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Protecting the food chain: Innovative post-harvest mycotoxin control

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Abstract:

The food chain is seriously endangered when molds and mycotoxins contaminate cereal goods, causing dry matter, quality, and nutritional losses. After being harvested and dried, the majority of grain is either stored on the farm or in silos for long-term storage. Numerous interrelated biotic and abiotic factors affect cereal quality. Grain and contaminant mold respiration, rodents, insect pests, temperature, water availability, intergranular gas composition, and preservatives—which are applied to preserve moist grain for animal feed—are all components of the so-called stored grain ecosystem. Therefore, creating successful post-harvest prevention techniques requires an understanding of the crucial control points during the harvesting, drying, and storage phases of the grain production chain. According to studies, relatively little dry matter loss from mold activity is acceptable. Visible mold growth, mycotoxin contamination, and lot downgrading may happen when there is a 0.5% dry matter loss. Penicillium verrucosum (ochratoxin) is the main mycotoxigenic mold found in partially dried grain in moist, chilly regions in Northern Europe, while Aspergillus flavus (aflatoxins), Aspergillus ochraceus (ochratoxin), and some Fusarium species (fumonisins, trichothecenes) are found in temperate and tropical cereals. Modeling of germination, growth, and mycotoxin minimum as well as the prediction of fungal contamination levels have been produced by studies on the ecology of these species.

Introduction:

In terrestrial ecosystems, microorganisms are common and spread widely, contaminating plant groups. A variety of bacteria, yeasts, and filamentous fungus can

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infect ripening seeds through the air, insects, rain splash, equipment, and agronomic techniques. As a result, grain has a variety of microbial pollutants that vary depending on the harvest climate. The impact that fungus may have on grain quality, particularly germinability, is mostly determined by the post-harvest handling of such grain and the current environmental conditions. Remember that under dry, secure storage circumstances, harvested grain and infecting microbes are living things that breathe slowly. The nutritional value of seeds can quickly decline as a result of inadequate post-harvest handling. Microbial activity can degrade lipids and proteins or change their digestibility, produce volatile metabolites that give off off-odors, cause germination loss, affect use as animal feed or as seed, cause discoloration, and contribute to heating and losses in dry matter through the utilization of carbohydrates as energy sources. Mycotoxins produced by filamentous fungal spoilage organisms have the potential to induce cancer, feed refusal, and emesis (Magan et al., 2004). Workers who are exposed to the spores of some fungi run the risk of developing respiratory illnesses.

The amount of stored grain lost to various causes differs significantly around the world. While global losses average around 10%, they can be much higher in tropical areas, reaching up to 50%. The variation can be extreme - for example, in southern India, wet rice losses reached 15-25% in just 9 days, while in West Malaysia, rice storage losses were only 1%.

When it comes to fungal spoilage of stored grain, there are four main categories of influencing factors:

1. The grain's nutritional properties
2. Environmental conditions
3. How the grain is processed
4. Characteristics of the microbes themselves

In the 1970s, Wallace and Sinha pioneered a new way of thinking about stored grain - they viewed it as an artificial ecosystem that needed to be studied comprehensively to better understand storage processes and improve grain management. This perspective led to better strategies for preventing damage from microbes and pests. Since most cereals are stored in dry conditions, bacterial spoilage is rare, but at medium moisture levels, fungi and pests become major concerns. Modern prevention strategies largely use the HACCP (Hazard Analysis Critical Control Points) approach to identify crucial control points throughout the food production chain, both before and after harvest. This has been particularly useful for managing specific problems like Fusarium fungi and their toxins in temperate cereals. Sometimes, decisions made before harvest can significantly affect how well the grain can be protected after harvest.

Respiration and dry matter losses

When stored in dry conditions, both grain and its microbial inhabitants breathe slowly. However, when moisture content rises to 15-19% (equivalent to 0.75-0.85 water activity in wheat), certain spoilage fungi - particularly Eurotium, Aspergillus, and Penicillium species - begin to grow actively. This leads to increased breathing activity, which can cause temperature increases and sometimes spontaneous heating as different types of fungi colonize the grain in succession, eventually including heat-loving fungi and actinomycetes. The energy is released by the following equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2835\text{kJ}$$

The heat is mainly generated through aerobic oxidation of carbohydrates like starch. Heating occurs when this energy is released faster than it can dissipate from the grain. The need for oxygen increases with temperature up to 40°C, and stays high until temperatures exceed 65°C. At this point, microbial growth largely stops, and heating continues through chemical oxidation alone. The respiratory quotient (RQ) - which measures the ratio of oxygen used to carbon dioxide produced - typically ranges from 0.7 to 0.9 up to 65°C, but drops below 0.5 at higher temperatures. Using the RQ, scientists can calculate grain dry matter loss from CO_2 production. In complete carbohydrate respiration, the RQ is about 1.0, and each 1% loss of grain dry matter produces 14.7g of CO_2 per kilogram of grain. During anaerobic fermentation, this drops to about 0.493g CO_2 per kilogram for each 1% dry matter loss. The RQ can be below 1.0 when fats or proteins are being broken down - for example, tripalmitim has an RQ of 0.7. Higher CO_2 production means shorter safe storage time before dry matter loss occurs.

Research has shown that the maximum safe storage time without mold growth can be cut in half if either:

- The harvest moisture content increases by 1-3% (equal to 0.05 water activity)
- Storage temperature rises by 5°C in temperate cereals

Some researchers suggest using CO_2 production rates as a "storability risk factor" to model and predict overall quality changes in stored grain.

Prevention of ochratoxin A (OTA) contamination

Recent European grain surveys, particularly of wheat and barley, have found that among fungi that produce OTA (ochratoxin A), Penicillium verrucosum is the most common, with Aspergillus ochraceus appearing occasionally, mainly in Mediterranean areas. This suggests that in Europe, OTA contamination primarily happens after harvest. Research has shown that P. verrucosum contamination occurs during harvesting, and most critically, during the drying and storage phases. This means that in Northern Europe's wet harvest seasons, effective post-harvest drying is crucial. Poor drying can allow P. verrucosum to grow, potentially creating pockets of mycotoxin-contaminated grain in storage silos. Managing this phase is therefore essential to prevent OTA contamination at this stage of the food chain. Both P. verrucosum and A. ochraceus are highly competitive fungi that can dominate stored grain when conditions are favorable - P. verrucosum in temperate regions and A. ochraceus in tropical areas. Recent studies suggest that P. verrucosum contamination levels might indicate potential OTA presence. For instance, when more than 7% of wheat grains are contaminated with P. verrucosum, OTA is likely present, though there isn't a direct linear relationship between the two.

The main environmental factors affecting fungal growth and OTA production are:

- Water availability
- Temperature
- Gas composition (when grain is moist)

The interaction of these factors primarily determines whether molds will grow and how the fungal community will develop. Understanding the minimum conditions needed for growth and OTA production by these fungi is crucial for assessing contamination risks throughout the food chain, but this requires detailed study of how these fungi colonize grain under various combined conditions.

Recent research has revealed important relationships between environmental conditions and fungal growth/toxin production for P. verrucosum and A. ochraceus. The studies found that: These fungi grow fastest when water activity (aw) is 0.98-0.99 (equivalent to more than 27-30% moisture content) at temperatures between 10-25°C. Growth almost stops at 0.80-0.83 aw (17.5-18% moisture content). While no OTA (ochratoxin A) is produced at 0.80 aw, some production occurs at 0.85 aw (19% moisture) at 15 and 20°C. The best conditions for toxin production are 0.93-0.98 aw (23.5-27.5%) at 10-25°C when grain is stored for up to 56 days. For P. verrucosum specifically, it takes 7-14 days to produce significant OTA levels above EU limits. These findings show that keeping grain moisture content below 17-18% is crucial to prevent fungal growth and OTA production. To avoid even the most drought-resistant molds (Eurotium species), moisture content should be below 14.5%. This low moisture level must be maintained throughout storage and transport. Recent statistical modeling has linked P. verrucosum population levels to the likelihood of exceeding EU's 5 µg/kg OTA limit under different storage conditions. The model suggests that when P. verrucosum reaches 1000 colony-forming units per gram of grain, there's a significant risk of OTA contamination above legal limits. While the fungus can produce spores at 0.80 aw, it doesn't necessarily produce OTA at this level. Earlier research estimated that P. verrucosum needs 0.81-0.83 aw to grow and 0.83-0.90 aw to produce OTA. The critical "zone of uncertainty" for OTA contamination lies between 15-17.5% moisture content. This range is crucial in determining the risk of dangerous OTA contamination levels.

Post-harvest control using preservatives

When storing moist grain for animal feed, it's common to use preservatives based on aliphatic acids, mainly propionic and sorbic acid salts. However, these preservatives only stop fungal growth temporarily (they're fungistats), so they must be applied evenly across all grain. Poor coverage can allow spoilage fungi to grow, particularly toxin-producing molds that can sometimes break down these acids. Research has shown that these acid mixtures don't effectively control certain Fusarium species or their production of fumonisins. This has led to a search for alternative or complementary preservation methods. Research has explored both essential oils and anti-oxidants as potential solutions. Studies found that only a few essential oils - mainly cinnamon and clove leaf oil - can effectively control toxin-producing fungi like Fusarium species, P. verrucosum, and A. ochraceus, as well as their toxin production (DON and OTA), though effectiveness depends on environmental conditions.

Several compounds have shown promise in wheat grain tests:

- Butylhydroxyanisole (BHA)
- Propyl paraben (PP)
- Cinnamon oil
- Resveratrol

These substances reduced DON and NIV toxin accumulation by more than 90%. Resveratrol has proven particularly effective against a wide range of mycotoxins, though it's currently too expensive for practical use. While these alternative preservation methods show promise, they face significant economic and technical challenges. Currently, these products may be too expensive for practical use, but they could become viable alternatives to existing preservation methods for animal feed grain if their costs decrease.

Conclusion

Only mycotoxins produced during this stage of the food chain can be effectively prevented by post-harvest measures. Only by using post-harvest processing methods that, when feasible, reduce subsequent entry into the food and feed chain can pre-harvest natural contamination be reduced. Nonetheless, there are essential management tools and traceability protocols that ought to be employed to enable the efficient conservation of stored commodities with the least amount of quality degradation. Among these are precise and frequent moisture readings to guarantee that safe thresholds are not crossed. Drying wet grains quickly and effectively, followed by long-term storage in sanitary silos free of mold and insect pests. traceability during processing transportation and silo storage. The implementation of recognized supplier chains and Good Agricultural Practices are crucial. Additionally, this called for efficient diagnostic instruments that could quickly monitor and measure mycotoxins (Magan, 2006). For commodities that are kept in storage, representative sampling is still an issue. Although there is legislation governing sampling techniques, it is difficult to follow them, and mistakes made when actually collecting samples can be much more serious than those made when analyzing the level of mycotoxin contamination.

By using volatile fingerprints and monitoring the composition of intergranular gases, it may be feasible to identify changes in stored commodities caused by insect or mold activity early on. It is crucial to create models of mycotoxigenic mold activity and the circumstances that will stop the production of mycotoxin and that can provide a tolerance indicator pertinent to the legal limitations. Combining data will help us achieve our objective of creating accurate and practical decision support systems for efficient grain post-harvest conservation. The current solid foundations for creating methods to stop damaged grain and mycotoxins from getting into the food chains of humans and animals will need to be strengthened in the upcoming years.

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