Comprehensive
REVIEWS
in Food Science and Food Safety

Traditionally Processed Beverages in Africa: A Review of the Mycotoxin Occurrence Patterns and Exposure Assessment

Chibundu N. Ezekiel, Kolawole I. Ayeni, Jane M. Misihairabgwi, Yinka M. Somorin, Ihuoma E. Chibuzor-Onyema, Oluwawapelumi A. Oyedele, Wilfred A. Abia, Michael Sulyok, Gordon S. Shephard, and Rudolf Krska

Abstract: African traditional beverages are widely consumed food-grade liquids processed from single or mixed grains (mostly cereals) by simple food processing techniques, of which fermentation tops the list. These beverages are very diverse in composition and nutritional value and are specific to different cultures and countries. The grains from which home-processed traditional beverages are made across Africa are often heavily contaminated with multiple mycotoxins due to poor agricultural, handling, and storage practices that characterize the region. In the literature, there are many reports on the spectrum and quantities of mycotoxins in crops utilized in traditional beverage processing, however, few studies have analyzed mycotoxins in the beverages themselves. The available reports on mycotoxins in African traditional beverages are mainly centered on the finished products with little information on the process chain (raw material to final product), fate of the different mycotoxins during processing, and exposure estimates for consumers. Regulations targeting these local beverages are not in place despite the heavy occurrence of mycotoxins in their raw materials and the high consumption levels of the products in many homes. This paper therefore comprehensively discusses for the 1st time the available data on the wide variety of African traditional beverages, the mycotoxins that contaminate the beverages and their raw materials, exposure estimates, and possible consequent effects. Mycotoxin control options and future directions for mycotoxin research in beverage production are also highlighted.

Keywords: beverages, exposure, food processing, food safety, mycotoxins

Introduction

Beverages are food-grade liquids mainly processed from animal or plant sources. They may be in the form of stimulants such as tea and coffee, as refreshers like soft drinks, juices, and water, or as nutritional drinks such as milk. Beverage processing could be by simple nonmicrobial processes (such as application of physical techniques) or may involve microbial fermentation and/or enzyme clarification (Tamang and Kailasapathy 2010; Kubo and others 2014; Tafere 2015). Depending on the processing steps involved which may include the application of a single fermentation step or extended fermentation steps with an advanced physical process (such as distillation), beverages are classified as alcoholic or nonalcoholic. Furthermore, based on whether the processes are technologically scaled-up or not, to meet wider consumer demands, they could be regarded as either industrially or traditionally processed. In Africa, diverse traditionally processed beverages exist; their processing methods as well as constituents and consumption patterns differ across ethnicities in countries and regions (Nikander and others 1991; Gaffa and others 2002; Nzigamasabo and Nimpagaritse 2009; Gadaga and others 2013; Aka and others 2014; Kubo and others 2014; Tafere 2015). Every country has its own recipe for the local production of beverages and fermentation is the basic process utilized in more than 90% of these traditionally processed foods (Gaffa and others 2002; Nzigamasabo and Nimpagaritse 2009; Amadou and others 2011; Aka and others 2014; Kubo and others 2014; Tafere 2015). African traditionally processed beverages can be made from single or mixed cereals/legumes, animal milk, and various plant parts (such as flowers, sap, and fruits). Cereal-based beverages are common and are constituted from grains such as maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum* L.), finger millet (*Eleusine coracana*), and sorghum (*Sorghum bicolour* L. *Moench*; Gaffa and others 2002; Sekwati-Monang 2011; Aka and others 2014). In terms of consumption, traditionally processed beverages

---

CRF3-2017-0190 Submitted 9/22/2017, Accepted 11/28/2017. *Authors Ezekiel, Ayeni, Chibuzor-Onyema, and Oyedele are with Dept. of Microbiology, Babcock Univ., Ilishan Remo, Ogun State, Nigeria. Authors Ezekiel, Sulyok, and Krska are with Dept. of Agrobiotechnology (IFA-Tulln), Center for Analytical Chemistry, Univ. of Natural Resources and Life Sciences Vienna (BOKU), Konrad Lorenzstr. 20, A-3430 Tulln, Austria. Author Misihairabgwi is with Dept. of Biochemistry and Microbiology, School of Medicine, Univ. of Namibia, P. Bag 13301, Windhoek, Namibia. Author Somorin is with Microbiology, School of Natural Sciences, Natl. Univ. of Ireland, Galway, Ireland. Author Abia is with School of Toxicology, Occupational Health/Safety and Risk Assessment, COSET, Inst. for Management and Professional Training (IMPT), Yaounde, Cameroon. Author Shephard is with Mycotoxicology and Chemoprevention Research Group, Inst. of Biomedical and Microbial Biotechnology, Cape Peninsula Univ. of Technology, PO Box 1906, Bellville 7535, South Africa. Direct inquiries to author Ezekiel (E-mail: chaugez@gmail.com).*

doi: 10.1111/1541-4337.12329

are popular because of the social, religious, nutritional, and therapeutic values that are associated with them, and they are cherished by both rural and urban populations (Aka and others 2008). In general, nonalcoholic beverages are widely consumed, especially by children, pregnant women, the sick, and the elderly. They are also used during the weaning of infants, whereas the alcoholic beverages are mostly preferred by men. One of the major threats to consumers of traditionally processed beverages in Africa is mycotoxins, mainly due to their frequent occurrences in the cereals used for making these drinks.

Mycotoxins are toxic secondary metabolites produced by filamentous fungi in a wide range of agricultural commodities worldwide, including cereals, nuts, legumes, spices, fruits, and their products (Bhat and Vashanti 2003). The spectrum of toxins produced in a commodity largely depends on one or more fungal species/strains contaminating the commodity, type and composition of commodity, environmental conditions, climatic factors, and also handling practices such as preharvest agricultural practices, harvesting, drying, storage, and processing. In Africa, climate and poor agricultural and storage practices are the major contributors to the mycotoxin menace. Similar to other regions of the world, aflatoxins (AFs), fumonisins (FUM), ochratoxin A (OTA), trichothecenes (mainly deoxynivalenol [DON]), and zearalenone (ZEN) have been reported to coexist in crops grown in Africa, although AFs and FUM are more prevalent (Ezekiel and others 2012; Warth and others 2012; Abia and others 2013, Shephard and others 2013; Adetunji and others 2014; Chala and others 2014; Ediage and others 2014; Matumba and others 2015a; Okeke and others 2015; Chilaka and others 2016; Hove and others 2016; Ogara and others 2017). In maize and other cereals, AFs and *Fusarium* toxins dominate, whilst AFs are more prevalent in tree nuts and peanuts (groundnuts). In low-income rural settings, where there is a reliance on home-grown crops, local grain is used for beverage production. These raw materials can be highly contaminated, either from poor pre- or postharvest practices or because better-quality grain has been sold for family income (Matumba and others 2014b, 2017; Ezekiel and others 2015; Ayalew and others 2016; Misihairabgwi and others 2017; Ogara and others 2017).

African populations, especially the rural dwellers who subsist on home-grown mycotoxin-prone crops (such as maize and groundnuts), have for many years suffered the adverse health effects of mycotoxin exposure. The effects could be acute or chronic, and in many cases, acute mycotoxicoses keep recurring across Africa with several deaths recorded (Lewis and others 2005; Probst and others 2007; Yard and others 2013; IARC 2015; All Africa 2016; Outbreak News Today 2017). The prevalent chronic health effects from mycotoxin exposure which have been reported across the continent include, but are not limited to liver, cancer, esophageal carcinoma, suppression of the immune system, malnutrition from poor micronutrient absorption, birth defects, growth faltering and stunting in children, neural tube defects, organ toxicities, gynecomastia with testicular atrophy, and increased severity of diseases such as malaria and HIV/AIDS (Rheeder and others 1992; Gong and others 2002, 2004, 2012; Turner and others 2003, 2007; Marasas and others 2004; Shephard and others 2008; Khlangwiset and others 2011; IARC 2012, 2015). These numerous health conditions, which several thousands of Africans are at risk of, make routine exposure determinations and estimations necessary in order to predict and forestall outbreaks which are usually not easy to cope with (Lewis and others 2005; Probst and others 2007; Yard and others 2013; IARC 2015).

Despite the wide-spread production and consumption of traditionally processed beverages across Africa and the high prevalence of mycotoxins in the grains used as raw materials, mycotoxin data in African traditional beverages are sparse owing to the challenges of monitoring household or traditionally processed foods circulated in the informal/local setting, lack of technical expertise and infrastructure, or less focus on locally produced food. Currently, there is no legislation for mycotoxins in locally processed beverages in African countries, even though monitoring of mycotoxins in foods processed at household level remains essential considering the connection between food safety and health. This review, therefore, presents for the 1st time comprehensive data on the diversity of locally processed beverages across Africa, mycotoxin occurrence in these beverages and their raw materials, fate of these mycotoxins during beverage production, where data are available, and attempts to assess exposure to mycotoxins through beverage consumption. Possible mycotoxin exposure control options in the beverage process chain and future perspectives in the area of mycotoxin research in beverage production are also highlighted.

Diversity of Traditionally Processed Beverages in Africa

African traditional beverage production dates back to the prehistoric era and has consistently been a home-made art involving an array of raw materials including cereal grains, legumes, flowers and juices from plants, fruits, and milk (Amadou and others 2011). The beverages produced across Africa vary according to raw materials, origin, and processing techniques employed, and are usually unique to particular ethnic or cultural groups where they are relished (Obahiagbon 2009; Kubo and others 2014; Tafere 2015). Beverages also define, to some extent, the socioeconomic class and tribe of the consumers. For example, *areki*, a distilled product from maize, millet, and sorghum in rural and semi-urban areas of Ethiopia (East Africa) is widely consumed by farmers and the low-income class who either have become addicted to alcohol or cannot afford the finer industrial alcoholic products (Tafere 2015), whereas *borde* (nonalcoholic), *keribo* (nonalcoholic), and *tella* (alcoholic) are popular traditional beverages that are consumed during traditional weddings, and naming and rain-making ceremonies (Tafere 2015). In Nigeria (West Africa), *burukutu* (alcoholic), *kunu* (nonalcoholic), and *pito* (alcoholic), which can be made from single or mixed grains, are peculiar to the northern areas where they are commonly served at festivals and social events and are presently being commercialized on a small scale within villages (Gaffa and others 2002; Ezekiel and others 2015). Similarly, palm wine (nonalcoholic; from the sap of the *Rafia* tree) is popular in the eastern parts of Cameroon (Central Africa) and Nigeria and is the acceptable wine at festivals and culturally-related ceremonies like weddings and social events (Obahiagbon 2009; Kubo and others 2014). In Namibia (Southern Africa), *oshikundu* (a nonalcoholic beverage from millet and sorghum) is served to visitors as a token of welcome and hospitality, and it is produced as part of the traditional initiation of young girls into womanhood (Mu Ashekele and others 2012). In general, African traditional beverages are produced by women and children as a home art, and when commercialized at the local setting, they become a means of economic empowerment to the women (Abawari 2013). Production of some traditional beverages, although not adequately accounted for across Africa, run into million liters per annum, and generally per capita consumption data are lacking (Gensi and others 2000; Kanyana and others 2013).

Beyond the cultural and socioeconomic usage and benefits of African traditional beverages are the nutritional and therapeutic values they offer, especially for the nonalcoholic grades (Aka and others 2014; Onuoha and others 2014). These beverages are rich in vitamins, minerals, and are easily utilizable carbohydrates (sugars) due to the mixtures of grains used and the fermentation process involved (Blandino and others 2003; Amadou and others 2011; Aka and others 2014). Supplementation of some of the beverages (such as *kunu gyada*, a variety of *kunu* from Nigeria) with nuts, tubers, and spices has further boosted their protein and amino acid contents as well as the antioxidant properties of the drinks (Gaffa and others 2002; Blandino and others 2003). Regional variations to the preparation of fermented beverages exist in different countries in Africa. A range of techniques (such as malting, boiling, pasteurization, fermentation, and distillation) are often utilized for the processing of these beverages (Amusa and Odunbaku 2009; Idonije and others 2012; Fadahunsi and others 2013; Egwaikhide and others 2014; Kubo and others 2014; Onuoha and others 2014). These techniques play important roles in flavor addition, complex compound digestion, anti-nutrient degradation, toxin biotransformation or elimination, and overall product quality improvement of the various alcoholic and nonalcoholic beverages.

Fermentation by autochthonous microbiota, which mainly performs acid/or acid–alcohol fermentation, is the major processing technique employed in the preparation of over 90% of the diverse beverages across Africa (Gaffa and others 2002; Nzigamasabo and Nimpagaritse 2009; Amadou and others 2011; Aka and others 2014; Kubo and others 2014; Tafere 2015). It is a vital step involved in alcoholic and nonalcoholic beverage production. Fermentation occurs naturally and spontaneously in many cases, causing breakdown of sugars to yield acids, and when extended alcohols are produced. The fermenters and saccharifying enzymes are usually intrinsic to the grains and other ingredients (Kubo and others 2014; Tafere 2015). In a few cases, backslopping is conducted by the local producers to enhance fermentation and to produce highly desirable product quality. The microbiology of traditionally processed beverages across Africa has been widely studied and lactic acid bacteria, together with yeasts, have been suggested to predominate during these fermentations (Tafere 2015). Usually, the end products of nonalcoholic fermentation of traditional grains into African beverages are very tasty, highly nutritious, and exude pleasant aroma and flavors.

Table 1 presents details of the origin, sources, and main technique(s) involved in the preparation of selected traditional beverages across Africa. Popular traditional beverages include the cereal-based nonalcoholic drinks and opaque beers commonly produced from single or combined grains of maize, millet, and sorghum in Central, East, West, and Southern Africa (Blandino and others 2003; Shephard and others 2005; Matumba and others 2011, 2014; Abia and others 2013; Egwim and others 2013; Aka and others 2014; Kubo and others 2014) and the banana- and plantain-based beverages common in Central Africa (Kubo and others 2014) and parts of East Africa (Nzingamasabo and Nimpagaritse 2009; Kanyana and others 2013). Other non-cereal-based beverages are mostly found in West Africa and include *nono* (a product of milk fermentation usually served with *fura*—a fermented product of millet or maize; Egwaikhide and others 2014), *zobo* drink extracted by boiling dried Roselle (*Hibiscus sabdariffa*) petals (Onuoha and others 2014), and products obtained from palm sap. Palm-based beverages are usually obtained from *Elaeis guineensis*, *Raphia* sp., or *Cocus nucifera* and when fermented into a non- or low-alcoholic drink, it is referred to as palm wine (Okagbue 1988) whereas the high-alcoholic variants (local gin) from distillation are known as *akpeteshi* (Ghana), *kaikai*, or *ogogoro* (Nigeria; Idonije and others 2012). The popularity and preference of African traditional beverages over imported beverages and wines in many cultural settings are mainly due to the low cost for producing these beverages and the basic equipment required for the process. Because most of Africa's traditional beverages are cereal-based, there is great possibility of mycotoxin occurrence in them. Hence, surveillance on mycotoxins becomes imperative in these traditionally processed beverages in the respective regions.

Short Overview on the Occurrence of Mycotoxins in African Crops Used for Beverage-making

The safety of African traditional beverages is influenced by several factors, including the quality of the raw materials used to produce the beverages. Most of the raw materials for making traditional beverages in Africa are cereals, mainly maize, sorghum, millet, and barley (Aka and others 2014). Some of these crops used for making beverages are highly contaminated with mycotoxins (Table 2), which might get into the final products (Table 3), thus making the beverages unsafe for consumption. Evidence of mycotoxin occurrences in African crops have excellently been reviewed recently (Darwish and others 2014; Ayalew and others 2016; Chilaka and others 2017; Udomkun and others 2017), but there has been little or no focus on the traditional beverage value chain which utilizes these crops. Occurrence of agriculturally important mycotoxins in crops commonly used for traditional beverage-processing across Africa is summarized in Table 2.

Mycotoxins in maize

Maize, a staple crop in Africa, is the major cereal used in different countries for the production of many traditional beverages such as *tchapalo* in Côte d'Ivoire, *gowé* in Benin, *burukutu, kunuzaki*, and *pito* in Nigeria and Ghana, *ice-kenkey* in Ghana, *sha* in Cameroon, *busaa* in Kenya, *kwete* in Uganda, *kachasu* in Zimbabwe, and *mahewu and mqomboti/umqombothi* in South Africa. Dried and stored maize, oftentimes moldy, and highly contaminated "low-grade" maize grains sorted out from the lot, is used to produce these beverages due to the perceived desirable taste they impart to the beverage (Shephard and others 2005). AFs, FUM, trichothecenes (DON and nivalenol [NIV]), ZEN and, more recently, citrinin (CIT), are the commonly reported mycotoxins in maize across Africa (Warth and others 2012; Probst and others 2014; Okeke and others 2015; Chilaka and others 2017; Ogara and others 2017). Although high levels of AFs are found in maize, *Fusarium* mycotoxins predominate in maize.

In West Africa, high levels of several mycotoxins have been found in maize from household stores and markets, sometimes with co-occurrences. Stored maize in Benin contained FUM up to 12000 μg/kg (Fandohan and others 2005). Perrone and others (2014) showed that maize at farm-gate in Ghana and Nigeria were highly contaminated with AFs (mean: 330 μg/kg; max: 1900 μg/kg) compared to those in market stores (mean: 84; max: 480 μg/kg). Adetunji and others (2014) also reported mean FB_1, ZEN, and DON concentrations in stored maize as 1552, 174, and 60 μg/kg, respectively. High levels of CIT (occurrence: 12%; median: 1784 μg/kg), FB_1 (occurrence: 81%; median: 269 μg/kg), and AFB_1 (occurrence: 50%; median: 24 μg/kg) were reported in maize from Burkina Faso, whereas DON (median: 31.4 μg/kg) and ZEN (median: 13.4 μg/kg) were documented in not more than 10% of 26 samples (Warth and others 2012). Fifty-one

Table 1–Some African traditional processed beverages.

Beverage	Beverage type	Origin	Raw material(s)	Major processing technique(s)	References
Ambga	Alcoholic	Cameroon	Sorghum	Germination, milling, fermentation, boiling	Chevassus-Agnes and others 1976; Aka and others 2014
Areki	Alcoholic	Ethiopia	Millet, sorghum, maize	Fermentation, distillation	Tafere 2015
Banana juice/beer	Nonalcoholic/ alcoholic	Rwanda	Banana	Ripening, mashing, juice extraction, fermentation	Kanyana and others 2013
Bouza	Alcoholic	Egypt	Sorghum	Fermentation	Blandino and others 2003
Borde	Non-alcoholic	Ethiopia	Barley, maize, wheat	Malting, roasting, fermentation, boiling	Aka and others 2014
Burukutu	Alcoholic	Nigeria	Sorghum	Germination, milling, boiling filtration, fermentation	Fadahunsi and others 2013
Busaa	Alcoholic	Kenya	Maize	Germination, frying, fermentation, filtration	Katongole 2008; Aka and others 2014
Bushera	Nonalcoholic	Uganda	Sorghum/millet	Germination, malting, fermentation	Muyanja and others 2003; Aka and others 2014
Cassava spirit	Alcoholic	Cameroon	Cassava tubers, maize	Steeping, fermentation, mashing, drying	Kubo and others 2014
Dolo	Alcoholic	Benin	Sorghum	Malting, boiling, fermentation	Michojehoun-Mestres and others 2005
Doro	Alcoholic	Zimbabwe	Finger and bulrush millet/ sorghum	Germination, boiling, fermentation	Gadaga and others 2013; Blandino and others 2003; Misihairabgwi and others 2015
Fura da Nono	Nonalcoholic	Nigeria	Fresh milk	Pasteurization, back-sloping, fermentation	Egwaikhide and others 2014
Gowé	Nonalcoholic	Benin	Sorghum, millet, maize	Malting, fermentation	Michojehoun-Mestres and others 2005
Ice- kenkey	Nonalcoholic	Ghana	Kenkey-maize	Steeping, cooking fermentation	Atter and others 2015
Kaikai	Alcoholic	Nigeria	Palm wine	Fermentation, distillation	Idonije and others 2012
Kachasu	Alcoholic	Zimbabwe	Maize	Fermentation, distillation	Blandino and others 2003
Keribo	Nonalcoholic	Ethiopia	Barley	Roasting, boiling, fermentation	Abawari 2013
Kunu/Kunu-zaki	Nonalcoholic	Nigeria	Sorghum/ millet/maize	Steeping, milling, boiling, fermentation, filtration	Amusa and Odunbaku 2009
Kwete	Alcoholic	Uganda	Maize	Steeping, germination, roasting, mashing, fermentation	Namugumya and Muyanja 2009
Mangisi	Nonalcoholic	Zimbabwe	Millet	Malting, boiling, filtration, fermentation	Zvauya and others 1997; Aka and others 2014
Mahewu	Nonalcoholic	South Africa	Maize	Boiling, fermentation	Aka and others 2014
Malwa	Nonalcoholic	Uganda	Finger millet	Germination, roasting, boiling, fermentation	Zvauya and others 1997; Aka and others 2014
Mqomboti/ Umqombothi	Alcoholic	South Africa	Sorghum/maize	Fermentation, boiling	Shephard and others 2005
Oshikundu	Alcoholic/ Nonalcoholic	Namibia	Millet/sorghum	Hot water treatment, back-slopping, fermentation	Mu Ashekele and others 2012; Embashu and others 2013
Oti-oka	Alcoholic	Nigeria	Maize/millet/ sorghum	Germination, boiling, fermentation	Ogunbanwo and Ogunsanya 2012
Palm spirit	Alcoholic	Cameroon	Palm sap	Fermentation, distillation	Kubo and others 2014.
Palm wine	Nonalcoholic	Nigeria/ Cameroon	Palm sap	Fermentation	Obahiagbon 2009
Pito	Alcoholic	Nigeria/Ghana	Maize/millet/ sorghum	Germination, boiling, filtration, fermentation	Egwim and others 2013
Raffia wine	Alcoholic	Cameroon	Raffia sap	Fermentation	Kubo and others 2014
Sha	Weak alcoholic	Cameroon	Maize	Fermentation, boiling	Abia and others 2013
Sorghum beer	Alcoholic	South Africa	Sorghum/maize	Fermentation	Blandino and others 2003
Sour sop Juice	Nonalcoholic	Nigeria	Sour sop	Extraction, fermentation, boiling	Vwioko and others 2013
Tchapalo	Alcoholic	Côte d'Ivoire	Maize	Malting, milling, fermentation, boiling	Aka and others 2008; Aka and others 2014
Tella	Alcoholic	Ethiopia	Barley, maize, millet, sorghum, *teff*, wheat	Malting, roasting, fermentation	Tafere 2015
Urwarwa	Weak alcoholic	Burundi	Banana	Extraction/fermentation	Nzigamasabo and Nimpagaritse 2009
Zobo	Nonalcoholic	Nigeria	Roselle flowers	Boiling, filtration	Onuoha and others 2014

maize flour samples from Côte d'Ivoire were found to be laden with very high AFs (mean: 107.9 μg/kg) whereas FUM (mean: 355.5 μg/kg), OTA (mean: 21.5 μg/kg), and ZEN (mean: 14.0 μg/kg) levels were relatively low (Kouadio and others 2014). In Cameroon (Central Africa), where maize is commonly used to produce a local beer known as *sha*, AFs, FUM, DON, and ZEN levels in maize have been shown to reach 645, 24,225, 3,842, and 334 μg/kg, respectively (Njobeh and others 2010; Abia and others 2013; Ediage and others 2014).

In East Africa where some countries have reported recurrent cases of aflatoxicosis, AFs concentration is very high in household maize samples. For example, the mean levels in maize from some regions in Kenya, Somalia, and Tanzania can run into hundreds of μg/kg (Lewis and others 2005; Probst and others 2007, 2014;

Table 2–Occurrence of agriculturally important mycotoxins and major metabolites in crops commonly used for traditional beverage processing across Africa.

Raw material for beverage	Mycotoxin^a	Country	Number of samples analyzed (% positives)	Mean ± SD concentration (Range) in μg/kg	Analytical technique^b	Source
Maize	AFs	Burkina Faso	50 (–)	25 (0 to 609)	ELISA	Probst and others 2014
Maize	AFs	Cameroon	40 (55)	1.5 (0.1 to 15)	HPLC	Njobeh and others 2010
Maize	AFs	DR Congo	12 (–)	63 (0 to 393)	ELISA	Probst and others 2014
Maize	AFs	Malawi	90 (100)	8.3 ± 8.2 (0.7 to 140)	LFIA	Mwalwayo and Thole 2016
Maize	AFs	Kenya	985 (49)	– (–)	ELISA	Mutiga and others 2015
Maize	AFs	Kenya	9 (–)	102 (0 to 525)	ELISA	Probst and others 2014
Maize	AFs	Senegal	20 (–)	47 (0.3 to 395)	ELISA	Probst and others 2014
Maize	AFs	Somalia	6 (–)	133 (1 to 1407)	ELISA	Probst and others 2014
Maize	AFs	Tanzania	– (45)	– (0.1 to 269)	HPLC	Kamala and others 2016
Maize	AFs	Tanzania	120 (18)	– (1 to 158)	HPLC	Kimanya and others 2008
Maize	AFs	Tanzania	574 (27)	3.12 ± 0.09 (2.1 to 10.1)	ELISA	Nyangi 2014
Maize	AFs	Uganda	17 (–)	95 (0 to 435)	ELISA	Probst and others 2014
Maize	AFs	Uganda	5 (100)	9.2 (7 to 12)	Fluorimetry	Osuret and others 2016
Maize	AFs	Uganda	150 (73)	22 (0 to 50)	TLC	Kaaya and Kyamuhangire 2006
Maize	AFs	Zambia	28 (–)	7 (0 to 108)	ELISA	Probst and others 2014
Maize	AFs	Zimbabwe	19 (–)	9 (0 to 123)	ELISA	Probst and others 2014
Maize	AFB$_1$	Burkina Faso	26 (50)	23.6 (3.4 to 636)	LC-MS/MS	Warth and others 2012
Maize	AFB$_1$	Cameroon	37 (30)	4 (<LOQ to 12)	LC-MS/MS	Abia and others 2013
Maize	AFB$_1$	Congo	13 (31)	0.86 (0.04 to 120.09)	ELISA	Manjula and others 2009
Maize	AFB$_1$	Côte d'Ivoire	10 (100)	– (<1.5 to 20)	HPLC	Sangare-Tigori and others 2006a
Maize	AFB$_1$	Ghana/Nigeria	56 (30)	74 (0.7 to 440)	HPLC	Perrone and others 2014
Maize	AFB$_1$	Lesotho	–	– (nd to 0.43)	HPLC	Mohale and others 2013
Maize	AFB$_1$	Mozambique	13 (46)	69.9 (16.3 to 363)	LC-MS/MS	Warth and others 2012
Maize	AFB$_1$	Nigeria	70 (67.1)	394 (0.4 to 6738)	LC-MS/MS	Adetunji and others 2014
Maize	AFB$_1$	Zimbabwe	95 (1)	11 (nd to 11)	LC-MS/MS	Hove and others 2016
Sorghum	AFB$_1$	Ethiopia	–	– (<LOD to 33.1)	ELISA	Taye and others 2016
Sorghum	AFB$_1$	Ethiopia	70 (12.9)	29.5(max: 62.5)	LC-MS/MS	Chala and others 2014
Sorghum	AFB$_1$	Ethiopia	82 (6.1)	10 (nd to 25.9)	HPLC	Ayalew and others 2006
Sorghum	AFB$_1$	Nigeria	168 (55)	199.51 ± 259.9 (0 to 1164)	TLC	Makun and others 2009
Finger millet	AFB$_1$	Ethiopia	34 (6)	1.12 (max: 1.43)	LC-MS/MS	Chala and others 2014
Millet	AFB$_1$	Nigeria	87 (7)	159.5 ± 156.3 (8.6 to 384.9)	LC-MS/MS	Hertveldt 2016
Barley	AFB$_1$	Ethiopia	115 (11.3)	3.8 (max: 11.7)	HPLC	Ayalew and others 2006
Teff	AFB$_1$	Ethiopia	35 (23)	5.1 (max: 15.6)	HPLC	Ayalew and others 2006
Sugarcane	AFB$_1$	Egypt	40 (58)	0.72 (<LOQ to 2.1)	LC-MS/MS	Abdallah and others 2016
Maize	AFB$_2$	Nigeria	70 (54.3)	44 (1 to 644)	LC-MS/MS	Adetunji and others 2014
Maize	AFG$_1$	Nigeria	70 (15.7)	47 (1 to 264)	LC-MS/MS	Adetunji and others 2014
Maize	AFG$_2$	Nigeria	70 (5.7)	16 (0.7 to 52)	LC-MS/MS	Adetunji and others 2014
Maize	AFM$_1$	Nigeria	70 (48.6)	14.5 (1.2 to 120)	LC-MS/MS	Adetunji and others 2014
Maize	FUM	Botswana	33 (85)	247 (20 to 1270)	HPLC	Siame and others 1998
Maize	FUM	Malawi	8 (88)	55.6 (nd to 135)	HPLC	Doko and others 1996
Maize	FUM	Malawi	90 (100)	900 ± 1000 (100 to 7000)	LFIA	Mwalwayo and Thole 2016
Maize	FUM	Mozambique	3(100)	360 (340 to 395)	HPLC	Doko and others 1996

(*Continued*)

Table 2–Continued.

Raw material for beverage	Mycotoxin[a]	Country	Number of samples analyzed (% positives)	Mean ± SD concentration (Range) in μg/kg	Analytical technique[b]	Source
Maize	FUM	Nigeria	136 (65)	935 (max: 8508)	LC-MS/MS	Chilaka and others 2016
Maize	FUM	Nigeria	–	228 ± 579 (5 to 2860)	HPLC	Vismer and others 2015
Maize	FUM	Tanzania	120 (52)	– (61 to 11048)	HPLC	Kimanya and others 2008
Maize	FUM	Tanzania	– (85)	– (49 to 18273)	HPLC	Kamala and others 2016
Maize	FUM	Tunisia	18 (50)	540.4 ± 658 (–)	HPLC	Ghali and others 2009
Maize	FUM	Zimbabwe	19 (–)	105000 (36000 to 159000)	ELISA	Probst and others 2014
Maize	FB$_1$	Botswana	30 (18)	380 (9 to 1146)	HPLC	Mokgatlhe and others 2011
Maize	FB$_1$	Burkina Faso	26 (81)	269 (22.5 to 1343)	LC-MS/MS	Warth and others 2012
Maize	FB$_1$	Burundi	6 (100)	– (12200 to 75200)	Fluorodensitometry	Munimbazi and Bullerman 1996
Maize	FB$_1$	Cameroon	37 (100)	508 (2 to 2313)	LC-MS/MS	Abia and others 2013
Maize	FB$_1$	Cameroon	40 (65)	3684 (37 to 24225)	HPLC	Njobeh and others 2010
Maize	FB$_1$	Congo	10 (–)	– (nd to 9620)	ELISA	Manjula and others 2009
Maize	FB$_1$	Côte d'Ivoire	10 (100)	– (0.3 to 1.5)	HPLC	Sangare-Tigori and others 2006a
Maize	FB$_1$	Lesotho	–	– (7 to 936)	HPLC	Mohale and others 2013
Maize	FB$_1$	Mozambique	13 (92)	869 (159 to 7615)	LC-MS/MS	Warth and others 2012
Maize	FB$_1$	Nigeria	70 (92.9)	1552 (1.8 to 10447)	LC-MS/MS	Adetunji and others 2014
Maize	FB$_1$	South Africa	142 (87)	– (101 to 53863)	HPLC	Phoku and others 2012
Maize (good)	FB$_1$	South Africa	54 (100)	2083 ± 3630 (56 to 14990)	LC-MS/MS	Shephard and others 2013
Maize (moldy)	FB$_1$	South Africa	38 (100)	27640 ± 38970 (514 to 190100)	LC-MS/MS	Shephard and others 2013
Maize	FB$_1$	Zimbabwe	95 (95)	242 (nd to 1106)	LC-MS/MS	Hove and others 2016
Barley (raw/malted)	FB$_1$	South Africa	24 (29.2)	– (12 to 170)	HPLC	Maenetje and Dutton 2007
Sorghum	FUM	Botswana	20 (15)	43 (20 to 60)	HPLC	Siame and others 1998
Sorghum	FUM	Ethiopia	39 (8)	1713.3 (1370 to 2117)	ELISA	Ayalew and others 2006
Sorghum	FUM	Ethiopia	–	– (907 to 2041)	ELISA	Taye and others 2016
Sorghum	FUM	Nigeria	–	131 ± 270 (5 to 1340)	HPLC	Vismer and others 2015
Sorghum	FUM	Nigeria	110 (8)	83 (max: 180)	LC-MS/MS	Chilaka and others 2016
Sorghum	FUM	Zimbabwe	18 (61)	– (8 to 187)	HPLC	Mupunga 2013
Sorghum	FB$_1$	Botswana	30 (11)	491 (8 to 1409)	HPLC	Mokgatlhe and others 2011
Finger millet	FUM	Ethiopia	574 (45)	0.68 ± 0.2 (2.1 to 90)	ELISA	Nyangi 2014
Millet	FUM	Nigeria	87 (14)	2113 (max: 22064)	LC-MS/MS	Chilaka and others 2016
Pearl millet	FUM	Nigeria	–	18 ± 7 (6 to 29)	HPLC	Vismer and others 2015
Maize	FB$_2$	Nigeria	70 (84.3)	442 (12.8 to 3455)	LC-MS/MS	Adetunji and others 2014
Maize	FB$_3$	Nigeria	70 (84.3)	161 (6.4 to 720)	LC-MS/MS	Adetunji and others 2014
Maize (good)	FB$_2$	South Africa	54 (100)	927 ± 1565 (38 to 6,444)	LC-MS/MS	Shephard and others 2013
Maize (moldy)	FB$_2$	South Africa	38 (100)	10580 ± 13810 (222 to 64840)	LC-MS/MS	Shephard and others 2013
Maize (good)	FB$_3$	South Africa	54 (93)	192 ± 268 (0.5 to 1312)	LC-MS/MS	Shephard and others 2013
Maize (moldy)	FB$_3$	South Africa	38 (100)	2438 ± 2739 (90 to 11280)	LC-MS/MS	Shephard and others 2013
Maize	Hydrolyzed FB$_1$	Nigeria	70 (52.9)	11 (0.4 to 135)	LC-MS/MS	Adetunji and others 2014
Maize	DON	Burkina Faso	26 (4)	31.4 (–)	LC-MS/MS	Warth and others 2012
Maize	DON	Cameroon	37 (100)	– (–)	LC-MS/MS	Abia and others 2013
Maize	DON	Cameroon	40 (73)	59 (18 to 273)	HPLC	Njobeh and others 2010
Maize	DON	Lesotho	–	– (1.30 to 1469.4)	HPLC	Mohale and others 2013
Maize	DON	Mozambique	13 (15)	120 (116 to 124)	LC-MS/MS	Warth and others 2012

(*Continued*)

Table 2–Continued.

Raw material for beverage	Mycotoxin[a]	Country	Number of samples analyzed (% positives)	Mean ± SD concentration (Range) in μg/kg	Analytical technique[b]	Source
Maize	DON	Nigeria	70 (100)	60 (11 to 479)	LC-MS/MS	Adetunji and others 2014
Maize	DON-glucoside	Nigeria	70 (10)	11 (0.1 to 76)	LC-MS/MS	Adetunji and others 2014
Maize	DON	Nigeria	136 (16)	99 (max: 225)	LC-MS/MS	Chilaka and others 2016
Maize (good)	DON	South Africa	54 (100)	4.7 ± 2.1 (2.2 to 14)	LC-MS/MS	Shephard and others 2013
Maize (moldy)	DON	South Africa	38 (100)	5.8 ± 26 (1.1 to 12)	LC-MS/MS	Shephard and others 2013
Maize	DON	Zimbabwe	95 (24)	217 (nd to 492)	LC-MS/MS	Hove and others 2016
Maize	DON	Zimbabwe	19 (-)	1000 (nd to 12000)	ELISA	Probst and others 2014
Sorghum	DON	Ethiopia	33 (91)	360 (50 to 2340)	HPLC	Ayalew and others 2006
Sorghum	DON	Nigeria	110 (3)	100 (max: 199)	LC-MS/MS	Chilaka and others 2016
Millet	DON	Nigeria	87 (13)	151 (max: 543)	LC-MS/MS	Chilaka and others 2016
Barley	DON	Ethiopia	20 (33)	70 (40 to 110)	HPLC	Ayalew and others 2006
Barley (raw/malted)	DON	South Africa	18 (100)	– (10 to 3125)	GC-MS	Maenetje and Dutton, 2007
Maize	NIV	Nigeria	70 (54.3)	14 (0.7 to 164)	LC-MS/MS	Adetunji and others 2014
Maize	OTA	Côte d'Ivoire	41 (100)	– (3 to 1738)	HPLC	Sangare-Tigori and others 2006b
Maize	OTA	Nigeria	17 (94.1)	26.96 ± 35.39 (0 to 139.2)	HPLC	Makun and others 2013
Maize	OTA	Nigeria	70 (10)	111 (4 to 580)	LC-MS/MS	Adetunji and others 2014
Maize	Ochratoxin-alpha	Nigeria	70 (1.4)	11 (11 to 11)	LC-MS/MS	Adetunji and others 2014
Millet	OTA	Côte d'Ivoire	33 (100)	– (17 to 204)	HPLC	Sangare-Tigori and others 2006b
Millet	OTA	Nigeria	18 (100)	24.74 ± 6.52 (10.2 to 46.57)	HPLC	Makun and others 2013
Barley	OTA	Ethiopia	103 (26.2)	17.2 (max: 164)	HPLC	Ayalew and others 2006
Sorghum	OTA	Nigeria	17 (94.1)	8.28 ± 6.23 (0 to 29.5)	HPLC	Makun and others 2013
Teff	OTA	Ethiopia	33 (27.3)	32.7 (max: 80)	HPLC	Ayalew and others 2006
Maize	OTB	Nigeria	70 (7.1)	7.5 (2 to 26)	LC-MS/MS	Adetunji and others 2014
Maize	ZEN	Botswana	30 (29)	297 (19 to 797)	HPLC	Mokgatlhe and others 2011
Maize	ZEN	Burkina Faso	26 (8)	13.4 (11 to 15.8)	LC-MS/MS	Warth and others 2012
Maize	ZEN	Cameroon	33 (89)	68 (0.2 to 309)	LC-MS/MS	Abia and others 2013
Maize	ZEN	Cameroon	40 (78)	69 (28 to 273)	HPLC	Njobeh and others 2010
Maize	ZEN	Côte d'Ivoire	10 (100)	– (0.3 to 1.5)	HPLC	Sangare-Tigori and others 2006a
Maize	ZEN	Mozambique	13 (23)	13.8 (10.9 to 18.1)	LC-MS/MS	Warth and others 2012
Maize	ZEN	Nigeria	70 (17.1)	174 (0.4 to 2044)	LC-MS/MS	Adetunji and others 2014
Maize	α-ZEN	Nigeria	70 (1.4)	17 (17 to 17)	LC-MS/MS	Adetunji and others 2014
Maize	β-ZEN	Nigeria	70 (1.4)	13 (13 to 13)	LC-MS/MS	Adetunji and others 2014
Maize	ZEN	Nigeria	136 (1)	65 (–)	LC-MS/MS	Chilaka and others 2016
Maize (good)	ZEN	South Africa	54 (39)	44 ± 88 (0.6 to 329)	LC-MS/MS	Shephard and others 2013
Maize (moldy)	ZEN	South Africa	38 (74)	184 ± 420 (0.1 to 1648)	LC-MS/MS	Shephard and others 2013
Sorghum	ZEN	Botswana	30 (28)	77 (3 to 248)	HPLC	Mokgatlhe and others 2011
Sorghum	ZEN	Ethiopia	70 (32.9)	43.8 (max: 374)	LC-MS/MS	Chala and others 2014
Sorghum	ZEN	Ethiopia	29 (7)	25.5 (19 to 32)	HPLC	Ayalew and others 2006
Sorghum	ZEN	Nigeria	110 (1)	38 (–)	LC-MS/MS	Chilaka and others 2016

(*Continued*)

Table 2–Continued.

Raw material for beverage	Mycotoxin[a]	Country	Number of samples analyzed (% positives)	Mean ± SD concentration (Range) in μg/kg	Analytical technique[b]	Source
Sorghum	ZEN	Nigeria	168 (37)	184.76 ± 328.31 (0 to 1454)	TLC	Makun and others 2009
Millet	ZEN	Nigeria	87 (14)	419 (max: 1399)	LC-MS/MS	Chilaka and others 2016
Finger millet	ZEN	Ethiopia	34 (51.5)	76.5 (max: 459)	LC-MS/MS	Chala and others 2014

–, Data not available.

[a] AFs, total aflatoxin; AFB$_1$, Aflatoxin B$_1$; DON, deoxynivalenol; FUM, Fumonisin; FB, fumonisin B$_1$; OTA, ochratoxin A; ZEN, Zearalenone.

[b] ELISA, enzyme-linked immunosorbent assay; HPLC, high performance liquid chromatography; LC-MS/MS, liquid chromatography tandem mass spectrometry; LFIA, lateral flow immunochromatographic assay; TLC, thin-layer chromatography.

Kamala and others 2016), whereas the contamination rates for many other regions and countries are relatively low (Kaaya and Kyamuhangire 2006; Probst and others 2014; Osuret and others 2016). The report from Probst and others (2014) also suggests that FUM and DON contamination rates and levels in maize grown in the East African region may be relatively low except for some regions in Tanzania where as much as 2284 and 825 μg/kg of FUM and DON, respectively, have been reported in maize flour used as complementary food for infants (Kimanya and others 2014) and levels up to >18000 μg/kg have been reported in more than one half of sampled maize (Kamala and others 2016). Similarly, FUM was found in 87% of maize samples from western Kenya and half of them were over 1000 μg/kg (Mutiga and others 2015).

In the southern African region, AF contaminations are less pronounced compared to FUM occurrence in maize. The countries which have reported AFs in maize include Malawi, Zambia, and Zimbabwe. Maize samples from Botswana had no detectable AFs (Siame and others 1998), whereas contamination in Zambian maize was relatively high with an average of 16 μg/kg (Kachapulula and others 2017). About 29% of 90 maize samples from Malawi contained more than 10 μg/kg of AFs (Matumba and others 2015a). Doko and others (1996) reported low levels of FUM in maize from Malawi. More recently, Mwalwayo and Thole (2016) reported co-occurrence of AFs and FUM in maize samples from Malawi. In their study, they showed that FUM contamination was also generally low (with 84% samples having <1000 μg/kg), however, higher occurrence and levels of FUM, as well as AFs, were recorded in maize from southern Malawi (Mwalwayo and Thole 2016). FUM as high as 105000 μg/kg were reported in maize from Zimbabwe (Probst and others 2014) whereas rural home-grown maize from South Africa contained extremely high levels of FUM up to 53863 μg/kg (Phoku and others 2012). Rheeder and others (2016) in a more recent study, however, reported low levels of FUM (mean: 575 μg/kg) from maize in South Africa. In other parts of Southern Africa, the main cereals used to produce traditional beverages varied in their levels of contamination with mycotoxins.

Mycotoxins in sorghum

Sorghum is widely grown in Africa, but is less consumed compared to maize. Sorghum has been previously suggested to be less prone to AF contamination than maize; thus proposing its use as replacement cereal for maize (Bandyopadhyay and others 2007). However, recent reports suggest that AFs, as well as FUM levels, could be high in sorghum grains as a consequence of poor handling, poor storage, and climate. In Nigeria, Makun and others (2009) reported that AFB$_1$ contamination was higher in stored sorghum (mean: 262.8 μg/kg) than sorghum at farm-gate (mean: 9.88 μg/kg). Similar trends were recorded for OTA and ZEN in their study (Makun and others 2009). Odoemelam and Osu (2009), however, reported lower AFB$_1$ (mean: 30.53 μg/kg) in sorghum (described as "guinea corn" in their study) collected from southern Nigeria compared to northern Nigeria. Recently, Apeh and others (2016) showed that 54% of sorghum grains from northern Nigeria were contaminated with AFs at a mean level of 5.31 μg/kg (range: 0.96 to 21.74 μg/kg) and with more than one half of the positive samples being above the maximum limit for AFB$_1$ for foods meant for human consumption in the EU (2 μg/kg; FAO 2004). Low incidences of AFs and FUM (<15% of 70 samples) but high AFB$_1$ levels (mean: 29.5 μg/kg) and low FB$_1$ (mean: 14.7 μg/kg) was reported for sorghum collected from farmers' stores in Ethiopia (Chala and others 2014), whereas in Malawi the AF contamination rates in 13 sorghum samples were very low (occurrence: 15%; mean: 2.35 μg/kg; range: 1.7 to 3 μg/kg; Matumba and others 2011). Other mycotoxins, including DON, NIV, OTA, and ZEN, were also reported at low levels in Ethiopian sorghum (Chala and others 2014). Lower levels of FUM were recorded in sorghum from Nigeria compared to maize (Vismer and others 2015; Chilaka and others 2016). Furthermore, no OTA, FUM, or DON was detected in sorghum grains from Cameroon (Djoulde 2013). In Botswana, aflatoxin levels in stored sorghum ranged from 0.1 to 25 μg/kg (Mpuchane and others 1997; Siame and others 1998). Mokgatlhe and others (2011) showed that 31% of 45 sorghum samples were contaminated with 8 to 1409 μg/kg of FB$_1$ whereas ZEN (range: 3 to 980 μg/kg) was reported in 95% of same samples, thus suggesting that FUM and ZEN contamination may be a challenge to sorghum in Botswana. Furthermore, Mupunga (2013) found FUM at concentrations ranging from 8 to 187 μg/kg in sorghum from Bulawayo (Zimbabwe).

Mycotoxins in millet, barley, and *teff*

Millet, a major cereal for *pito* and *burukutu* production in Nigeria, has been shown to be contaminated with AFB$_1$ at slightly higher incidence but lower levels (≤10 μg/kg) than sorghum (Apeh and others 2016). Conversely, Hertveldt (2016) showed that millet sampled mainly from northern Nigeria had low incidence (7%) of AFB$_1$ but very high levels (mean: 159.5 μg/kg). A 2010 study on different crops in Nigeria reported all 18 millet samples from Niger state to contain OTA (mean: 24.74 μg/kg; range: 10.2 to 46.57 μg/kg) above the EU stipulated 5 μg/kg limit for this toxin in foods (Makun and others 2013). According to Chilaka and others (2016), maize, and millet had higher FUM, DON, and ZEN contaminations than sorghum in Nigeria, most of which exceeded the maximum regulatory limit of 1000 μg/kg set for the sum of FB$_1$ and FB$_2$ by the EU (FAO 2004). Interestingly, pearl millet and finger millet, which are also used in preparing traditional beverages, especially in West and East Africa, were less susceptible to mycotoxin contamination as they had very low levels of AFB$_1$ (Chala and others 2014) and FUM

Table 3–Mycotoxins reported in traditionally processed beverages and their raw materials in Africa.

	Analytical technique and distribution of mycotoxins in raw material(s) for beverage production							Analytical technique and distribution of mycotoxins in final product (beverage)							
Country	Raw material(s)	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Beverage	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Source for beverage and raw material
Nigeria	Millet	NS	NS	NS	NS	NS	NS	Pito	20	AFB_1	17	72.81 ± 37.65	15.98–134.91	TLC	Okoye and Ekpenyong 1984
	Millet	NS	NS	NS	NS	NS	NS	Buruku	20	AFB_1	15	54.71 ± 44.11	137.74	TLC	Okoye and Ekpenyong 1984
	Millet	NS	NS	NS	NS	NS	NS	Pito	46	ZEN	28	81.75 ± 50.16	200	TLC	Okoye 1986
	Millet	NS	NS	NS	NS	NS	NS	Buruku	10	AFB_1	NS	25	3.7–>50	Velasco fluorometry	Obasi and others 1987
	Millet	NS	NS	NS	NS	NS	NS	Buruku	10	AFB_2	NS	23.6	4.5–>50	Velasco fluorometry	Obasi and others 1987
	Millet	NS	NS	NS	NS	NS	NS	Buruku	10	AFG_1	NS	5.9	1.1–18.9	Velasco fluorometry	Obasi and others 1987
	Millet	NS	NS	NS	NS	NS	NS	Buruku	10	AFG_2	NS	4	0.5–12.7	Velasco fluorometry	Obasi and others 1987
	Millet	NS	NS	NS	NS	NS	NS	Buruku	10	AFM_1	NS	25.1	2.7–>50	Velasco fluorometry	Obasi and others 1987
	Millet	NS	NS	NS	NS	NS	NS	Buruku	10	AFM_2	NS	9.1	0.5–>50	Velasco fluorometry	Obasi and others 1987
	Maize	NS	DON	NS	74.7	NS	LC-MS/MS	Kunu-zaki	NS	DON	NS	0.8	NS	LC-MS/MS	Ezekiel and others 2015
	Sorghum	NS	DON	NS	15.2	NS	LC-MS/MS	Pito	NS	DON	NS	3.5	NS	LC-MS/MS	Ezekiel and others 2015
	Maize	NS	FB_1	NS	21,844.80	NS	LC-MS/MS	Kunu-zaki	NS	FB_1	NS	122.9	NS	LC-MS/MS	Ezekiel and others 2015
	Sorghum	NS	FB_1	NS	Nd	NS	LC-MS/MS	Pito	NS	FB_1	NS	Nd	NS	LC-MS/MS	Ezekiel and others 2015
	Maize	NS	tFUM	NS	31,243.80	NS	LC-MS/MS	Kunu-zaki	NS	tFUM	NS	170.3	NS	LC-MS/MS	Ezekiel and others 2015
	Sorghum	NS	tFUM	NS	5.9	NS	LC-MS/MS	Pito	NS	tFUM	NS	2.4	NS	LC-MS/MS	Ezekiel and others 2015
	Maize/malted maize	NS	HFB_1	NS	1,694.60	NS	LC-MS/MS	Kunu-zaki	NS	HFB_1	NS	<0.16	NS	LC-MS/MS	Ezekiel and others 2015
	Maize	NS	ZEN	NS	0.84	NS	LC-MS/MS	Kunu-zaki	NS	ZEN	NS	0.2	NS	LC-MS/MS	Ezekiel and others 2015
	Sorghum malt	NS	ZEN	NS	3.85	NS	LC-MS/MS	Pito	NS	ZEN	NS	0.2	NS	LC-MS/MS	Ezekiel and others 2015
	Sorghum malt	NS	α-ZEL	NS	2.3	NS	LC-MS/MS	Pito	NS	α-ZEL	NS	<0.4	NS	LC-MS/MS	Ezekiel and others 2015
	Sorghum malt	NS	β-ZEL	NS	NS	NS	LC-MS/MS	Pito	NS	β-ZEL	NS	0.42	NS	LC-MS/MS	Ezekiel and others 2015
Burkina Faso	Sorghum malt	20	AFB_1	5	97.6 ± 88.2	NS	HPLC	Dolo	50	AFB_1	NS	NS	NS	HPLC	Bationo and others 2015
	Sorghum malt	20	OTA	NS	NS	NS	HPLC	Dolo	50	OTA	NS	NS	NS	HPLC	Bationo and others 2015
Ghana	Maize	NS	NS	NS	NS	NS	NS	Ice-kenkey	12	AFB_1	NS	NS	7.01–20.54	HPLC	Atter and others 2015

(*Continued*)

Table 3–Continued.

	Analytical technique and distribution of mycotoxins in raw material(s) for beverage production							Analytical technique and distribution of mycotoxins in final product (beverage)							
Country	Raw material(s)	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Beverage	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Source for beverage and raw material
	Maize	NS	NS	NS	NS	NS	NS	Ice-kenkey	12	AFB_2	NS	NS	0.51–1.63	HPLC	Atter and others 2015
	Maize	NS	NS	NS	NS	NS	NS	Ice-kenkey	12	AFG_1	NS	NS	7.0–0.47	HPLC	Atter and others 2015
Cameroon	Sorghum	NS	NS	NS	NS	NS	NS	Bil-bil	70	DON	NS	450 ± 9 ng/ml	140–730 ng/ml	HPLC/ELISA	Roger 2011
	Sorghum	NS	NS	NS	NS	NS	NS	Bil-bil	70	FB_1	NS	150 ± 24	0.0–230	HPLC/ELISA	Roger 2011
	Sorghum	NS	NS	NS	NS	NS	NS	Kpata	50	DON	NS	520 ± 70	0.0–680	HPLC/ELISA	Roger 2011
	Sorghum	NS	NS	NS	NS	NS	NS	Kpata	50	FB_1	NS	210±10	0.5–340	HPLC/ELISA	Roger 2011
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	AFB_1	5	1.8	0.7–3	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	FB_1	14	334	15–741	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	FB_2	14	55	0.6–127	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	FB_3	14	43	0.7–100	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	FB_6	1	76.13	76.13	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	DON	13	21	3.0–57	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	DON-G	12	8	0.3–27	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	DOM	4	2	1.7–3	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	ZEN	12	17	1.6–35	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	ß-ZEL	13	4	0.03–8	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	α-ZEL	12	1.5	0.6–2	LC-MS/MS	Abia and others 2013
	Maize	NS	NS	NS	NS	NS	NS	Sha (maize-beer)	14	ZEN-S	13	0.3	0.01–0.6	LC-MS/MS	Abia and others 2013
Tanzania	Maize, finger millet	NS	NS	NS	NS	NS	NS	Komoni	15	AFB_1	9	20 μg/L	NS	TLC	Nikander and others 1991
	Maize, finger millet	NS	NS	NS	NS	NS	NS	Kindi	15	AFB_1	9	10	NS	TLC	Nikander and others 1991
	Maize, sorghum	NS	NS	NS	NS	NS	NS	KibukuMtwara	15	AFB_1	9	25	NS	TLC	Nikander and others 1991
	Maize, sugar	NS	NS	NS	NS	NS	NS	Kangara	15	AFB_1	9	10	NS	TLC	Nikander and others 1991
	Banana, finger millet	NS	NS	NS	NS	NS	NS	Mbege	15	AFB_1	9	50	NS	TLC	Nikander and others 1991
	Sugarcane, honey	NS	NS	NS	NS	NS	NS	Dengelua	15	AFB_1	9	20	NS	TLC	Nikander and others 1991
Rwanda	Banana	NS	NS	NS	NS	NS	NS	Banana beer	NS	DON	NS	14.2 ± 5.7	10.0–20	ELISA	Shale and others 2012

(Continued)

Table 3–Continued.

	Analytical technique and distribution of mycotoxins in raw material(s) for beverage production							Analytical technique and distribution of mycotoxins in final product (beverage)							
Country	Raw material(s)	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Beverage	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Source for beverage and raw material
	Banana	NS	NS	NS	NS	NS	NS	Banana beer	NS	FB_1	NS	18 ± 16	3.7–34	ELISA	Shale and others 2012
	Banana	NS	NS	NS	NS	NS	NS	Banana beer	NS	ZEN	NS	1.5 ± 0.64	1.1–2.2	ELISA	Shale and others 2012
Kenya	Maize, finger millet	NS	NS	NS	NS	NS	NS	Busaa	61	tAF	NS	5.2 ± 0.2	2.8–11	Envirologix-QuickTox Kit for Quickscan	Kirui and others 2014
	Maize, finger millet	NS	NS	NS	NS	NS	NS	Busaa	61	tFUM	NS	1460 ± 188	4000	Envirologix-QuickTox Kit for Quickscan	Kirui and others 2014
	Maize, finger millet	NS	NS	NS	NS	NS	NS	Busaa	61	DON	NS	259 ± 5.2	200–360	Envirologix-QuickTox Kit for Quickscan	Kirui and others 2014
Zambia	Maize	17	ZEN	NS	0.29 mg/kg	0.1–0.8 mg/kg	TLC	Opaque maize beer	23	ZEN	NS	0.92 mg/l	0.09–4.6 mg/l	TLC	Lovelace and Nyathi 1977
	Maize malt	13	ZEN	NS	0.68 mg/kg	0.8–4.0 mg/kg	TLC	NS	NS	NS	NS	NS	NS	NS	Lovelace and Nyathi 1977
	Sorghum malt	8	ZEN	NS	<0.1 mg/kg	<0.1 mg/kg	TLC	NS	NS	NS	NS	NS	NS	NS	Lovelace and Nyathi 1977
South Africa	Maize, sorghum	NS	NS	NS	NS	NS	NS	Mqomboti (umqombothi)	11	ZEN	2	11 μg/L	NS	HPLC	Odhav and Naicker 2002
	Maize	NS	NS	NS	NS	NS	NS	Isiqatha	11	ZEN	4	980 μg/L	NS	HPLC	Odhav and Naicker 2002
	Maize	NS	NS	NS	NS	NS	NS	Isiqatha	11	tAF	1	12 μg/L	NS	HPLC	Odhav and Naicker 2002
	Maize	NS	NS	NS	NS	NS	NS	Isiqatha	11	OTA	4	2534.5 μg/L	NS	HPLC	Odhav and Naicker 2002
	Maize	NS	NS	NS	NS	NS	NS	Imfulamfula	7	ZEN	1	2.6 μg/L	NS	HPLC	Odhav and Naicker 2002
	Maize	NS	NS	NS	NS	NS	NS	Imfulamfula	7	OTA	3	1440 μg/L	NS	HPLC	Odhav and Naicker 2002
	Maize	NS	NS	NS	NS	NS	NS	Mqomboti (umqombothi)	NS	FB_1	NS	281 ± 262ng/mL	38–1066 ng/mL	HPLC	Shephard and others 2005
	Maize	NS	NS	NS	NS	NS	NS	Mqomboti (umqombothi)	NS	$FB_1+FB_2+FB_3$	NS	369 ± 345 ng/mL	43–1329 ng/mL	HPLC	Shephard and others 2005
Botswana	Sorghum	NS	NS	NS	NS	NS	NS	Sorghum beer	44	ZEN	21	92 μg/L	20–201 μg/L	TLC/HPLC	Nkwe and others 2005

(*Continued*)

Table 3–Continued.

	Analytical technique and distribution of mycotoxins in raw material(s) for beverage production							Analytical technique and distribution of mycotoxins in final product (beverage)							
Country	Raw material(s)	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Beverage	N	Mycotoxin	Np	Mean (μg/kg)	Range (μg/kg)	Analytical technique	Source for beverage and raw material
Malawi	Sorghum malt	6	tAF	6	17.57 ± 7.52	6.1–54.6	VICAM fluorometry	Traditional opaque beverage (thobwa)	7	tAF	3	4.50 ± 1.45	2.1–7.1	VICAM fluorometry	Matumba and others 2011
	Sorghum malt	21	tAF	21	408.05 ± 67.97	4.3–1138.8	VICAM fluorometry	Traditional sorghum opaque beer	5	tAF	5	22.32 ± 4.93	8.8–34.5	VICAM fluorometry	Matumba and others 2011
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	AFB_1	8	36 ± 38 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	AFB_2	5	4 ± 3 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	AFG_1	7	55 ± 54 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	AFG_2	3	8 ± 2 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	tAF	8	90 ± 96 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	FB_1	9	1522 ± 1192 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	FB_2	8	251 ± 206 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	FB3	6	229 ± 161 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	FB1+FB2	9	1745 ± 1294 (SD)	NS	LC-MS/MS	Matumba and others 2014a
	Maize	NS	NS	NS	NS	NS	NS	Traditional maize opaque beer	9	FB1+FB2+ FB3	9	1898 ± 1405 (SD)	NS	LC-MS/MS	Matumba and others 2014a

Notes: NS = Not stated Nd = no data N = Number of samples Np = Number of positive samples tAF = total aflatoxin tFUM = total fumonisin DON-G = deoxynivalenol glucoside DOM = deepoxy-DON α-ZEL = alpha zearalenol β-ZEL = beta zearalenol

(Nyangi 2014; Vismer and others 2015). It is thought that ZEN is the most common mycotoxin in both sorghum and finger millet (Chala and others 2014). Because of the restricted application of barley and *teff* in local beverage production in mostly Ethiopia, the documented report on both crops originates from that country, as well as from South Africa (for barley), even though the barley is not reported for local beverage production. Barley and *teff* from Ethiopia had a low incidence ($<10\%$) of AFs but with concentrations reaching 15.6 μg/kg, whereas no *Fusarium* mycotoxin (FUM, NIV, DON, and ZEN) was detected in *teff* and no FUM, NIV, and ZEN in barley (Ayalew and others 2006). However, in the same study, OTA was reported in barley and *teff* in quantities above the EU limit for OTA in foods. Raw and malted barley from South Africa also contained varying levels of AFB_1, DON, FB_1, and OTA (Maenetje and Dutton 2007). At present, there is no information on mycotoxin contamination in other grains such as sorghum and finger millet and banana used in making traditional beverages in Eastern Africa. Although there are limited data on cereals other than maize, such foods seem to be less susceptible to AFs and FUM contamination (Bandyopadhyay and others 2007; Vismer and others 2015).

Mycotoxins in banana and other fruits

Banana fruit is used to make banana juice and beer in East Africa. Although there is little information on the occurrence of mycotoxins in banana, Li and others (2013) showed that *Fusarium oxysporum f.* ssp. *cubense* can infect several parts of banana leading to the natural contamination of banana fruits with beauvericin and fusaric acid. Similarly, dried petals of the Roselle flower are used in *zobo* production; however, there has been no report on mycotoxin contamination of neither the plant part nor the boiled beverage.

Mycotoxin Occurrence in Beverages and Their Fate During Traditional Processing Across Africa

A range of analytical techniques including the immunoassay (ELISA), fluorimetric test strips/kits, and chromatographic assays (TLC, HPLC, and LC-MS/MS) have enabled the determination of diverse mycotoxins in African traditional beverages. The occurrence data on mycotoxins and their major metabolites reported in 18 papers for locally produced and consumed beverages in African countries is presented in Table 3. A total of 6 papers reporting on 5 beverages (*burukutu*, *dolo*, *ice-kenkey*, *kunu-zaki*, and *pito*) were identified from West Africa (Burkina Faso, Ghana, and Nigeria) whereas 2 reports from Cameroon (Central Africa) provided data on 3 beverages (*bil-bil*, *kpata*, *sha*). In East Africa (Rwanda, Kenya, and Tanzania), 3 reports provided data on 8 beverages (banana beer, *busaa*, *dengelua*, *kangara*, *kibukuMtwara*, *kindi*, *komoni*, and *mbege*) whereas 7 papers reporting on 8 beverages (*imfulamfula*, *isiqatha*, *mqomboti/umqombothi*, opaque maize beer, sorghum beer, *thobwa*, traditional maize opaque beer, and traditional sorghum opaque beer) were retrieved across the southern African region (Botswana, Malawi, South Africa, and Zambia). With the exception of Lovelace and Nyathi (1977), Matumba and others (2011), Bationo and others (2015), and Ezekiel and others (2015) who analyzed raw materials together with processing by-products and/or finished product (beverage), all other studies discussed here focused on mycotoxin occurrences in beverages sold in various local markets in the studied communities. The highest mycotoxin levels reported in traditionally processed beverages across Africa have been in traditional maize opaque beer from Malawi (mean AFs: 90 μg/kg; mean FUM: 1898 μg/kg; Matumba and others 2014a), maize/finger millet-based *busaa* from Kenya (mean DON: 259 μg/kg; Kirui and others 2014), and maize-based *isiqatha* from South Africa (mean OTA: 2534.5 μg/L; Odhav and Naicker 2002).

The major raw materials used in the preparation of traditional beverages in Africa are the meals and malts of the mycotoxin-susceptible cereals such as maize, millet, and sorghum. Processing steps such as sorting, washing, steeping, dehulling, milling, boiling, roasting, and fermentation have been reported to reduce the level of mycotoxins in contaminated raw materials (Ezekiel and others 2015; Matumba and others 2015b; Okeke and others 2015; Karlovsky and others 2016). This was the case with a fermentation process during *kunu-zaki* and *pito* productions from sorghum and maize, respectively, leaving the final product with mycotoxin levels reduced by at least 76% in the case of *kunu-zaki* and 59% in the case of *pito* (Ezekiel and others 2015). In addition, sorghum malt obtained during the production of *dolo* (beer) in Burkina Faso had AFB_1 (mean: 97.6 μg/kg) but no detectable level was found in beer (Bationo and others 2015). Similarly, milling and fermentation during *thobwa* processing from sorghum malt caused drastic reduction in aflatoxin levels (Matumba and others 2011). Malting, however, is a step which has shown potential to elevate mycotoxin contents up to 3-fold during processing (Matumba and others 2011; Ezekiel and others 2015); this is most likely due to the increased moisture content which favors biosynthesis of many mycotoxins under the poor conditions of storage of malting grains in sub-Saharan Africa. With respect to mycotoxin degradation products or metabolites during beverage processing in Africa, the only available report is by Ezekiel and others (2015) who found up to 3-fold higher quantities of hydrolyzed FB_1 in malted maize grains for *kunu-zaki* production than the levels in raw grains, but this metabolite was not detected in the finished beverage. In the same study, ZEN and α-zearalenol were reported in malted sorghum grains, whereas only β-zearelenol was detected in the fermented beverage (*pito*), most likely due to the conversion of ZEN by the fermentation microbiota to its less estrogenic form (Mizutani and others 2011).

An interesting aspect of mycotoxins in beverages worldwide is the issue of masked mycotoxins, which have been widely reported in commercial beverages across Europe and North America (Kostelanska and others 2009; Bertuzzi and others 2011; Varga and others 2013). However in Africa, only the masked form of DON (DON-3-glucoside) has been reported in local beverages and it was found in 85.7% of 14 locally brewed maize beers (*sha*) in Cameroon at concentrations of 0.3 to 27 μg/kg (mean: 8 μg/kg; Abia and others 2013). Although that study did not consider the beer/beverage process chain, which may have provided further information on possible transfer of this masked mycotoxin from grain to beer, transfer of DON-3-glucoside was reported to be about 21% to 210% of the original quantities in malted barley to beer (Kostelanska and others 2009). This is supported by the report from Varga and others (2013) who found more DON-3-glucoside (93%) than parent compound DON (77%) in 374 beers from Europe. Lancova and others (2008) had previously shown that DON-3-glucoside levels are higher during malting than in the raw grains and final beer. There is therefore need to conduct wider surveys of locally processed beverages across Africa similar to the extensive surveys conducted in Europe and North America in order to determine the presence and concentrations of masked mycotoxins in the beverages. Unraveling the prevalence of masked mycotoxins (such as DON-3-glucoside) in beverages is imperative to understand and tackle DON exposure in this population because this metabolite is often cleaved in the gastrointestinal tract to release free/parent DON, thus increasing DON amounts on exposure (Nagl and others 2012, 2014).

Exposure Estimations from Mycotoxin Levels in Beverages and Control Options

The available data on mycotoxin contamination of African beverages indicates that exposures and co-exposures, especially from AFs and FUM, are high. However, currently it is difficult to estimate mycotoxin exposure via consumption of traditionally processed beverages in many African countries due to lack of critical and country-specific data required for exposure estimations, including consumption frequency, consumption quantity, and actual body weight and age of consumers. Nonetheless, there are broader data on alcohol/beer consumption volume in some countries in Africa, although these data are limited as regards traditional beverages including nonalcoholic types (Global Data 2016). It is therefore imperative that future studies on beverages in Africa take into consideration exposure estimates.

Attempts to estimate exposures to mycotoxins in the African population have focused mainly on crops/grains and their meal portions, but with only 3 attempts for beverages in 2 countries (Malawi and South Africa), all within the southern African region (Shephard and others 2005; Burger and others 2010; Matumba and others 2014a). The earliest exposure estimation attempt focused on FUM in *mqomboti/umqombothi* beer and based calculations on consumption data for commercial beer in South Africa due to lack of consumption data for home-brewed beer. In that report, mean total FUM in the beer was 369 μg/kg, which translated to 12 to 59 μg/person/d intakes and 0.2 to 1.0 μg/kg bw/d; ranges based on different beer consumption estimates. In the study conducted by Burger and others (2010), the authors attempted to characterize FUM exposure by categories of *mqomboti/umqombothi* beer drinkers based on actual frequencies of consumption and also using total FUM content of the local beer reported by Shephard and others (2005). Unlike the earlier study where FUM exposure from beverage consumption did not exceed the provisional maximum tolerable daily intake of 2 μg/kg bw/d set by the Joint FAO/WHO Expert Committee on Food Additives, exposure estimates per drinking event for *mqomboti/umqombothi* beer drinkers who consumed the beer 2 to 7 d a wk was 6 times (12.0 μg/kg bw) higher than the limit. The most recent study on this subject, considered traditional maize-based opaque beers in Malawi (Matumba and others 2014a) and based the beer consumption estimates of 1 to 6 L on the reports of Nikander and others (1991) for similar beer consumption level of 5 to 6 L in Tanzania. In the study, mean total AFs and total FUM contents of the opaque beer were 90 and 1898 μg/kg, respectively, and these concentration levels translated to daily exposure levels that were several tens of folds higher than the recommended exposure levels for both toxins, with increasing exposures as beer consumption level increased. Taking a cue from further data presented by Burger and others (2010), which showed that the regular local beer drinkers had been drinking for an average of 16 y, a scenario common among beverage (both alcoholic and nonalcoholic) drinkers across Africa, exposure to mycotoxins *via* contaminated beverage consumption could lead to serious chronic health challenges if efforts to minimize toxin contamination of raw materials used for beverage processing are downplayed. The exposure from beverages adds to that from the diet of contaminated cereals and is often overlooked in exposure estimates. Co-exposure from multiple mycotoxins in the drinks may worsen the case.

Considering the foregoing, it is imperative to employ strategies for mycotoxin reduction in the traditional beverage processing chain. The local practice of utilizing moldy grains, as well as heavily contaminated grains sorted out from the harvested lot for local beverage processing, is a norm which needs to be systematically erased from the local people through awareness and educational interventions. It should also be noted that the extent of mycotoxin degradation during beverage production depends on the quantities of mycotoxins in the starting material, whereas the fate of carried-over mycotoxins is hinged on the efficiency of the processing methods to modify or degrade the toxins. Therefore, an integrated approach should be taken to mitigate mycotoxins in the crops in order to have raw materials with low toxin levels, which beverage processing can conveniently handle without any carry-overs into the final product. Some listed options include timely planting of high-quality seeds, application of available biological control technologies especially for AFs reduction in maize, timely harvesting of crops, proper drying of crops, proper transportation of crops (farm to household store, farm to market), storage of grains under aerated and dry conditions free from insect infestation, and careful sorting of grains (Bandyopadhyay and others 2016; Chilaka and others 2017; Misihairabgwi and others 2017). Based on the study of Bandyopadhyay and others (2007) who reported that maize was significantly more colonized by aflatoxin-producing *Aspergillus* spp. than either sorghum or millet and had higher aflatoxin levels, it is advised that maize be substituted with sorghum or millet in the processing of beverages that could be made from mixed grains or novel beverages using less mycotoxin-susceptible crops be developed. This will support diet diversification and may reduce mycotoxin (especially aflatoxin)-related risks greatly.

Future Perspectives

To further research efforts in this area in Africa, future research on locally processed beverages in Africa is required and efforts should adopt the value chain approach towards elucidating the impact of traditional processing on mycotoxins during beverage production, defining consumption patterns across age groups, gender, and socio-economic classes, estimating mycotoxin intakes and exposures among different groups of local beverage consumers through biomonitoring studies, and optimizing processes to better reduce mycotoxin levels and exposure from consumption of these beverages. Fate of mycotoxins, including the masked forms during the processing, is also very essential to provide insights into possible degradation or transformation products formed and their biological activities. The application of high-end analytical technologies, such as liquid chromatography coupled to high-resolution mass spectrometry (LC-HRMS), may be relevant in determining toxin products in collaboration with European laboratories where the technology and expertise are adequate and available. Furthermore, there is the need to explore technological options for mycotoxin monitoring in these traditionally processed drinks. Rapid and sensitive low-cost techniques such as the immunoassays (such as ELISA) and fluorimetric test strips need to be developed specifically for screening of products at the local setting while building human and infrastructural capacity for mycotoxin testing on the continent.

Conclusion

This review paper has presented, for the 1st time, comprehensive up-to-date data on the beverages of traditional origin across Africa and the spectrum of mycotoxins that contaminate the beverages as well as their raw materials. Several regulated mycotoxins have been found in locally processed beverages and their raw grains across Africa, although AFs and FUM are more prevalent, thereby presenting the most risks to consumers. It has been shown that traditionally processed beverage consumption contributes to mycotoxin exposure across Africa; specifically, AF and FUM exposure levels for local beer drinkers exceeded the recommended values by at least 6-fold. Practical solutions to reduce mycotoxins in the beverage value chain include: educational interventions to promote the utilization of high-quality grains for processing, application of traditional (visual) or improved (optical) sorting techniques and grain-cleaning methods prior to fermentation/brewing, and optimizing processing conditions/steps. At present, several continental and international collaborative efforts that contribute to mitigation of mycotoxin exposure on the African continent are ongoing and they include: the "aflasafe" project led by IITA (www.aflasafe.com), which utilizes a novel biological control technique for aflatoxin mitigation in crops such as maize and peanut; African Union Commission-led Partnership for Aflatoxin Control in Africa program (www.aflatoxinpartnership.org), which drives and supports policy changes at country levels to promote aflatoxin-free foods on the continent; and AflaNet (www.mri.bund.de), MycoKey (www.mycokey.eu), MyToolBox (www.mytoolbox.eu), and MytoxSouth (www.mytoxsouth.org) projects—EU programs geared towards promoting safer foods through mycotoxin control in crops.

Authors' Contributions

Conception of study: CNE; Planning: CNE, KIA, OAO, and IC-O; Drafting and review of study outline: CNE, KIA, OAO, IC-O, JMM, and WAA; Sourcing for papers: CNE, KIA, IC-O, OAO, YMS, JMM, WAA, and RK; Data compilation and preparation of tables: CNE, KIA, YMS, IC-O, JMM, and WAA; Interpretation of data, writing, critical review, and fine-tuning of draft: CNE, KIA, JMM, YMS, IC-O, OAO, WAA, MS, GSS, and RK.

Conflicts of Interest

Authors have no conflicts of interest to declare regarding this manuscript.

References

Abawari RA. 2013. Indigenous processing methods and raw material of *keribo*: an Ethiopian traditional fermented beverage. J Food Resour Sci 1:13–20.

Abdallah MF, Krska R, Sulyok M. 2016. Mycotoxin contamination in sugarcane grass and juice: first report on detection of multiple mycotoxins and exposure assessment for aflatoxins B1 and G1 in humans. Toxins 8:343.

Abia WA, Warth B, Sulyok M, Krska R, Tchana AN, Njobeh PB, Dutton MF, Moundipa PF. 2013. Determination of multi-mycotoxin occurrence in cereals, nuts, and their products in Cameroon by liquid chromatography tandem mass spectrometry (LC-MS/MS). Food Contr 31:438–53.

Adetunji MC, Atanda OO, Ezekiel CN, Sulyok M, Warth B, Beltrán E, Krska R, Obadina O, Bakare A, Chilaka CA. 2014. Fungal and bacterial metabolites of stored maize (*Zea mays* L.) from five agro-ecological zones of Nigeria. Mycotoxin Res 30:89–102.

Aka S, Camara F, Nanga YZ, Loukou YG, Dje KN. 2008. Evaluation of organic acids and sugars contents during the production of *tchapalo* a traditional sorghum beer in Cote d'Ivorie. J Food Technol 6:189–95.

Aka S, Konan G, Fokou G, Dje KM, Bonfoh B. 2014. Review on African traditional cereal beverages. Am J Res Comm 2:103–53.

All Africa. 2016. Tanzania: Food poisoning linked to 14 deaths in 2 regions. Available from: http://allafrica.com/stories/201607290685.html. Accessed 2017 August 21.

Amadou I, Gbadamosi OS, Le GW. 2011. Millet- based traditional processed foods and beverages—a review. Cer Foods World AACC Int 56:115–21.

Amusa NA, Odunbaku OA. 2009. Microbiological and nutritional quality of hawked *kunu-zaki* (a sorghum-based non-alcoholic beverage) widely consumed in Nigeria. Pak J Nutr 8:20–5.

Apeh DO, Ochai DO, Adejumo A, Muhammad HL, Saidu AN, Atehnkeng J, Adeyemi RH, Mailafiya SC, Makun HA. 2016. Mycotoxicological concerns with sorghum, millet and sesame in Northern Nigeria. J Anal Bioanal Techniq 7:336.

Atter A, Ofori H, Anyebuno GA, Amoo-Gyasi M, Amo-Awua WK. 2015. Safety of a street-vended traditional maize beverage, *ice-kenkey*, in Ghana. Food Contr 55:200–5.

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

Ayalew A, Hoffmann V, Lindahl J, Ezekiel CN. 2016. The role of mycotoxin contamination in nutrition: The aflatoxin story. In: Covic N, Hendriks SL, editors. Achieving a nutrition revolution for Africa: the road to healthier diets and optimal nutrition, ReSAKSS Annual Trends and Outlook Report 2015. Washington, DC: Int Food Policy Res Inst. p 98–114.

Bandyopadhyay R, Kumar M, Leslie JF. 2007. Relative severity of aflatoxin contamination of cereal crops in West Africa. Food Addit Contam 24:1109–14.

Bandyopadhyay R, Ortega-Beltran A, Akande A, Mutegi C, Atehnkeng J, Kaptoge L, Senghor AL, Adhikari BN, Cotty PJ. 2016. Biological control of aflatoxins in Africa: current status and potential challenges in the face of climate change. World Mycotoxin J 9:771–89.

Bationo JF, Nikiema PA, Koudougou K, Ouedraogo M, Bazie SR, Sanou E, Barro N. 2015. Assessment of aflatoxin B_1 and ochratoxin A levels in sorghum malts and beer in Ouagadougou. Afr J Food Sci 9:417–20.

Bertuzzi T, Rastelli S, Mulazzi A, Donadini G, Pietri A. 2011. Mycotoxin occurrence in beer produced in several European countries. Food Contr 22:2059–64.

Bhat RV, Vasanthi S. 2003. Mycotoxin food safety risk in developing countries. In: Unnevehr LJ, editor. 2020 Focus 10: food safety in food security and food trade. Washington, DC: Int Food Policy Res Inst.

Blandino A, Al-Aseeri MC, Pandiella S, Cantero D, Webb C. 2003. Cereal-based fermented foods and beverages. Food Res Int 36:527–43.

Burger H-M, Lombard MJ, Shephard GS, Rheeder JR, van der Westhuizen L, Gelderblom WCA. 2010. Dietary fumonisin exposure in a rural population of South Africa. Food Chem Toxicol 48:2103–8.

Chala A, Taye W, Ayalew A, Krska R, Sulyok M, Logrieco A. 2014. Multimycotoxin analysis of sorghum (*Sorghum bicolor* L. Moench) and finger millet (*Eleusine coracana* L. Garten) from Ethiopia. Food Contr 45:29–35.

Chevassus-Agnes S, Favier JC, Orstom AJ. 1976. Technologie traditionnelle et valeur nutritive des bieres de sorgho du Cameroun. Cah Nutri Dietll 2:89–104.

Chilaka CA, De Boevre M, Atanda OO, De Saeger S. 2016. Occurrence of *Fusarium* mycotoxins in cereal crops and processed products (*ogi*) from Nigeria. Toxins 8:342.

Chilaka CA, De Boevre M, Atanda OO, De Saeger S. 2017. The status of *Fusarium* mycotoxins in sub-Saharan Africa: a review of emerging trends and post-harvest mitigation strategies towards food control. Toxins 9:19.

Darwish WS, Ikenaka Y, Nakayama SM, Ishizuka M. 2014. An overview on mycotoxin contamination of foods in Africa. J Vet Med Sci 76:789–97.

Djoulde DR. 2013. Sustainability and effectiveness of artisanal approach to control mycotoxins associated with sorghum grains and sorghum-based food in Sahelian zone of Cameroon. In: Makun HA, editor. Mycotoxins and food safety in developing countries. Croatia: INTECH. p 137–51.

Doko MB, Canet C, Brown N, Sydenham EW, Mpuchane S, Siame BA. 1996. Natural co-occurrence of fumonisins and zearalenone in cereals and cereal-based foods from eastern and southern Africa. J Agric Food Chem 44:3240–3.

Ediage EN, Hell K, De Saeger S. 2014. A comprehensive study to explore differences in mycotoxin patterns from agro-ecological regions through maize, peanut, and cassava products: a case study, Cameroon J Agric Food Chem 62:4789–97.

Egwaikhide IA, Malu PS, Lawal U, Adelagun RO, Andrew C. 2014. Physico-chemical and microbiological analysis of fermented cow milk (*nono*) consumed within Kaduna Town, north-western Nigeria. Food Sci Qual Man 29:44–8.

Egwim E, Amanabo M, Yahaya A, Bello M. 2013. Nigerian indigenous fermented foods: processes and prospects. In: Makun HA, editor.

Mycotoxins and food safety in developing countries. Croatia: INTECH. p 153–80.

Embashu W, Cheikhyoussef A, Kahaka GK, Lendelvo S. 2013. Processing methods of *oshikundu*, a traditional beverage from sub-tribes within Aawambo culture in northern Namibia. J Stud Human Soc Sci 2:117–27.

Ezekiel CN, Abia WA, Ogara IM, Sulyok M, Warth B, Krska R. 2015. Fate of mycotoxins in 2 popular traditional cereal-based beverages (*kunu-zaki* and *pito*) from rural Nigeria. LWT Food Sci Technol 60:137–41.

Ezekiel CN, Sulyok M, Warth B, Odebode AC, Krska R. 2012. Natural occurrence of mycotoxins in peanut cake from Nigeria. Food Contr 27:338–42.

Fadahunsi IF, Ogunbanwo ST, Fawole AO. 2013. Microbiological and nutritional assessment of *burukutu* and *pito* (indigenously fermented alcoholic beverages in West Africa) during storage. Nat Sci 11:98–103.

Fandohan P, Gnonlonfin B, Hell K, Marasa WFO, Wingfield MJ. 2005. Natural occurrence of *Fusarium* and subsequent fumonisin contamination in preharvest and stored maize in Benin. West Africa. Int J Food Microbiol 99:173–83.

FAO (Food and Agriculture Organization). 2004. Worldwide regulations for mycotoxins in food and feed in 2003. Food and Nutrition Papers No. 81, Rome: FAO.

Gadaga TH, Lehola M, Ntuli V. 2013. Traditional fermented foods of Lesotho. J Microbiol Biotech Food Sci 2:2387–91.

Gaffa T, Jideani IA, Nkama I. 2002. Traditional production, consumption and storage of *kunu* – a non-alcoholic cereal beverage. Plant Food Hum Nutr 57:73–81.

Gensi RM, Kyamuhangire W, Carasco JF. 2000. Traditional production method and storage characteristics for banana beer (*tonto*) in Uganda. Acta Hort 540: 569–74.

Ghali R, Ghorbel H, Hedilli A. 2009. Fumonisin determination in Tunisian foods and feeds. ELISA and HPLC methods comparison. J Agric Food Chem 57:3955–60.

Global Data. 2016. Beer consumption (volume and growth) forecast to 2021 – Africa, Available from: https://www.globaldata.com/store/report/bv0755mg-beer-consumption-volume-and-growth-forecast-to-2021-africa/. Accessed 2017 July 24.

Gong YY, Cardwell K, Hounsa A, Egal S, Turner PC, Hall AJ, Wild CP. 2002. Dietary aflatoxin exposure and impaired growth in young children from Benin and Togo, West Africa: cross sectional study. Br Med J 325:20–1.

Gong YY, Hounsa A, Egal S, Turner PC, Sutcliffe AE, Hall AJ, Cardwell K, Wild CP. 2004. Post-weaning exposure to aflatoxin results in impaired child growth: a longitudinal study in Benin, West Africa. Environ Health Perspect 112:1334–8.

Gong YY, Wilson S, Mwatha JK, Routledge MN, Castelino JM, Zhao B, Kimani G, Kariuki HC, Vennervald BJ, Dunne DW, Wild CP. 2012. Aflatoxin exposure may contribute to chronic hepatomegaly in Kenyan school children. Environ Health Perspect 120:893–6.

Hertveldt K. 2016. Mycotoxins occurrence in Nigerian cereal crops (sorghum and millet). Masters Dissertation. Ghent University, Ghent, Belgium.

Hove M, De Boevre M, Lachat C, Jacxsens L, Nyanga LK, De Saeger S. 2016. Occurrence and risk assessment of mycotoxins in subsistence farmed maize from Zimbabwe. Food Contr 69:36–44.

Idonije OB, Festus OO, Asika ECA, Ilegusi MI, Okhiai O. 2012. A comparative biochemical analysis of local gin (*ogogoro)* from different parts of Nigeria and imported gin (dry gin)—toxicogenic, carcinogenic, and sociopolitical implications. Sci J Med Clin Trials. 2012:4.

IARC (International Agency for Research on Cancer). 2012. IARC Scientific Publication No. 158. In: Pitt JI, Wild CP, Baan RA, Gelderblom WCA, Miller JD, Riley RT, Wu F, editors. Improving public health through mycotoxin control. ISBN-13:978-92-832-2158-6.

IARC (International Agency for Research on Cancer). 2015. Mycotoxin control in low- and middle-income countries. In: Wild CP, Miller JD, Groopman JD, editors. IARC Working Group Report No. 9, Lyon.

Kaaya AN, Kyamuhangire W. 2006. The effect of storage time and agroecological zone on mold incidence and aflatoxin contamination of maize from traders in Uganda. Int J Food Microbiol 110:217–23.

Kachapulula PW, Akello J, Bandyopadhyay R, Cotty PJ. 2017. Aflatoxin contamination of groundnut and maize in Zambia: observed and potential concentrations. J Appl Microbiol 122:1471–82.

Kamala A, Kimanya M., Haesaert G, Tiisekwa B, Madege R, Degraeve S, Cyprian C, De Meulenaer B. 2016. Local post-harvest practices associated with aflatoxin and fumonisin contamination of maize in 3 agro ecological zones of Tanzania. Food Addit Contam 33:551–9.

Kanyana I, Ouma E, Van Asten P. 2013. Quality assessment of banana juice and beer in Rwanda. J Food Technol 11:38–43.

Karlovsky P, Suman M, Berthiller F, De Meester J, Eisenbrand G, Perrin I, Oswald IP, Speijers G, Chiodini A, Recker T, Dussort P. 2016. Impact of food processing and detoxification treatments on mycotoxin contamination. Mycotoxin Res 32:179–205.

Katongole JN. 2008. The microbial succession in indigenous fermented maize products. Magister Scientiae Agriculrae. University of Free State, Bloemfontein, South Africa.

Khlangwiset P, Shephard GS, Wu F. 2011. Aflatoxins and growth impairment: a review. Crit Rev Toxicol 41:740–55.

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

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

Kirui MC, Alakonya AE, Talam KK, Tohru G, Bii CC. 2014. Total aflatoxin, fumonisin, and deoxynivalenol contamination of *busaa* in Bomet county, Kenya. Afr J Biotech 13:2675–8.

Kostelanska M, Hajslova J, Zachariasova M, Malachova A, Kalachova K, Poustka J, Fiala J, Scott PM, Berthiller F, Krska R. 2009. Occurrence of deoxynivalenol and its major conjugate, deoxynivalenol-3-glucoside, in beer and some brewing intermediates. J Agric Food Chem 57:3187–94.

Kouadio JH, Lattanzio VM, Ouattara D, Kouakou B, Visconti A. 2014. Assessment of mycotoxin exposure in Côte d'ivoire (Ivory Coast) through multi-biomarker analysis and possible correlation with food consumption patterns. Toxicol Int 21:246–57.

Kubo R, Funakawa S, Araki S, Kitabatake N. 2014. Production of indigenous alcoholic beverages in a rural village of Cameroon. Inst Brew Distill 120:133–41.

Lancova K, Hajslova J, Poustka J, Krplova A, Zachariasova M, Dostalek P, Sachambula L. 2008. Transfer of *Fusarium* mycotoxins and 'masked' deoxynivalenol (deoxynivalenol-3-glucoside) from barley through malt to beer. Food Addit Contam 25:732–44.

Lewis L, Onsongo M, Njapau H, Shurz-Rogers H, Luber G, Kieszak S, Nyamongo J, Backer L, Dahiye AM, Misore A, DeCock K, Rubin C, Nyikal J, Njuguna C, Langat A, Kilei IK, Tetteh C, Likimani S, Oduor J, Nzioki D, Wanjiku Kamau B, Onsongo J, Slutsker L, Mutura C, Mensah P, Kessel F, Park DL, Trujillo S, Funk A, Gieseker KE, Azziz-Baumgartner E, Gupta N. 2005. Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in Eastern and Central Kenya. Environ Health Perspect 113:1763–7.

Li C, Zuo C, Deng G, Kuang R, Yang Q, Hu C, Sheng O, Zhang S, Ma L, Wei Y, Yang J, Liu S, Biswas MK, Viljoen A, Yi G. 2013. Contamination of bananas with beauvericin and fusaric acid produced by *Fusarium oxysporum* f. sp. *cubense*. PLoS ONE 8:e70226.

Lovelace CEA, Nyati CB. 1977. Estimation of the fungal toxins, zearalenone, and aflatoxin, containing opaque maize beer in Zambia. J Sci Food Agric 28:288–92.

Maenetje PW, Dutton MF. 2007. The incidence of fungi and mycotoxins in South African barley and barley products. J Environ Sci Hlth Part B 42:229–36.

Makun HA, Adeniran AL, Mailafiya SC, Ayanda IS, Mudashiru AT, Ojukwu UJ, Jagaba AS, Usman Z, Salihu DA. 2013. Natural occurrence of ochratoxin A in some marketed Nigerian foods. Food Contr 31:566–71.

Makun HA, Gbodi TA, Akanya OH, Salako EA, Ogbadu GH. 2009. Fungi and some mycotoxins found in moldy sorghum in Niger state, Nigeria. World J Agric Sci 5:5–17.

Manjula K, Hell K, Fandohan P, Abass A, Bandyopadhyay R. 2009. Aflatoxin and fumonisin contamination of cassava products and maize grain from markets in Tanzania and Republic of the Congo. Toxin Rev 28:63–9.

Marasas WFO, Riley RT, Hendricks KA, Stevens VL, Sadler TW, Gelineau-van Waes J, Missmer SA, Cabrera J, Torres O, Gelderblom WCA, Allegood J, Martínez C, Maddox J, Miller JD, Starr L, Sullards MC, Roman AV, Voss KA, Wang E, Merrill Jr. AH. 2004. Fumonisins disrupt sphingolipid metabolism, folate transport, and neural tube development in embryo culture and in vivo: a potential risk factor for human neural tube defects among populations consuming fumonisin-contaminated maize. J Nutr 134:711–6.

Matumba L, Monjerezi M, Biswick T, Mwatseteza J, Makumba W, Kamangira D, Mtukuso A. 2014b. A survey of the incidence and level of aflatoxin contamination in a range of locally and imported processed foods on Malawian retail market. Food Control 39:87–91.

Matumba L, Monjerezi M, Khonga EB, Lakudzala DD. 2011. Aflatoxins in sorghum, sorghum malt and traditional opaque beer in southern Malawi. Food Contr 22:266–8.

Matumba L, Sulyok M, Monjerezi M, Biswick T, Krska R. 2015a. Fungal metabolites diversity in maize and associated human dietary exposures relate to micro-climatic patterns in Malawi. World Mycotoxin J 8:269–82.

Matumba L, Van Poucke C, Biswick T, Monjerezi M, Mwatseteza J, De Saeger S. 2014a. A limited survey of mycotoxins in traditional maize based opaque beers in Malawi. Food Contr 36:253–6.

Matumba L, Van Poucke C, Ediage EN, De Saeger S. 2017. Keeping mycotoxins away from the food: does the existence of regulations have any impact in Africa? Crit Rev Food Sci Nutr 57:1584–92.

Matumba L, Van Poucke C, Ediage EN, Jacobs B, De Saeger S. 2015b. Effectiveness of hand sorting, flotation/washing, dehulling, and combinations thereof on the decontamination of mycotoxin-contaminated white maize. Food Addit Contam 32(6):960–9.

Michojehoun-Mestres L, Hounhhouigan DJ, Dossou J, Mestres C. 2005. Physical, chemical and microbiological changes during natural fermentation of *gowe*, a sprouted or non-sprouted sorghum beverage from West Africa. Afr J Biotech 4:487–96.

Misihairabgwi JM, Ezekiel CN, Sulyok M, Shephard GS, Krska R. 2017. Mycotoxin contamination of foods in southern Africa: a 10-year review (2007-2016). Crit Rev Food Sci Nutr. Available from: https://doi.org/10.1080/10408398.2017.1357003. Accessed 2017 September 26.

Misihairabgwi JM, Kock L, Pretorious E, Pohl C, Zvauya R. 2015. Characterization of yeasts isolated from traditional opaque beer beverages brewed in Zimbabwean households. Afr J Microbiol Res 9:549–56.

Mizutani K, Nagatomi Y, Mochizuki N. 2011. Metabolism of zearalenone in the course of beer fermentation. Toxins 3:134–41.

Mohale S, Medina A, Rodríguez A, Sulyok M, Magan N. 2013. Mycotoxigenic fungi and mycotoxins associated with stored maize from different regions of Lesotho. Mycotoxin Res 29:209–19.

Mokgatlhe TM, Siame BA, Taylor JE. 2011. Fungi and *Fusarium* mycotoxins associated with maize (*Zea mays)* and sorghum (*Sorghum bicolor)* in Botswana. Afr J Plant Sci Biotech 5:26–32.

Mpuchane SF, Taligoola HK, Gashe BA, Zinzombe I, Matsheka M. 1997. A mycological study of stored maize and sorghum grains. Botswana Notes Rec 29:81–91.

Mu Ashekele H, Embashu W, Cheikhyoussef A. 2012. Indigenous knowledge system best practice from Namibia: the case of *Oshikundu* processing methods. Trends Appl Sci Res 7:913–21.

Munimbazi C, Bullerman LB. 1996. Molds and mycotoxins in foods from Burundi. J Food Protect 59:869–75.

Mupunga I. 2013. A comparative study of natural contamination with aflatoxins and fumonisins in selected food commodities from Botswana and Zimbabwe. Master of Science Dissertation. University of South Africa.

Mutiga SK, Hoffmann V, Harvey JW, Milgroom MG, Nelson RJ. 2015. Assessment of aflatoxin and fumonisin contamination of maize in western Kenya. Phytopath 105:1250–61.

Muyanja CMBK, Narvhus JA, Treimo J, Langstrud T. 2003. Isolation, characterization and identification of Lactic acid bacteria from *bushera*: a Ugandan traditional fermented beverage. Int J Food Microbiol 80:201–10.

Mwalwayo DS, Thole B. 2016. Prevalence of aflatoxin and fumonisins (B_1 + B_2) in maize consumed in rural Malawi. Toxicol Rep 3:173–9.

Nagl V, Schwartz H, Krska R, Moll W-D, Knasmuller S, Ritzmann M, Adam G, Berthiller F. 2012. Metabolism of the masked mycotoxin deoxynivalenol-3-glucoside in rats. Toxicol Lett 213:367−73.

Nagl V, Woechtl B, Schwartz-Zimmermann HE, Hennig-Pauka I, Moll W-D, Adam G, Berthiller F. 2014. Metabolism of the masked mycotoxin deoxynivalenol-3-glucoside in pigs. Toxicol Lett 229:190−7.

Namugumya BS, Muyanja CMBK. 2009. Traditional processing, microbiological, physicochemical, and sensory characterization of *Kwete*, a Ugandan fermented maize based beverage. Afr J Food Agric Nutr Dev 9:1046–59.

Nikander P, Seppala T, Kilonzo GP, Huttunen P, Saarinen L, Kilima E, Pitkanen T. 1991. Ingredients and contaminants of traditional alcoholic beverages in Tanzania. Transact Royal Soc Trop Med Hyg 85:133–5.

Njobeh PB, Dutton MF, Koch SH, Chuturgoon AA, Stoev SD, Mosonik JS. 2010. Simultaneous occurrence of mycotoxins in human food commodities from Cameroon. Mycotoxin Res 26:47–57.

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

Nyangi CJ. 2014. Aflatoxin and fumonisin contamination of maize and beans along the food and feed value chain in Babati district, Tanzania. Master of Science Dissertation. Sokoine University of Agriculture, Morogoro, Tanzania.

Nzigamasabo A, Nimpagaritse A. 2009. Traditional fermented foods and beverages in Burundi. Food Res Int 42:588–94.

Obahiagbon FI. 2009. A review of origin, morphology, cultivation, economic products, health, and physiological implications of *Raphia* palm. Afr J Food Sci 3:447–53.

Obasi OE, Ogbadu GH, Ukoha AI. 1987. Aflatoxins in *burukutu* (millet beer). Transact Royal Soc Trop Med Hyg 81:879.

Odhav B, Naicker V. 2002. Mycotoxins in South African traditionally brewed beers. Food Addit Contam 19:55–61.

Odoemelam SA, Osu CI. 2009. Aflatoxin B_1 contamination of some edible grains marketed in Nigeria. E-J Chem 6:308–14.

Ogara IM, Zarafi AB, Alabi O, Banwo O, Ezekiel CN, Warth B, Sulyok M, Krska R. 2017. Mycotoxin patterns in ear rot-infected maize: a comprehensive case study in Nigeria. Food Control 73:1159–68.

Ogunbanwo ST, Ogunsanya BT. 2012. Quality assessment of *oti-oka* beverage produced from pearl millet. J Appl Biosci 51:3608–17.

Okagbue RN. 1988. A note on the leavening activities of yeasts isolated from Nigerian palm oil. J Appl Bacteriol Microbiol 64:235–40.

Okeke CA, Ezekiel CN, Nwangburuka CC, Sulyok M, Ezeamagu CO, Adeleke RA, Dike SK, Krska R. 2015. Bacterial diversity and mycotoxin reduction during maize fermentation (steeping) for *ogi* production. Front Microbiol 6:1402.

Okoye ZSC. 1986. Zearalenone in native cereal beer brewed in Jos Metropolis of Nigeria. J Food Safety 7:233–9.

Okoye ZSC, Ekpenyong KI. 1984. Aflatoxin B_1 in native millet beer brewed in Jos suburbs. Transact Royal Soc Trop Med Hyg 78:1.

Onuoha OG, Haruna US, Yelmi BM, Samuel E, Uhiara NS, Ngwu PC. 2014. Storage study on color retention in *zobo* concentrates by increasing concentration of ginger (*Zingiber officinale)*. Afr J Food Sci 8:292–6.

Osuret J, Musinguzi G, Mukama T, Halage AA, Kaaya AN, Ssempebwa JC, Wang J-S. 2016. Aflatoxin contamination of selected staple foods sold for human consumption in Kampala markets, Uganda. J Biol Sci 16:44–8.

Outbreak News Today. 2017. Aflatoxin kills 4 children in Tanzania, linked to consumption of maize: July 24, 2017. http://outbreaknewstoday.com/aflatoxin-kills-4-children-in-tanzania-linked-to-consumption-of-maize-54210/. Accessed 2017 August 21.

Perrone G, Haidukowski M, Stea G, Epifani F, Bandyopadhyay R, Leslie JF, Logrieco A. 2014. Population structure and aflatoxin production by *Aspergillus* sect. *Flavi* from maize in Nigeria and Ghana. Food Microbiol 41:52–9.

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

Probst C, Bandyopadhyay R, Cotty PJ. 2014. Diversity of aflatoxin-producing fungi and their impact on food safety in sub-Saharan Africa. Int J Food Microbiol 174:113–22.

Probst C, Njapau H, Cotty PJ. 2007. Outbreak of an acute aflatoxicosis in Kenya in 2004: identification of the causal agent. Appl Environ Microbiol 73:2762–4.

Rheeder JP, Marasas WFO, Thiel PG, Sydenham EW, Shephard GS, Van Schalkwyk DJ. 1992. *Fusarium moniliforme* and fumonisins in corn in relation to the human esophageal cancer in Transkei. Phytopath 82:353–7.

Rheeder JP, van der Westhuizen L, Imrie G, Shephard GS. 2016. *Fusarium* species and fumonisins in subsistence maize in the former Transkei region, South Africa: a multi-year study in rural villages. Food Addit Contam Part B 9:176–84.

Roger DD. 2011. Deoxynivanol (DON) and fumonisins B_1 (FB_1) in artisanal sorghum opaque beer brewed in north Cameroon. Afr J Microbiol Res 5:1565–7.

Sangare-Tigori B, Dem AA, Kouadio HJ, Betbeder A-M, Dano DS, Moukha S, Creepy EE. 2006b. Preliminary survey of ochratoxin A in millet, maize, rice, and peanuts in Côte d'Ivoire from 1998 to 2002. Human Exp Toxicol 25:211–6.

Sangare-Tigori B, Moukha S, Kouadio HJ, Betbeder AM, Dano DS, Creppy EE. 2006a. Co-occurrence of aflatoxin B_1, fumonisin B_1, ochratoxin A and zearalenone in cereals and peanuts from Côte d'Ivoire. Food Addit Contam 23:1000–7.

Sekwati-Monang B. 2011. Microbiological and chemical characterization of *ting*, a sorghum-based gluten-free fermented cereal product from Botswana. Ph.D. Thesis. University of Alberta, Edmonton, Canada.

Shale K, Mukamugema J, Leus RJ, Venter P. 2012. Toxicity profile of commercially produced indigenous banana beer. Food Addit Contam 29:1300–6.

Shephard GS. 2008. Impact of mycotoxins on human health in developing countries. Food Addit Contam 25:146–51.

Shephard GS, Burger H-M, Gambacorta L, Krska R, Powers ST, Rheeder JP, Solfrizzo M, Sulyok M, Visconti A, Warth B, van der Westhuizen L. 2013. Mycological analysis and multi-mycotoxins in maize from rural subsistence farmers in the former Transkei, South Africa. J Agric Food Chem 61:8232–40.

Shephard GS, van der Westhuizen L, Gatyeni PM, Somdyala NIM, Burger H, Marasas WFO. 2005. Fumonisin mycotoxins in traditional Xhosa maize beer in South Africa. J Agric Food Chem 53:9634–7.

Siame BA, Mpuchane SF, Gashe B, Allotey J, Teffera G. 1998. Occurrence of aflatoxins, fumonisin B_1, and zearalenone in foods and feeds in Botswana. J Food Protect 61:1670–3.

Tafere G. 2015. A review on traditional fermented beverages of Ethiopia. J Nat Sci Res 5:94–102.

Tamang P, Kailasapathy K. 2010. Fermented foods and beverages of the world. USA: CRC Press Taylor and Francis Group. p 434.

Taye W, Ayalew A, Chala A, Dejene M. 2016. Aflatoxin B_1 and total fumonisin contamination and their producing fungi in fresh and stored sorghum grain in east Hararghe, Ethiopia. Food Addit Contam Part B 9:237–45.

Turner PC, Moore SE, Hall AJ, Prentice AM, Wild CP. 2003. Modification of immune function through exposure to dietary aflatoxin in Gambian children. Environ Health Perspect 111:217–20.

Turner PC, Collinson AC, Cheung YB, Gong YY, Hall AJ, Prentice AM, Wild CP. 2007. Aflatoxin exposure in utero causes growth faltering in Gambian infants. Int J Epidemiol 36:1119–25.

Udomkun P, Wiredu AN, Nagle M, Bandyopadhyay R, Muller J, Vanlauwe B. 2017. Mycotoxins in sub-Saharan Africa: present situation, socio-economic impact, awareness, and outlook. Food Contr 72:110–22.

Varga E, Malachova A, Schwartz H, Krska R, Berthiller F. 2013. Survey of deoxynivalenol and its conjugates deoxynivalenol-3-glucoside and 3-acetyl-deoxynivalenol in 374 beer samples. Food Addit Contam 30(1):137–46.

Vismer HF, Shephard GS, Rheeder JP, van der Westhuizen L, Bandyopadhyay R. 2015. Relative severity of fumonisin contamination of cereal crops in West Africa. Food Addit Contam 32:1952–8.

Vwioko DE, Osemwegie OO, Akawe JN. 2013. The effect of garlic and ginger phytogenics on the shelf life and microbial contents of homemade sour sop (*Annona muricata* L) fruit juice. Biokemistri Int J Nig Soc Exp Biol 25:31–8.

Warth B, Parich A, Atehnkeng J, Bandyopadhyay R, Schuhmacher R, Sulyok M, Krska R. 2012. Quantitation of mycotoxins in food and feed from Burkina Faso and Mozambique using a modern LC-MS/MS multitoxin method. J Agric Food Chem 60:9352–63.

Yard EE, Daniel JH, Lewis LS, Rybak ME, Paliakov EM, Kim AA, Montgomery JM, Bunnell R, Abudo MU, Akhwale W, Breiman RF, Sharif SK. 2013. Human aflatoxin exposure in Kenya, 2007: a cross-sectional study. Food Addit Contam 30:1322–31.

Zvauya R, Mygochi T, Parawira W. 1997. Microbial and biochemical changes occurring during production of *masvusvu* and *mangisi* traditional Zimbabwean beverages. Plant Foods Hum Nutr 51:43–51.