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Technological and community-based methods to reduce mycotoxin exposure

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ABSTRACT

In developing countries the enforcement of compliance to detailed mycotoxin regulations ensures protection of the population from adverse health effects of mycotoxin exposure. In low-income or developing countries mycotoxin regulations are either lacking or poorly enforced which create scenarios where mycotoxin exposures occur above levels set by health regulatory bodies. Population groups that are the worst affected include subsistent maize growing farmer communities where mono-cereal crops are cultivated and locally consumed, and mycotoxin contamination are not monitored. Other factors that aggravate the situation include the consumption of highly mycotoxin contaminated unprocessed maize, the lack of knowledge about the adverse effects as well as traditional uses of maize products not intended for human consumption during periods of food insecurity. These scenarios require ingenious ways to reduce mycotoxin exposure in poor rural communities where access to sophisticated mycotoxins reduction techniques is not available or practically viable. Although community-based and culturally acceptable methods have, to some extent, been adapted the efficacy thereof varies due to the lack of sufficient training. Integration of these methods with more sophisticated technological methods is envisaged, and will be based on a better understanding of mycotoxin biosynthesis and fungus-host interactions on a molecular level. In addition, other methods which include the detoxification of mycotoxins utilising degradation enzymes, clay adsorbents, utilisation of non-toxigenic fungal strains and resistant maize cultivars to fungal infections are just a few approaches under scrutiny. The introduction of good agriculture practices and storage techniques and the identification of critical control points during hazard analyses need to be further explored. Introduction of mycotoxin monitoring programs and validated screening procedures to monitor exposure should be a priority in the future, to facilitate community-based and effective intervention programmes of mycotoxin reduction.

1. Introduction

Mycotoxins are produced by food borne fungi and are important environmental and carcinogenic agents occurring in many parts of the world. The majority of Africa's grain supplies are at risk to be contaminated by mycotoxins, which is further threatened by food insecurity (Wagacha & Muthomi, 2008). As mycotoxins exhibit a variety of biological effects and are implicated in many human diseases (Wu, Groopman, & Pestka, 2014a), the prevention of chronic exposure, particularly in developing countries such as sub-Saharan Africa and parts of Latin America, is of critical importance (IARC, 2012). Co-contamination of food and co-exposure of especially young children to multiple mycotoxins have been widely documented in low socioeconomic areas in African (Tanzania, Cameroon and Nigeria) and Latin American (Guatemala) countries, and is of particular concern (Ezekiel et al., 2014; Shirima et al., 2015; Torres et al., 2015). A coordinated international response was suggested by an International Agency for Research on Cancer (IARC) Working Group, with emphasis on mycotoxin monitoring; sustained use of intervention technologies for low-income countries; and establishment and enforcement of food regulations (IARC, 2015).

Strict regulations of mycotoxins in food exist in developed

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countries with high standards of monitoring food quality to protect against the adverse effects on human health. The introduction of food safety regulations impact on international trade, as maximum tolerated levels on mycotoxin contamination differ between countries which has important implications on food safety and security measures (Wu, 2004). Globally, separate maize trading communities emerge and nations tend to trade with other nations that have similar food safety standards (Wu & Guclu, 2012). In Africa only 15 countries have mycotoxin regulations, which is mainly related to aflatoxin contamination of major dietary staples (FAO, 2003). As a result of the mycotoxin contamination of staple food, such as grain, high levels often enter the food chain of countries with less strict and/or lacking any regulations such as in sub-Saharan Africa. In addition, the best-quality food products from this region are exported to countries with regulations resulting in the poor quality food contaminated with high mycotoxin levels, being utilised domestically (IARC, 2012). In addition developing countries are often confronted with food insecurity due to severe climatic conditions, poor socioeconomic status and economic instability, and lack of the necessary agricultural expertise regarding crop management pre- and postharvest (Adegoke & Letuma, 2013; Wagacha & Muthomi, 2008). Apart from the economic losses encountered, as it hampers exports to countries with strict mycotoxins regulations, these conditions increase the risk of mycotoxin exposure on a daily basis and the associated adverse health effects.

Contamination of food resources with mycotoxins is widespread, affecting many crops, with maize being one of the major dietary staple in many parts of the world. Maize consumption varies between different regions with the highest consumption encountered in Africa (52–328 g/person/day) and the Americas with Mexico (267 g/person/day) representing the highest intake (Ranum, Pena-Rosas, & Garcia-Casal, 2014). Household consumption of maize in rural subsistent farming communities in parts of Southern Africa often exceeds these intake patterns up to 3–4 fold and could reach intake of 1–2 kg/person/day (Burger et al., 2010). The effects of maize milling on mycotoxin levels also need to be considered as they are generally located in the outer layers of the kernel (Ranum et al., 2014). Although the mycotoxins are not destroyed during milling, they are redistributed across the various milling products. Thus products such as bran, which contain the outer parts of the kernel and are generally used as animal feed, have increased levels and the fine flours much lower mycotoxin levels (Burger, Shephard, Louw, Rheeder, & Gelderblom, 2013). Although this may reduce the exposure of communities utilising sophisticated milling products, the prevalence in subsistence communities of simpler milling processes in which no separation of kernel components is achieved, implies that no such reduction occurs.

Of the different mycotoxins, aflatoxin produced by *Aspergillus* spp. and the fumonisins, produced by *Fusarium* spp. are common mycotoxin contaminants of maize and are known to adversely affect human and animal health (IARC, 2012). Implementation of the maximum levels of fumonisin set by the Codex Alimentarius Commission (FAO, 2014) for raw maize and maize flour (including maize meal) of 4 mg/kg and 2 mg/kg, respectively, will dramatically increase fumonisin exposure among southern African maize consumers. This has become apparent as the cooked maize intake among South African consumers range between 475 and 690 g/person/day (Nel & Steyn, 2002) with raw maize intake varying between 100 and 210 g/person/day (Burger, Lombard, Shephard, Danster-Christians, & Gelderblom, 2014). When superimposing these maximum levels to the Mycotoxin Risk Assessment Model (MYCORAM) for fumonisins, depending on the geographical area or Province, 73–97% of South African maize consumers will, under these regulatory conditions, be exposed to levels above the Provisional Maximum Tolerable Daily Intake (PMTDI) of 2 μg/kg bw/day (Burger et al., 2014). Subsistent farmer communities in rural areas will be worst affected with fumonisin exposure levels far above the PMTDI.

The population in low income countries countries is not protected by strict international regulatory measures, underlining the necessity for implementation of mycotoxin control regulations. In this regard the World Health Organisation (WHO) made several recommendations for mycotoxin reduction and control involving an integrated approach including awareness campaigns, strengthened laboratory and surveillance capacities and establishing early warning systems (WHO, 2006). Other approaches such as the implementation of simple and affordable mycotoxin reduction techniques at household level and/or subsistence maize farming communities to effectively reduce exposure are becoming increasingly important. Integration of some of these community-based approaches with recent technological advances to control mycotoxin production and detoxification will be critically discussed in this review.

2. Technological methods for reduction

Technological approaches for mycotoxin reduction are mainly aimed at commercialization and application in areas with established infrastructure, i.e. developed countries. Genetic resources are utilised for breeding of maize cultivars resistant to fungal infection and subsequent mycotoxin contamination, and transgenic maize cultivars resistant to insect infestation and fungal colonisation (Cleveland, Dowd, Desjardins, Bhatnagar, & Cotty, 2003; Duvick, 2001). Information on the role of environmental factors influencing fungal growth and expression of mycotoxin biosynthetic genes could provide more gene targeting strategies to interrupt mycotoxin biosynthesis pre-harvest. The availability of genomic resources are essential for investigations into the biochemical and regulatory pathways of mycotoxin biosynthesis, pathogenesis of fungal-host interactions and the development of targeted and innovative approaches for breeding and engineering crops for resistance (Desjardins & Proctor, 2007). Whole genome sequences and expression sequence tags (ESTs) are important tools for understanding disease caused by fungi, fungal lifecycles and secondary metabolism (Brown, Butchko, & Proctor, 2006). Available genomic resources include genetic maps, genome sequences, EST libraries and integrated gene indexes. Genomic studies on several *Aspergillus* and *Fusarium* fungal species are well underway. Among these are structural, functional and comparative genomics of the toxin-producing species *Fusarium graminearum* (trichothecene producer), *Fusarium verticillioides* (fumonisin producer), and *Aspergillus flavus* (aflatoxin producer) (Xu, Peng, Dickman, & Sharon, 2006). As the number of fungi whose genome sequences have been elucidated continues to rapidly grow, so too does the potential to perform high throughput proteomic analysis on these organisms.

Fanelli, Iversen, Logrieco, and Mulè (2013) studied the effect of environmental conditions (temperature, water activity, pH and salinity) on fumonisin production and *FUM1* and *FUM21* gene expression by *F. verticillioides in vitro*. Gene expression mirrored fumonisin production profiles under all conditions with the exception of temperature: *FUM1* and *FUM21* expression was highest at 15 °C, while maximum fumonisin production was at 30 °C. These data indicate that a post-transcriptional regulation mechanism could account for the different optimal temperatures for *FUM* gene expression and fumonisin production. While transcriptional to translational correlations are often not very strong, it is essential to determine the gene expression to protein translation relationship in fumonisin production to better understand the mechanism