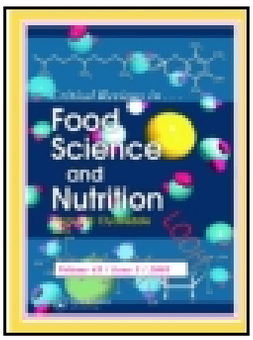

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Mycotoxin contamination of foods in Southern Africa: a 10-year review (2007-2016)

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Abstract

Major staple foods in Southern Africa are prone to mycotoxin contamination, posing health risks to consumers and consequent economic losses. Regional climatic zones favor the growth of one or more main mycotoxin producing fungi, *Aspergillus*, *Fusarium* and *Penicillium*. Aflatoxin contamination is mainly reported in maize, peanuts and their products, fumonisin contamination in maize and maize products and patulin in apple juice. Lack of awareness of occurrence and risks of mycotoxins, poor agricultural practices and undiversified diets predispose populations to dietary mycotoxin exposure. Due to a scarcity of reports in Southern Africa, reviews on mycotoxin contamination of foods in Africa have mainly focused on Central, Eastern and

Western Africa. However, over the last decade, a substantial number of reports of dietary mycotoxins in South Africa have been documented, with fewer reports documented in Botswana, Lesotho, Malawi, Mozambique, Zambia and Zimbabwe. Despite the reported high dietary levels of mycotoxins, legislation for their control is absent in most countries in the region. This review presents an up-to-date documentation of the epidemiology of mycotoxins in agricultural food commodities and discusses the implications on public health, current and recommended mitigation strategies, legislation, and challenges of mycotoxin research in Southern Africa.

Keywords

mycotoxin, aflatoxin, fumonisin, health impacts, legislation

1. Introduction

Mycotoxins, which are toxic secondary fungal metabolites, contaminate various food substances and agricultural products worldwide, posing serious health risks to humans and animals (IARC, 2012, 2015; DeRuyck *et al.*, 2015). Toxicologically significant mycotoxins of concern in foods are aflatoxins, fumonisins, ochratoxin A (OTA), deoxynivalenol (DON) and other trichothecenes, and zearalenone (ZEA), produced by fungi from the genera *Aspergillus*, *Fusarium* and *Penicillium* (Shephard, 2004, 2008a; Gnonlonfin et al., 2013; Raiola et al., 2015; Mostrom, 2016; Udomkun et al., 2017).

Multi-mycotoxin contamination of predominantly consumed food commodities can exert serious health problems in consumer populations. The toxins may be carcinogenic, mutagenic, teratogenic, estrogenic, neurotoxic, hepatotoxic, nephrotoxic and cytotoxic or may induce immunosuppression in humans (Liu and Wu, 2010; De Ruyck et al., 2015; IARC, 2012, 2015; Raiola et al., 2015; Mostrom, 2016). Acute mycotoxicoses have been reported in Africa and prolonged exposure to low amounts of various mycotoxins is a risk factor for human diseases including cancer and childhood stunting (Matumba et al., 2014d; Kimanya et al., 2015; IARC, 2015).

Aflatoxins and fumonisins are reportedly widespread in major dietary and export targeted crops in Southern Africa, with fewer reports of DON and patulin (PAT) contamination (Shephard et al., 2010; Warth *et al.*, 2012; Probst et al., 2014; Matumba et al., 2014c; Hove et al., 2016a,b; Mwalwayo and Thole, 2016). Mycotoxin susceptible foods such as maize and peanuts are primary staples and sources of revenue in the Southern African region, while sorghum, millet,

wheat and cassava are also important secondary dietary crops (Ncube et al., 2011; Chiona et al., 2014; Probst et al., 2014; Hove et al., 2016; Mwalwayo and Thole, 2016; Njoroge et al., 2016). Because the primary staples are also the main cash crops, the highest quality crops are often exported, leaving the poor quality ones for home consumption. The secondary crops are mainly used for home consumption, beer brewing and sale in the informal sector (Matumba et al., 2014b, 2015a). Low income economies characterizing the region contribute to high food insecurity, food scarcity and undiversified diets, predisposing the population to consumption of mycotoxin contaminated foods (Shephard et al., 2008b; Mukanga et al., 2010; Mupunga et al., 2014; Udomkun et al., 2017).

Many of the agriculturally productive areas in Southern Africa have sub-tropical or tropical climate, typified by hot and humid conditions, which, coupled by erratic rains and frequent drought spells, provide an ideal environment for toxigenic fungal proliferation (Darwish et al., 2014; Mboya and Kholanisi, 2014; Matumba et al., 2014d). Inadequate drying of crops, exacerbated if harvesting is early, and drought spells in the region may necessitate food storage for long term periods allowing for insect infestation, fungal proliferation and mycotoxin production (Matumba et al., 2015b). Storage facilities frequently have no pest control, poor aeration, poor moisture and temperature control, thus promoting aflatoxin production during storage. Aflatoxins may also be carried over into milk when farm animals are fed on contaminated feed (MacLachlan, 2011; Gnonlonfin et al., 2013; Matumba et al., 2015b).

Although mycotoxin contamination is a major concern in many countries in Southern Africa, relatively few studies have been conducted on dietary mycotoxins in the region compared to other regions worldwide, mainly due to lack of advanced laboratory equipment, inadequate

research funds, capacity and expertise, and limited surveillance systems. Limited information on dietary mycotoxins exists outside of South Africa, while monitoring and enforcement of regulatory standards are rare or non-existent (Matumba et al., 2015b). Over the last decade, mycotoxin occurrence has been reported in maize, peanuts, barley and barley products, wheat, apple juice and in milk in South Africa (Katerere et al., 2007; Maenetje and Dutton, 2007; Shephard et al., 2010, 2013a; Kamika et al., 2014; Mboya and Kholanisi, 2014; Rheeder et al., 2016). Limited reports, however, exist of mycotoxin occurrence in major dietary products such as maize, peanuts and their products in the other Southern African countries, including Botswana, Malawi, Mozambique, Zambia and Zimbabwe (Warth et al., 2012; Matumba et al., 2014a, b, 2015a; Mukanga et al., 2014; Mwalwayo and Thole, 2016; Njoroge et al., 2016; Murashiki et al., 2017). Although mycotoxin research reports exist for foods in Botswana, Lesotho and Swaziland in previous decades (Siame et al., 1998; Nkwe et al., 2005; Bankole et al., 2006), there has been a dearth of reports in the decade under review. There is also less emphasis on legislating maximum levels and even when such legislation exists, the capacity to enforce it is frequently lacking (Matumba et al., 2015b).

This review documents and discusses current research, highlighting the mycotoxin menace in Southern Africa with respect to health impacts, exposure and risk, and current and possible mitigation strategies, awareness, regulation and recommendations on the way forward.

2. Dietary mycotoxins: health impacts and risks in Southern Africa

The chronic health risks of mycotoxins are prevalent in Southern Africa because mycotoxins occur more frequently under tropical conditions and staple diets in the region are often

constituted by mycotoxin susceptible crops (Shephard 2004, 2008a, b; IARC, 2015; Matumba et al., 2014c, 2015b).

Preliminary evidence suggests that there may be an interaction between chronic mycotoxin exposure and malnutrition, immunosuppression, impaired growth and diseases such as malaria and HIV/AIDS (Gong et al., 2004, 2008; Katerere et al., 2008; Khlangwiset et al., 2011; Warth et al., 2012; Matumba et al., 2014d; Kimanya et al., 2015). Aflatoxins may contribute to growth stunting during early childhood and together with other mycotoxins, are commonly suspected to play a role in development of edema in malnourished people as well as a causal or aggravating factor in the pathogenesis of kwashiorkor, a frequent condition in African children (IARC, 2015; Kimanya et al., 2015).

Aflatoxin B_1 (AFB_1) has been extensively linked to human primary liver cancer in which it acts synergistically with hepatitis B virus (HBV) infection and was classified by the International Agency for Research on Cancer (IARC) as a human carcinogen (group 1 carcinogen) (IARC, 2002; Shephard, 2008b; Wu et al., 2014). In high doses, aflatoxins have caused deaths from aflatoxicosis (Williams et al., 2004; Liu and Wu, 2010; Kimanya et al., 2015). Significant negative effects of aflatoxin on child growth have been reported. African studies carried out in Swaziland and Mozambique helped establish the link between aflatoxins, liver cancer and HBV infection (Van Rensburg *et al*., 1985). In Durban, South Africa, in 1992, cases of kwashiorkor, marasmus, and underweight that were reported during this period correlated with findings of impaired liver function. Katerere *et al*. (2008) reviewed available studies and data for a link between chronic aflatoxicosis and infant malnutrition in Southern Africa and concluded that there is mounting evidence implicating aflatoxin contamination as an important factor in infant

under-nutrition, increased morbidity and mortality due to negative impact on immune function and micronutrient absorption. Immune modulation effects of aflatoxins may intensify health impacts of major diseases troubling Africa such as malaria, kwashiorkor and HIV/AIDS (Matumba et al., 2014d; Gnonlonfin et al., 2013; IARC, 2015). Aflatoxin M_1 is a mammalian hydroxylated metabolite of AFB_1 excreted in urine and, importantly, in mothers' milk, and has been classified as a possible human carcinogen (group 2B) (IARC, 2012; Iqbal et al., 2015).

Fumonisins, which were discovered in South Africa in 1988 (Marasas, 1995), are a class of mycotoxins primarily produced by *Fusarium verticillioides* and *F. proliferatum*, but can also be formed by other Fusaria. Certain strains of *Aspergillus niger* possess the capacity to biosynthesize some types of fumonisins, specifically fumonisin B_2 (FB_2), FB_4 and FB_6 (Nielsen et al., 2009). Human exposure is reportedly highest in regions like Transkei, South Africa, where moldy, home-grown maize, damaged by insects, is often consumed. Occurrence on sorghum has also been reported (Bulder et al., 2012). The consumption of maize highly contaminated with fumonisins has been correlated to the high incidence of esophageal carcinoma in certain parts of South Africa and China (Rheeder et al., 1992; Wagacha and Muthomi, 2008; Mostrom, 2016; Sun *et al*., 2007). Accordingly, FB_1, the most abundant of numerous fumonisin analogues, was classified by the IARC as a group 2B carcinogen (possibly carcinogenic in humans) (IARC 2002). It is noteworthy that Malawi has the highest esophageal cancer prevalence rate (24.2 per 100,000 people) in the world (Ferlay et al., 2013) which could be attributed to high dependence on maize and high fumonisin levels (Matumba et al., 2014).

Fumonisins have also been implicated in the high incidence of neural tube defects (NTDs) in rural populations known to consume contaminated maize, such as the former Transkei region of

South Africa (Marasas et al., 2004; Shephard 2008a). In Southern Africa, where maize is a dietary staple and where there is chronic fumonisin exposure, NTD rates are often very high. For example, in South Africa, high NTD incidence has been reported in parts of rural Transkei (61/10 000) and in rural areas in Limpopo Province (35/10 000). In contrast, the incidence is much lower in urban communities such as Cape Town (1.06/10 000), Pretoria (0.99/10 000), and Johannesburg (1.18/10 000) (Marasas et al., 2004, IARC, 2015).

DON, which is produced by *Fusarium graminearum* and *Fusarium culmorum*, is probably the most commonly detected trichothecene in cereal grains throughout the world (Mostrom, 2016).

Consumption of DON contaminated cereals has been linked to acute gastroenteritis and emesis in India (Bhat et al., 1989).

ZEA is commonly produced by various *Fusarium* species such as *F. culmorum*, *F. graminearum* and *F. sporotrichioides*. It is most often found in maize, yet it can also be observed in other grain crops such as wheat, barley, sorghum, millet, and rice (Matumba et al., 2014c; De Ruyck et al., 2015; Mostrom, 2016). ZEA has relatively low toxicity but is a naturally occurring endocrine-disrupting chemical and has been associated with clinical manifestations of hyper-oestrogenism in humans, including gynecomastia with testicular atrophy in rural males in Southern Africa (Shephard et al., 2008). In Southern Africa, it has been found in limited surveys conducted in Botswana, Lesotho, Malawi, South Africa, Swaziland and Zambia.

PAT, a mycotoxin produced by various *Aspergillus* and *Penicillum* species, has antibiotic properties and damages the immune system in animals. It is generally associated with moldy fruits and vegetables, where it is produced by *P. expansum*, and has been found above regulatory

levels in apple juices in South Africa (Katerere et al., 2007; Shephard et al., 2010). Levels of patulin in apple juice are regulated at 50 ng/g in South Africa. PAT has also been reported to be produced by *Aspergillus clavatus* (Lopez-diaz and Flannigan, 1997).

Although there is limited empirical evidence on the relationship between undernourishment and the consumption of mycotoxin contaminated food, studies have shown that fungi and mycotoxins have capacity to reduce the nutritive value of food (Wu, 2013). Although stunting cannot be ascribed to mycotoxin contamination alone, there is growing concern that the consumption of mycotoxin contaminated food is a major underlying contributing factor causing this health problem (Mboya and Kolanisi, 2014; Raiola et al., 2015).

3. Mycotoxin occurrence patterns in various food commodities in Southern Africa

3.1 Maize and maize products

Maize is a major staple cereal in Southern Africa, commonly consumed fresh or processed into milled, cooked or fermented products (Matumba et al., 2009; Shephard et al., 2012; Hove et al., 2016). Household consumption of maize in rural subsistence farming communities in South Africa could reach intake levels of 1--2 kg/person/day (Burger et al., 2010; Alberts et al., 2016). Throughout its growth, harvest, transport and storage, maize is susceptible to fungal infections from *Fusarium* and *Aspergillus* species and consequent contamination with their mycotoxins, principally fumonisins and aflatoxins (Shephard et al., 2008a; Matumba et al., 2009).

Table 1 documents the reported occurrence of mycotoxins in maize and maize products in Southern Africa. Maize and maize products are reported to be frequently contaminated with unacceptable levels of fumonisins and aflatoxins, with FB_1 and AFB_1 being the most prevalent

(Matumba et al., 2014a, 2014b; Mngqawa et al., 2015; Alberts et al., 2016; Hove et al., 2016; Murashiki et al., 2016; Mwalwayo and Thole, 2016). High levels of fumonisin contamination in maize have been reported in several studies in Malawi, South Africa and Zimbabwe (Shephard et al., 2011, 2012, 2013a; Boutigny et al., 2012; Matumba et al., 2014; Hove et al., 2016a). Noteworthy is the maximum FB_1 level of 11,624 µg/kg that was reported for maize samples from cultivar evaluation in localities in South Africa (Boutigny et al., 2012). In a study carried out by Probst *et al*. (2014) on maize samples in various sub-Saharan African countries, including Malawi, Mozambique, Zambia and Zimbabwe, all 19 maize samples from Zimbabwe were contaminated with greater than 10 µg/kg total fumonisins, with 53% of the samples having levels above 100 µg/kg. Two out of the samples with deoxynivalenol (DON) above 5µg/g originated in Zimbabwe while about 20% of the samples contained aflatoxin levels above 4 µg/kg. A recent report from Murashiki et al. (2017) showed 100% FB_1 contamination in 388 samples from rural households in Shamva and Makoni districts of Zimbabwe, although all levels were below FDA (2,000 µg/kg) and EC (1,000 µg/kg) regulatory limits. Murashiki et al. (2017) reported the co-occurrence, levels and daily intake estimates of AFB_1 and FB_1 in maize from rural households in Zimbabwe. Eighteen samples exceeded the Zimbabwe regulatory limits of 5µg/kg for AFB_1 (Siwela and Nziramasanga, 1999). No significant differences in FB_1 levels between maize meal and maize grain samples were recorded. Humans in Zimbabwe may thus be exposed to unacceptable levels of aflatoxins and fumonisins.

Total aflatoxin levels exceeding the EU limit of 4 µg/kg for maize intended for direct human consumption were reported in the nine samples from farmsteads and homesteads in Malawi while no aflatoxins were detected in the 42 samples from Mozambique (Probst et al., 2014). In a

survey of the incidence and level of aflatoxin contamination in a range of locally and imported processed foods on the Malawian retail market, no aflatoxins were detected in all samples of imported baby cereal, whereas all locally processed maize-based baby foods had aflatoxins above EU maximum level of 0.1 μg/kg for infant food. In addition, 75% locally produced maize puffs contained aflatoxins at levels of up to 2 μg/kg (Matumba et al., 2014b). Malwayo and Thole (2016) also reported as high as 140 μg/kg of aflatoxins in maize from rural households in Malawi. Furthermore, in a limited survey of mycotoxins in nine traditional maize-based opaque beers sampled from tribal rituals and commercial village brewers in Malawi, Matumba et al. (2014a) reported a mean aflatoxin level of 1898±1405 μg/kg which is way above the maximum limits for all regulatory bodies. Data obtained in the study of Matumba and co-workers (2014a) is useful in facilitating improved mycotoxin risk management in Malawi and possibly the Southern African region.

The distribution and levels of mycotoxins in maize in the region are being influenced by climatic and seasonal variations. In a survey of pre-harvest maize ear rot diseases in Zambia, Mukanga and coworkers (2010) reported a relationship between disease incidence and climatic data such as rainfall, relative humidity and temperature. Thus, there's likely to be a carryover of mycotoxins from pre-harvest contaminated crop to diet. Mohale et al. (2013) reported seasonal variation in mycotoxin levels of maize samples from Lesotho, recording FB_1 levels ranging from 7–936 μg/kg for the 2010/2011 season, which were higher than the 2009/10 season in which FB_1 levels ranged from 2–3 μg/kg. Rheeder et al. (2016) reported that drought conditions in 2003 led to a substantial increase in fumonisin levels in two areas in South Africa, dry sub-humid Centane, compared to humid sub-tropical Mbizana. The study emphasized the seasonal

fluctuation in fumonisin levels. The co-occurrence of toxins from *Aspergillus* and *Fusarium* species has also been reported in subsistence farmed maize from Zimbabwe, with higher mycotoxin contamination being attributed to higher rainfall and humidity regions compared to other regions (Hove et al., 2016a).

There is a large commercial maize growing industry in the central agricultural area of South Africa, which supplies internal commercial needs except in periods of drought and consequent reduced yields. Crop quality data, including mycotoxin levels, on an annual basis are available and can be accessed on-line at www.sagl.co.za. Regular annual analyses show that *Fusarium* mycotoxins predominate and that aflatoxin contamination is absent.

3.2 Peanuts and peanut products

Peanuts are important dietary and cash crops in Southern Africa (Derlagen and Phiri, 2012; Monyo et al., 2012; Kamika et al., 2014; Mupunga et al., 2014; Matumba et al., 2015a; Njoroge et al., 2016). Peanut butter, a popular peanut product, is one of the cheap sources of protein, especially among the poor socioeconomic groups (Kamika et al., 2014; Mupunga et al., 2014) and is widely used in children's food including sandwiches, porridge and vegetables. In Botswana and Zimbabwe, peanuts are mainly grown by small scale farmers for household consumption and processing (Mupunga et al., 2014). Peanuts are reportedly prone to pre- and post-harvest *Aspergillus* colonization and mycotoxin contamination (Ezekiel et al., 2012; Monyo et al., 2012; Udomkun *et al*., 2017). Aflatoxin contamination has been reported in peanut and peanut products in South Africa (Ncube et al., 2010; Kamika et al., 2014), Malawi (Monyo et al., 2012, 2015; Matumba et al., 2014b; 2015a), Zimbabwe and Botswana (Mupunga et al., 2014) and Zambia (Njoroge et al., 2016).

Mycotoxin contamination of peanut and peanut products from Southern Africa is summarized in Table 2. Monyo (2012) reported that 8% of 1,397 samples of peanuts from farm homesteads, local markets, warehouses and retail shops in Malawi exceeded national regulatory limits of 20 µg/kg. In another investigation of mycotoxin contamination of locally and imported processed foods from Malawian markets, total aflatoxin levels ranging from 7--500µg/kg were reported for 93% of fresh peanuts sourced from local markets, exceeding the EU regulatory limit of 4 µg/kg. In comparison, aflatoxin levels with a maximum of 9.3 µg/kg were detected in 59% of fresh peanut samples destined for export (Matumba et al., 2014b; 2015a). In Bulawayo, Zimbabwe, Siwela et al. (2011) reported high levels of aflatoxin contamination exceeding 80 ng/g in raw peanuts and consequent aflatoxin carryover during large scale peanut butter production. More recently, peanuts and peanut butter samples from retail shops and informal markets in Zimbabwe were also analyzed, with a reported incidence of 91% total aflatoxins in 11 peanut butter samples and 17% total aflatoxin in 18 peanut butter samples (Mupunga et al., 2014). In the same study, no aflatoxins were detected in peanuts collected from retail and informal markets in Botswana. Ncube and co-workers (2010) reported 100% total aflatoxin contamination of peanuts, averaging 22.66 µg/kg from subsistence farmers in South Africa, warranting public health concern. A more recent analysis of mycotoxin contamination of peanuts from informal markets in South Africa also resulted in a report of 90% contamination of the peanuts by AFB_1 (Kamika et al., 2014). The authors encourage regular aflatoxin monitoring in peanut butter in the southern African region, given that a number of peanut butter samples were imported from Malawi and Zimbabwe.

3.3 Sorghum and Wheat

Sorghum plays a role as a food source in Southern Africa, where it is a major ingredient in cereal gruels, alcoholic and non-alcoholic cereal beverages and thick porridges (Janse van Rensburg, 2011; Matumba et al., 2011; Mupunga et al., 2014). The cereal is susceptible to colonization by a range of fungal species, during cultivation as well as after harvest. Mycotoxin contamination has been reported in sorghum and sorghum products in South Africa (Janse van Rensburg, 2011), Malawi (Matumba et al., 2011), Mozambique (Warth et al., 2012), Zimbabwe and Botswana (Mupunga et al., 2014). Table 3 shows mycotoxin contamination levels of sorghum and wheat samples from Southern Africa. In an analysis of samples of sorghum grain, sorghum malt and traditional sorghum beverages in Malawi, aflatoxins were detected at low levels, ranging from 1.7-3.0 µg/kg in sorghum grains, whereas significantly higher aflatoxin levels were found in the malt prepared for beverages, ranging from 340--476 µg/kg (Matumba et al., 2011). The final aflatoxin content in beer samples was 22.32 µg/kg, which is much higher than the regulatory levels for direct human consumption as set by the EU. Malting was reported as the main point of mycotoxin contamination of sorghum grain. Aflatoxins have been detected in sorghum from commercial production areas in South Africa at below allowable limits of 5 µg/kg for AFB_1 (Janse van Rensburg, 2011).

Wheat is a cereal of secondary importance to maize in South Africa and may probably be the cereal food of choice for the urban population (Mashinini and Dutton, 2006).DON levels equal to or below 100 µg/kg were detected in wheat flour commercial samples from South Africa (Shepherd et al., 2010).

3.4 Other foods

3.4.1 Milk

Another pathway for human exposure to aflatoxins is by ingestion of dairy products contaminated with AFM_1, a mammalian metabolite of AFB_1 consumed in the feed of dairy cattle (MacLachlan, 2011; Iqbal et al., 2015; Matumba et al., 2015b). The occurrence of AFM_1 in milk has been documented in South Africa (Dutton et al., 2012; Mwanza and Dutton, 2014) (Table 4). In an analysis of milk from farmsteads in South Africa, AFM_1 levels in milk up to 1.32 µg/kg were reported, above the national regulatory limit of 0.05 µg/l for AFM_1 in milk and milk products (Dutton et al., 2012). Mwanza and Dutton (2014) analyzed milk from commercial and rural areas in South Africa and reported that higher incidences of AFM_1 contamination were observed in commercial samples as compared to rural samples. Levels of AFM_1 in milk from rural subsistence dairy farms and commercial dairy farms in South Africa were reported at mean levels of 0.15 µg/kg and 0.14 µg/kg respectively.

3.4.2 Cassava

Cassava tuber is a starch-rich crop, relatively new in Southern Africa and consumed mainly in Malawi, Mozambique, and Zambia (Tivana et al., 2005; Nyirenda et al., 2011; Chiona et al., 2014). Tubers are processed by several methods, including sun drying and fermentation, mainly in order to detoxify the food due to high content of cyanogenic glycosides (Tivana et al., 2005). Chiona et al. (2014) investigated aflatoxin contamination in processed cassava in Malawi and Zambia and reported aflatoxin levels below 2.0 µg/kg in Malawian and below 4.2 µg/kg in Zambian samples (Table 4). No aflatoxins were detected at unacceptable levels in cassava,

consistent with various other reports within and beyond the Southern African region in which either very few cassava samples exceeded defined mycotoxin limits (Sulyok et al., 2015) or no aflatoxins were detected (Gnonlonfin et al., 2012).

3.4.3 Barley

In mycotoxin analysis of barley and barley products in South Africa by Maenetje and Dutton, (2007), four major mycotoxins, AFB_1, DON, OTA and ZEA were detected and these persisted at low levels during processing from barley to beer. Concern was expressed by the authors that exposure may occur from these products on a regular basis.

3.4.4 Apple juice

In an analysis of PAT in apple juice samples from local retail markets in Cape Town, South Africa, Katerere and co-workers (2007) detected toxin range of <10-166 μg/kg. Higher levels of PAT were found in samples collected from local markets in low income areas as opposed to the more affluent shops, where national brands are sold. The lower quality products appeared to have a localized and limited distribution, and were presumably processed from cheap poor quality apples. Shephard et al. (2010) detected a range of <10 to 1,650 μg/kg PAT in 33% of commercial apple juice samples from South Africa.

3.4.5 Edible stink bugs

Musundire et al. (2016) reported aflatoxin contamination in edible stink bug, which is widely consumed in Southern Africa. Average levels were below 1 μg/kg (Table 4). An association of aflatoxin contamination with traditional harvesting and storage practices was reported as there

were no aflatoxins detected in the clean zip-lock bags used to store the edible stink bugs, in comparison to other storage methods.

4. Implications of food contamination patterns

Ample, mounting evidence shows that the rural subsistence farming communities in Southern Africa are at a high risk of exposure and negative health impacts of mycotoxins (IARC, 2015; Mostrom, 2016). Exposure to high levels of fumonisins, largely FB_1, from maize consumption has been reported among rural subsistence farming communities in Malawi, South Africa and Zimbabwe (Shephard et al., 2010; 2013c; Matumba et al., 2014a,b; Hove et al., 2016a; Murashiki et al., 2017), with aflatoxin exposure having been reported mainly from peanuts in Malawi, South Africa, Zambia and Zimbabwe (Monyo et al., 2012; Kamika et al., 2014; Mupunga et al., 2014; Matumba et al., 2014b, 2015a; Njoroge et al., 2016). The data on mycotoxin occurrence patterns in this region further demonstrates that co-exposures of aflatoxins and fumonisins are likely to be high, especially among maize-consuming populations in this region (Probst et al., 2014; Hove et al., 2016b).

Based on estimates of typical maize and peanut consumption, contamination levels and body weight, Liu and Wu (2010) estimated aflatoxin exposures in Mozambique (39–180 ng/kg bw per day), in South Africa (0–17 ng/kg bw per day) and in Zimbabwe (18–43 ng/kg bw per day), which were much higher than those in Western Europe and North America (0–1 ng/kg bw per day) (Turner et al., 2012). Aflatoxin M_1 from milk of livestock consuming AFB_1 contaminated feed is a further source of exposure that is often neglected or under-represented. Data on the aflatoxin carryover to human breast milk is limited, but it has been estimated at 0.1–0.4% (Zarba et al., 1992). Exposure of infants to AFM_1 from human breast milk has been reported in

developing countries in Africa but not in the Southern African region (Shephard, 2004; Turner, 2013; Magoha et al., 2014; Warth et al., 2015). Studies are therefore necessary to assess the exposure level of suckling babies to mycotoxins and to determine the consequences of AFM_1 ingestion from breast milk and/or from the milk of livestock in Southern Africa.

Given the high maize consumption rates in Southern Africa, it is likely that maize consuming inhabitants of Southern Africa can exceed the provisional maximum tolerable daily intake (PMTDI) for fumonisin of 2 μg/kg bw per day set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (Burger et al., 2010; IARC, 2015). A survey of maize consumption levels in the subsistence farming area of Centane, Transkei, South Africa showed that adults were consuming on average around 450 g of raw maize per day in an area with high fumonisin contamination (Shephard *et al*., 2007a, b). Resultant adult exposures were on average over 4 times above the PMTDI and at the 90^{th} percentile of population, exposures were 7 times greater than PMTDI. Exposures in young children (ages 1–9 years) were found in some cases to be an order of magnitude greater than PMTDI. These high maize consumption levels complicate the establishent of regulations on maximum levels. In order to protect these populations, maximum levels should be low, whereas to accommodate the low maize consumption in developed countries, maximum levels can be allowed to be relatively high (Shephard et al., 2013c). Consequently, the recent setting of Codex maximum levels for raw maize and maize flour (including maize meal) of 4 mg/kg and 2 mg/kg, respectively, would not be health protective in these high maize consumption populations (FAO, 2014). Apart from fumonisin exposure via maize-based foods, traditional beers, frequently brewed using mouldy maize, can be an important route of exposure. Consumption of 1.0-6.0 L of the traditional beer from a study of

fumonisin exposure in Malawi translated to daily fumonisin exposure of 29--174 µg/kg bw per day (Matumba et al., 2014a). In a study in Malawi (Matumba et al., 2014c), estimated daily intakes for all maize samples from hot ecologies were well above the JECFA's PMTDI for fumonisins, whereas the PMTDI of 1.0 µg/kg bw/day for DON was exceeded in relatively more (90%) samples from the cool highlands than the other climatic zones.

In a preliminary exposure assessment of DON and PAT in South Africa, Shephard et al., (2010) reported that DON in wheat consumers contributed 6–13% of the PMTDI; 1 µg/kg body weight per day for DON set by JECFA. In maize meal samples, the probable daily DON intakes ranged from 3.67 µg/kg body weight per day in rural infants to 1.39 µg/kg body weight per day in urban adults, posing health risks to consumers. PAT levels in apple juice reportedly showed the possibility of a brief but high exposure of 37 µg/kg body weight per day (or 9,250% of the JECFA PMTDI of 0.4 µg/kg body weight per day) in young children (Shephard et al., 2010). Although PAT levels in apple juices or blends available on the South African market were found to be generally low, vigilance is urged to avoid the occasional sample that is heavily contaminated (Shephard et al., 2010).

Due to stringent mycotoxin standards imposed in developed countries, the least contaminated foods in Southern Africa are destined for export, whereas highly contaminated products are retained for local consumption, exacerbating the high exposure levels of local populations (Katerere et al., 2007; Pitt et al., 2012; Matumba et al., 2015a; Njoroge et al., 2016). In a survey in Malawi by Matumba and co-workers (2015), it was reported that all locally made peanut butters unfit for human consumption and grade outs were reported to have been sold to the local public as food at cheaper prices. In Zambia, oil extraction is carried out from contaminated

peanuts for the making of cooking briquettes (Njoroge et al., 2016), posing a threat to consumers of the oil considering that aflatoxins have been reported in oil from several crops (Keliani et al., 2014).

Limited data on mycotoxin exposure and risk assessment exists for Southern Africa, primarily due to a lack of country-specific data on food consumption patterns, limited human resource capacity and technical expertise to effectively monitor and evaluate mycotoxin levels (IARC, 2015; Matumba et al., 2015). Data on the likely human exposure to mycotoxins is challenging to collect due to variation in food contamination levels and intake amounts in subsistence farming situations, as well as the differences and variations in toxicokinetics and toxicodynamics of individuals in these rural communities, which may simultaneously be suffering poor overall nutrition. The development of sensitive biomarkers of exposure would help to alleviate some of these measurement problems. Although several biomarkers of exposure to aflatoxins have been developed, similar ones for fumonisin have been elusive (Shephard et al., 2007a). Initial candidates investigated included sphingoid bases in serum and urine, and FB_1 in faeces and hair (Shephard *et al.*, 2007b; 2013b; Van der Westhuizen et al., 2011). Urinary FB_1 has been proposed as an exposure biomarker and has been measured in human samples in regions with known high exposure to dietary fumonisins in South Africa (Van der Westhuizen et al., 2011, 2014). Generally, statistically significant relationships between the urinary level and either estimated or measured FB_1 intakes were reported. This biomarker was used to validate an intervention method to reduce fumonisin exposure in a rural population in South Africa by a maize sorting and washing technique (Van der Westhuizen et al., 2011). In a study applying urinary multi-mycotoxin LC–MS/MS methods to determine multiple exposure biomarkers in the

Transkei region of South Africa, results confirmed that this population of subsistence farmers consuming home-grown maize is exposed not only to fumonisin, but simultaneously to other *Fusarium* mycotoxins but not to aflatoxins (Shephard et al., 2013a).

5. Current and recommended mitigation strategies for mycotoxin control in Southern Africa

In Southern Africa, where resources are limited and sophisticated technologies are lacking, culturally acceptable, simple, economically feasible, practical and sustainable methods of mycotoxin reduction are relevant in rural subsistence farming communities (Wagacha and Muthomi, 2008; Alberts et al., 2016). For example, hand-sorting and washing of maize kernels proved to be effective in reducing fumonisin exposure in rural subsistence farming communities in South Africa and in maize from local markets in Malawi (Van der Westhuizen et al., 2011; Matumba et al., 2015c). Recommended mitigation strategies include awareness creation, use of improved varieties and dietary diversity.

5.1 Awareness creation

Education of smallholder farmers concerning mycotoxin contamination of staples is hardly being implemented in Southern Africa (Mukanga et al., 2011; Mboya and Kolanisi, 2014; Matumba et al., 2016). Investigations in South Africa, Malawi and Zambia have shown that there is a lack of knowledge concerning mycotoxins and their health impacts among smallholder farmers (Mukanga et al., 2011; Mboya and Kolanisi, 2014; Matumba et al., 2016). Data collected from interviews and surveys in South Africa revealed that people used fungi-infected staples for food, implying that people are not fully aware of the health hazards associated with the ingestion of

mycotoxins (Mboya and Kolanisi, 2014). An investigation of smallholder farmers' perceptions and management of maize ear rots in Central Zambia revealed that less than 7% of the farmers were aware of the mycotoxins produced on fungi-infected grain and farmers disposed infected maize ears and kernels by burning, throwing away, feeding to livestock and at times selling to illicit beer brewers (Mukanga et al., 2011). Another survey conducted to assess the respondents' knowledge, attitudes, and practices on mold colonization of their foodstuffs and the associated health risks in Malawi showed that the respondents had minimal knowledge of the link between mold colonization and the health risk factors associated with mycotoxins such as aflatoxins (Matumba et al., 2015c). The lack of effective and sustained awareness and education of the threat of mycotoxins to human health hinders any reduction strategy (Alberts et al., 2016). Country or region specific knowledge enables the identification of susceptible edible crops that are responsible for toxin exposure in specific populations.

Education and training to raise awareness of smallholder farmers and consumers on mycotoxins is critical to enable them to deliberately make efforts to find appropriate means to prevent fungal infections of crops (Mboya and Kolanisi, 2014; Matumba et al., 2016). Introduction of mycotoxin control programmes in provincial, national and regional agenda, establishing standard surveillance systems and promoting awareness creation will result in economic gains as well as health improvement in the region (WHO, 2006). The involvement of government bodies, private organizations, non-governmental organizations and use of national media networks such as radio and television programmes as well as features in newspapers and magazines will be critical to ensure local sustainability of mycotoxin interventions (IARC, 2015). Upgrading primary and secondary school curricula with courses that focus on proper food handling techniques as well as

basic pre- and post-harvest practices that could benefit household farming and food production are urgent to reduce mycotoxin exposure in the region.

5.2 Use of Improved varieties

Maize genotypes exhibiting some resistance to fumonisin accumulation have been identified, including germplasm lines adapted to South Africa (Small et al., 2011, Santiago et al., 2013). Transgenic *Bt* maize is less prone to insect damage and fumonisin accumulation compared to non-*Bt* hybrids (Abbas et al., 2013; Pray et al., 2013), but the effectiveness of *Bt* in reducing aflatoxin contamination is reportedly inconclusive (Albert et al., 2016). Results from a study conducted in rural areas in KwaZulu-Natal Province of South Africa, from 2004--2007 (Pray et al., 2013) demonstrated a clear advantage of *Bt* maize over conventional hybrids and traditional maize seeds, in which *Bt* maize had 40% and 16% less fumonisin than traditional maize varieties and non-*Bt* commercial maize hybrids, respectively. Field trials conducted in 2002 and 2003 at two locations in a commercial maize growing area of South Africa showed that the fumonisin levels in the *Bt* hybrids were generally between 39 and 83% lower than their respective non-*Bt* isolines (Rheeder et al., 2005). However, due to the higher cost of *Bt* hybrids, in South African rural areas, farmers are more likely to purchase herbicide tolerant transgenics than *Bt* hybrids (Alberts et al., 2016).Breeding for resistance to maize ear rot should aim at developing cultivars that also possess farmers' preferred traits such as large grain size, taste and white flour (Mukanga et al., 2011). Rarely are farmers' perceptions included in the planning phase of a breeding programme. Breeders tend to design programmes to meet the policies of the government for ensuring household food security; hence, high yield becomes the main focus, leading to the non-adoption of new varieties (Mukanga et al., 2011).

5.3 Technological and community based methods to reduce mycotoxin exposure

Traditional food processing methods form a sustainable, practical and inexpensive post-harvest intervention strategy to reduce mycotoxin contamination and exposure (Alberts et al., 2016). Hand sorting or segregation of crops prior to storage or cooking is a common practice in many countries in Southern Africa (Van der Westhuizen et al., 2010, 2011; Alberts et al., 2016; Matumba et al., 2016b). Common post-harvest practices for maize include shelling, winnowing, dehulling and milling (Matumba et al., 2009; Abass et al., 2014; Alberts et al., 2016).While commercial milling of maize is known to distribute the mycotoxins preferentially into animal feed products such as bran, mechanical dehulling and milling technologies are only available in some areas. The effectiveness of hand-sorting of maize by removing visibly infected and damaged kernels, resulting in a significant reduction of fumonisins has been demonstrated in several African countries including South Africa (Van der Westhuizen et al., 2010) and Malawi (Matumba et al., 2016). In South Africa, Van der Westhuizen and coworkers (2010, 2011) developed, implemented and validated a simple, practical and culturally acceptable hand-sorting and washing method for reduction of fumonisin exposure from maize. The intervention in a rural village reduced fumonisin levels by 84% and the reduced exposure was confirmed by urinary biomarker measurements (Van der Westhuizen et al., 2010, 2011).Sustainability of these reduction strategies is, however, dependent on the available maize supply (food security), as well as the socio-economic status and education of a community (Alberts et al., 2016).

Matumba et al. (2009) reported reduced AFB_1 levels of 11.7%, 29.3±5.4% and up to 80.9±5.3% by sun drying, dehulling and soaking of maize during maize flour production. A maximum AFB_1 reduction of 88.1±3.1% was achieved using a sequence of dehulling, soaking for 72 h and sun

drying the flour for 4.5 h. Through dry blanching and manual sorting, the peanut sector has been able to gain access to markets with very stringent aflatoxin regulatory limits (Derlagen and Phiri, 2012).

The fate of rejected food is however a concern, as it might still be consumed by humans in times of food insecurity (IARC, 2015; Alberts et al., 2016). Normally, rejected food is used either as animal feed or in some circumstances for the preparation of traditional maize-based beer (Shephard et al., 2005; Matumba et al., 2014a, b); however the residue levels in animal organs and tissues and carryover levels from grains to finished beverage calls for reconsideration on the use of highly contaminated grains for such purposes.

In an investigation of the effect of the traditional cooking practice on fumonisin content of maize porridge consumed in South Africa, a mean decrease in total fumonisin levels of 11.3% was reported following processing of maize meal into porridge in a rural village, confirming that preparation of traditional porridge has only a limited effect on fumonisin exposure in the South African population (Shephard et al., 2012).

5.4 Dietary diversity

In rural Southern Africa, a high percentage of calories come from maize, which is commonly contaminated by aflatoxins and fumonisins (IARC, 2012). Another major source of exposure to aflatoxin is through the consumption of peanuts (Liu and Wu, 2010; IARC, 2012). The high levels of mycotoxin exposure are directly related to a lack of dietary diversity (Chen *et al*., 2013). Access to a greater variety of foods and replacement of those at high risk of contamination will lower the risk of exposure by lessening the intake of these commonly

contaminated foods (Groopman et al., 2008). Increased dietary diversity is one intervention for which the strongest evidence of improvement of health exists (Chen et al., 2013), but which is also the most difficult to achieve. Challenges to implementing dietary diversity may include environmental factors, food insecurity, cultural traditions and economic constraints facing Southern Africa (Matumba et al., 2014c; IARC, 2015; Alberts et al., 2016).

6.0 Mycotoxin legislation and regulation in Southern Africa

In a worldwide survey of mycotoxin regulation carried out by FAO in 2003, only 15 countries in Africa were reported to have regulations for aflatoxins (FAO, 2004). Since the 2003 FAO report, there is apparently little or no improvement regarding mycotoxin regulation in Africa (Matumba et al., 2015b). In Southern Africa, mycotoxin regulations are either lacking or poorly enforced, which creates scenarios where mycotoxin exposures occur above levels set by health regulatory bodies (Alberts et al., 2016). The non-existence of mycotoxin legislation might be due to lack of prevalence data of certain toxins, capacity and resources to obtain toxicological and exposure data and enforce regulations (FAO, 2004; Williams et al., 2004; Wild, 2007; Wild and Gong, 2010).

A strategy for keeping mycotoxin levels in food low, reducing healthcare costs and accessing high-value markets is through the institutionalisation of mycotoxin regulations (IARC; 2015; Matumba et al., 2015b). Enforcement of regulatory procedures is appropriate for export crops, but has little relevance to the largely small scale and subsistence farmers (Matumba et al., 2015b).The quality of food produced by commercial farmers may be easier to regulate or manage, as compared to that produced by the small-scale household farmers where food is grown in the households and consumed locally. High costs involved in inspection, sampling and

analyses of exports and imports of food crops, detoxification, research, training and extension programmes may be prohibitive to the implementation of regulatory procedures.

Internationally, while US FDA maximum allowable limits for aflatoxins and fumonisins in human foods are 20 µg/kg and 4,000 µg/kg respectively (Codex, 2001), the European Commission has stricter guidelines, 15 µg/kg and 2,000 µg/kg for aflatoxins and fumonisins respectively (EC, 2006). In South Africa maximum limits for all foods are 10 µg/kg and 5 µg/kg for total aflatoxins and AFB_1, respectively (Viljoen, 2003) and 0.05 µg/kg of AFM_1 in milk and milk products (Mwanza and Dutton, 2014). Patulin in apple juice and apple juice-based products is set at a legal limit of 50µg/kg (Katerere et al., 2007). Although fumonisin research was pioneered in South Africa and evidence of high dietary exposures from maize were reported, there are no fumonisin regulations in that country (Shephard et al., 2007a; Shephard, 2013; Leroux, 2014; Matumba et al., 2016). Botswana and Zimbabwe have set 15 µg/kg as the maximum limits for aflatoxins in all food. Mozambique stated a maximum level for total aflatoxins with a tolerated concentration of 10 µg/kg in peanuts, peanut milk, and feedstuff (FAO, 2004). In the FAO survey of 2003, Malawi was reported to have an AFB_1 regulation for peanuts of 5 µg/kg, specified for exports and had none for the local market (FAO, 2004; Matumba *et al.*, 2015b). Mauritius has set maximum levels for AFB_1 and total aflatoxins at 5 and 15 µg/kg for peanuts and 5 and 10 µg/kg for all other food (FAO, 20014). No national regulations are currently documented in Botswana, Lesotho, Namibia, Swaziland and Zambia, and none of the countries in Southern Africa has regulations or guidelines for fumonisins (IARC, 2015).

To be considered in formulating and implementing mycotoxin legislation in Southern Africa are the food security concerns of many of the people at risk, which means that even knowing that a food is contaminated would not help because the people have no alternative sources of food. Matumba et al. (2015b) argue that regulatory rules have no relevance to most people in Africa since their consumption of traded items is small and laboratories to test their foods are not available or are inaccessible.

7.0 Challenges to mycotoxin research in Southern Africa

Research on mycotoxins does not appear on top of the agenda in Southern Africa as the region prioritizes research on more pressing human health issues such as HIV/AIDS, malaria and infant mortality (IARC, 2015). Country specific data on occurrence and exposure to mycotoxins is limited in Southern Africa and the limited reported data is usually based on only a limited number of samples of uncertain quality especially in terms of robust sampling design. As a result, there is a widening gap between the quality and quantity of prevalence data generated by laboratories in developed countries compared with developing countries (IARC, 2015). To date, there have been limited efforts to compare methods from different laboratories. Quantification technique, sample size, replicate number and laboratory where analyses are conducted, appear to be important sources of variation for quantification of fumonisins (Janse van Rensburg et al., 2011).

Technological development of highly sensitive liquid chromatography-mass spectrometry (LC-MS(/MS)) techniques will help support mycotoxin monitoring, though the approach may be limited by instrumentation costs, restricting analysis to specialist laboratories, outside Southern Africa. With the development of multi-toxin analytical techniques for food based on LC-MS/MS,

multi-biomarker methods have been developed for urinary biomeasures for toxins, including AFM_1 and FB_1 (Shephard *et al*., 2007a; Warth et al., 2012). While LC-MS provides robust data, the analytical costs are prohibitive for most laboratories. These methods have been applied in African foods, in collaboration with EU laboratories, to evaluate exposure (Abia et al., 2013; Shephard et al., 2013; Ezekiel et al., 2012, 2015; Matumba et al., 2015a,2015b). An additional concern is that some of the multi-mycotoxin methods, especially for foods, may be measuring contaminants of limited relevance to human health (IARC, 2015).

8. Conclusions

This review has provided a recent documentation of mycotoxin occurrence, health impacts, mitigation and legislation in the Southern African region, highlighting the challenges of mycotoxin research in the region. Due to the consumption of undiversified diets, typified by staple foods that are prone to fungal and mycotoxin contamination, populations in this region are clearly at high risk for chronic exposure to dangerous levels of mycotoxins, predominantly aflatoxins and fumonisins, posing serious health concerns. Mycotoxin contamination of major agricultural food commodities also reduces the commercial value of the crops. Creating awareness on the occurrence and toxic effects of mycotoxins, surveillance and introduction of control measures are critical initial steps towards food safety, economic sustainability and public health promotion in the region. Further research should be focused on the generation of data dealing with epidemiological, exposure and toxicity effects.

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Table 1: Mycotoxin contamination of maize and maize products in Southern Africa

Country	Year of study	Food commodity	Source of food commodity	Number of samples	Mycotoxin type	Positive samples (%)	Mean (µg/kg) /*Median	Range (µg/kg)	Reference
Malawi	2012	Traditional maize based opaque beers	Tribal rituals and commercial village brewers	9	AF	89	90±95	NS	Matumba et al., 2014a
	2012	Traditional maize based opaque beers	Tribal rituals and commercial village brewers	9	AF	100	1898±1405	NS	Matumba et al., 2014a
	2012	Maize puffs	Retail markets	12	AF	75	*1.1	0.3-2.0	Matumba et al., 2014a
	2006-2007	Maize	Farmsteads and local markets	9	AF	100	12	5-20	Probst et al., 2014
			Farmsteads and local markets	9	FM	NS	2000	1000-9000	Probst et al., 2014
		Maize	Rural households	90	AF	100	8.3±8.2	0.7-140	Mwalwayo& Thole, 2016
		Maize	Rural households	90	FB_1+FB_2	NS	900±1000	100-7000	Mwalwayo& Thole, 2016
	2008	Maize	Households	108	AFB_1	45.3	1.71± 3.17	NS	Matumba et al., 2009
Mozambique	2010	Maize	Local markets, traders, rural villages	13	AFB_1	46	*69.9	16-636	Warth et al., 2012
				13	FB_1	92	*869	159-7615	Warth et al., 2012
	2006-2007	Maize	Farmsteads and local markets	42	AF	0	0	0	Probst et al., 2014
				42	FM	NS	2000	0-10000	Probst et al., 2014
Zambia	2006-2007	Maize	Farmsteads and local markets	28	AF	NS	7	0-108	Probst et al., 2014
				28	FM	NS	2000	0-	Probst et al.,

								21000	2014
	2006	Maize	Villages	114	FM	100	73300	3700-192000	Mukanga et al., 2014
					AF	100	5.4	0.2-10	Mukanga et al., 2014
Zimbabwe	2014	Maize meal	Subsistence farmer household stores	95	FB_1	95	242±236	nd-1106	Hove et al., 2016a
					FB_2	31	120±0.3	nd-334	
					FB_3	1	57±12	nd-67	
					AFB_1	1	11	nd-11	
					AFG_1	1	4	nd-4	
					AFB2	1	3	nd-3	
					DON	24	217±165	nd-492	
					ZEN	15	110±101	nd-369	
					AME	2	60±67	nd-108	
	2006-2007	Maize	Farmsteads and local markets	19	AF	NS	9	0-123	Probst et al., 2014
				19	FM	100	105000	36000-159000	Probst et al., 2014
		Maize	Rural households Shamva	166	AFB_1	22	*3.33	0.65-26.60	Murashiki et al., 2016
				166	FB_1	100	*295.15	10.43-432.32	Murashiki et al., 2016
		Maize	Rural households Makoni	222	AFB_1	20	*2.98	0.57-9.22	Murashiki et al., 2016
		Maize		222	FB_1	100	*360.18	13.84-606.64	Murashiki et al., 2016
South Africa	2011	Commercial maize	Commercial companies	40	AFB_1	33	94	0-741	Chilaka et al., 2012
		Commercial maize	Commercial companies	40	FB_1	45	331	8-892	Chilaka et al., 2012

		Home grown maize	Village households	54	FB_1	100	2083± 3630	56-14 990	Shephard et al., 2013a
	2006	Maize meal	Retail stores	18	DON	89	262±326	<10-960	Shephard et al., 2010
		Maize	Subsistence farmers	400	FM	15	1	1840-142800	Mogensen et al., 2011
				400	AF	0	0	0	Mogensen et al., 2011
	2008-2009	Maize	Cultivar evaluation localities	45	FB_1	62	1793	NS-11624	Boutigny et al., 2012
	2006-2007	Maize	Subsistence farmers	261	FM	NS	NS	0-21800	Ncube et al., 2011
	2011	Home grown maize	Rural households Limpopo province	29	AF	21	NS	1-149	Mngqawa et al., 2015
				52	FM	92	NS	12-8514	Mngqawa et al., 2015
		Home grown maize	Rural households Mpumalanga province		AF				
				62	FM	47	NS	12-2732	Mngqawa et al., 2015
	2003	Maize	Rural villages Centane area	24	FM	96	NS	nd-8385	Rheeder et al., 2016
	2005-2006	Maize	Homestead farms Cape Province	201	FM	15	NS	>1000	Waalwijk et al., 2008
	2006-2007	Maize	Homestead farmsCape province	126	FM	12	NS	>1000	Waalwijk et al., 2008
	2003	Good maize	Subsistence farmers	7	FB	100	NS	2.75±2.24	Shephard et al., 2011
		Mouldy maize		7	FB	100	NS	23.4±12.5	Shephard et al., 2011
		Good maize		7	FC	86	NS	0.107± 0.099	Shephard et al., 2011

		Mouldy maize		7	FC	100	NS	0.814± 0.391	Shephard et al., 2011
		Maize meal	Villages	10	FB	100	NS	2130-13268	Shephard et al., 2012
		Maize porridge	Villages	10	FB	100	NS	1564-12268	Shephard et al., 2012
Lesotho	2010-2011	Maize	Subsistence farmers	40	FB_1	NS	NS	7–936	Mohale et al., 2013
	2010-2011	Maize	Subsistence farmers	40	AFB_1	NS	NS	nd-3500	Mohale et al., 2013
Key									
nd: not detected		**FC: Total Fumonisin C**							
NS: Not stated									
AF: Total Aflatoxin									
FM: Total Fumonisin									
FB: Total Fumonisin B									

Table 2: Mycotoxin contamination of peanut and peanut products in Southern Africa

Country	Year of study	Food commodity	Source of food commodity	Number of samples	Mycotoxin type	Positive samples (%)	Mean/* Median(µg/kg)	Range (µg/kg)	Reference
Malawi	2012-2013	Fresh peanuts	Local markets	69	AF	93	122.3	7-500	Matumba et al., 2014b; 2015a
		Fresh peanuts	Mycotoxin Lab Export samples	27	AF	59	2.6	NS-9.3	Matumba et al., 2014b;2015a
		Locally processed peanut butter	Local supermarkets	14	AF	100	*72	34.3-115.6	Matumba et al., 2014b;2015a
		Imported peanut butter	Local supermarkets	11	AF	73	*0.7	2.7-4.3	Matumba et al., 2014b;2015a
	2012	Unskinned roasted peanuts	Local markets	9	AF	56	*0.5	0.5-2.5	Matumba et al., 2014b
		Deskinned roasted peanuts	Local markets	15	AF	73	*8.2	0.6-36.9	Matumba et al., 2014b
		Peanut based therapeutic foods	Local supermarkets	6	AF	100	*2.1	1.6-2.9	Matumba et al., 2014b
	2009	Peanuts	Farm homesteads, local markets	1397	AFB_1	46	>4	NS	Monyo et al., 2012
			Warehouses, retail shops		AFB_1	21	>20	NS	Monyo et al., 2012
Zambia	2012	Peanut butter	Retail outlets	11	AFB_1	73	>20	NS-130	Njoroge et al., 2016
	2013	Peanut butter	Retail outlets	15	AFB_1	80	>20	NS-10000	Njoroge et al., 2016
	2014	Peanut butter	Retail outlets	19	AFB_1	53	>20	NS-1000	Njoroge et al., 2016
Zimbabw		Peanuts	Retail outlets and informal	18	AF	17		6.6-622	Mupunga

e			markets						et al., 2014
		Peanut butter	Retail outlets and informal markets	11	AF	91	75.66	NS	Mupunga et al., 2014
						0		6.1-247	Mupunga et al., 2014
Botswana		Peanuts	Retail outlets and informal markets	16	AF				
South Africa	2011	Peanuts	Informal markets	20	AFB_1	90	NS	0-35.39	Kamika et al., 2014
		Peanuts		1189	AFB_1		NS	0-3871	Icrisat, 2010
	2007	Peanuts	Subsistence farmers	18	AF	100	22.66	0.26-131.03	Ncube et al., 2010
Mozambique		Peanuts	Local markets, traders, rural villages	23	AFB_1	14	NS	3.4-123	Warth et al., 2012
Key									
nd: not detected		**FC: Total Fumonisin C**							
NS: Not stated									
AF: Total Aflatoxin									
FM: Total Fumonisin									
FB: Total Fumonisin B									

Table 3: Mycotoxin contamination of sorghum, wheat and their products in Southern Africa

Country	Year of study	Food commodity	Source of food commodity	Number of samples	Mycotoxin type	Positive samples (%)	Mean/* Median	Range (µg/Kg))	Reference
Botswana	2011	Sorghum	Retail markets/Farmsteads	16	AF	0	0	0	Mupunga et al., 2014
Zimbabwe	2011	Sorghum	Informal markets	18	AF	0	0	0	Mupunga et al., 2014
				18	FM	61	NS	8-187	Mupunga et al., 2014
Malawi	2009	Traditional sorghum beer	Rural households	5	AF	100	22.3 ±4.93	NS	Matumba et al., 2011
		Non alcoholic beverage (Tobwa)	Rural households	7	AF	43	4.50 ±1.45	NS	Matumba et al., 2011
		Sorghum	Rural households	13	AF	15	2.35 ±0.65	NS	Matumba et al., 2011
		Sorghum malt	Rural households	6	AF	100	*17.57 ±7.52	NS	Matumba et al., 2011
	2009	Sorghum malt beer	Rural households	21	AF	100	408.45±67.97	4.3-1138.8	Matumba et al., 2011
South Africa	2007-2009	Sorghum	Commercial production areas	NS	AF	NS	NS	0.01-2.53	Janse van Rensburg, 2011
	2006	Wheat flour	Retail outlets	23	DON	52	19±22	<10 to 100	Shephard et al., 2010
Key									
nd: not detected		**FC: Total Fumonisin C**							

NS: Not stated									
AF: Total Aflatoxin									
FM: Total Fumonisin									
FB: Total Fumonisin B									

Table 4: Mycotoxin contamination of other food commodities in Southern Africa

Country	Year of study	Food commodity	Source of food commodity	Number of samples	Mycotoxin type	Positive samples (%)	Mean/* Median	Range (µg/Kg))	Reference
South Africa		Cow milk	Farmsteads	42	AFM_1	10	0.12	0.04-1.32	Dutton *et al*., 2010
	NS	Apple juice	Retail outlets	8	Patulin	63	NS	<10-75.2	Katerere *et al*., 2007
	2006	Apple juice	Retail outlets	30	Patulin	33	73±300	<10 to 1,650	Shephard et al., 2010
	2010-2011	Raw milk	Rural subsistence dairy farms	125	AFM_1	78	0.15	NS	Mwanza and Dutton, 2014
		Raw milk	Commercial dairy farms	100	AFM_1	85	0.14	NS	Mwanza and Dutton, 2014
Zimbabwe	2014	Edible stink bugs (unprocessed)	Forests	2.5 Kg	AFB_1	NS	0.50±0.17	NS	Musundire *et al*., 2016
		Edible stink bugs (processed)	Forests	2.5Kg	AFB_1	NS	0.59±0.18	NS	Musundire *et al*., 2016
Malawi	2008-2009	Processed cassava products		88	AF	2	NS	NS	Chiona *et al*., 2014
Zambia	2009	Dried cassava chips and flour		22	AF	9.1	NS	NS	Chiona *et al*., 2014
Key									
nd: not detected		**FC: Total Fumonisin C**							
NS: Not stated									
AF: Total Aflatoxin									
FM: Total Fumonisin									

FB: Total Fumonisin B									