: Leif Sundheim. E-mail: leif.sundheim@bioforsk.no.

Fumonisin may be reduced during food processing, but resistance to thermal degradation is a characteristic of fumonisin. Porridge cooking of maize meal reduced fumonisin content by only 11.3% (Shepard et al., 2012). More than a century ago mouldy maize was associated with animal diseases in the USA, and Sheldon described the fungus *Fusarium moniliforme* J. Sheld. from infected maize (Sheldon, 1904). The name has been changed to *Fusarium verticillioides* (Sacc.) Nirenberg, and *F. moniliforme* is a synonym that should no longer be used (Seifert et al., 2003). In a region of South Africa high incidence of human esophageal cancer was related to consumption of maize infected with *F. verticillioides* (Marasas et al. 1981). South African scientists isolated a toxin from *F. verticillioides* cultures and named the toxin fumonisin (Gelderblom et al., 1988), and the molecular structure of the toxin was published (Bezuidenhout et al., 1988) (Figure 1). Purified fumonisin administered to a horse induced equine leukoencephalomalacia (ELEM) (Marasas et al., 1988). Occurrence of fumonisin in *F. verticillioides* infected maize was demonstrated (Sydenham et al., 1990a). Association between consumption of fumonisin-contaminated maize and incidence of human esophageal cancer was found in the Transkei region of South Africa (Sydenham et al., 1990b). In USA swine fed on *F.verticillioides* infected maize died from porcine pulmonary edema and hydrothorax (Harrison et al., 1990). The International Agency for Research on Cancer (IARC, 2002) classified FB_1 as a group 2B carcinogen (probably carcinogenic in humans). Phytotoxic effects of fumonisin have been shown on maize seedling growth (Doehlert et al., 1994) and tomato (Lamprecht et al., 1994). Seed-borne *F. verticillioides* did not reduce emergence, plant growth and yield of maize in field trials in Zambia (Naik et al., 1982). The fungus has been linked with the development of symptoms such as necrotic leaf lesion, seedling blight, and reduced root development in maize seedlings inoculated with fumonisin producing *F. verticillioides* strains (Williams et al., 2007).

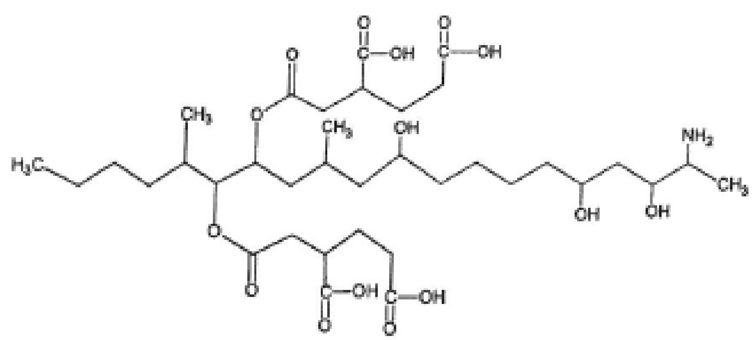

Figure 1. Chemical structure of fumonisin B_1.

1.1. Fumonisin Producing Fungi

A number of different fumonisin analogues are described from nature or synthesized in the laboratory, and they are grouped in the A, B, C and P series. In naturally infected maize only members of the fumonisin B (FB) series occur in biologically important quantities (Desjardins, 2006). The fumonisins of the B series contaminate maize in the field, while fumonisins of the A, C and P series are metabolites produced at low levels on synthetic media in the laboratory (Desjardins, 2006). The fumonisins FB_1, FB_2 and FB_3 are the most abundant of the naturally occurring fumonisins, with FB_1 being the most toxic, and in infected maize FB_1 accounts for 70-80% of the fumonisins (Rheeder et al., 2002). In maize *F. verticillioides* and *F. proliferatum* (Matsush.) Nirenberg are the most important fumonisin producers. Both species are widely distributed, and they yield high levels of the toxin. Thirteen other *Fusarium* species are minor fumonisin producers (Rheeder et al., 2002).

1.2. Fumonisin Contamination of Maize

In most tropical countries maize is grown in short rotations or in the same field as previous year. *Fusarium verticillioides* is soil borne and seed transmitted, and in maize the pathogen causes seedling blight, root and stalk rot, ear rot and fumonisin contamination of the kernels (Kucharek and Kommedahl, 1966) (Fig 2). Senescent maize stalks, leaves and cobs are important for survival of the pathogens in the field from one season to the next (Munkvold, 2003). *Fusarium verticillioides* and *F. proliferatum* produce large amounts of asexual conidia, while the sexual stage is not commonly detected. Field trials in Iowa, USA showed that *F. verticillioides* survived at least 630 days in maize residues in the field, and the pathogen survived equally well when the residue was buried at 30 cm in the soil as on the soil surface. (Cotten and Munkvold, 1998).

Systemic growth of *F. verticillioides* in maize plants was first shown by Foley (1962). The endophytic phase of *F. verticillioides* was studied by Munkvold and colleagues. Growth of the fungus in maize following seed inoculation and silk inoculation was monitored in field experiments. Seed infection resulted in systemic infection of plants and kernels, but silk inoculation of *F. verticillioides* was more important for kernel infection than was endophytic growth (Munkvold et al., 1997a). Silk inoculation with *F. verticillioides* resulted in a mean kernel infection of 83.7%, and in some ears 100% of the kernels were infected (Munkvold et al., 1997b). In controlled environment high temperature resulted in more rapid development of *F. verticillioides*, but temperature did not affect the incidence of kernel infection (Murillo-Williams and Munkvold, 2008). Field trials at 17 locations in USA showed decrease in fumonisin content of maize as the latitude increased, and there is a parallel decrease in temperature during the growing season from South to North in the country (Shelby et al., 1994). When fumonisins were analysed in 26 maize genotypes grown in two African and three European countries, there was a positive correlation between high FAO maturity class of the genotype and fumonisin contamination (Doko et al. 1995). In field trials at two locations in North Carolina, USA accumulation of FB_1 was monitored in three maize hybrids (Bush et al., 2004). Four weeks after pollination, as kernels neared physiological maturity, the FB_1 contamination first appeared, and it increased up to the date of harvest (Bush et al., 2004). Inoculation experiments with *F. verticillioides* in France revealed that the most conducive period for fumonisin biosynthesis in maize kernels is the dent stage (Picot et al., 2011).

Several *FUM* genes for fumonisin biosynthesis in *F. verticillioides* are known. The *FUM1* gene catalyzes an early step in fumonisin biosynthesis, and when the *FUM1* gene was mutated to obtain strains that did not produce fumonisin, the mutants were capable of infecting maize ears and cause ear rot like the wild type strains (Desjardins and Plattner, 2000). Maize ears are commonly attacked by numerous insect species, but the importance of various insects varies from country to country. Insects may be stimulated by *F. verticillioides* infection. At the International Institute of Tropical Agriculture (IITA) in Benin there were higher levels of coleopteran beetles and lepidopteran borers in maize inoculated with *F. verticillioides* than in non-inoculated maize (Cardwell et al., 2000). The European corn borer (ECB) (*Ostrinia nubilalis*) larvae develop in the stalks and ears of maize. Genetically modified (GMO) maize hybrids which express *Bacillus thuringiensis* genes coding for the Cry1Ab protein had increased level of resistance to feeding by ECB larvae, and the GMO maize had reduced ear rot and kernel infection caused by *Fusarium* spp. compared to non GMO hybrids (Munkvold et al., 1997c). In France there was a 90% reduction in fumonisin contamination of GMO maize modified to express the Cry1Ab protein compared to non-GMO isogenic lines (Folcher et al., 2010). In Iowa, USA GMO maize hybrids which expressed both the Vip3Aa protein and the Cry1Ab protein to get protection against several lepidopteran pests were planted in field experiments, and the average fumonisin content was 0.56 $\mu g\ g^{-1}$ in GMO maize hybrids and 5.47 $\mu g\ g^{-1}$ in non-GMO hybrids (Bowers et al., 2013).

Figure 2. Maize cobs infected with *Fusarium verticillioides*. Photo: Hadush Tsehaye.

1.3. Fumonisin in Cereals Other Than Maize

The African food crops sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) may suffer from *Fusarium* ear rot and stalk rot. *Fusarium nygamai* L.W. Burgess & Trimboli and *F. verticillioides* isolated from these crops produced FB_1 and FB_2 on culture media (Leslie et al.,2005). *Fusarium* spp. isolated from sorghum grains collected at 21 localities in South Africa during three years were analysed for fumonisin production. Fumonisin producing *Fusarium* spp. were absent in 2007, and the next two years there were only small amounts of fungal infection with no fumonisin detected. The authors concluded that fumonisin is not a threat to sorghum production in South Africa (Van Janse Rensburg et al., 2011). Of 33 *Fusarium* isolates obtained from finger millet (*Eleusine coracana*) in Uganda 13% were *F. verticillioides*, and isolates of the fungus produced fumonisins under laboratory conditions (Saleh et al., 2012). In Italy *F. proliferatum* was the most common *Fusarium* species in durum wheat, and in 2007 the levels of fumonisin varied from 0.01 to 1.25 $\mu g\ g^{-1}$, while only very low levels were detected in 2008 (Palacios et al., 2011). Only very low levels of fumonisin were detected in rice from retail markets in Thailand (Tansakul et al., 2012). When imported rice samples were analysed for fumonisins in Canada only trace levels, average 4.5 ng g^{-1}, were detected (Bansal et al., 2011).

1.4. Human Exposure to Fumonisins

A survey of human exposure to FB_1 in households of rural and urban areas of KwaZulu Natal, South Africa showed that rural communities are at a much higher risk of consuming FB_1 contaminated maize than urban communities (Chelule et al., 2001). Among 50 maize samples from rural areas 32% had FB_1 levels from 0.1 to 22.2 μg g^{-1}, while 6.1% of 49 urban maize samples contained FB_1 in the range 0.1 to 0.4 μg g^{-1}. The exposure of people living in KwaZulu Natal was lower than what has been reported from other regions of South Africa, and especially in dry areas people eating sorghum-based food have lower risk of FB_1 contamination than people consuming maize (Chelule et al., 2001). In an area of high risk for esophageal cancer incidence in the Transkei province, South Africa the daily exposure to fumonisins (FB_1+ FB_2) was 8.67 ± 0.18 μg kg^{-1} body weight, while in an area with low risk for oesophageal cancer the daily exposure of fumonisins (FB_1+ FB_2) was 3.43 ± 0.15 μg kg^{-1} body weight (Shephard et al., 2007). In both the high risk and the low risk areas the mean fumonisin exposure was above the provisional maximum tolerable intake of 2.0 μg kg^{-1} body weight per day set by the Joint FAO/WHO Expert group (Shephard et al., 2007). When monitoring *Fusarium* spp. and FB_1 in maize and porridge prepared from maize by a rural population in Limpopo province, South Africa, *F. verticillioides* was the most prevalent of the four *Fusarium* spp. identified (Phoku et al., 2012). The traditional process of soaking maize-meal overnight in water and discarding the water prior to cooking porridge reduced the level of FB_1 by approximately 90 %, because fumonisin is water soluble (Phoku et al., 2012).

Urinary FB_1 was detected in 96% of 148 children, aged 12-22 months, from three geographically distant villages of Tanzania, and the mean levels of urinary FB_1 ranged from 82.8 ppb to 327.2 ppb (Shirima et al., 2013). In Northern Tanzania the carry-over of FB_1 from contaminated feed into dairy milk and from contaminated food into human breast milk were studied. Of 131 breast milk samples 44.3% contained FB_1 and of the contaminated samples 10.3% had FB_1 levels above the EU maximum tolerable intake of 200 ppb fumonisins in infant food (Magoha et al., 2014). In Uganda finger millet contaminated with fumonisin represents a potential health risk when used as weaning food for infants (Saleh et al., 2012). Studies of exposure to fumonisins in 215 infants consuming maize-based food in Tanzania revealed that exposure to fumonisin in ready-to-cook maize flour was associated with growth retardation (Kimanya et al., 2010). Maize consumed by 131 of the infants contained 0.02-3.20 μg g^{-1} of FB_1 and exceeded the provisional maximum tolerable FB_1 daily intake of 2.00 μg kg^{-1} body weight in 26 of the infants. At one year of age infants exposed to fumonisin contaminated maize above 2.00 μg kg^{-1} FB_1 were 1.3 cm shorter and 328 g lighter than the control group (Kimanya et al., 2010). Co-exposure of fumonisin with aflatoxin was detected in 29%, and co-exposure of fumonisin and deoxynivalenol was found in 41% of a group of 57 children at weaning age in a Tanzania village (Kimanya et al., 2014).

2. Fumonisins in Africa

Cultivation of maize is expanding in the tropical and subtropical climates of Africa, and the crop is commonly contaminated with fumonisin (Bankole et al., 2006). A fumonisin incidence of 92.5% was detected in 40 randomly selected samples from cereals and cereal based products from nine countries in East and South Africa (Doko et al., 1996). The levels of FB_1 + FB_2 + FB_3 ranged from 0.02 μg g^{-1} to 2.74 μg g^{-1}, and linear regression analysis showed no correlation between the contents of fumonisins and zearalenone in cereals from the nine countries (Doko et al., 1996). Wagacha and Muthomi discussed intervention strategies in management of mycotoxins in Africa, and they considered prevention of exposure, decontamination and surveillance of moulds in stored commodities as important control strategies (Wagacha and Muthomi, 2008). The authors emphasized that there is need for efficient cost effective sampling and analytical methods that can be used for detection of mycotoxins in developing countries. Early harvesting, proper drying, sanitation, proper storage, and insect management were listed as good agricultural practices to reduce the risk for fumonisin contamination (Wagacha and Muthomi, 2008). In African countries the occurrence of aflatoxin is highest (43.8%) followed by fumonisins (21.9%), ochratoxin (12.5%), nivalenol (6.3%) and beauvericin (6.3%) (Darwish et al., 2014). Based on the limited data available for mycotoxin contamination of food in Sub-saharan Africa, fumonisin levels appear to be higher in maize from West Africa, compared to fumonisin in maize from East and South Africa (Bankole et al., 2006).

2.1. Fumonisins in Zambia

Maize is the most important food crop in Zambia, and maize is grown throughout the country. Production has increased over the past years, and in the 2012 crop season the total maize harvest was 2.85 million tons (FAOSTAT, 2012). Ear rot is one of the most important maize diseases in Zambia, and when four 20 kg samples of white, dent maize grown in Zambia during 1974-75 were sampled, *F. verticillioides* and *Diploida macrospora* were the dominant fungi isolated from maize kernels (Marasas et al., 1978). In maize meal *F. verticillioides* was the most prevalent fungus, and isolates of the fungus were acutely toxic in feeding trials with ducklings and rats (Marasas et al., 1978). In locally produced maize hybrids in Zambia *F. verticillioides* was present in 38.5 % of seed samples, and the fungus was the most important ear rot pathogen (Naik et al., 1982). Samples of 20 maize genotypes supplied by the Golden Valley Regional Research Station, Lusaka, Zambia were analysed for FB_1 and FB_2. The incidence of fumonisin contamination was 100%, and the FB_1 + FB_2 content of the samples ranged from 0.02 μg g^{-1} to 1.71 μg g^{-1}, with median FB_1 + FB_2 content of 0.10 μg g^{-1} (Doko et al., 1995). In a survey of mycotoxins from East Africa a Zambian sample of maize contained 1.21 μg g^{-1} of FB_1 + FB_2 + FB_3, and a pellets sample from Zambia contained 0.07 μg g^{-1} FB_1 (Doko et al., 1996).

During the 2006 harvest maize was sampled from 114 farms, randomly selected in 11 districts in the Lusaka and the Southern provinces of Zambia. At each farm both symptomatic and asymptomatic maize cobs were collected, and fungal infection and fumonisin content were determined. *Fusarium verticillioides* and *Stenocarpella maydis* (Berk.) B. Sutton were the dominant causes of ear rot, and the incidence of *F. verticillioides* ranged from 2% to 21% in diseased maize kernels (Mukanga et al., 2010). Most symptomless infections in healthy kernels were caused by *F. verticillioides* and *F. subglutinans*. Analysis revealed large variation in fumonisin content among districts, and in six of the eleven districts the fumonisin contamination was above the 2.0 μg g^{-1} level recommended by FAO/WHO (Mukanga et al., 2010). Farmers in four districts of Central Zambia were interviewed on their perception and management of maize ear rot (Mukanga et al., 2011). Most farmers cultivate maize hybrids, and they regarded high precipitation, planting of susceptible hybrids and lack of crop rotations as the most important factors responsible for ear rot in maize (Mukanga et al., 2011). Maize samples from household storage facilities and growers cooperatives in all three agroecological zones of Zambia were analysed for fungi and fumonisin (Muimba-Kankolongo et al., 2009). Zone I is semi-arid with annual precipitation of less than 800 mm, zone II is the central plateau with precipitation of 800 to 1200 mm and zone III in the north has annual precipitation over 1200 mm. In each zone samples were grouped according to three ecosystems: closed forest, valley and savannah grassland, and while there was no difference in fumonisin content of maize from the three agroecological zones, fumonisin contamination was highest in samples from the forest ecosystems (Muimba-Kankolongo et al., 2009). In 96.4% of the samples the fumonisin levels were between 0.02 μg g^{-1} and 21.44 μg g^{-1}, and some samples contained fumonisin above the level acceptable for human consumption (Muimba-Kankolongo et al., 2009). Maize hybrids were artificially inoculated with Zambian strains of *F. verticillioides* in field experiments at Misamfu Regional Research Station, Kasama, Northern Province and at Golden Valley Regional Research Station, Chisamba, Central Province (Schjøth et al., 2009). Kasama is located in the high rainfall zone III, and Chisamba is in the medium rainfall zone II. Maize from the high rainfall zone had low incidence (mean 41%) of FB_1 + FB_2 positive samples, while maize from the medium rainfall zone had 67% incidence and higher concentration as 40 % of the samples contained >1.0 μg g^{-1} FB_1 + FB_2 in two years of comparison (Schjøth et al., 2009). At both experimental sites there were large variation in fumonisin content between years, and maize from the medium rainfall zone had mean FB_1 + FB_2 content of 1.02 μg g^{-1}, while maize from the high rainfall zone had mean FB_1 + FB_2 content of 0.13 μg g^{-1} for two years of field experiments (Schjøth et al., 2009). When the kernel infection was determined in field experiments at the Misamfu and Golden Valley research stations, the *Fusarium* spp. kernel infections were 37% and 14%, respectively, and *F. verticillioides* was the dominant species at both sites (Schjøth and Sundheim, 2013).

2.2. Fumonisins in Some Other East and South African Countries

In Botswana maize and sorghum are the most important food crops. Analysis of six samples of maize meal and maize kernels showed that they contained from 0.04 to 0.53 μg g^{-1} fumonisin, while two samples of sorghum meal both contained 0.02 μg g^{-1} fumonisin. The fumonisin contamination in the eight maize and sorghum samples was from 0.02 to 0.53 μg g^{-1} (Doko et al., 1996). Analysis of samples from the maize crops in Botswana showed that 85 % of the samples were contaminated with FB_1 with concentrations from 0.02 to 1.27 μg g^{-1} (Siame et al., 1998). Sorghum is commonly used for beer production in Botswana, and when

142 sorghum malt samples were analysed for FB_1 only three samples were contaminated and contained from 0.05 to 1.32 μg g^{-1} FB_1 (Nkwe et al., 2005).

When Ethiopian cereals, including barley, wheat, sorghum and teff (*Eragrostis tef*) were analysed for mycotoxins, only sorghum samples contained fumonisins with a maximum concentration of 2.12 μg g^{-1} (Ayalew et al., 2006). The Ethiopian practice of storing sorghum in underground pits increases moisture content in the grain, which supports growth of fungi producing fumonisin in the grain (Ayalew et al., 2006). Microbiological investigation identified *F. verticillioides* as the most common *Fusarium* spp. on maize in Ethiopia, and of 17 maize samples 4 contained fumonisin at 0.3, 0.3, 0.7 and 2.4 μg g^{-1}, respectively (Ayalew, 2010). In Southern Ethiopia one-hundred maize samples had a mean fumonisin contamination of 1.68 μg g^{-1} (Alemu et al., 2009).

The highland of Western Kenya is a maize growing region, and maize is the most important cereal crop of the country. *Fusarium* incidence and FB_1 contamination were determined in 197 maize samples from smallholder farm storage facilities (Kedera et al., 1999). Almost half of the samples (47%) contained FB_1 levels above the detection limit of 0.1 μg g^{-1}, and the range of FB_1 was from 0.11 μg g^{-1} to 11.60 μg g^{-1} in the positive samples, with a mean FB_1 content of 0.67 μg g^{-1} for the samples. Only 5% of the maize samples had > 1.0 μg g^{-1} FB_1 (Kedera et al., 1999). *Fusarium verticillioides* is the dominant cause of maize ear rot in Kenya, and 74 % of *F. verticillioides* isolates produced FB_1 in the range of 0.07 to >5.0 μg g^{-1} with a mean of 1.51 μg g^{-1} (Alakonya et al., 2008). The FB_1 contamination in maize increases after physiological maturity, and mean FB_1 levels in one district of Kenya 4, 8, and 12 weeks after physiological maturity were 0.04 μg g^{-1}, 0.18 μg g^{-1} and 0.59 μg g^{-1}, respectively (Alakonya et al., 2009). In symptomless maize at one site the FB_1 levels varied from 0.04 to 1.38 μg g^{-1}, while in rotten maize the FB_1 content was from 0.04 to above 5.00 μg g^{-1}(Alakonya et al., 2009). In the Eastern province of Kenya *F. verticillioides* was isolated from 39.9 % and *F. proliferatum* from 15.1 % of maize samples obtained in two districts (Bii et al., 2012). Most samples contained >1.0 μg g^{-1} of FB_1, and there was significant correlation between *Fusarium* spp. count and fumonisin levels. In the Makueni district of Kenya the mean fumonisin content of the maize samples was 1.2 μg g^{-1}, and in maize from the Kitui district the mean fumonisin content was 0.9 μg g^{-1} (Bii et al., 2012).

When eight samples of maize kernels from Malawi were analysed, seven samples contained from 0.03 to 0.14 μg g^{-1} fumonisin, the mean fumonisin content was 0.07 μg g^{-1} (Doko et al., 1996). Higher incidence of *Stenocarpella maydis* (Berk.) B. Sutton than of *F. verticillioides* was detected, when evaluating causes of maize cob rot on smallholder farms in Malawi (Kapindu et al., 1999).

Research groups in South Africa have been very active in elucidating the occurrence of fumonisins and exposure of people and domestic animals to the toxins. In an extensive sampling of maize highest levels of FB_1 and FB_2 were found in areas with high rates of esophageal cancer (Rheeder et al., 1992). In low esophageal cancer rate areas the mean FB_1 contents were 0.67 μg g^{-1} and 4.05 μg g^{-1} in healthy looking and mouldy maize, respectively, while in the high esophageal cancer rate areas the mean FB_1 contents were 1.84 μg g^{-1} and 53.74 μg g^{-1} in healthy looking and mouldy maize, respectively. The highest levels they recorded were 117.52 μg g^{-1} of FB_1 and 22.96 μg g^{-1} of FB_2 in areas with high rates of esophageal cancer (Rheeder et al., 1992). In 142 maize samples obtained from a village in Limpopo province, South Africa *F. verticillioides* was the most prevalent fungus in maize grains, porridge made from maize and in fecal samples from individuals in households consuming maize products (Phoku et al., 2012). A quantitative method for detection of *F. verticillioides* DNA was developed and proved useful in determination of daily fumonisin intake by subsistence farmers (Waalwijk et al., 2008). In maize samples collected from subsistence farming in South Africa fumonisin contamination levels ranged from undetectable to 21.8 μg g^{-1} (Ncube et al., 2011). Highest fumonisin levels were found in samples obtained from the KwaZulu-Natal province, where 52% of the samples exceeded 2 μg g^{-1} in 2006, and 17% of the samples in 2007 exceeded 2 μg g^{-1}. In commercial animal feeds contamination of fumonisins ranged from 0.104 to 3 μg g^{-1} (Njobeh et al., 2012).

Maize is the staple food for most of the people in Tanzania, but there are limited data on fumonisin contamination in the country. When nine samples of maize kernels from Tanzania were analysed, eight samples contained from 0.03 to 0.23 μg g^{-1} fumonisin, and the mean fumonisin content of the samples was 0.09 μg g^{-1} (Doko et al., 1996). A survey in Tanzania revealed that 52% of 120 samples were contaminated with FB_1 at levels up to 4.92 μg g^{-1}, median 0.49 μg g^{-1}. Total FB_1 + FB_2 ranged from 0.06 to 11.05 μg g^{-1} (median =0.36 μg g^{-1}), and in 15% of the samples the fumonisin content exceeded 1.0 μg g^{-1} (Kimanya et al., 2008). The highest fumonisin content was in the Kilimanjaro region of Tanzania with a median fumonisin content of 0.52 μg g^{-1} (Kimanya et al., 2008). In a study of mycotoxin contamination of maize and cassava collected at markets in Tanzania the level of fumonisin in maize ranged from 0.02 μg g^{-1} to 9.4 μg g^{-1}, while cassava samples contained up to 0.07 μg g^{-1} fumonisin (Manjula et al., 2009).

In Uganda maize is the dominant crop and provides about 40% of the calories consumed per capita, and maize is an important export commodity (Atukwase et al., 2009). Maize grain stored in traditional structures were analysed for *Fusarium* spp and fumonisins, and the results showed that all maize samples analysed contained fumonisins in the range of 0.27 μg g^{-1} to 10.0 μg g^{-1} (Atukwase et al., 2009). Studies of fumonisin contamination and occurrence of *Fusarium* spp. in maize from three agro-ecological zones of Uganda revealed that maize from the high altitude zone had higher *Fusarium* spp. incidence than maize from the mid altitude zone (Atukwase, 2009). All samples from farmers contained fumonisin and the fumonisin content varied from 0.27 to 10.0 μg g-^{1}. Maize from the high altitude zone had higher fumonisin content, mean total fumonisin 4.93 μg g-^{1}, than maize from dry mid altitude zone, mean 4.50 μg g-^{1} and the moist mid altitude zone, mean 4.53 μg g-^{1} (Atukwase, 2009). Further studies in Uganda revealed that after harvest the *Fusarium* incidence level increased from 61.9% to 77.5% during the first two months of storage and then decreased to 31.9% by the sixth month (Atukwase et al., 2012a). Investigation on the fumonisin producing potential of the *Gibberella fujikuroi* species complex indicated that most isolates, twenty three out of twenty five, able to produce the toxin ranging from 19.4 to 99.8 μg g^{-1} (Atukwase et al., 2012b).

3. CLIMATE EFFECTS ON FUMONISIN PRODUCING FUNGI

Humidity and temperature are the important climatic factors for infection and growth of *Fusarium* spp. and accumulation of fumonisin in maize. Field experiments in the eleven major maize producing states of USA showed that June precipitation was the most important climatic factor for the fumonisin contamination of maize, and fumonisin content was inversely correlated with June rainfall (Shelby et al., 1994). Field data from Argentina and the Philippines showed that the most important factors for fumonisin contamination of maize were weather (47%), insect damage to the ear (17%) and hybrid (11%), and weather around silking were identified as critical for fumonisin contamination at harvest (de la Campa et al., 2005). In the state of São Paulo, Brazil thirty maize cultivars were planted at three locations during two years, and the fumonisin contamination of the maize was negatively correlated with precipitation in the period from silking to kernel milky stage, while precipitation in the month before harvest increased the fumonisin content of maize (Camaragos et al., 2001). In Spain wet and cool conditions around silking limited *F. verticillioides* infection and fumonisin contamination, while high temperatures during silking increased fumonisin content (Cao et al., 2014). Parsons and Munkvold studied climatic conditions and insect infestation in six field trials in four states of the USA, and they concluded that dry weather after pollination and thrips infestation of the ears increased the risk for fumonisin contamination (Parsons and Munkvold, 2012).

3.1. Predicted Climate Changes

The Intergovernmental PaneI on Climate Change (IPPC) has published the opinion that increased concentrations of greenhouse gases and aerosols in the atmosphere will result in warming of the environment and changes in the precipitation patterns. There is high confidence in temperature increase in the Northern Hemisphere and low confidence in warming in other parts of the world (Stocker et al., 2013). There is medium confidence in changes of precipitation patterns in tropical and subtropical climate. Precipitation will increase at higher latitudes, but in the major maize producing areas of the world increased precipitation will not compensate for the temperature-driven increase in evaporation, which will result in more droughts for most maize producing countries. The risk for summer drought will be greatest in mid-continental areas (Stocker et al., 2013).

The UNU-WIDER working paper No 2013/040 analysed the likelihood of changes in precipitation and temperature for the greater Zambezi River Basin through the middle of this century based on IPPC Fourth Assessment Report (Schlosser and Strzepek, 2013). The authors concluded that with unconstrained emissions there is a likelihood of reduced spring precipitation by 2050, while for summer precipitation a few models predicts widespread drying and the remaining models show a mixture of drier and wetter weather conditions as climate warms (Schlosser and Strzepek, 2013). The models employed predicted warming over the entire Zambezi River Basin region, and most of the models predicted a stronger regional warming during spring than in summer. The authors of the UNU-WIDER working paper emphasized that there are uncertainties involved in predicting future climate in the region (Schlosser and Strzepek, 2013). The complex interactions between the maize plant and its endophytic, fumonisin producing pathogens in the genus *Fusarium* are not well understood. Strains of *F. verticillioides* that lack the ability to produce fumonisin are pathogenic and cause ear rot on maize (Desjardins and Plattner, 2000). The relationship between fungal growth in the host plant and fumonisin production is not elucidated, and a better insight into the relationship between *F. verticillioides* and the maize plant is required to understand the epidemiology of the disease (Munkvold, 2003).

Based on the current state of knowledge it is not possible to conclude how climate change during this century will affect the risk for fumonisin contamination of maize in Zambia and other countries of East and South Africa.

REFERENCES

Alakonya AE, Monda EO, Ajanga S. 2008. Variation in *in vitro* fumonisin B_1 production by different *Fusarium verticillioides* isolates in Kenya. *American-Eurasian J Agric Environ Sci.* 4,368-71.

Alakonya AE, Monda EO, Ajanga S. 2009. Fumonisin B_1 and aflatoxins B_1 levels in Kenyan maize. *J Plant Pathol.* 91,459-64.

Alemu T, Brhanu G, Azerefegn F, Skinnes H. 2009. *Occurrence of selected mycotoxin in Southern Ethiopia: Implication for food safety and food security*. Plant Protection Society of Ethiopia, 16^{th} Annual Conference, Book of Abstracts, 39.

Atukwase A, Kaaya AN, Muyanja C. 2009. Factors associated with fumonisin contamination of maize in Uganda. *J Sci Food Agric.* 89,2393-8.

Atukwase A, Kaaya AN, Muyanja C. 2012a. Dynamics of *Fusarium* and fumonisins in maize during storage – A case of the traditional storage structures commonly used in Uganda. *Food Control* 26,200-5.

Atukwase A, Muyanja C, Kaaya AN. 2012b. Potential for fumonisin production by the strains of *Gibberella fujikuroi* species complex isolated from maize produced in Uganda. *J Biol Sci.* 12,225-31.

Ayalew A, Fehrmann H, Lepschy J, Beck R, Abate D. 2006. Natural occurrence of mycotoxins in staple cereals from Ethiopia. *Mycopathologia* 162,57-63.

Ayalew A. 2010. Mycotoxins and surface and internal fungi of maize from Ethiopia. *African J Food Agr Nutr Developm.* 10, 4110-22.

Bankole S, Schollenberger M, Drochner W. 2006. Mycotoxins in food systems in Sub-Saharan Africa: A review. *Mycotox Res.* 22,163-9.

Bansal J, Pantazopoulus P, Tam J, Cavlovic P, Kwong K, Turcotte A-M, Lau BP-Y, Scott PM. 2011. Surveys of rice sold in Canada for aflatoxins, ochratoxin A and fumonisins. *Food Addit Contam.* 28,767-74.

Bezuidenhout SG, Gelderblom WCA, Gorst-Allman CP, Horak RM, Marasas WFO, Spiteller G, Vleggaar R. 1988. Structure elucidation of the fumonisins, mycotoxins from *Fusarium moniliforme*. *J Chem Soc Chem Commun.* 11,743-5.

Bii F, Wanyoike W, Nyende AB, Gituru RW, Bii C. 2012. Fumonisin contamination of maize (*Zea mays*) in aflatoxin 'hot' zones in Eastern province of Africa. *Afr J Health Sci.* 20,28-36.

Bowers E, Hellmich R, Munkvold G. 2013. Vip3Aa and Cry1Ab proteins in maize reduce *Fusarium* ear rot and fumonisins by deterring kernel injury from multiple Lepidopteran pests. *World Mycotox J.* 6,127-35.

Bush BJ, Carson ML, Cubeta MA, Hagler WM, Payne GA. 2004. Infection and fumonisin production by *Fusarium verticillioides* in developing maize kernels. *Phytopathology* 94,88-93.

Camargos SM, Valente Soares LM, Sawazaki E, Bolonhezi D, Castro JL, Bortolleto N. 2001. Accumulation of fumonisin B_1 and B_2 in freshly harvested Brazilian commercial maize at three locations during two nonconsecutive seasons. *Mycopathologia* 155,219-28.

Cao A, Santiago R, Ramos AJ, Souto XC, Aguin O, Malver RA, A Butrón 2014. Critical environmental and genotypic factors for *Fusarium verticillioides* infection, fungal growth and fumonisin contamination in maize grown in northwestern Spain. *Int J Food Microbiol.* 177,63-71.

Cardwell KF, Kling JG, Maziya-Dixon B, Bosque-Pérez NA. 2000. Interactions between *Fusarium verticillioides* , *Aspergillus flavus*, and insect infestation in four maize genotypes in lowland Africa. *Phytopathology* 90,276-84.

Chelule PK, Gqaleni N, Dutton MF, Chuturgoon AA. 2001. Exposure of rural and urban populations in KwaZulu Natal, South Africa to fumonisin B_1 in maize. *Eviron Health Perspect*. 109,253-6.

Cotten TK, Munkvold GP. 1998. Survival of *Fusarium moniliforme, F. proliferatum,* and *F. subglutinans* in maize stalk residue. *Phytopathology* 88,550-5.

Darwish WS, Ikenaka Y, Nakayama SMN, Ishizuka M. 2014. An overview of mycotoxin contamination of foods in Africa. *J Vet Med Sci* 76,789-97.

de la Campa R, Hooker DC, Miller JD, Schaafsma AW, Hammond BG. 2005. Modelling effects of environment, insect damage, and *Bt* genotypes on fumonisin accumulation in maize in Argentina and the Philippines. *Mycopathologia* 159,539-52.

Desjardins A. 2006. *Fusarium* mycotoxins. *Chemistry, genetics, and biology*. American Phytopathological Society, St. Paul, Minnesota, USA,1-260.

Desjardins AE, Plattner RD. 2000. Fumonisin B_1 –Nonproducing strains of *Fusarium verticillioides* cause maize (*Zea mays*) ear infection and ear rot. *J Agric Food Chem.* 48,5773-80.

Doehlert DC, Knutson CA, Vesonder RF 1994. Phytotoxic effects of fumonisin B_1 on maize seedling growth. *Mycopathologia.* 127,117-21.

Doko MB, Canet JC, Brown N, Sydenham EW, Mpuchane S, Siama BA. 1996. Natural co-occurrence of fumonisins and zearalenone in cereals and cereal based foods from Eastern and Southern Africa. *J Agric Food Chem.* 44,3240-3.

Doko MB, Rapior S, Visconti A, Schjøth JE. 1995. Incidence and levels of fumonisin contamination in maize genotypes grown in Europe and Africa. *J Agric Food Chem.* 43,429-34.

EC (European Commission) 2007. Commission Regulation (EC) No 1126/2007 of 28.9.2007 amending Regulation (EC) No 1181/2006 setting maximum levels for certain contaminants in foodstuffs as regards *Fusarium* toxins in maize and maize products (2007). Vol 1126/2007 *Official Journal of the European Union* L 254,14-17.

FAOSTAT 2012 http://faostat.fao.org/site/567/DesktopDefault.aspx? PageID=567#ancor

Folcher L, Delos M, Marengue E. Jarry M, Weissenberger A, Eychenne N, Regnault-Roger C. 2010. Lower mycotoxin levels in Bt maize grain. *Agron Sustain Dev.* 30,711-9.

Foley DC. 1962. Systemic infection of corn by *Fusarium moniliforme*. *Phytopathology* 52,870-2.

Gelderblom WCA, Jaskiewicz J, Marasas WFO, Thiel PG, Horak RM, Vleggaar R, Kriek NPJ. 1988. Fumonisins - novel mycotoxins with cancer-promoting activity produced by *Fusarium moniliforme. Appl Environ Microbiol.* 54,1806-11.

Harrison LR, Colvin BM, Greene JT, Newman LE, Cole JR. 1990. Pulmonary edema and hydrothorax in swine produced by fumonisin B_1, a toxic metabolite of *Fusarium moniliforme. J Vet Diagn Investig.* 2,217-21.

International Agency for Research on Cancer 2002. Some traditional herbal medicines, some mycotoxins, naphthalene and styrene. *Fumonisin B_1. WHO IARC Monographs on the evaluation of carcinogenic risks to humans.* 82,301-66.

Kapindu SJ, Saka VW, Julian AM, Hillocks R, Msuku WAB. 1999. The significance and management of maize cob rots in smallholder farms in Central Malawi. *Afr Crop Sci J.* 7, 531-7.

Kedera CJ, Plattner RD, Desjardins AE. 1999. Incidence of *Fusarium* spp. and levels of fumonisin B_1 in maize in Western Kenya. *Appl Environ Microbiol.* 65,41-4.

Kimanya ME, De Meulenaer B, Roberfroid D, Lachat C, Kolsteren P. 2010. Fumonisin exposure through maize in complementary foods is inversely associated with linear growth of infants in Tanzania. *Mol Nutr Food Res. 54, 1659-67.*

Kimanya ME, De Meulenaer B, Tiisekwa B, Ndomondo-Sigonda M, Devlieghere F, Van Camp J, Kolsteren P. 2008. Co-occurrence of fumonisins with aflatoxins in home-stored maize for human consumption in rural villages of Tanzania. *Food Addit Contam.* 25,1353-64.

Kimanya ME, Shirima CP, Magoha H, Shewiyo DH, De Meulenar B, Kolsteren P, Gong YY. 2014. Co-exposures of aflatoxins with deoxynivalenol and fumonisins from maize based complementary foods in Rombo, Northern Tanzania. *Food Control.* 41,76-81.

Kucharek TA, Kommedahl T. 1966. Kernel infection and corn stalk rot caused by *Fusarium moniliforme. Phytopathology* 56,983-4.

Lamprecht SC, Marasas WFO, Alberts JF, Cawood ME, Gelderblom WCA, Shephard GS, Thiel PG, Calitz FJ. 1994. Phytotoxicity of fumonisins and TA-toxin to corn and tomato. *Phytopathology* 84,383-91.

Leslie JF, Zeller KA, Lamprecht SC, Rheeder JP, Marasas WFO. 2005. Toxicity, pathogenicity and genetic differentiation of five species of *Fusarium* from sorghum and millet. *Phytopathology* 95,275-83.

Magoha H, De Meulenaer B, Kimanya M, Hipolite D, Lachat C, Kolsteren P. 2014. Fumonisin B_1 contamination in breast milk and its exposure in infants under 6 months of age in Rombo, Northern Tanzania. *Food Chem Toxicol.* 74,112-6.

Manjula K, Hell K, Fandohan P, Abass A, Brandyopadhyay R. 2009. Aflatoxin and fumonisin contamination of cassava products and maize grain from markets in Tanzania and republic of the Congo. *Toxin reviews.* 28,63-69.

Marasas WFO, Kellerman TS, Gelderblom WCA, Coetzer JAW, Thiel PG, van der Lugt JJ. 1988. Leukoencephalomalacia in a horse induced by fumonisin B_1 isolated from *Fusarium moniliforme. Onderstepoort J Vet Res.* 55,197-203.

Marasas WFO, Kriek NPJ, Steyn M, van Rensburg SJ, Schalkwyk DJ. 1978. Mycotoxicological investigations on Zambia maize. *Food Cosmet Toxicol.* 16,39-45.

Marasas WFO, Wehner FC, van Rensburg SJ, van Schalkwyk DJ. 1981. Mycoflora of corn produced in human esophageal cancer areas in Transkei, Southern Africa. *Phytopathology* 71,792-6.

Marasas WFO. 1995. Fumonisins: Their implications for human and animal health. *Nat Toxins.* 3,193-8.

Muimba-Kankolongo A, Hell K, Nawa IN. 2009. Assessment for fungal, mycotoxin and insect spoilage in maize stored for human consumption in Zambia. *J Sci Food Agric.* 89,1366-75.

Mukanga M, Derera J, Tongoona P, Laing MD. 2010. A survey of pre-harvest ear rot diseases of maize and associated mycotoxins in south and central Zambia. *Int J Food Microbiol.* 141,213-21.

Mukanga M, Derera J, Tongoona P, Laing MD. 2011. Farmers' perceptions and management of maize ear rots and their implications for breeding for resistance. *African J Agr Res.* 6,4544-54.

Munkvold GP, Carlton WM. 1997a. Influence of inoculation method on systemic *Fusarium moniliforme* infection of maize plants grown from infected seeds. *Plant Dis.* 81,211-6.

Munkvold GP, McGee DC, Carlton WM. 1997b. Importance of different pathways for maize kernel infection by *Fusarium moniliforme. Phytopathology* 87,209-17.

Munkvold GP, Hellmich RL, Showers WB. 1997c. Reduced *Fusarium* ear rot and symptomless infection in kernels of maize genetically engineered for European corn borer resistance. *Phytopathology* 87,1071-7.

Munkvold GP. 2003. Epidemiology of *Fusarium* diseases and their mycotoxins in maize ears. *Eur J Plant Pathol.* 109,705-713.

Murillo-Williams A, Munkvold GP. 2008. Systemic infection by *Fusarium verticillioides* in maize plants grown under three temperature regimes. *Plant Dis.* 92,1695-1700.

Naik DM, Nawa IN, Raemaekers RH. 1982. Absence of an effect from internally seed-borne *Fusarium moniliforme* on emergence, plant growth and yield of maize. *Seed Sci Technol.* 10,347-56.

Ncube E, Flett BC, Waalwijk C, Viljoen A. 2011. *Fusarium* spp. and levels of fumonisins in maize produced by subsistence farmers in South Africa. *South African J Sci. 107*, 1-7.

Njobeh PB, Dutton MF, Åberg AT, Haggblom P. 2012. Estimation of multi-mycotoxin contamination in South African compound feeds. *Toxins.* 4**,** 836-848.

Nkwe DO, Taylor JE, Siame BA. 2005. Fungi, aflatoxins, fumonisin B_1 and zearalenone contaminating sorghum-based traditional malt, wort and beer in Botswana. *Mycopathologia.* 160,177-86.

Palacios SA, Ramirez ML, Zalazar MC, Farnochi MC, Zappacosta D, Chiacchiera SM, Reynoso MM, Chulze SN, Torres AM. 2011. Occurrence of *Fusarium* spp. and fumonisin in durum wheat grains. *J Agric Food Chem.* 59,12264-9.

Parsons MW, Munkvold GP. 2012. Effects of planting date and environmental factors on fusarium ear rot symptoms and fumonisin B_1 accumulation in maize grown in six North American locations. *Plant Pathol.* 61,1130-42.

Phoku JZ, Dutton MF, Njobeh PB, Mwanza M, Egbuta MA, Chilaka CA. 2012. *Fusarium* infection of maize –based products and exposure of a rural population to fumonisin B_1 in Limpopo Province, South Africa. *Food Addit Contam.* Part A. 29,1743-51.

Picot A, Barreau C, Pinson-Gadais L, Piraux F, Caron D, Lannou C, Richard-Forget F. 2011. The dent stage of maize kernels is the most conducive for fumonisin biosynthesis under field conditions. *Appl Environ Microbiol.* 77,8382-90.

Rheeder JP, Marasas WFO, Thiel PG, Sydenham EW, Shepard GS, van Schalkwyk DJ. 1992. *Fusarium moniliforme* and fumonisins in corn in relation to human esophageal cancer in Transkei. *Phytopathology.* 82,353-7.

Rheeder JP, Marasas WFO, Vismer HF. 2002. Production of fumonisin analogs by *Fusarium* species. *Appl Environ Microbiol.* 68,2101-5.

Saleh AA, Esele JP, Logrieco A, Ritieni A, Leslie JF. 2012. *Fusarium verticillioides* from finger millet in Uganda. *Food Addit Contam.* Part A. 29,1762-9.

Schjøth JE, Sundheim L. 2013. Epidemic significance of planting time and hybrid on *Fusarium* infection of maize in two agroecological zones of Zambia. *Acta Agric Scand.* Sect B. 63,153-161.

Schjøth JE, Visconti A, Sundheim L. 2009. Fumonisins in maize in relation to climate, planting time and hybrids in two agroecological zones in Zambia. *Mycopathologia.* 167,209-219.

Schlosser CA, Strzepek K. 2013. Regional climate change of the greater Zambezi river basin. *UNU-Wider Working Paper No*. 2013/040. 1-24.

Seifert KA, Aoki T, Baayen RP, Brayford D, Burgess LW, Chulze S, Gams W, Geiser D, deGruyter J, Leslie JF, Logrieco A, Marasas WFO, Nirenberger HI, O'Donnell K, Rheeder JP, Samuels GJ, Summerell BA, Thrane U, Waalwijk C . 2003. The name *Fusarium moniliforme* should no longer be used. *Mycol Res.* 107,643-4.

Shelby RA, White DG, Bauske EM. 1994. Differential fumonisin production in maize hybrids. *Plant Dis.* 78,582-4.

Sheldon JL. 1904. A corn mold. *Annu Rep Agric Exp Stn Nebr* 17,23-32.

Shephard GS, Marasas WFO, Burger H-M, Somdyala NIM, Rheeder JR, Van der Westhuizen L, Gatyeni P, Van Schalkwyk DJ. 2007. Exposure assessment for fumonisins in the former Transkei region of South Africa. *Food Addit Contam.* 24,621-9.

Shephard GS, Rheeder JR, van der Westhuizen L. 2012. Effect of traditional cooking practice on fumonisin content of maize porridge consumed in the former Transkei region of South Africa. *World Mycotox J.* 5,405-7.

Shirima CP, Kimanya ME, Kinabo JL, Routledge MN, Srey C, Wild CP, Gong YY. 2013. Dietary exposure to aflatoxin and fumonisin among Tanzanian children as determined using biomarkers of exposure. *Mol Nutr Food Res.* 57,1874-81.

Siame BA, Mpuchane SF, Gashe BA, Allotey J, Teffera G. 1998. Occurrence of aflatoxins, fumonisin B_1, and zearalenone in foods and feeds in Botswana. *J Food Prot.* 61, 1670-3.

Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.) IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Sydenham EW, Gelderblom WCA, Thiel PG, Marasas WFO. 1990a. Evidence for natural occurrence of fumonisin B_1, a mycotoxin produced by *Fusarium moniliforme*, in corn. *J Agric Food Chem.* 38,285-90.

Sydenham EW, Thiel PG, Marasas WFO, Shephard GS, Van Schalkwyk DJ, Koch KR. 1990b. Natural occurrence of some *Fusarium* mycotoxins in corn from low and high esophageal cancer prevalence areas of the Transkei, Southern Africa. *J Agric Food Chem.* 38,1900-3.

Tansakul N, Limsuwan S, Trongvanichnam K. 2012. Fumonisin monitoring in Thai red cargo rice by reversed-phase high-performance liquid chromatography with electrospray ionization trap mass spectrometry. *Int Food Res J.* 19,1561-6.

Van Janse Rensburg B, Mc Laren NW, Viljoen A, Flett BC. 2011. Aflatoxin and fumonisin on sorghum grain from commercial production areas of South Africa. *South African J Plant Soil.* 28,236-8.

Waalwijk C, Koch SH, Ncube E, Allwood J, Flett B, de Vries I, Kema GHJ. 2008. Quantitative detection of *Fusarium* spp. and its correlation with fumonisin content in maize from South African subsistence farmers. *World Mycotox J.* 1,39-47.

Wagacha JM, Muthomi JW. 2008. Mycotoxin problem in Africa: Current status, implications to food safety and health and possible management strategies. *Int J Food Microbiol.* 124,1-12.

Williams LD, Glenn AE, Zimeri AM, Bacon CW, Smith MA, Riley RT. 2007. Fumonisin disruption of ceramide biosynthesis in maize roots and the effects on plant development and *Fusarium verticillioides*-induced seedling disease. *J Agric Food Chem.* 55, 2937-2946.