International Journal of Integrated Science and Technology (IJIST)
Vol. 3, No. 11 November, 2025: 2429-2442

Review of Occurrence and Public Health Implications of Mycotoxins in Fish Feeds: A Global Toxicological Concern

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ARTICLE INFO
Keywords: Occurrence, Implications, Mycotoxins, Toxicological

Received : 20, September
Revised : 25, October
Accepted: 20, November

ABSTRACT
Mycotoxin contamination in fish feeds poses a major challenge to aquaculture due to its harmful impact on fish health, growth, and productivity. Filamentous fungi, particularly *Aspergillus*, *Fusarium*, and *Penicillium* species, are the primary producers of these toxic metabolites, which threaten both aquatic organisms and human consumers. This review summarizes current findings on the prevalence and distribution of mycotoxins in aquafeeds and their toxicological risks to farmed fish globally. Evidence shows that fingerlings and juveniles are especially vulnerable to high toxin levels, often resulting from the use of contaminated crop-based feed ingredients. Such contamination leads to poor growth performance, reduced immunity, and increased mortality in fish. Moreover, certain mycotoxins can bioaccumulate in fish tissue, facilitating their transfer into the human food chain and posing genotoxic, carcinogenic, and immunosuppressive risks. The paper highlights major mycotoxins—aflatoxins, fumonisins, ochratoxins, trichothecenes, and zearalenone—and emphasizes the importance of continuous monitoring of mycotoxinogenic fungi in feed components. It advocates for the use of alternative, fungi-resistant ingredients and improved feed management strategies to enhance food safety and promote sustainable aquaculture production.

DOI: https://doi.org/10.59890/ijist.v3i11.199
https://ntlmultitechpublisher.my.id/index.php/ijist

INTRODUCTION

An increasingly important component of the world's food production is aquaculture, supplying high-quality protein and essential nutrients to an ever-growing human population. Over recent decades, per capita consumption of fish and seafood has more than doubled from 9 kg in 1961 to over 20 kg in 2015, reflecting both rising demand and shifts in dietary preferences. While capture fisheries continue to contribute to the sustained growth in fish supply has been largely fueled by expansion in aquaculture, which in many regions now grows faster than any other food production sector (FAO, 2018). To sustain this growth, aquaculture relies heavily on formulated fish feeds that deliver concentrated sources of protein, energy, lipids, vitamins, and minerals. Historically, fishmeal and fish oil were key ingredients. However, constraints on availability and rising costs have driven the incorporation of plant-based protein sources and alternative raw materials (Jackson *et al.,* 2016). However this shift helps with sustainability and cost control, it also introduces vulnerability to fungal contamination and mycotoxin presence, especially under suboptimal storage or handling conditions (Oliveira and Vasconcelos 2020).

LITERATURE REVIEW

What are Fish Feed?

About 50–80% of aquaculture's overall production expenses are related to fish feed, making nutrition a critical determinant of success in the sector. Achieving sustainable aquaculture requires nutritionally balanced and cost-effective diets. The cost and nutritional value of feed are influenced by the quality and price of the raw materials and additives used in feed composition. Both organic and inorganic components are typically included in these substances. (TNFU, 2019).

Types of Fish Feeds

Feeding constitutes the largest operational cost in most aquaculture systems, frequently exceeding 50 % of variable expenses. Selecting a suitable feeding method depends on species, life stage, feed size and type, labor availability, and production system. Proper evaluation of these factors is crucial for achieving efficient and profitable fish production (Cao *et al.,* 2015). Aquatic feeds are available in various forms, each designed to fulfill specific functions and feeding conditions. Feed classification can be based on factors such as origin, moisture content, fish life stage, and buoyancy characteristics.

Types of Dry Feed

- **Pellet Feeds:** These are feeds mechanically compressed into specific shapes and sizes, typically through processes involving moisture, heat, and pressure. Pelleting refers to the agglomeration of fine feed particles into larger, uniform solids with defined texture and structure. This process enhances feed handling, stability, and consumption efficiency. Based on the production technique, pellets are generally categorized as compressed pellets, expanded pellets, or extruded pellets (Sanal *et al.,* 2023).
- **Flake Feeds:** Flake feeds are among the most widely used diets for ornamental and aquarium fish due to their ease of use and balanced nutritional formulation. They are typically produced using a **double-**

drum drying process, in which finely ground feed is created by combining components with water which turn to a homogenous suspension.

- **Microencapsulated Feeds:** Microencapsulation is an advanced feed technology that involves enclosing fine feed particles or nutrient cores (the payload) within a protective coating material (the wall). This encapsulating layer serves to **minimize nutrient leaching and dissolution** when the feed comes in contact with water, thereby maintaining the nutritional integrity of the feed and improving its stability.
- **Microbound Feeds:** Microbound feeds are made by mixing nutrients with binding agents like agar, gelatin, alginate, or carrageenan to form a slurry that is dried and ground into fine particles. These feeds allow direct contact between nutrients and water, making them prone to leaching and bacterial degradation. Despite this, they provide balanced nutrition and are useful for larval and juvenile aquaculture species when freshly prepared and well-managed (Sanal *et al.,* 2023).
- **Micro-coated Diet:** Micro-coated diets are tiny feed particles coated with materials such as zein, cholesterol, or lecithin to enhance stability and nutrient retention. The coating prevents nutrient leaching and improves water resistance, making the feed more effective for larval and juvenile fish. This technique enhances feed quality, digestibility, and nutrient delivery in aquaculture systems (Sanal *et al.,* 2023).

Feeds Based on the Life Stages of Fish

Fish feeds can be classified according to the life stage of the fish as starter, fry, fingerling, grow-out, and brood stock feeds, collectively known as phase feeds. Larval feeds typically include mash feed, microencapsulated diets, micro bound diets, micro-coated diets, flake feeds, and crumble feeds, each formulated to meet the specific nutritional needs of developing fish.

Based on Buoyancy

- **Floating Feed:** Floating feeds are designed to float on the water surface for an extended period, allowing easy monitoring of feeding activity and reducing waste. Their buoyancy is influenced by the fineness of ground ingredients, moisture level, and the mixing or extrusion process used during production. These feeds promote efficient feeding, minimize water pollution, and are particularly suitable for species that feed at the surface (Welker *et al.,* 2018).
- **Sinking Feed:** Sinking feeds are dense, non-extruded pellets that quickly settle to the bottom of aquaculture systems. They are commonly used in earthen ponds, where fish can easily access them along with natural food sources. These feeds are ideal for bottom-feeding species and help reduce surface competition during feeding. Their effectiveness is often enhanced by the presence of natural feed in pond environments.

Figure 2.0 Types of fish feeds (Seafood Media)

Nutritional Benefits of different Fish Feeds

Fish feed ingredients influence both fish performance and the surrounding environment, making it important to evaluate their sustainability and potential alternatives. High-quality feeds should provide necessary nutrients such as **omega-3 fatty acids, proteins, amino acids**, and be highly digestible and palatable, while containing low levels of insoluble carbohydrates, fiber, and heavy metals to optimize growth and feed conversion ratios. Marine-derived ingredients, including fish meals, oils from small pelagic species, and seafood processing by-products, are particularly valuable for supplying macro- and micronutrients, enhancing digestibility, and supporting growth in aquaculture species (Newton *et al.,* 2023).

Fish Meal and Plant-Based alternatives

Fishmeal is an important source of high protein in aquaculture because of its balanced amino acid profile, high digestibility, palatability, and ability to enhance nutrient absorption. Approximately 70% of global aquaculture production relies on protein-rich feeds containing fishmeal (FAO, 2022). Currently, aquaculture consumes around 70% of fishmeal and 76% of fish oil worldwide (Naylor *et al.,* 2022). The growing demand has contributed to the depletion of marine pelagic fish stocks, prompting the substitution in part of fishmeal with plant-based protein sources in fish diets to maintain sustainability and reduce pressure on wild fisheries (Elumalai *et al.,* 2020). Plant-based protein ingredients offer several advantages, including high protein content, year-round availability, lower cost, and greater environmental sustainability (Hixson, 2014). They also provide dietary carbohydrates that serve as an energy source, depending on the species' ability to metabolize carbohydrates.

Insect based Fish Feeds

Insects are increasingly known as a sustainable and economically viable option to traditional fishmeal, providing high levels of polyunsaturated fatty acids (PUFAs) and promoting gut health in fish, with Black Soldier Fly larvae being particularly effective (Fisher *et al.,* 2021). The mealworm industry is evolving from a largely manual and inefficient sector to a more mechanized, profitable production system (Halloran *et al.,* 2018). Microalgae-derived pigments enhance meat coloration in salmonids and shrimp, increase antioxidant content, and support reproductive performance (Nagarajan *et al.,* 2021). Plant oils such as soybean, rapeseed, linseed, sunflower, palm, and olive oil are commonly used in fish feeds, providing essential fatty acids, especially linoleic and oleic acids, though they lack n-3 PUFAs (Bartek *et al.,* 2021). The nutritional quality, PUFA content, and physical properties of feed are critical for aquatic species, as feed texture, buoyancy, and water stability directly affect feeding efficiency, health, and growth performance. Evaluating new ingredients must consider both their nutritional value and their impact on feed processing and technical characteristics.

Filamentous Fungi

Microbial proteins, including bacterial, algal, and fungal biomass, are increasingly explored as sustainable fish feed ingredients (Nalage *et al.,* 2016). Filamentous fungi, such as *Aspergillus*, *Neurospora*, and *Rhizopus* species, are rich in protein (up to 50% w/w) and provide essential fatty acids, vitamins, minerals, antioxidants, and immunostimulants, making them promising feed supplements (Karimi *et al.,* 2018). These fungi are Generally Regarded as Safe (GRAS) and have long-standing applications in food production (Ferreira *et al.,* 2016). Their ability to degrade organic substrates, including plant and animal residues or industrial by-products, through complex enzymatic systems makes them highly versatile for sustainable aquaculture feed production.

METHODOLOGY

What are Mycotoxins?

The word “mycotoxin” is coined from a Greek word *mykes*, which means fungus, and the Latin word *toxicum*, meaning poison, referring to toxic component from a certain fungus (Mwihia *et al.,* 2020). Ingestion of mycotoxins by humans or animals can lead to mycotoxicosis, a condition that ranges from mild illness to severe toxicity or death (Patil & Kakde, 2017). Mycotoxins are chemically diverse, with biological effects including carcinogenicity, mutagenicity, neurotoxicity, and suppression of the immune system (Shahba *et al.,* 2021). The leading mycotoxin-producing fungi belong to the genera *Aspergillus*, *Penicillium*, and *Fusarium*, which commonly contaminate food and feed products. Other genera such as *Trichoderma*, *Trichothecium*, and *Alternaria* act as toxins or plant pathogens, causing significant economic losses and health risks (Albero *et al.,* 2022).

Types of Mycotoxins associated with Fish Feed

Mycotoxins are typically accumulated in the barn and outer grain layers, while the endosperm contains lower levels (Marijani *et al.,* 2017). Consequently, feeds made from whole meal grains or bran are more likely to carry higher mycotoxin loads compared to those produced from refined flour or endosperm-derived grits. Using contaminated bran or other grain-based ingredients in fish feed can therefore introduce these toxins into the final feed, posing potential health risks to cultured fish.

Aflatoxins

Aflatoxins were initially discovered following a severe outbreak known as “Turkey X disease” in the 1960s, which resulted in the loss of roughly 150,000 turkeys due to acute aflatoxicosis (Blount, 1961). Among all mycotoxins, aflatoxins have received the most research attention and are well-characterized. The key types found in crops are B1, B2, G1, and G2. Production of these poisons is primarily associated with *Aspergillus flavus* (producing only B-type aflatoxins), although *A. parasiticus* and occasionally *A. nomius* can also generate them. Additional filamentous fungi, including species from the genera *Penicillium*, *Rhizopus*, *Mucor*, and *Streptomyces*, are known to produce aflatoxins as well (Agag, 2004). The bioproduction of aflatoxin B1 involves sterigmatocystin as a precursor that is mainly synthesized by *A. versicolor* and *A. nidulans*.

Fumonisins

Fumonisin B1 is considered the most lethal among fumonisins and is produced by several *Fusarium* species, most notably *Fusarium verticillioides*, as well as *F. proliferatum* and *F. nygamai*. Additionally, *Alternaria alternata* has been reported to produce fumonisin B1. Contamination is primarily associated with maize and maize-derived products, with studies detecting this toxin in 80–100% of corn samples from countries such as Mozambique, Burkina Faso, China, and Malaysia (Warth *et al.,* 2012). Regulatory limits for fumonisins have been established primarily for the combined presence of fumonisin B1 and B2. For raw maize, except when used for wet milling, the maximum allowable concentration is 4000 μg/kg. In feed materials, fumonisin levels should not beyond 59 mg/kg in maize and maize-based materials, and in total fish feed, the limit is 10 mg/kg (Oliveira and Vasconcelos, 2020).

Ochratoxin

Ochratoxin A is the strongest toxin member of the ochratoxin group and is primarily produced by *Penicillium* species, such as *P. verrucosum*, and *Aspergillus* species, notably *A. ochraceus* and *A. carbonarius*. Contamination commonly observed at post-harvest, especially in cereal grains including wheat, barley, oats, and maize, though other commodities can also be affected (Yu and Pedroso, 2023). Ochratoxin A is highly stable and has a long half-life, which allows it to persist in food and feed and facilitates its transfer along the food chain. Regulatory standard established by the European Commission set a maximum of 5 μg/kg for unprocessed cereals and 3 μg/kg for products derived from unprocessed cereals, including processed cereal-based foods. For cereals and cereal products used in animal feed, the limit is 0.25 mg/kg of ochratoxin A. No standard has been established for whole feed for animals other than pigs and poultry, possibly attributed to the insufficient understanding of the toxin's impact in these species (Yu and Pedroso, 2023).

Trichothecenes

Trichothecenes are mycotoxins produced in crops such as maize, and other cereal by fungi from genera including *Fusarium*, *Myrothecium*, *Phomopsis*, *Stachybotrys*, *Trichoderma*, and *Trichothecium*. The most known trichothecenes in crops, due to their toxicity to animals, are deoxynivalenol and T-2 toxin. While T-2 toxin has been shown to affect zebrafish embryos causing increased mortality, malformations, cardiovascular defects, and behavioral alteration it does not appear to pose a significant risk to overall fish wellbeing (Pietsch, 2019). In contrast, deoxynivalenol, also known as vomitoxin, though considered the less toxic trichothecene, can still be harmful to both fish and humans. This toxin is primarily produced by *Fusarium* species, especially *F. graminearum*, and is more commonly found in animal feed than in food in Europe. Regulatory limits set by the European Commission allow a maximum deoxynivalenol concentration of 1750 µg/kg in unprocessed durum wheat, oats, and maize (excluding maize intended for wet milling) and 1250 µg/kg in other unprocessed cereals (Pandey *et al.*, 2023).

Zearalenone

Zearalenone (ZEN) is predominantly synthesized by *Fusarium* species, especially *F. graminearum*, and to a lesser extent by *F. culmorum*, *F. equiseti*, and *F. crookwellense*. Uptake with these fungi commonly occurs at pre-harvest, particularly in crops such as maize. Zearalenone is a potent mycoestrogen with strong estrogenic properties which disrupt the reproductive functions of various animal species (Zhang *et al.*, 2018). According to the European Commission, the allowed limit of zearalenone in unprocessed maize (excluding maize destined for wet milling) is set at 350 µg/kg, while for other unprocessed cereals, the limit is 100 µg/kg. In animal feeds, maize by-products should not contain more than 3.0 mg/kg of deoxynivalenol, and the threshold for other cereals and cereal-derived products is 2.0 mg/kg.

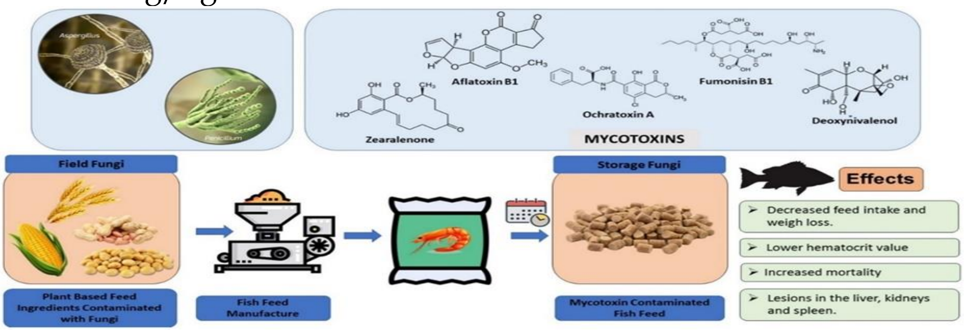

Figure 3.0 Risk and Effects associated with Types of Mycotoxin Occurrence in Fish Feeds (Meenakshisundaram *et al.*, 2025).

RESULTS

Routes of Contamination of Fish Feed with Mycotoxin

Mycotoxin adulteration in crops intended for fish feed production can occur before harvest, especially in agricultural products rich in bran or fiber, which tend to retain higher moisture and support mold development. Post-harvest contamination is also common, especially when storage conditions favor fungal growth such as elevated temperature and water activity that promote optimal environments for mycotoxin synthesis. Once feed ingredients or finished feeds become contaminated, effective decontamination methods are currently unavailable. Nonetheless, certain processing techniques, especially those involving heat treatment, can help lower mycotoxin concentrations (Marijani *et al.*, 2019).

Detection and Analytical Methods for Mycotoxins in Fish Feeds

Because mycotoxins possess diverse chemical structures, no single analytical technique can effectively detect all types; each mycotoxin requires a specific detection technique. after their discovery, a variety of analytical approaches have been developed for mycotoxin detection, ranging from conventional quantitative techniques such as chromatography and immunoassays to more advanced methods including ultra-high-performance liquid chromatography (UHPLC), fluorescence polarization immunoassay, nanoparticle-based assays, microfluidic systems, and phage display technologies (Singh & Mehta, 2020).

Table 3.1: Documented mycotoxin occurrence and detection method in fish feeds (Meenakshisundaram *et al.*, 2025)

Fish feed/Ingredient	Country/Region	Mycotoxin and reported level (µg/kg)	Detection method	Reference
Complete feed	Brazil	Fumonisin B1 (0.3–4.94); Aflatoxin B1 (non-detectable); Ochratoxin A (non-detectable)	ELISA and LC–MS/MS	Barbosa et al. (2013)
Complete feed	Brazil	Aflatoxin B1 (3.8)	ELISA	Carvalho Gonçalves-Nunes et al. (2016)
On-farm made feed	Nigeria	Aflatoxin B1 (550.8)	ELISA	Foluke et al. (2016)
Farm-made feed and feed ingredients	East Africa	Aflatoxins (<2–806); Deoxynivalenol (69.1–984.3); Fumonisin (33.2–3970.1).	LC–MS/MS	Marijani et al. (2017)
Complete feed	East Africa	Aflatoxins (<2–2.6);	LC–MS/MS	Marijani et al. (2017)
Complete feed	Kenya	Aflatoxin B1 (1.8–39.7)	ELISA and LC-HRMS/MS	Mwihia et al. (2018)
Complete feed	Kenya	Aflatoxin B1 (<14.7–43.6); Deoxynivalenol (<40.4–819.9); Zearalenone (<38.0–757.9); Fumonisins B (<63.0–2076.6)	HPLC-HRMS	Mwihia et al. (2020)
Complete feed	Central Europe	Deoxynivalenol (66–825); Zearalenone (3–511)	HPLC-DAD and HPLC with fluorescence detection	Pietsch et al. (2013)
Complete feed	Asia	Aflatoxin B1 (1.83–15.94); Ochratoxin A (1.56–7.63)	ELISA	Bashorun et al. (2023)
Complete feed	Europe	Aflatoxins (2.01–4.61); Ochratoxin A (1.49–2.89)	ELISA	Bashorun et al. (2023)
Complete feed	Iran	Aflatoxins (0.46–68.5)	HPLC	Fallah et al. (2014)
Complete feed	Turkey	Aflatoxin B1 (18.4–42.4)	TLC and ELISA	Altuğ and Özyurt (2003)
On-farm feed	Uganda	Aflatoxin B1 (97–403); Fumonisin (0.1–4.1 mg/kg)	ELISA	Namulawa et al. (2020)
Complete feed	Brazil	Aflatoxin B1 (1.6–9.8)	ELISA	Carvalho Gonçalves-Nunes et al. (2016)
Feed ingredients	India	Aflatoxin B1 (<10–80); Aflatoxin B2 (10–35); Aflatoxin G1 (10–25); Aflatoxin G2 (10–25)	HPLC	Jaiswar et al. (2022)
Complete feed	United Kingdom	Deoxynivalenol (19.4–79.2); Fumonisin (112–754).	LC–MS/MS	Nácher-Mestre et al. (2015)

Potential Impact of Mycotoxins on Fish Feeds and Fish and the Consumers

Plant-derived ingredients commonly used as alternatives to fishmeal in fish feeds contain soybean meal, cottonseed meal, corn meal, groundnut meal, sunflower meal, rapeseed (canola) meal, maize, wheat bran, and wheat (Kaiser *et al.,* 2022). These ingredients, however, are highly susceptible to mycotoxin alteration. Mycotoxins occur as natural toxins in plant-based feed ingredients, particularly cereals and oilseeds (Albero *et al.,* 2022). Their occurrence is most prevalent in tropical and subtropical climates, where feed materials such as corn, soybean, cottonseed, and wheat are commonly affected (Gonçalves *et al.,* 2018). Mycotoxins are reported to induce a wide range of pathological conditions in fish, which are cellular and organ-level changes, functional and morphological impairments, and, in extreme cases, death, leading to substantial economic losses in aquaculture. The degree of toxicity and physiological impact varies with the specific mycotoxin, its concentration, the duration of exposure, and the biological characteristics of the fish, such as species, sex, and age.

Fumonisin exposure has been reported to cause significant hematological and biochemical alterations in fish species. In channel catfish (*Ictalurus punctatus*) and Nile tilapia (*Oreochromis niloticus*), it leads to reduced hematocrit levels and an increased free sphinganine/free sphingosine ratio in the liver, indicating disturbance of sphingolipid metabolism (Deng *et al.,* 2010). Furthermore, fumonisin has been shown to heighten mortality rates in *I. punctatus* infected with *Cytophaga columnaris*, suggesting a compromised immune response. Ochratoxin A (OTA) toxicity manifests through several pathological symptoms and organ damage in different fish species. In sea bass (*Dicentrarchus labrax*), OTA exposure results in hemorrhagic spots on the dorsal surface, fin removal, rusty discoloration on the abdomen and dorsal musculature, and visible congestion in the kidney, gills, and liver (El-Sayed and Khalil, 2009). Similarly, *I. punctatus* exposed to OTA exhibits hepatic and renal lesions, characterized by elevated occurrence and intensity of melanomacrophage centers within the hepatopancreatic tissue and posterior kidney, along with degeneration of exocrine pancreatic cells around the portal veins (Manning *et al.,* 2003).

In *O. niloticus*, OTA induces extensive hepatic, renal, and splenic lesions, accompanied by organ enlargement, vascular dilation, and necrosis of kidney tissues and hepatocytes. These effects are also correlated with high serum levels of alanine aminotransferase (ALT), aspartate transaminase (AST), creatinine, and urea, reflecting systemic toxicity and impaired metabolic function (Diab *et al.,* 2018). The primary route of human contamination of mycotoxins is through the consumption of altered food, with dietary contamination being notably higher in advancing nations (Barbosa *et al.,* 2013). Indirect exposure may also occur via the consumption of fish that have accumulated aflatoxin residues in their tissues.

Public Health Implication of Mycotoxins in Fish Feed

Public Health Implications of Aflatoxins

Several classes of aflatoxins (AFs) are known, including B1, B2, G1, and G2, with the capital letters indicating their light color under ultraviolet (UV) light blue (B) or green (G). These toxins are predominantly found in peanuts, maize, and various oilseeds. Among them, aflatoxin B1 (AFB1) is the most widespread and toxic. Within the liver, AFB1 undergoes biotransformation to aflatoxin M1 (AFM1), which can be secreted in the milk of lactating mammals, including dairy animals. AFM1 is known to induce both severe and long-term toxic effects. Its occurrence in milk and dairy products poses a public health concern, as even trace concentrations may lead to adverse effects following long-term exposure (Giovati *et al.,* 2015). Aflatoxins (AFs) are among the most extensively studied mycotoxins due to their widespread occurrence and potent toxicity.

The health consequences of AF exposure vary depending on the concentration and time of contact, whether severe or long-term exposure. Acute aflatoxicosis can be severe and potentially fatal, presenting with symptoms such as abdominal pain, vomiting, internal hemorrhage, hepatic injury, impaired growth and development, immunosuppression, pulmonary and limb edema, vascular fragility, and, in extreme cases, coma (Campbell and Wiston, 2021). Trichothecenes are small amphipathic compounds capable of diffusing passively through cell membranes. They are readily consumed through the skin and di tract, which enables them to act quickly on rapidly dividing tissues. Although several types of trichothecenes have been identified, *deoxynivalenol* (DON), T-2, and HT-2 toxins remain the most significant from a public health perspective (Stroka and Goncalves, 2019). Zearalenone (ZEN) is a mycotoxin mainly produced by *Fusarium* species, commonly contaminating cereals like maize, wheat, and barley (Ropejko *et al.,* 2021).

Fumonisins (FBs) constitute a group of over 25 mycotoxins typically synthesized by *Fusarium* species, with fumonisin B_1 (FB_1) and fumonisin B_2 (FB_2) being the most prevalent and biologically significant forms (Munkvold *et al.,* 2019). Maize is particularly vulnerable to *Fusarium* infection, although traces of these toxins have also been detected in sorghum, wheat, barley, and soybeans. Among cereal crops, maize typically exhibits the highest levels of fumonisin contamination. FBs are highly hydrophilic in nature and differ structurally from many other mycotoxins that are soluble in organic solvents. Owing to this hydrophilicity, fumonisins do not transfer readily into milk, though small residues may accumulate in animal tissues later utilized for food production. These compounds have been linked to kidney dysfunction and are also considered neurotoxic agents, as they interfere with sphingolipid metabolism particularly the biosynthesis of sphingosine, a key constituent of neural tissue (Munkvold *et al.,* 2019).

DISCUSSION

Path to Resolution

Complete elimination of mycotoxins from fish feed remains unfeasible, therefore, mitigation strategies are employed to reduce their bioavailability within the gastrointestinal tract of animals. Among these strategies, the application of natural substances has shown considerable promise. For instance, a review investigated the effects of different dose of a zeolite and bee brood mixture in the meal of broilers exposed to the T-2 mycotoxin. The results demonstrated that supplementing diets with this mixture enhanced body weight gain and improved blood biochemical parameters, thereby alleviating the adverse impacts of mycotoxin exposure. Similarly, incorporating zeolite and bee brood into fish feed formulations was found to form a protective cause against T-2 toxin toxicity produced by *Fusarium* species. The World Health Organization (WHO) recognizes natural antioxidants as effective, affordable, and safe alternatives for the elimination and management of different toxins when contracted to conventional therapeutic agents (Ramos-Tovar and Muriel, 2020). Notably, mycotoxin contamination accounts for a significant proportion approximately 20% of all notifications within the European RASFF network (Pigłowski *et al.,* 2019).

CONCLUSIONS

The incorporation of plant-derived ingredients into fish feeds poses potential risks to aquaculture productivity due to the heightened likelihood of mycotoxin contamination. Exposure to these toxins in fish has been associated with increased disease susceptibility, higher mortality rates, reproductive impairments, and reduced growth performance, all of which contribute to notable economic losses. Therefore, stringent measures must be implemented to eliminate and control mycotoxin contamination throughout the aquafeed production chain. Selecting ingredients with smaller, more compact grains such as wheat, rice, oats, and sorghum or those protected by hard seed coats like beans and soybeans may help decrease fungal infection and subsequent mycotoxin contamination, as these are generally less susceptible compared to larger grains such as maize.

RECOMMENDATIONS

Therefore, effective storage of grains and feed ingredients is essential to prevent mycotoxin contamination at levels that could harm cultured fish. Therefore, effective pest management, along with appropriate drying, moisture control, and clean storage practices, is vital for maintaining the quality, safety, and nutritional value of fish feeds.

FURTHER STUDY

Subsequent efforts ought to concentrate on the formulation of mycotoxin free fish feeds with good shelf-life fortified with essential nutrients which will enhance aquacultural productivity in Nigeria,

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