International Journal of Economic Plants 2021, 8(2):103-108 Review Article Crossref

Doi: HTTPS://DOI.ORG/10.23910/2/2021.0415a

Management of Storage Pathogens of Cereal Grains: A Review

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Article History

Article ID: IJEP0415d
Received on 23rd March, 2021
Received in revised form 12th May, 2021
Accepted in final form 25th May, 2021

Abstract

Storage is the cultural process of preserving grains because grains were stored after harvesting and till manufactured to the factory or consumer directly. There were many pathogens (like bacteria, fungi, yeast etc.) playing a significant role in infecting grain and destroying the grains partly or completely. Many remedies used for solving this problem are insufficient. Among the phytopathogens, fungi have devastating power to destroy plants by its mycelium. Fungi can infect seeds through generation after generation and trouble in the storage process. Different microorganisms produce different types of myco-toxins within the cereal grains in the storage and cause the loss of food value. Several techniques are available to determine the factor affecting store grain cereals. Many cultural and conventional established techniques were applied to overcome the loss of grains during storage. In this regard, drying in different ways is effective. In recent years, the convention of storage techniques for cereal grains has evolved with the help of hermetic storage, aeration, updated atmospheric storage and refrigerated storages. Mainly, three grains from cereals i.e. rice, wheat, maize were taken into consideration for this review and only fungal pathogens of stored grains and their modern agriculture remedies are discussed.

Keywords: Cereals, mycotoxin, phyto-pathogen, store grain pathogens

1. Introduction

Rice (*Oryza sativa*) is placed as the world's second most important food grain after wheat. It provides 20% of the calories consumed worldwide by humans and as staple food in Asia and Africa (Bitew, 2016). Rice provide the third highest production (741.5 million tonnes in 2014), after sugarcane (1.9 billion tonnes) and maize (1.0 billion tonnes). Wheat also plays a significant role as a source of carbohydrate. Universally, it is the main vegetable protein in human food, having a protein substance of about 13%, which is generally high contrasted with other significant cereals, yet moderately low in protein quality for providing fundamental amino acids. When eaten as the entire grain, wheat is the different supplements and dietary fiber (Shewry and Hey, 2015). Wheat is the most significant food grain on the planet. Global demand for wheat is increasing due to the unique properties of gluten proteins, which facilitate the production of processed foods (Mir et al., 2019). Maize becomes a staple food in different part of the world, with the total production of maize that of wheat or rice. Maize is utilized for corn ethanol, animal feed, and other maize items, for example, and corn syrup. Other significant kinds of maize are mark corn, stone corn, unit corn, popcorn, flour corn, and sweet corn. Maize is additionally utilized in making ethanol and different biofuels.

There are many grain-producing plants but commercially two types of grain plants are considered such as cereals and legumes (Barr, 2019). These cereals are optimally stored for many years and need protection against pests, fungi, rodents, mites and bacteria. Due to the damage of the cereal grains, the food value of the grains reduce dramatically as well as their mass, the viability of these grains also decreases significantly (Bhargava et al., 2007). Generally, fungi like *Aspergillus* spp. and *Penicillium* spp. are pathogens which affect on the storage cereal grains through mycotoxins and enzymatic activity causes decreasing the seed germination ability, loss of seed mass, and seed discoloration (Wicklow et al., 1998). All these fungi which affect the storage food as well as stored grains are called storage fungi or storage mold. These may be invading grains or seeds during storage. Minute quantity of spore like conidia, oidia, chlamydospore or special structure like sclerotia of storage fungi may be present on grain going into storage. Micro-organism (bacteria, yeast and fungi) have significant role in damage of stored cereal grains. Fungi behaves like parasite within the stored grain caused the severe disease to the consumers and due to growth of fungi the respiration rate of food grain within storage increased gradually and create hot-spot which hampered the good milling characteristics of stored grains. Different mycotoxins also have been produced

due to multiplication of fungi which treated as highly toxic for consumers. Spores of fungus are aggressive to reproduce themselves many folds and spoil the stored food grains. Humid and hot atmospheric condition is favorable for fungus growth. The growth of fungi is retarded by dry weather. However, the spores are not destroyed due to high resisting capacity in dry conditions (Beeson and Perry, 1958). Many cultural and conventional established techniques were applied to overcome the loss of grains during storage; this can be ceased by using modern machine and updated equipments. In recent years, convention of storage techniques for cereal grains has been evolved with the help of hermetic storage, aeration, updated atmospheric storage and refrigerated storages (Pekmez, 2016). The present reviewtried to search different fungal and bacterial pathogen attack on rice, wheat and maize in storage and their optimum treatment against this pathogen. This also includes merit and demerit of modern cereal storage techniques. There is lacking of time and location specific fruitful and economical measures for reducing the store grain pathogen of cereals. Keeping in view the above points, the present review work has been carried out for the search of appropriate techniques for reducing store grain pathogen of cereals.

2. Pathogens in Store Grain

2.1. Bacteria

Generally, bacteria are not significantly involved in the spoilage of dry grain due to storage conditions unfavorable for their growth. However, it was found that some bacterial pathogens and spore forming species are able to survive during storage and may contaminate processed products. Lactic acid bacteria present in the raw grain may be carried over through the processing and spoil dough prepared from flour and cornmeal (Bullerman and Bianchini, 2009; Juste et al., 2011). Gram negative coliforms, pseudomonas and actinomycetes were also found on dry stored cereals (Hill and Lacey, 1983). Wachowska et al. (2013) reported that the number of bacteria of the genus *Azotobacter* colonizing winter wheat grain was relatively low at harvest, but the counts increased after 6 months of storage.

Levels of cereal grains contamination with bacterial pathogens are usually very low and although contamination with species such as *Salmonella, Escherichia coli*, and *Bacillus cereus* can occur, bacteria associated with cereals are generally nonpathogenic. The most often they belong to the families Pseudomonadaceae, Micrococcaceae, Lactobacillaceae and Bacillaceae (Hocking, 2003; Laca et al., 2006). Some species of enteric bacteria that are found on cereal grains are plant saprophytes and their presence is not related to fecal contamination (Harris et al., 2013). Numerous bacteria belonging to *Streptomyces* genus was recently found on barley and spring wheat grains. The authors also reported the presence of antimycin-A toxin producing strains in barley, which is the first report of antimycin A in a food substance (Rasimus sahari et al., 2016).

2.2. Filamentous fungi and yeasts

The fungi growing on crops have been traditionally divided into two groups—"field" and "storage" fungi (Pitt and Hocking, 2009). The main difference between these groups is the time at which they invade the grains and growth conditions, however, the distinction between field and storage fungi is not absolute. It was found that although some field fungi invade the grains on the field, they are still able to grow in storage conditions. Similarly, some fungi commonly classified as storage fungi may invade the grains at earlier stages. Spoilage of grains with filamentous fungi during storage occurs usually due to inefficient drying, what favors microbial growth and may result in increased mycotoxins levels (Harris et al., 2013). If drying is delayed and the moisture content of the harvested grain is suitable, growth of the field fungi, for example, *Fusarium* spp, may occur. Storage fungi for cereals including species of *Eurotium*, *Aspergillus*, *Penicillium*, *Rhizopus*, *Mucor* and *Wallemia* invade stored grains at low relative humidity's (65% to 90%) and lower moisture contents (14% to 16%) of the grains (Bullerman and Bianchini, 2009).

Among *Penicillium* species, *P. verrucosum* is important as contamination with this fungus may result in the production of carcinogenic mycotoxin ochratoxin a (OTA), especially in cool climates (Lund and Frisvad, 2003). It was shown that *P. verrucosum* attacks wheat and barley only after harvest (Pitt and Hocking, 2009). Birck et al. (2005) compared fungal contamination in wheat grain during 180 days of storage. It was observed that *Fusarium* spp. was the most numerous funguses after harvest and after 30 days of storage, however, the counts decreased gradually until the end of the storage period. After 180 days of storage *Aspergillus*, *Fusarium* and *Penicillium* were found in 96.7%, 46.7%, and 80.0% of wheat samples, respectively. Krnjaja et al. (2015) investigated mycobiota of maize—mycological analyses showed the presence of *Aspergillus*, *Fusarium* and *Penicillium* on both freshly harvested and stored grains, however, the predominant species varied for each stage of processing.

Yeasts found on cereal grains during storage are often amylolytic yeasts. Similarly lactic acid and spore forming bacteria, yeasts present on cereals may also be carried through into processed products (Bullerman and Bianchini, 2009).

3. Distribution of Microorganisms within Cereal Grains

The typical structure of a cereal grain constitutes three edible parts: the bran which consists of the outer coat (pericarp, testa and aleurone layers), the germ (the embryo) and the starchy endosperm and an inedible husk that protects the kernel (Merali et al., 2013). Microbial colonization is generally restricted to the outer layers of cereal grains, that is, the husk, between the husk and pericarp and within the pericarp tissue. Several studies showed that after de-branning, cereals are

microbiologically purer (Laca et al., 2006). However, there are species able to invade the inner part of the grains and penetrate into the endosperm, causing internal infections (Nierop, 2006).

Aspergillus spp and *Penicillium* spp were the major fungus that destroys the stored rice around the globe (Atanda et al., 2011). The effects of toxin produce in rice invading fungi like *Penicillium*, *Aspergillus* is very risky because some of this can reduce immune system (Bennett and Klich, 2003). *Penicillium* (the second most important fungal group in stored rice) is responsible for other mycotoxins (e.g., patulin, citrinin and ochratoxin) which also produce many other alkaloids (Mannaa and Kim, 2016).

Many fungi inhabited in stored wheat grains mostly consisted of omnipresent genera like *Aspergillus*, *Alternaria*, *Cladosporium*, *Fusarium*, *Mucor*, *Rhizopus* and *Penicillium* possibly everywhere with wide range of temperature and humidity. Many types of fungi are present in stored maize like *Fusarium*, *Penicillim* and *Aspergillus*, *Nigropora* spp. *Aspergillus* and *Fusarium* play crucial role in damaging of the maize grain. (Abdel-Azeem et al., 2016; Mohapatra et al., 2017).

4. Microbial Contamination within a Cereal Grain

According to the study, most of the contamination is located in the outer layers and colonization by *Alternaria* spp (black fungi discoloration) is observable on the surface of the kernels as well as beneath the pericarp of wheat, barley and oats, and is believed to be a result of rainfall just before harvest (Kosiak et al., 2004). Andersen and Thrane (2006) reported that wheat and barley surface disinfection with sodium hypochlorite removed only 10–15% of *Alternaria* and *Bipolaris*, which indicates that the grains were contaminated beneath the pericarp. The presence of toxic metabolites may reflect the deterioration of grain and indicate possible feed and food hazards.

5. Remedies

5.1. Moisture and temperature determination during storage of cereals

Variation in grain moisture is the rule in bulk storage, and fungi grow where moisture is suitable and not according to the average moisture content (MC). A substantial problem is accurate determination of grain moistures (Kaufmann and Christensen, 1970; Christensen and Kaufmann, 1969), particularly in excess of 23-25%. There are many remedy, ideally, grain should be cooled after drying and maintained at 1 to 4^0C for the duration of storage. At this temperature, fungal metabolism is minimal. During the summer months, grain temperature can be maintained between 10 and 15^0C. Temperature control is achieved by aerating the grain when outside air temperature is within the desired range and humidity is low. Aeration is essential for maintaining grain quality in storage, by controlling temperature and evaporating moisture that has migrated and condensed in the bin.

EMC of grain is influenced by genotype (Hubbard et al., 1957), previous drying temperatures (Tuite and Foster, 1963), storage temperature (Pixton and Warburton, 1971) and hysteresis (Hubbard et al., 1957). As a result of these variables, even if accurate moistures are determined, the prediction of microbial growth is imprecise. It is the inter-seed relative humidity that determines fungal activity (Christensen and Kaufmann, 1969).

5.2. High temperature drying

High temperature drying is the method of choice in conditioning corn for storage and marketing. It is used because of its high capacity and rapidity, making the grain immediately suitable for movement in commercial channels. Grain dried at high temperatures is decreased in hygroscopicity and as a result is in equilibrium with a higher relative humidity than low temperature dried grain. It is therefore recommended that dent corn that reached temperatures of 83°C and above be stored at moistures of 0.5 to 1.0% lower than corn dried at lower temperatures (Tuite and Foster, 1963).

5.3. Low temperature drying

A development of no heat drying is low heat drying. One simulation study did not indicate any particular advantage to low heat drying in locations where relative humidity is not high. The bin may be filled initially or filled in layers, the latter permitting higher moisture grain. As in natural air drying, depth of grain and fan capacity (both determining air flow rates) is the main factors that determine which moistures may be dried before deterioration takes place (Pierce and Thompson, 1978).

5.4. Natural or ambient air drying

It was used to cool grain so as to slow fungal and insect growth and to prevent moisture migration. Moisture migration occurs when temperature gradients develop in grain bulks and is an important cause of moisture accumulation and resultant molding (Brooker et al., 1974). Aeration was developed as an alternative to “turning” the grain (moving the grain from bin to bin) because it saves money and time and prevents damage to the grain when it is moved.

5.5. Solar drying

Solar drying has been confined to low heat drying where air temperature is increased as much as 16-17°C. It is based on an intermittent and a not always reliable source of energy. The collector area required for high temperature drying is unrealistic. Solar drying appears more rapid than natural air drying, particularly in areas with high relative humidity (Pierce and Thompson, 1978). Solar drying appears more efficient than no heat drying in cold weather (Tiwari, 2016).

5.6. Hermetic storage

This is a proven method of preserving high moisture corn

(HMC) for feed. It was developed initially in France (Vayssiere, 1948) and has been used in the Midwest with corn primarily fed to beef cattle (Beeson and Perry, 1958; Jones et al., 1974). HMC may be stored in glass-lined bins (Foster et al., 1955) or other kinds of airtight bins that have a breathing system to prevent structural failure because of differential pressures and to limit the exchange of in-storage gas with outdoor air. The grain undergoes fermentation, O_2 is depleted and CO_2 is increased by the respiration of the grain, yeast, and bacteria (Burmeister et al., 1966).

6. Chemical Control

The search for chemical preservatives is encouraged by the potential flexibility, low capital outlay, and high capacity they lend to preserving grain. However, pesticides including fungicides use raise several concerns, related especially to its environmental impacts like biodiversity reduction as well as direct harmful impact on humans and other nontarget species (Liu et al., 2015). Repeated use of pesticide may develop pesticides resistance (Jess et al., 2014). The European Union introduced a strategy on the sustainable use of pesticides through the use of Integrated Pest Management (IPM) that is combining chemical and nonchemical control methods and use alternative approaches such as nonchemical alternatives to reduce the reliability on pesticides which is the most effective strategy to prevent the evolution of pesticide resistance. A successful chemical must have very low mammalian toxicity but wide and usually long-lasting microbial-inhibiting properties.One such alternative is the use of natural plant protectants that have pesticidal activity. They tend to have low mammalian toxicity, less environmental effects and wide public acceptance (Hamilton-Kemp et al., 2000). Use of organic acid is one of the significant finding in chemical control of storage fungi. Propionic acid (PA) has been one of the most effective and the most widely used. Its value was demonstrated in England in the early 1960s on barley and wheat (Huitson, 1968; Jones et al., 1974) and it has since been used commercially on corn in the United States. Acetic and formic acid are much less inhibitory but are used in combination with propionic acid (Lavermicocca et al., 2003).

Methylene bis-propinate, which breaks down into formaldehyde and propionic acid, is equal or superior to PA (Sauer et al., 1975) but may have some negative effects on animal weight gain. Isobutynite and ammonium butyrate are promising volatile fatty acids (Bothast et al., 1975). The calcium and sodium salts of propionic acid are inhibitory in feeds but of less primary value in shelled corn. Sorbic acid is effective in an ethanolic solution but not as a powder when applied to grain. Its fungicidal value is lessened greatly at a pH above 5 (Bell et al., 1959). There are various proprietary mixtures of PA with butylated hydroytoluene (BHT), benzoic acid, formaldehyde, or formic acid.

Fungi that are often found in failing acid treatments include *Monascus*, *Paeciliomyces varioti. Penicillium* spp, *Aspergillus glaucus*, *A. fumigatus* and occasionally *A .flavus* (Sauer et al., 1975). The first two fungi, by their rarity in moldy grain and prevalence in acid-treated grain, indicates some tolerance to organic acids. The occurrence of the four other fungi may simply reflect favoring environments of temperature, moisture, and atmosphere. Mycotoxins may or may not be found in treated grain that has molded. Mycotoxins seem unaffected by common chemical fumigants or preservatives except for ammonia which is used to destroy aflatoxin (Brekke et al., 1975).

Food additives and preservatives originated from organic acids are successfully used because they reduce the environmental pH and thus prevent food deterioration (Olmez and Kretzschmar, 2009).

7. Conclusion

Prevention of microbial deterioration especially by fungi of stored grains is varied and many methods employed are strongly influenced by economic incentives. Rapid methods of estimating the extent of deterioration to help the prediction storability are needed. Therefore, potential technologies are required to degrade and eliminate these toxic metabolites. From the above review, it may be concluded that there is ample scope of research for identification of store grain pathogens of cereals and their control to reduce losses in storage.

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