Journal of Stored Products Research 71 (2017) 22–40

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Review

Integrated management of the risks of stored grain spoilage by seedborne fungi and contamination by storage mould mycotoxins – An update

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A R T I C L E I N F O

Article history:
Received 25 June 2016
Received in revised form
23 September 2016
Accepted 15 October 2016

Keywords:
Stored-grain ecosystem
Seed-borne fungi
Grain spoilage
Mycotoxin contamination
Preventive management
Deterioration indicators
Integrated management

A B S T R A C T

Fungal spoilage of stored grains may occur when activity of water (*aw*) in cereal grain exceeds a critical limit enabling mould growth. Because it is not feasible to maintain all parts of large grain bulks below this critical moisture limit during prolonged storage time, an infection by seed-borne fungi is not rare in cereal grain stored under humid temperate or hot climates, inducing irreversible qualitative losses. Additionally, some fungal species produce harmful mycotoxins. The most harmful toxigenic species belong to the group of xerophilic species (genera *Aspergillus* and *Penicillium*). Because mycotoxin contamination of cereal grain is a worldwide issue for public health and a permanent concern for cereal-food industries facing the challenge of a permanent monitoring mycotoxin content in their primary matters, tolerable levels of mycotoxins are severely regulated worldwide. Mycotoxin-producing species growth is closely dependent of grain moisture levels enabling biological activity in grain ecosystem. Consequently, mould growth in stored grain bulks can be anticipated through early detection of grain and mould respiration. The prevention of mycotoxigenic fungi spoilage of stored grain can be managed by a preventive strategy. The main objective of the review was to describe the different methods, material and practices combined in such an integrated preventive approach. Some solutions potentially acceptable for the decontamination of moderately contaminated grain are also discussed.

Integrated management of mould spoilage risks in stored grain is based on five pillars: i/Prevention of mould development by keeping grain moisture below the critical limit of fungal growth; ii/Accurate monitoring of grain *aw* and temperature changes during the storage period, associated to the monitoring of early indicators of respiration activity of storage fungi; iii/Reduction of grain bulk moistening trends by physical intervention means; iv/Use of physical treatments (ozone, grain peeling or abrasion) to limit mycotoxin contamination transfer to processed cereal products; v/Possible use of bio-competitive strains of fungi or bacteria to prevent the development of mycotoxigenic fungi in grain bulks. The future research needs on this topic are also evocated.

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http://dx.doi.org/10.1016/j.jspr.2016.10.002

1. Introduction

Cereals are basic food supply of billion people in the world. They are grown in a large number of countries and under very different climatic zones which allow for small and large scale cereal grain production. The highly variable environmental conditions at which are exposed cereals before and after the harvest in so different grain-producing regions are determining the risk level of qualitative issues occurrence up to the moment of the delivery of stored grain to food processing users (Fleurat-Lessard, 2002; Anonymous, 2014). In developed countries that have an important cereal grain production for food and feed uses, huge amounts of grains are stored after harvest, often more than a year, in order to supply domestic cereal industries and satisfy import/export demand. According to the definition of the stored grain ecosystem from Dunkel (1992), *stored grain ecosystems are composed of dormant autotrophs, seeds, which serve both as an energy source and as habitat for many heterotrophic species of fungi, bacteria, insects and mites* (Fig. 1). Under conditions of grain storage in developed countries, fungi are the major cause of loss on long term storage periods without an efficient control of temperature and, above all, moisture content of stored grain (Christensen and Kaufmann, 1969; Wicklow, 1995). During long term storage, when grain moisture and temperature exceed critical limits of safe storage, sometimes in limited re-humidified zones of the bulk, the ever-present mould inoculum will start to develop and deterioration process will be initiated (Multon, 1988).

The most important ecological situations initiating deterioration process are grain moisture increase due to water condensation by the “cold wall contact” effect (especially with metallic bin structures) and the creation of a “hot spot” by a load of wet grain with a moisture content level exceeding the limit for safe storage. The consequences of these two phenomena for stored grain quality deterioration rate or dry matter loss they can induce were described by numerous authors (e.g.: loss of germination capacity: Ellis and Roberts, 1980; Bason et al., 1994; dry matter loss: Kreyger, 1972; Latif and Lissik, 1986; apparition of visible moulding on grain: Frazer and Muir, 1981). The modeling of these kinds of qualitative or quantitative losses is presented in a previous review (Fleurat-Lessard, 2002). Nevertheless, the processes leading to the activation of major biological factors implicated in the genesis of the deterioration process were rarely investigated. For instance, the frequent observations of heavy infestation by insects within hot spots have supported the hypothesis that insect multiplication can be at the origin of hot spot formation in bulk grain. In developed countries, the population of insects infesting cereal grain is generally limited to small densities thanks to storekeeper's use of adequate insect control technologies (Sinha, 1995). Thus, in most situations of stored grain spoilage due to grain moisture and temperature local increase in a hot spot or at a cold wall -where insects may be found in numbers-the insect presence is more likely the consequence of hot spot formation by storage mould respiration and active growth rather than the multiplication of “cold blood” insects. To support this close relationship between storage mould intense growth and hot spot formation, the respiratory rate from insects and from moulds was compared and published respectively by Magan et al. (2003) and Fleurat-Lessard and Dupuis (2010). The production of carbon dioxide by storage moulds in a kilogram of grain (depending of the grain original moisture content) is 10–100 times higher than the production of 100 insects (*Sitophilus zeamais* Motschulsky). Considering that this level of density of insects is rarely found in practical storage situations, when a high insect density is observed in a hot spot (), in most cases, it is the consequence of natural increase of temperature and moisture content induced by an intense respiratory activity of storage moulds. It is also well known that adult (mobile) insects are able to detect moisture and temperature gradients in a grain bulk and locations within a grain bulk more favorable to their multiplication (Cox and Collins, 2002).

As evidence, moulds are among the most important spoilage risks in stored cereal grain and derived cereal food (Christensen and Kaufmann, 1965; Pitt and Hocking, 2009). They may cause grain