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Review

Innovative technologies to manage aflatoxins in foods and feeds and the profitability of application – A review

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ABSTRACT

Aflatoxins are mainly produced by certain strains of *Aspergillus flavus*, which are found in diverse agricultural crops. In many lower-income countries, aflatoxins pose serious public health issues since the occurrence of these toxins can be considerably common and even extreme. Aflatoxins can negatively affect health of livestock and poultry due to contaminated feeds. Additionally, they significantly limit the development of international trade as a result of strict regulation in high-value markets. Due to their high stability, aflatoxins are not only a problem during cropping, but also during storage, transport, processing, and handling steps. Consequently, innovative evidence-based technologies are urgently required to minimize aflatoxin exposure. Thus far, biological control has been developed as the most innovative potential technology of controlling aflatoxin contamination in crops, which uses competitive exclusion of toxigenic strains by non-toxigenic ones. This technology is commercially applied in groundnuts maize, cottonseed, and pistachios during pre-harvest stages. Some other effective technologies such as irradiation, ozone fumigation, chemical and biological control agents, and improved packaging materials can also minimize post-harvest aflatoxins contamination in agricultural products. However, integrated adoption of these pre- and post-harvest technologies is still required for sustainable solutions to reduce aflatoxins contamination, which enhances food security, alleviates malnutrition, and strengthens economic sustainability.

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1. Introduction

Food security is effectually achieved when the food pillars, including food availability, food access, food utilization, and food stability are at levels that allow all people at all times to have physical and economic access to affordable, safe, and nutritious food to meet the requirement for an active and a healthy life (FAO, 1996). When one of these four pillars weakens, then a society undermines its food security. Factors related to food insecurity and malnutrition not only influence human health and welfare, but also affect social, economic, and political aspects of society. With regards to the previous points, pre- and post-harvest losses due to mycotoxin contamination are documented as one of the driving factors of food insecurity since these substances occur along most food chains from farm to fork.

Among the different type of mycotoxins, aflatoxins (AFs) are widespread in major food crops such as maize, groundnuts, tree nuts, and dried fruits and spices as well as milk and meat products (Iqbal, Jinap, Pirouz, & Ahmad Faizal, 2015; Mutegi, Ngugi, Hendriks, & Jones, 2009; Perrone et al., 2014). When animal feeds are infected with AF-producing fungi, AFs are introduced into animal source food chain. AFs are toxic metabolites produced via a polyketide pathway by various species and by unnamed strains of *Aspergillus* section Flavi, which includes *A. flavus*, *A. parasiticus*, *A. parvisclerotegenus*, *A. minisclerotigenes* (Pleadin et al., 2014), Strain SBG (Cotty & Cardwell, 1999), and less commonly *A. nomius* (Kurtzman, Horn, & Hessetline, 1987). Normally, *A. flavus* produces only B-type aflatoxins, whereas the other *Aspergillus* species produce both B- and G-type aflatoxins (Creppy, 2002; Zinedine & Mañes, 2009). The relative proportions and level of AF contamination depends on *Aspergillus* species, growing and storage conditions, and additional factors (Paterson & Lima, 2010). For instance, genotype, water or heat stress, soil conditions, moisture deficit, and insect infestations are influential in determining the frequency and severity of contamination (Wagacha & Muthomi, 2008). For M-type aflatoxins, these compounds are normally not found on crops, but their metabolites are found in both the meat and milk of animals whose feedstuffs have been contaminated by AF-B_1 and AF-B_2 (Iqbal et al., 2015; de Ruyck, De Boevre, Huybrechts, & De Saeger, 2015; Sherif, Salama, & Abdel-Wahhab, 2009).

Recently, emphasis on the health risks associated with consumption of AFs in food and feedstuffs has increased considerably. As a result of this, many experimental, clinical, and epidemiological studies have been conducted showing adverse health effects in humans and animals exposed to AFs contamination, depending on exposure (Binder, Tan, Chin, Handl, & Richard, 2007; Fung & Clark, 2004; Sherif et al., 2009). High-dose exposure of the contaminant can result in vomiting, abdominal pain, and even possible death, while small quantities of chronic exposure may lead to liver cancer (Etzel, 2002; Sherif et al., 2009). The International Agency for Research on Cancer (IARC) has classified both B- and G-type aflatoxins as Group 1 mutagens, whereas AF-M_1 is classified in Group 2B (IARC, 2015). Furthermore, AFs may contribute to alter and impair child growth (Turner, Moore, Hall, Prentice, & Wild, 2003; Wu & Khlangwiset, 2010). Together with other mycotoxins, AFs are commonly suspected to play a role in development of edema in malnourished people as well as in the pathogenesis of kwashiorkor in malnourished children (Coulter et al., 1986; Hendrickse, 1982). Moreover, AF contamination negatively impacts crop and animal production leading not only to natural resource waste, but also decreased market value that causes significant economic losses.

Due to these effects, different countries and some international organizations have established strict regulations in order to control AF contamination in food and feeds and also to prohibit trade of contaminated products (Juan, Ritieni & Mañes, 2012). The regulations on “acceptable health risk” usually depend on a country's level of economic development, extent of consumption of high-risk crops, and the susceptibility to contamination of crops to be regulated (Kendra & Dyer, 2007). Indeed, the established safe limit of AFs for human consumption ranges 4–30 μg/kg. The EU has set the strictest standards, which establishes that any product for direct human consumption cannot be marketed with a concentration of AF-B_1 and total AFs greater than 2 μg/kg and 4 μg/kg, respectively (EC, 2007; EC, 2010). Likewise, US regulations have specified the maximum acceptable limit for AFs at 20 μg/kg (Wu, 2006). However, if the EU aflatoxin standard is adopted worldwide, lower-income countries such as those in Asia and Sub-Saharan Africa will face both economic losses and additional costs related to meeting those standards. This situation requires alternative technologies at pre- and post-harvest levels aimed to minimize contamination of commercial foods and feeds, at least to ensure that AF levels remain below safe limits (Prietto et al., 2015).

Implementation of innovative technologies is invaluable to address the challenges related to AFs and their effects. Reduction of AF contamination through knowledge of pre- and post-harvest managements is one of the first steps towards an appropriate strategy to improve of agricultural productivity in a sustainable way. This has direct positive effects on enhancing the quality and nutritional value of foods, conserving natural resources, as well as advancing local and international trade by increasing competitiveness. It is important to identify and document available technologies that can effectively control and minimize aflatoxin contamination to sustain healthy living and socioeconomic development. There exists ample literature on tools for AF control and their benefits. Therefore, this review compiles data on innovative pre- and post-harvest technologies developed that can manage AF contamination in foods. The benefits of these technologies are also discussed in terms of food security, human health, and economic value. Finally, implications for research and management policies addressing AF issues are highlighted.

2. Innovative management strategies of AF reduction

A wide range of AF management options exist in literature. Depending on the “type” or mode of application, management has been classified in this review as pre-harvest stage, specifically biological control, while sorting technology, treatments with electromagnetic radiation, ozone fumigation, chemical control agents, biological control agents, and packaging material are grouped as

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