Presence of Fusarium Species and Fumonisin Contamination of Maize in Sub-Saharan Africa: A Systematic Review

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Abstract

Fumonisin is the second most commonly isolated mycotoxin in maize, produced mainly by Fusarium verticillioides. Fumonisins are associated with health effects in humans and animals. We reviewed the available literature on fumonisin contamination of maize in Sub-Saharan Africa (SSA) and the Fusarium species linked to the contamination. We searched for articles in Science Direct, PUBMED, and Google Scholar databases in June 2018 and updated in August 2018. We employed narrative synthesis in data synthesis. Out of the 2,156 records obtained from the search, 39 met the inclusion criteria. Of the included studies, 37 were cross-sectional studies, while two were controlled trials. Fourteen of the included studies were based on South Africa. The Fusarium species predominantly responsible for fumonisin production was Fusarium verticillioides. Other notable Fusarium species included F. proliferatum and F. graminaerum. In 13 studies, all samples tested positive for fumonisins. The levels of Fumonisin varied from one country to another and region to another in the same country. With maize fumonisin contamination reported in several SSA countries, there is a higher risk of human exposure and hence, health effects on individuals.

Keywords*:* *Fusarium;* fumonisins*; maize;* Sub-Saharan Africa

INTRODUCTION

Fusarium is a genus of fungi with species that produce mycotoxins with the ability to cause toxicity in animals, plants and humans (Abbas *et al*., 2013). *Fusarium* species can infect plants during different development stages. They cause diseases in plants such as seed rot, rudimentary ear rot, ear and kernel rot, root and stem rot (Meissle *et al.,* 2010). The most common mycotoxins produced by *Fusarium* species are fumonisins, moniliformins, zearalenone, and trichothecenes (Schollenberger *et al*., 2005).

Mycotoxins that are toxicologically significant in food include aflatoxin, fumonisins, ochratoxin A (OTA), zearalenone (ZEA), trichothecenes and deoxynivalenol (DON). Most of these mycotoxins are produced by *Fusarium, Aspergillus* and *Penicillium* species of fungi (Gnonlonfin *et al.,* 2013).

Aflatoxin is the most prevalent mycotoxin in Africa (43.8%) with fumonisin being the second most prevalent (21.9%). Other reported mycotoxins in Africa include ochratoxin (12.5%), nivalenol (6.3%), beauvericin (6.3%) and deoxynivalenol (DON) (Darwish *et al.,* 2014).

Fumonisins were first discovered in South Africa in the year 1988 (Marasas, 2001). They are the most detected mycotoxins in maize, especially in Africa (Marasas, 1982). Fumonisin is one of the mycotoxins that contaminate cereals and its products posing a health threat to both humans and animals (De Ruyck *et al.,* 2015).

The *Fusarium spp* known to produce fumonisin includes; *Fusarium verticillioides* previously *Fusarium moniliforme, F. proliferratum, F. globosum* and *F. oxysporum* (Weidenbörner, 2001). Of the different species, *F. verticillioides and F. proliferatum* are the primary fumonisins producers (Zhang *et al.,* 2013). However, the existing environmental conditions and the region have been reported to influence the presence of a given *Fusarium* species which produce fumonisin in a particular geographical location (Ferrigo *et al.*, 2016). There are more than 28 forms of fumonisins (Alberts *et al.,* 2016). Fumonisin B_1 and B_2 are the main isolated forms of fumonisin and are the main maize contaminants in many regions (Alizadeh *et al.*, 2012).

Ingestion of maize and its products contaminated by or with fumonisin is fatal to animals. Fumonisins cause leukoencephalomalacia in horses and pulmonary oedema syndrome in procine. It also causes liver, heart and kidney toxicity in cattle, sheep, horses, rabbits, pigs and rats (Bucci & Howard, 1996). Experiments in rats and mice have shown that fumonisin B_1 results in liver tumours in mice and, kidney and liver tumours in rats (International Agency for Research on Cancer, 1988).

In humans, fumonisin B_1 ingestion has been linked with the occurrence of oesophageal and liver cancer (Sun *et al.,* 2007). It has also been reported to cause food poisoning outbreaks associated with abdominal pain, diarrhoea and borborygmi (Bhat *et al.,* 1997). Other studies have associated fumonisin ingestion with neural tube defects in foetuses (Missmer *et al.,* 2006).

Many countries, especially among the Low and Middle-Income Countries (LMICs), depend on maize and its products for food with maize being a staple food in many of these countries. Maize fumonisin contamination is prevalent in many regions globally, with the contamination being associated with health consequences in both humans and animals. An understanding of the existing *Fusarium* species diversity and maize infestation is vital in informing strategic policy on mycotoxin contamination prevention.

Several mycotoxins contamination mitigations measures have been suggested, including; prevention of exposure, surveillance of mold infestations in stored maize grains, and decontamination (Wagacha & Muthomi, 2008). Harvesting early, drying of the maize to the required moisture content below 14%, observing hygiene of the grains, proper storage and insect control have been reported to be useful agricultural practices for the reduction of fumonisin contamination threat (Wagacha & Muthomi, 2008).

Despite the known effects of fumonisin contamination in maize, there is a dearth of evidence to inform control and management practices. Several studies have attempted to look at mycotoxins in Sub-Saharan Africa in general in different foods and products (Bankole *et al.,* 2006; Chilaka *et al.,* 2017; Sibanda, 1997; Udomkun, 2017). There was also an attempt to review information on *Fusarium* and fumonisin in Africa, but this review was non-systematic (Fandohan *et al.,* 2003). Hence, there exists a gap on information regarding maize fumonisin contamination in Sub-Saharan African while maize is a staple food of most residents of the region. This review aims at providing the much-needed data to inform policies and practices towards the control of fumonisin contamination in Sub Saharan Africa.

This paper reviewed the available information on the presence of *Fusarium* species and fumonisin contamination of maize in SSA in order to highlight the magnitude of the problem and the need to put in place control and management measures for the problem. This will help contain the threat posed by the contamination.

METHODOLOGY

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines (Moher *et al.,* 2009). We did not include a meta-analysis due to the differences in study designs and statistical analyses employed in individual studies. These differences and the high heterogeneity made it difficult to carry out a meta-analysis (Ioannidis *et al.,* 2008); hence, we only carried out a systematic review.

We included articles that met the following criteria;
Articles on *Fusarium* and fumonisin contamination in maize
Published between the year 2000 and 2018.
Articles published in English language or whose translation to English were available for those published in other languages.
Articles based on Sub-Saharan Africa Countries.
We excluded studies dealing with crops other than maize.
We searched for articles in PUBMED, Science Direct and Google Scholar databases in June 2018 and updated it in August 2018. We selected these databases due to their relevance as most of biomedical, health and agriculture-related articles are indexed in them. We used different databases as a single databases does not index all the articles (Popay *et al.,* 2006). Besides, studies on fumonisin and *Fusarium* are done by multidisciplinary researchers from different fields necessitating the use of different databases to exhaustively access relevant articles (Ogilvie *et al*., 2005).

We also searched for references of selected articles in Google Scholar. We attempted to contact the experts and researchers in the field and sought more information and articles from them.

In PUBMED, we searched using the MESH terms that we joined using (AND/OR) Boolean terms. The search term we employed in the PUBMED search was; *("Fusarium"[Mesh]) AND ("Fumonisins"[Mesh] OR "fumonisin* B_1*" OR "fumonisin* B_2*" [Supplementary Concept] AND "Zea mays"[Mesh])*. We used the Science Direct advanced search. We used the key terms; *Fusarium, fumonisin, maize OR Zea mays, Sub-Saharan Africa,* for the search in Science Direct and Google Scholar. In addition, we carried out a manual search on references of selected articles.

We first screened the records by title where we excluded those that did not meet the criteria of eligibility. We then screened the abstracts of the remaining ones and removed those that did not meet the set criteria. For those articles where we could not arrive at a definitive agreement by titles and abstracts, we downloaded their full articles together with those that remained after eliminating by title and abstract. We screened the downloaded full articles by reading their full content and eliminated those that did not meet the inclusion criteria. We included in the review the remaining articles that satisfied all the inclusion requirements.

We prepared a manual data extraction tool. We carried out a pilot of the tool to test its reliability and validity. We then used it in extracting data from the articles. Two authors; PK and PM, working independently, did data extraction manually. The items extracted from each article included, (i) first author and year of publication, (ii) study setting, iii) study design, iv) sample size (v) fumonisin quantification method, (vi) *Fusarium* species vii) mean/level/range of fumonisin levels and viii) factors affecting *Fusarium* and fumonisin levels.

We used narrative synthesis in this review where the synthesis of the findings from the different studies depended mainly on the use of text summaries (Popay *et al.,* 2006). Although we applied statistical manipulation of data to some extent, we mainly used the textual approach in the synthesis process.

Ethical considerations

We did not seek ethical approval for the review since human subjects were not directly involved. However, we followed ethical guidelines when dealing with systematic reviews. We observed transparency while maintaining integrity in the process (Wager & Wiffen, 2011). We took measures to eliminate bias in the process.

RESULTS

Search results

We obtained a total of 2,156 article records; 300 from the PubMed database, 780 from Science Direct journals collection, and 1,070 from the Google Scholar database. A manual search on the references of selected articles generated six records. After eliminating the duplicates, 1,076 records remained. We assessed the remaining record by title against the eligibility criteria from which we excluded 600 records. We assessed the remaining records by abstract from which we excluded 391. On those articles of which we could not conclude by abstract, we downloaded their whole articles for a full review. Of the 85 full articles we downloaded, 46 did not meet the criteria, and we excluded them. Hence, 39 articles remained, and we included them in this paper (Figure 1).

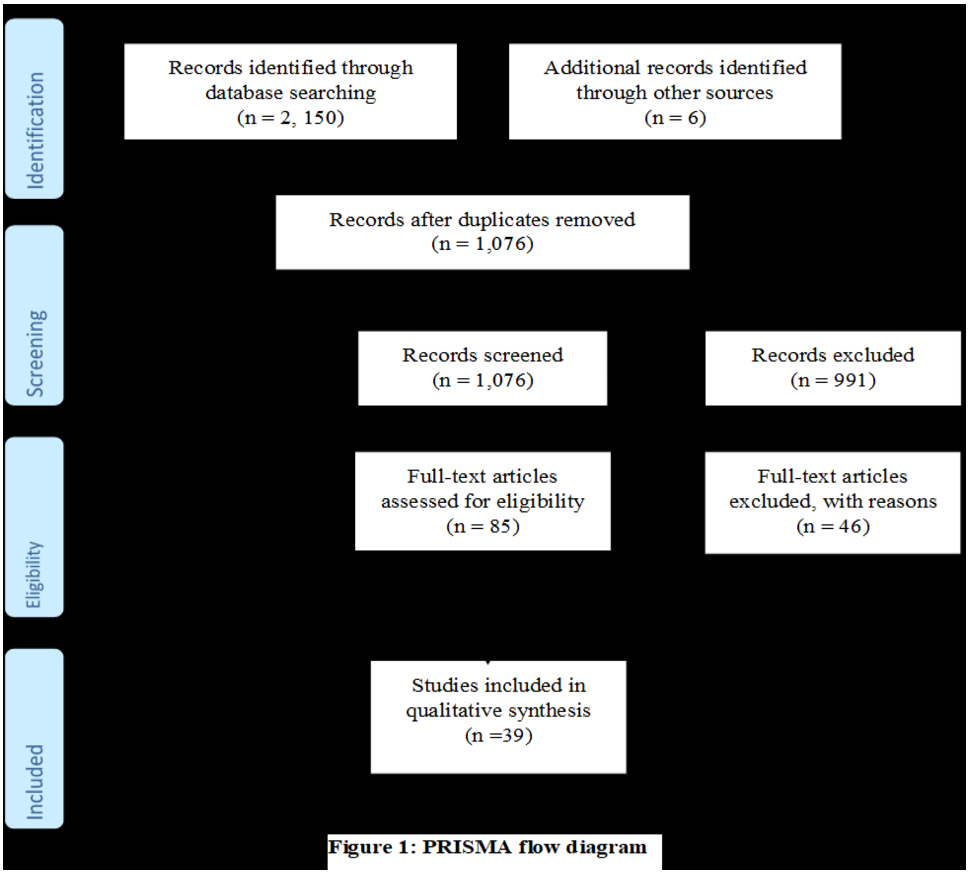

Figure 1: PRISMA flow diagram

Of the included studies, 37 were cross-sectional studies while two were controlled trials (Janse van Rensburg, McLaren, & Flett, 2017; Janse van Rensburg, McLaren, Flett, & Schoeman, 2015). Of the 39 studies, 14 were conducted in South Africa (Boutigny *et al.,* 2012; Chelule *et al.,* 2001; Chilaka *et al.,* 2012; Fandohan *et al.,* 2006; Mngqawa *et al.,* 2016; Mogensen *et al.,* 2011; Ncube *et al.,* 2011; Phoku *et al.,* 2012; Rheeder, Van der Westhuizen *et al.,* 2016; Shephard *et al.,* 2013; Van der Westhuizen *et al.,* 2010; Van der Westhuizen *et al.,* 2008; Janse van Rensburg *et al.,* 2017; Janse van Rensburg *et al.,* 2015). Four were conducted in Nigeria (Adejumo *et al.,* 2007; Adetuniji *et al.,* 2014; Afolabi *et al.,* 2006; Bankole & Mabekoje, 2004), four in Kenya (Alakonya *et al.,* 2009; Bii, 2012; Bii *et al.,* 2012; Mutiga, Hoffmann *et al.,* 2015; Mutiga *et al.,* 2014) and another four were from Tanzania (Kamala *et al.,* 2016; Kimanya *et al.,* 2010; Kimanya *et al.,* 2008; Nyangi *et al.,* 2016). Zimbabwe (Gamanya & Sibanda, 2001; Hove *et al.*, 2016; Murashiki *et al.,* 2017) had three articles. Benin (Fandohan *et al.,* 2005), Cameroon (Ngoko *et al.,* 2001), Ghana (Kpodo *et al.,* 2000), Lesotho (Mohale *et al.,* 2013), Ethiopia (Tsehaye *et al.,* 2017), Uganda (Atukwase *et al.,* 2012), Zambia (Mukanga *et al.,* 2010) , Malawi (Mwalwayo & Thole, 2016), Burkina Faso (Nikiema *et al.,* 2004) and Cote d'Ivoire (Sangare-Tigori *et al.,* 2006) had one each. High Performance Liquid Chromatography (HPLC) was used for fumonisin quantification in 23 of the studies with Enzyme-Linked Immunosorbent Assay (ELISA) being used in twelve studies.

RESULTS FROM INDIVIDUAL STUDIES

Fusarium and Fumonisin

The dominant *Fusarium* species in the included studies was *Fusarium verticillioides* (Adejumo *et al.,* 2007; Afolabi *et al.,* 2006; Alakonya *et al.,* 2009; Atukwase *et al.*, 2012; Bankole & Mabekoje, 2004; Boutigny *et al.,* 2012; Chilaka *et al.,* 012; Fandohan *et al.,* 2005; Gamanya & Sibanda, 2001; Kpodo *et al.,* 2000; Mohale *et al.,* 2013; Mukanga *et al.*, 2010; Ncube *et al.*, 2011; Phoku *et al.,* 2012; Rheeder *et al.,* 2016; Shephard *et al.,* 2013; Tsehaye *et al.,* 2017). In the study by Shephard et al. (Shephard *et al.,* 2013), all samples tested positive for *F. verticillioides* while in the study by Bankole and Mabekoje (Bankole & Mabekoje, 2004), 89.3% of the samples tested positive. The study by Chilaka *et al.* (2012) had 88% *F. verticillioides* positive samples. Other studies where the incidence of *F. Verticillioides* was high included study by Atukwase *et al*. (2012) where 61.9%-77.5% of the sample were positive, study by Phoku *et al.,* (2012) where 70.3% of the samples were positive, study by Adejumo *et al.,* (2007) where the positive samples were 70% and the study by Kpodo *et al.,* (2000) where the positive samples for *F. Verticillioides* were 65.9%.

Other common *Fusarium* species identified in the studies were *F. proliferatum* with an incidence of 73% in the study by Chilaka *et al.,* (2012), 31% in the study by Fandohan *et al.,* (2005), 18.5% in the study conducted by Phoku *et al.,* (2012), 15.1% in the study by Bii *et al.*, (2012), and 12% in the study by Adejumo *et al.,* (2007); *F. graminearum* with an incidence of 30% in the Adejumo *et al.,* (2007) study, 27% in the study by Ngoko *et al.,* (2001) and 22.5% in the study by Tsehaye *et al.*, (2017).

Apart from *F. verticillioides* that was dominant in the majority of the studies, followed by *F. proliferatum* and *F. graminaerum*, other *Fusarium* species were identified although at low incidence with the species varying from one study to another. These species included *F. oxysporum* (Bii *et al.,* 2012; Phoku *et al.,* 2012; Tsehaye *et al.*, 2017) , *F. subglutinans* (Alakonya *et al.,* 2009; Boutigny *et al.*, 2012; Mohale *et al.*, 2013; Ncube *et al.*, 2011; Shephard *et al.,* 2013; Tsehaye *et al.,* 2017), *F. equiseti* (Kpodo *et al.,* 2000), *F. sporotuichoides* (Adejumo *et al.,* 2007), *F. psuedoanthophilium* (Bii *et al.,* 2012; Tsehaye *et al.,* 2017), *F. solani* (Bankole & Mabekoje, 2004), *F. pollidoseum* (Bankole & Mabekoje, 2004), *F. lateritium* (Bii *et al.,* 2012) and *F. semilectum* (Kpodo *et al.,* 2000).

In 13 studies, all samples tested were positive for fumonisins (Afolabi *et al.,* 2006; Alakonya *et al.,* 2009; Atukwase *et al.,* 2012; Chilaka *et al.,* 2012; Fandohan *et al.,* 2005, 2006; Gamanya & Sibanda, 2001; Kpodo *et al.,* 2000; Mutiga *et al.,* 2014; Nikiema *et al.,* 2004; Sangare-Tigori *et al.,* 2006; Shephard *et al.,* 2013; Van der Westhuizen *et al.,* 2010). The number of fumonisin positive samples in most of the studies were above 50% except in three studies by Nyangi *et al.,* (2016) with 35% positive samples, Mngqawa *et al.,* (2016) where only 47% of the samples from one of the two districts were positive and Chelule *et al.*, (2001) where only 31.9% of the rural samples were fumonisin positive (Table A1).

The level of fumonisin varied from one study to another with some samples having high levels than recommended. However, the levels of fumonisin in most of the studies were low, when compared to the minimum allowable level of 4000 µg/kg set by Unites States (US Food Drug Administration, 2001) and South African Standards (Ministry of Health, 2016).

The highest mean fumonisin level (8,819 µg/kg) was observed in the study by Phoku et al. (Phoku et al., 2012). The levels of fumonisin B_1 were higher than those of fumonisin B_2 and B_3 in studies where the three were differentiated (Boutigny *et al.,* 2012; Hove *et al.,* 2016;

Kimanya *et al.,* 2010; Murashiki *et al.,* 2017; Ngoko *et al.,* 2001; Shephard *et al.,* 2013) (Table A1).

When compared to the set allowable minimum limits of 4000 µg/kg by FDA (US Food Drug Administration, 2001) and South African Standards (Ministry of Health, 2016), analyzed samples in the study by Phoku *et al.,* (2012) and Fandohan *et al.,* (2005), had a mean fumonisin levels in excess of these limits. It is only the study by Fandohan *et al.,* (2005) where all the 48 analyzed samples had fumonisin levels in excess of the allowable limits with the level of fumonisins in the study being in the range of 8, 240- 16690 µg/kg. Ten of the studies also had a number of their samples having more fumonisin levels than recommended (Kamala *et al.,* 2016; Kimanya *et al.,* 2008; Kpodo *et al.,* 2000; Mngqawa *et al.,* 2016; Mukanga *et al.,* 2010; Nikiema *et al.,* 2004; Phoku *et al.,* 2012; Rheeder *et al.,* 2016; Shephard *et al.*, 2013; Tsehaye *et al.,* 2017). In the study by Kpodo *et al.,* (2000), the range of fumonisin levels in the 15 samples analyzed was 70- 4,222 µg/kg while in the study by Phoku *et al.*, (2012), the range of fumonisin levels was 101- 53, 863 µg/kg. According to the findings of the study by Kimanya *et al.,* (2008), the levels of fumonisin in the 120 analyzed samples were in the range of 61 -11,048 µg/kg. Kamala *et al.,* (2016), reported that out of the 120 samples, fumonisin levels were in the range of 49-18273 µg/kg. However, for the majority of the studies, the fumonisin levels were within the allowed limits for human and animal consumption (Table A1).

Factors associated with fumonisin levels

The level of fumonisin varied from region to another in the same country as was the case in eight studies (Adejumo *et al.,* 2007; Boutigny *et al.,* 2012; Hove *et al.,* 2016; Mukanga *et al.,* 2010; Mutiga *et al.,* 2014; Mwalwayo & Thole, 2016; Ncube *et al.,* 2011; Nyangi *et al.,* 2016), and from country to country. It also varied with the season and period of the year (Boutigny *et al.,* 2012; Fandohan et al., 2005; Janse van Rensburg *et al.,* 2017).

The level of rainfall and humidity influenced fumonisin levels (Atukwase *et al.,* 2012; Mukanga *et al.,* 2010; Tsehaye *et al.,* 2017; Janse van Rensburg *et al.,* 2017; Janse van Rensburg *et al.,* 2015). In a study by Atukwase *et al.* (2012), high moisture content was positively correlated with fumonisin levels, while rainfall severity was positively correlated with the level of fumonisin in the study by Mukanga *et al.* (2010). Tsehaya and colleagues' study showed a significant positive correlation between high humidity and fumonisin levels (Tsehaye *et al.,* 2017).

Another environmental factor associated with fumonisin levels was temperature (Fandohan *et al.,* 2005; Tsehaye *et al.,* 2017; Janse van Rensburg *et al.,* 2017; Janse van Rensburg *et al.,* 2015). According to Tsehaye and colleagues, high temperatures during the growing season and storage period results in increased levels of fumonisin in maize (Tsehaye *et al.*, 2017).

Some of the after-harvest maize handling practices were also associated with fumonisin contamination. In the study by Hove *et al.,* (2016) transporting maize while still on cobs, or as grains without placing it in polypropylene bags was associated with high contamination levels of maize with fumonisins.

The storage method of maize after harvesting was also linked with the level of fumonisin contamination. Maize stored in traditional mudsilos had higher levels of fumonisins when compared to maize stored in granaries after six months of storage (Atukwase *et al.,* 2012). The storage of maize in well-ventilated structures was associated with a significant reduction in the fumonisin contamination level (Fandohan *et al.,* 2005).

Some maize handling practices were also shown to influence fumonisin levels. Sorting of maize before storage was associated with low fumonisin levels (Kamala *et al.,* 2016; Mutiga *et al.,* 2014). A study by Mutiga *et al.* (2014) showed that sorting maize reduces fumonisin contamination by 65%. Methods of drying and storage were also shown to influence fumonisin levels. In a study by Kamala *et al*. in Tanzania, storage of unsorted maize, drying of the maize on bare ground, and not using chemical insecticides before storage increased the likelihood of maize contamination with fumonisins (Kamala *et al.,* 2016).

Damage of maize grains by insects (Fandohan *et al.,* 2005) or during shelling (Fandohan *et al.,* 2006) was shown to be associated with high fumonisin contamination. There was a significant positive correlation between pest infestation in maize and level of fumonisin (Fandohan *et al*., 2005). Damage by shelling was also associated with a significant increase in the fumonisin levels (Fandohan *et al.,* 2006).

High level of farmers' knowledge on mycotoxins was significantly associated with a low level of fumonisin contamination (Nyangi *et al.,* 2016). The variety of maize grown was also shown to influence the level of fumonisins contamination with some maize varieties being associated with high levels of contaminated than others (Mutiga *et al.,* 2015). (Table 1).

Table 1: Factors associated with fumonisin

No	Variable	Study
1	Season or year	(Boutigny *et al.,* 2012; Fandohan *et al.*, 2005; Janse van Rensburg *et al.,* 2017)
2	Level of *Fusarium* spp	(Ncube et al., 2011)
3	Region and area	(Adejumo *et al.,* 2007; Boutigny *et al.,* 2012; Hove *et al., 2016*; Mutiga et al., 2015; Mutiga *et al.,* 2014; Ncube et al., 2011; Nyangi *et al.,* 2016)
4	Method of maize storage	(Fandohan *et al.,* 2005)
5	Period of storage	(Atukwase *et al.,* 2012; Fandohan *et al.,* 2005; Ngoko *et al.*, 2001)
6	Rainfall	(Mukanga *et al.,* 2010; Tsehaye *et al.,* 2017; Janse van Rensburg *et al.,* 2017)
7	Temperature	(Fandohan *et al.,* 2005; Tsehaye *et al.,* 2017; Janse van Rensburg *et al.,* 2017; Janse van Rensburg *et al.,* 2015)
8	Humidity and moisture content	(Atukwase *et al.,* 2012; Tsehaye *et al.,* 2017; Janse van Rensburg *et al.,* 2017; Janse van Rensburg *et al.,* 2015)
9	Insect damage	(Fandohan *et al.,* 2005)
10	Storing unsorted maize	(Kamala *et al.,* 2016; Mutiga *et al.,* 2014)
11	Storage without insecticides	(Kamala *et al.,* 2016)
12	Drying on bare grounds	(Kamala *et al.,* 2016)
13	Handling of residue from previous harvest	(Hove *et al.,* 2016)
14	Method of transportation of harvested maize	(Hove *et al.,* 2016)
15	Time taken to remove from the field after harvesting	(Hove *et al.,* 2016)
16	Length of drying	(Hove *et al.,* 2016)
17	Damage	(Fandohan *et al.,* 2006)
18	Ventilation in storage	(Fandohan *et al.,* 2005)
19	Maize variety	(Mutiga *et al.,* 2015)
20	Sampling period	(Mutiga *et al.,* 2015)
21	Mycotoxin awareness among farmers	(Nyangi *et al.,* 2016)

DISCUSSION

Fusarium and fumonisin levels

Fusarium verticillioides was the predominant *Fusarium* species reported in the majority of the studies examined. This species is the leading producer of fumonisin, followed by *F. proliferatum* (Marasas, 2001). Although several other *Fusarium* species have been shown to cause fumonisin contamination, *F. verticillioides* is the leading cause, especially in tropical and sub-tropical regions (Logrieco *et al.,* 2002; Picot *et al.,* 2010).

Fumonisin presence was found in all study regions covered by the papers reviewed. These findings were in agreement with those of other studies, which have shown fumonisin to be the most common maize contaminant in the world. Fumonisin contaminates maize more than any other crops that are also known to be contaminated by it (Waśkiewicz *et al.,* 2012).

The fumonisin levels in maize differed by region. In most of the studies, some samples had very high levels of Fumonisin B_1 and B_2 above the recommended levels by most regulatory bodies. The United States Food and Drug Administration (FDA) recommends an allowed

FB_1 level of 4000 µg/kg (4ppm) for whole dry milled maize products meant for human consumption and 2000 µg//kg (2ppm) in de-germed dried, milled maize (US Food Drug Administration, 2001). Similarly, South Africa regulations have 4000 µg/kg as the maximum allowable level of $FB_1 + FB_2$ in maize meant for human consumption which is yet to be processed (Ministry of Health, 2016). Unfortunately, most Sub-Saharan countries do not have their set standards, as was noted by (Marasas, 2001), something which might be contributing to the unregulated consumption of contaminated maize.

With maize being a staple food in most of the countries, there is a likelihood that individuals are consuming maize and maize products with fumonisin levels that are higher than the set standards.

Exposure to fumonisin occurs in many countries with varying levels of fumonisin being detected in humans. Maize and its products are essential components of the human diet in most developing countries. Hence, individuals in these regions are at risk of exposure to high fumonisin levels. Exposure to FB_1 in Tanzania was reported to be within the range of 0.78 - 141.97 µg/kg bw/ day (Kimanya *et al.,* 2008). Another study by Kimanya showed that infants were exposed to fumonisins through maize-based foods with levels ranging from 0.003 µg/kg bw/day to 28.838 µg/kg bw/day (median; 0.48 µg/kg bw/day) with 26 of the 131 infants being exposed to levels higher than the allowable levels of 2 µg/kg bw/day (Kimanya *et al.,* 2010). Human exposure was shown to be 0.063 µg/kg bw/day in individuals living in Brazilian. However, this is within the recommended limits (Bordin *et al.,* 2014).

This puts them at risk of diseases and conditions associated with fumonisin. Exposure of children or infants to fumonisins can lead to impairments and growth retardation, as was reported in Tanzania (Chen *et al.,* 2018; Kimanya *et al.,* 2010; Shirima *et al.,* 2015). Studies from different regions have shown consumption of fumonisin contaminated food can lead to oesophageal cancer as was reported in South Africa (Marasas, 1982, 1988; Marasas, Wehner, Janse Van Rensburg, & Van Schalkwyk, 1981; Rheeder et al., 1992) Iran (Shephard et al., 2000) and Italy (Franceschi *et al.,* 1990). Studies in China showed an increased incidence of liver cancer in people who consumed fumonisin contaminated maize (Chu & Li, 1994; Li *et al.,* 2001). WHO has classified fumonisin to be carcinogenic in the class 2B group (IARC, 2011). Apart from cancer, fumonisin contamination has been associated with neural tube defects (Hendricks, 1999; Marasas *et al.*, 2004; Placinta *et al.,* 1999).

Factors associated with fumonisin contamination

Fusarium spp. infestation and fumonisin contamination of maize varied from one region to another in the same country and from country to another, with some having higher levels of contamination than others. This was also observed by (Dorn *et al.,* 2011). This has been widely linked to the varying environmental conditions existing in the different regions during the growth and harvesting of maize.

As was the case in some of the studies, a study by (Picot *et al.,* 2010) found rainfall level and the temperature to influence fumonisin levels. However, the association reported in the included article cannot be conclusively depended on, as a result of the small sample sizes involved in the studies.

Strengths and limitations of the review

There was some consistency in results providing evidence of prevalence of fumonisin in maize grown in most parts of sub-Saharan African countries. However, in most of the studies, the levels are within the allowed limits. Most of the studies used small sample sizes making it hard to generalize and to draw conclusive associations. There was high heterogeneity between the studies with the methodologies employed varying from one study to another, making it hard to carry out a meta-analysis, which would have provided critical evidence. With observational studies, there is always a high change of more extreme heterogeneity as compared to when dealing with interventional studies (Stroup *et al.,* 2000).

There were also differences in low fumonisin detection limits in the different studies making it hard to make some comparison between the studies. While some studies attempted to show the different types of fumonisns, from fumonisin B_1 to B_3, this was not done in most of the studies. This is because, most of the time, total fumonisins (FB_1 +FB_2 + $FB_{3)}$ are reported or only those analogues that are regulated (FB_1 +FB_2).

CONCLUSION

Fusarium verticillioides, a species associated with fumonisin contamination was the most predominant *Fusarium* species causing maize infestation with fumonisins. The review showed that fumonisin contamination of maize is common in sub-Saharan Africa, with the level of contamination varying from one region to another. However, few studies have been carried out on the same in the region. While there were cases of fumonisin levels above the allowed limits, most studies found fumonisin in maize at low levels. The presence of high fumonisin levels is likely to cause human exposure, as maize is a staple food in many countries in the region. It is expected that people in the region are at risk of health conditions associated with fumonisins, including neural tube defects in the foetus, liver cancer, and oesophageal cancer if maize and its products with high levels of fumonisin is consumed. The likely risk factors associated with fumonisin contamination in the region are; temperature, humidity and rainfall level, maize grains storage structure, and ventilation. However, this association should be interpreted with caution, as the sample size used in most of the studies was small. Besides, some of the studies did not account for all the likely variables.

Implication for practice

There is a need to put in place fumonisins contamination control and intervention strategy in order to cut out the health risks linked to fumonisin exposure. Various approaches have been proposed, including monitoring of contamination and improving the agricultural practices. However, with most countries lacking legislation and policies on the same, there is an urgent need for more data to inform policies on preventive measures.

The Implication for future research

Data on fumonisin contamination in maize in SSA and *Fusarium* species responsible for this contamination is limited with data on most countries in the region being unavailable or limited to inform policies and practices. There is need for more research on this subject in the region. There is also the need for well-designed studies to offer robust evidence on factors that are associated with *Fusarium* spp and fumonisin contamination in maize. Such information will be useful in intervention formulation.

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