The Future of Biology

FSA

Article

Preventive and Biological Strategies for Reducing Mycotoxin Contamination in Poultry Feed: A Review

Ahmed M. TH. Q. AL-Niemy*; Anwar M. Y. AL-Hamed and Khalid H. Mustafa

Animal Production Department, College of Agriculture and Forestry, University of Mosul, Iraq

CrossMark

https://doi.org/10.37229/fsa.fjb.2026.04.03

***Corresponding author:** ahmed.alniemy@uomosul.edu.iq

Future Science Association

Available online free at
www.futurejournals.org

Print ISSN: 2572-3006

Online ISSN: 2572-3111

Received: 15 January 2026
Accepted: 4 February 2026
Published: 3 April 2026

Publisher's Note: FA stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

CC BY

Abstract: Many things become clear to us regarding methods of combating mycotoxins and treating their effects. The role of pelleted feeds, and indeed the exacerbation of the mycotoxin crisis, along with their devastating effects on the liver and kidneys, are also evident. The proposed solutions boil down to one of two things: firstly, if reliance on pelleted feeds is unavoidable, we must import high-quality raw materials that do not require prior processing (raw materials that are naturally free of mycotoxins). This will solve the mycotoxin problem, but it will not solve the acrylamide problem. Secondly, if we cannot import high-quality raw materials that do not require prior processing (which is not feasible for economic reasons), then we must return to using crushed feeds, which can be subjected to prior processing systems, The precise scientific needs of the species, breed, age, production goal, temperature, and climatic conditions imperative to take into consideration when formulating the feed and using biological and mechanical antitoxins developed together in the proportions necessary for complete control of mycotoxins in the feed.

Key words: Mycotoxins, Poultry feed, Prevention strategies, Biological decontamination, Adsorption.

Introduction

Mycotoxins first appeared in 1960 when a sudden, unexplained disease in England Caused the mortality of more than 100,000 turkey chicks, as well as high mortality rates in ducks, chickens, and cattle**.(Blount, 1961)** The cause of these cases was unknown, and they were attributed to an unknown disease then called Turkey X , After a year of research and investigation, a toxic chemical compound was discovered and examined at this time in the peanut seeds found in the feed provided to dead animals **(Sargeant *et al.*, 1961)**. Mycotoxins are by their nature toxins produced by fungi as byproducts of metabolic processes in the fungus itself, It proved difficult to manage because of a shortage of relevant scientific knowledge and compounded by inadequate information on the fungi's toxic byproducts, coupled with the potential for contamination throughout the entire forage to feed pipeline, from crop growth to final feed storage, Mycotoxins have several toxic effects on animals that enter their bodies, such as immunosuppression, impaired vital organ functions, and reduced productivity rates **(Haque *et al.*, 2020)**. "The cause of these symptoms remained unknown until the discovery of the toxin-producing fungus, *Aspergillus flavus*, in peanut meal imported from Brazil. Testing proved it contained toxins, which were then named after the fungus: aflatoxins (**Nesbitt *et al*., 1962)**. Contamination with these mycotoxins is a growing problem in human food products and animal feed worldwide, and numerous studies and tests have been conducted across wide areas in several countries to detect the presence of mycotoxins. The analysis revealed that a significant portion of the raw material samples were contaminated with one or more mycotoxins. The results showed that corn was among the raw materials most contaminated with mycotoxins **(Peng *et al*., 2018)**. Mycotoxins in animal feed lead to major economic losses, not only due to damage to the feed material, but also to the effects on the poisoned animal through a decrease in feed conversion ratio, increased rates of disease and mortality, as well as a decrease in fertility and overall productive performance, In addition to the high probability of toxin residues transferring to meat and eggs, which poses an inevitable risk to the health of the human consumer **(Olariu *et al*., 2025)**, in recent times advanced methods have emerged to determine whether a food item contains mycotoxins through the (ELISA), Then came the emergence of a newer technology (HPLC) and (LC-MS/MS), which is considered one of the newest and most accurate technologies for detecting the type of mycotoxin **(Murugesan *et al*., 2015)**. Mycotoxins have toxic effects on the liver and kidneys and can damage the immune and reproductive systems. While it was possible to remove toxins using the traditional mechanical method by relying on the adsorption process to treat mycotoxins in food and feed, it had a limited effect, in addition to leading to the loss of some nutrients and secondary pollution of the environment, this created an urgent need to develop and implement novel control methods to effectively mitigate mycotoxin contamination **(Xu *et al*., 2021)**. Consequently, biological detoxification has emerged as a prominent solution, by utilizing enzymes or microorganisms that adsorb or break down mycotoxins, this technology enables effective removal from ration, offering a highly efficient treatment strategy. and low toxicity in the body without limiting the utilization of nutrients available in feed **(Muhammad *et al*., 2025)**. To understand how both mechanical (physical) and biological antitoxins function, and the extent of their effectiveness in controlling mycotoxins and their effect on body organs and productive performance A comparative review was undertaken to comprehensively analyze the action mechanisms of physical and biological mycotoxin antitoxins, the effectiveness of using mechanical or biological antitoxins in poultry diets, future trends in scientific research in this field, and to analyze its positive implications for public health.

Definition Mycotoxins

A large and varied a broad class of biochemical compounds, produced by numerous toxigenic fungi as natural byproducts of their metabolism (secondary fungal active metabolites), More than 350 mycotoxins that can appear in feed ingredients have been identified using modern techniques for isolating mycotoxins in a pure form and accurately identifying them **(Bennett and Klich, 2003)**. The term "mycotoxins" refers specifically to those fungal secondary metabolites that exhibit toxicity to humans and animals, Phytotoxins are fungal metabolites that specifically target and harm plants, while the toxic products of microorganisms called Antibiotics, and the resulting poisoning processes are called (Mycotoxicosis) **(Bennett, 1987)**. These toxins present a formidable challenge for the poultry industry worldwide because of their disastrous economic impact on the sector through their negative effect on production performance, public health, and immunity **(Eskola *et al*., 2020)**. And Because mycotoxins are biologically and chemically active compounds, and because they are considered non-antigenic due to their molecular structure, they lack anything that stimulates the body to form antibodies against them **(Richard, 2007)**. It has been proven most common mycotoxins are aflatoxin and ochratoxin, and subsequently trichothecin, fumonisin, dioxynylphenol, zearalenone, and others, which lead to reduced growth rates, damage to vital body organs, direct disruption of immunity, and decreased effectiveness of vaccines given to poultry, and an increased chance of contracting diseases including coccidiosis, salmonella, and E. coli. When the body's immunity decreases, it opens the door to multiple viral infections such as (I.B.H.) and infectious laryngitis and tracheitis **(Olariu *et al*., 2025)**. Poultry feed is a very favorable environment for fungal growth. Although in excess of 350 Numerous mycotoxin varieties have been detected, the number that affect poultry is limited, but this relatively small number has a very severe and influential pathogenic effect **(Eskola *et al*., 2020)**. Feeds that are diagnosed with mycotoxins usually contain more than one type, as most studies that have dealt with the interaction between mycotoxins in poultry indicate synergistic or cumulative effects on animal production performance, and that these interactions were either synergistic or antagonistic between the toxins themselves, Even interventions that were at harmless concentrations varied in their negative effects on animals **(Grenier and Loureiro-Bracarense, 2022)**.

Methods of Mycotoxin Contamination

An overview of the possibility of contamination, spread, and transfer to human or animal food through direct contamination, which occurs when food is contaminated by toxin-producing fungi from the early stages of production, during transport, or during storage if stored under poor conditions, this type of contamination is concentrated in animals and poultry and occurs less frequently in humans **(Milicevic *et al*., 2010)**. The second method of mycotoxin contamination is indirect contamination, meaning contamination of food components with mycotoxins. This takes place when a creature is given food derived from livestock that consumed mycotoxin-tainted feed, it is considered one of the most dangerous forms of contamination, with the Possible to occur in poultry and humans **(Streit *et al*., 2013)**. Mycotoxin contamination spreads rapidly if suitable conditions are present at any stage, from crop cultivation to storage and feed manufacturing, this speed of infection and spread usually appears in the corn crop, which is one of the most important basic components in the formation of feed rations, as weather conditions affect the speed of contamination and spread, especially when the level of climatic humidity increases **(Holanda *et al*., 2021)**. Furthermore, Domestic animals can be Subjected to mycotoxins via ingestion, or dermal contact of the animals' skin or feathers with contaminated materials. **(Muñoz-Solano *et al*., 2024)**.

Mycotoxin Classification

1- (Pathological Classification)

This classification is based on the pathological effects of mycotoxins on body organs. It is of great importance as it provides a good indicator in the diagnosis of mycotoxin poisoning symptoms and in determining the correct treatment plan. Based on the information mentioned above, mycotoxins can be divided, in terms of their health effects on animals into:

A. **(Hepatotoxins)** This term refers to the direct pathological effect of toxins that cause liver necrosis. Aflatoxins are one such toxin even when their toxicity is within normal limits, their cumulative toxicity causes damage. Ochratoxins, on the other hand, only cause liver damage when their toxicity is higher than normal.

B. **(Nephrotoxins)** This term refers to the direct pathological effects of toxins that cause necrosis and fibrosis in the kidneys. Ochratoxin is one such toxin; even when its toxicity is within normal limits, its cumulative toxicity causes damage, aflatoxin, on the other hand, only necrosis and fibrosis in the kidneys when its toxicity is higher than normal.

C. **(Cardiotoxins)** This term is used when there is a negative impact on the heart's function and work, and these toxins include ochratoxin and caffeic acid.

D. **(Gastrointestinal toxins)** This term is used when there is a negative impact on digestive system function and work, and these toxins include trichothecenes.

E. **(Genitotoxins or Hormonal toxins)** This term is used when there is a harmful effect on the functions of the reproductive system, and these toxins include zearalenone.

F. **(Dermatotoxins)** is the term used to describe the pathological effect of fungal toxins that have a harmful effect on the skin, such as trichothecines.

G. **(Neurotoxins)** This term is used when there is a harmful effect on the functions of the nervous system, and these toxins include aflatoxin.

H. **(Carcinogenic toxins)** This term is used when there are carcinogenic effects on the body's cells, and these toxins include aflatoxin **(Richard, 2007 and Bennett and Klich, 2003)**.

2- (Electrical Classification)

This classification is based on the electrical nature of mycotoxins (whether they carry an electrical charge or not). This classification is important in developing preventive strategies against mycotoxins in feed, and accordingly, they are classified into:

A. **(Polar mycotoxins**) or electrically charged, because they carry an electrical charge, such as aflatoxin and ochratoxin.

B. **(Non-polar mycotoxins)** or non-electrically charged, because they do not carry an electrical charge, such as trichothecinate, zearalenone, citrinine, ochratoxin A, and dioxynephalinol.

(Huwig. *et al*., 2001).

Types of mycotoxins

(Aflatoxins)

They are among the most important and widespread types of toxins, as well as in terms of their harmful effects in the world, and they are secreted by the fungal strains Aspergillus parasiticus and Aspergillus flavus **(Kensler *et al*., 2011)**. Aflatoxin type B are considered one of The predominant widespread types and shows symptoms of high toxicity. Aflatoxins appear before harvest due to humidity and bad weather conditions, or after harvest as a result of the crop being exposed to poor storage conditions. Manufactured poultry feed is one of the predominant suitable environments for the multiplication of fungi, which work to form these toxins **(Magnoli *et al*., 2011)**. It should be noted that waterfowl such as ducks and geese are among the birds most susceptible to poisoning, especially aflatoxin. Turkeys are second in terms of sensitivity to poisoning, followed by chickens and then pigeons. It is worth mentioning that rabbits are among the living creatures that suffer and are quickly affected by aflatoxin poisoning **(Rawal *et al*., 2010)**.

Table (1). Regulatory Limits for Aflatoxin Contamination (Lower and Upper Bounds) poisoning according to the type of bird (parts per million - ppm)

Symptoms of poisoning	**Type of bird that consumed the poisoned feed**	**Aflatoxin concentration (in feed (ppm**	**References**
Liver swelling and necrosis with high mortality rates occur	Broiler Chickens	5_10	**(Siller, 1985)**
Weight loss	Broiler Chickens	1.5 - 2.5	**(Denli and Okan, 2006)**
occurrence of immune relapses	Broiler Chickens	0.6 - 1.0	**(Bondy and Pestka, 2000)**
Decreased egg production rate	Laying hens	2_10	**(Verma *et al*., 2004)**

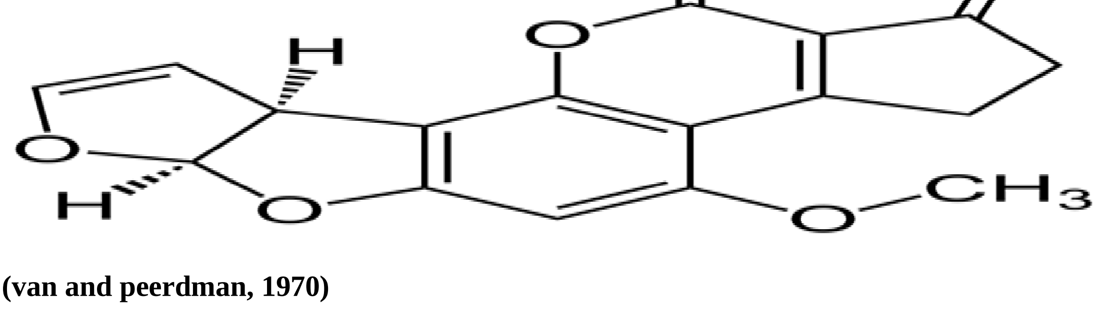
Pathological mechanism of aflatoxins and methods to reduce their effect

Aflatoxins cause severe damage and disruption of liver function, in addition to the possibility of cirrhosis **(Kensler *et al*., 2011)**. The liver is considered one of the most vital organs, and when it is damaged or harmed in any way, the body cannot fully repair it. Any part of the liver that is damaged, whether as a result of a specific infection or as a result of poisoning by mycotoxins, cannot be replaced. Rather, fibrous tissue takes the place of the damage **(Siller, 1985)**. This tissue is considered non-functional and does not perform any vital functions, which leads to the liver losing part of its multiple vital functions, as it is the main pillar in the body for getting rid of toxins, in addition to being the body's factory for producing (Albumin), (Globulin), (Fibrinogen), (Prothrombin), (Antibodies), (Enzymes, proteins, and hormones), (glycogen formation, bile secretion, and vitamin D activation), and other vital functions **(Rawal *et al*., 2010)**. Albumin is considered the primary protein in plasma that is responsible for maintaining osmotic pressure in the blood. Any deficiency in this protein reduces osmotic pressure in the blood, leading to an imbalance in blood fluids and leakage of fluids from veins and arteries into the abdominal cavity of the body, causing ascites or watery ascites **(Squires and Fisher, 1986)**, When dissecting a bird suffering from acute aflatoxin poisoning, we find between a quarter and half a liter of serous fluid inside its abdomen **(Siller, 1985)**. As for the deficiency of fibrinogen and prothrombin, they are considered responsible for creating the biological balance between blood fluidity and the occurrence of bleeding and its clotting, as when performing an autopsy on a bird infected with aflatoxin poisoning, we notice the presence of hemorrhagic spots in different locations of the body, especially the joints **(Pande *et al.*, 2021)**. Mycotoxins cause a weakened immune response to live and dead vaccines, making a bird infected with aflatoxin more susceptible to infectious viral diseases such as (N.D.), (I.B.), and others, in addition to the possibility of the activity of harmful bacteria such as E. coli, Sal., and Coccidia **(Oswald *et al.*, 2005)**. As for the effect of aflatoxin on the effectiveness of antibiotics, it leads to a reduction in the bird's benefit from a large percentage of antibiotics belonging to the aminoglycoside and tetracycline groups **(Pande *et al.*, 2021)**. As for the possibility of observing the bird's infection with aflatoxin mycotoxins on the bird's vital organs, this is done through the change of the liver from red to a color that tends towards white as a result of fibrosis, with an increase in its size, in addition to the occurrence of general pallor due to blood poisoning, as well as lethargy and the change of the color of the comb and wattles to yellow **(Kensler *et al.*, 2011)**. One of the negative effects of aflatoxins is causing economic losses for the breeder through poor overall growth of the herd and an increase in the (F.C.R.) **(Bryden, 2012)**. In addition to a high mortality rate that may reach 10% or more, there is atrophy of the thymus and spleen and a general deterioration of the immune system with a weak cellular and humoral response to vaccines **(Bondy and Pestka, 2000)**. This leads to a decrease in blood levels of (ca., ph., and vit. D) resulting in osteoporosis and reduced eggshell thickness in laying flocks **(Wu *et al.*, 2019)**. Therefore, rapid and effective treatment is necessary to mitigate the adverse effects of this mycotoxin, which is widespread in grains and manufactured feed.

Table (2). Shows the effectiveness of traditional and novel antitoxins against Aflatoxin

Indicator	Mechanical antitoxins	Biological antitoxins	References
Feed consumed is contaminated with aflatoxins.	Very effective, more than (90%)	Effective between (70-90%)	**(Shetty and Jespersen, 2006)**
Most effective substances for combating Aflatoxin	Aluminosilicate, bentonite clay	Saccharomyces yeast, Lactobacillus	**(Vila-Donat *et al.*, 2018)**
Antitoxin works	Adsorption in the digestive tract	By adsorption on yeast cell wall or by conversion and biolysis by bacteria	**(Hathout and Aly, 2014)**

Chemical structure of aflatoxin B_1



(van and peerdman, 1970)

Ochratoxin (A)

This toxin has a direct effect on the kidneys when its toxicity is at minimal levels, in addition to affecting liver tissue when its toxicity is at very high levels **(Ringot *et al*., 2006)**. It is synthesized by the fungal species *Aspergillus ochraceus*, and is the most widespread and toxic *Penicillium veridicatum*, which is abundant in temperate and cold regions such as Europe and Canada and It is frequently detected in stored cereals **(Malir *et al*., 2016)**.

Table (3). Shows the minimum and maximum limits of Ochratoxin toxicity according to the type of bird (parts per million - ppm)

Symptoms of poisoning	Type of bird that consumed the poisoned feed	Ochratoxin concentration in feed (ppm)	References
Impaired kidney function	Broiler Chickens	2_4	**(Stoev *et al*., 2002)**
Reduced weight and growth	Broiler Chickens	2_4	**(Stoev, 2010)**
Low egg production rate	Laying hens	2	**(Huff *et al*., 1988)**

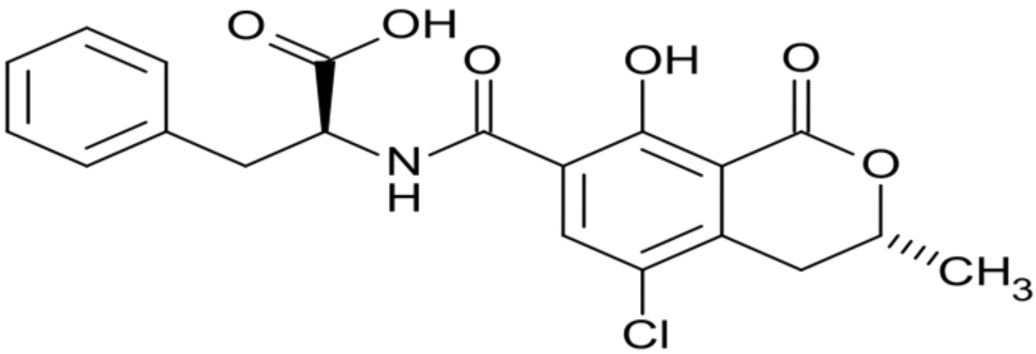
The pathological mechanism of ochratoxin and methods to reduce its effects

Scientifically, after consuming feed contaminated with ochratoxin, the body absorbs it through the digestive system, then it is metabolized mainly in the liver and then binds strongly to plasma proteins, the reason it remains in the body for a long period of about 35 days is that it causes its bioaccumulation in the body if it continues to enter the host. It is mainly excreted from the body through urine and feces, but its binding to plasma proteins is one of the most important reasons for the continuation of its effect and the occurrence of chronic toxicity **(Ringot *et al*., 2006)**. Because it is primarily excreted from the body via urine, it induces nephrotoxicity by damaging renal parenchymal tissue and changes their color to a yellowish-brown color, along with an increase in the percentage of urea-containing substances in the body **(Stoev *et al*., 2002)**. If both the kidney and liver are damaged by these toxins, this leads to poor production performance, in addition to a decline in feed utilization efficiency and a general decrease in cellular immunity, which leads to an increased likelihood of exposure to diseases **(Stoev, 2010)**. Visceral gout is likely to occur because the kidneys are not functioning properly, especially in excreting uric acid and preventing its accumulation in the body **(Braun, 2016)**.

Table (4). Shows the effectiveness of traditional and novel antitoxins against Ochratoxin A

Indicator	Mechanical antitoxins	Biological antitoxins	References
Feed consumed is contaminated with Ochratoxin A toxins.	Low effectiveness (30-60%)	Effective at (70-85%)	**(Avantaggiato *et al*., 2007)**
Most effective substances for combating Ochratoxin A	Activated charcoal, some zeolites	Pseudomonas bacteria, aryl sulfase enzyme	**(Abrunhosa *et al*., 2006)**
Antitoxins affected by pH	Strongly affected by pH	Less affected by pH	**(Adebo *et al*., 2017)**

Chemical structure of Ochratoxin A



(van der *et al*., 1965)

(Fusarium Toxins)

This category includes several types of mycotoxins, each with its own specific effect, including:

1- (T2 -Trichothecene)

A highly virulent Fusarium mycotoxin as its strongest effect is on parts of the digestive system, especially on the mucous membrane lining it, resulting in necrosis of the oral, lingual, and pharyngeal mucosa **(Pestka, 2007)**. In addition, it inhibits protein and DNA synthesis in cells, impairs the body's immune system, and can cause internal bleeding **(Li *et al*., 2011)**. Clinical and anatomical symptoms that appear when these toxins are present in the body include the appearance of small white spots in the mouth, a decrease in the amount of feed consumed, inflammation of the mucous membrane of the stomach and intestines, in addition to malabsorption where feed residues appear in the feces, an increase in the feed conversion ratio, increased water consumption, and the occurrence of diarrhea **(Richard, 2007)**. The permissible concentrations of T-2 Trichothecene in feed for all types of poultry are (0.1 - 0.2 ppm) **(Eriksen and Pettersson, 2004)**.

2- (DON- Deoxynivalenol)

It is synthesized by some species of *Fusarium graminearum*, and corn, wheat, and barley grains are among the crops most susceptible to contamination by a variety of toxins, especially (DON) **(Gautier *et al*., 2020)**. One of the most important symptoms that appear on the body when poisoned by this type of toxin is a change in the color of the tongue of the affected bird from red to gray or black concurrently with reduced egg production. In addition, the chronic toxicity of this toxin causes significant deterioration of the immune system, increasing the likelihood of live animals contracting infectious diseases **(Pestka, 2010)**. The permissible concentrations of DON in feed for all types of poultry are 1-5 ppm **(Dänicke and Brezina, 2013)**.

3- (Zearalenone)

This compound is an estrogen-mimicking mycotoxin synthesized by specific fungal species belonging to the general Fusarium *graminearum* and *Gibberella zeae* , It is characterized by containing a nucleus (resorcylic acid lactone) in its structural framework, a chemical structure similar to the natural estrogenic chemical structure in the body, enabling it to bind to estrogen receptors and cause hormonal effects. Based on the above, it is considered a reproductive toxin or also called a hormonal toxin that affects poultry in general, and the turkey breed is the most affected. Anatomical and clinical symptoms of this toxin on the chicken's body include swelling of the comb, ovary, and cloaca, with the possibility of cysts appearing in the oviduct **(Zain Al-Din *et al*., 2007)**. As for the permissible concentrations in poultry feed for these toxins, they are between (0.1 - 0.5) parts per million **(Leo *et al*., 2019)**.

4- (Fumonisin B1)

Fusarium proliferatum, Fusarium moniliforme Fusarium verticillioides is the predominant fungal source of this compound, this toxin has a structure similar to that of sphingolipids, which are involved in the formation of the cell membrane, which leads to its ability to affect cell function **(Smith *et al.*, 2016)**. This effect causes an accumulation of sphinganin in the body's cells, which is the building block of sphingolipid formation, leading to a deficiency in them, which causes a defect in the formation of the cell membrane **(Fos *et al.*, 2018)**. This toxin has detectable clinical and anatomical symptoms such as black, sticky diarrhea, decreased egg production and body weight, and the possibility of rickets in laying hens due to reduced calcium absorption from the small intestine, as well as swelling and enlargement of internal vital organs, this reduces the amount of thiamine available to the body (vitamin B1) **(Stockmann-Jovala and Savolainen, 2008)**. As for the permissible concentrations in poultry feed for these toxins, they are between (5 - 20) parts per million **(EFSA, 2018)**.

5- Moniliformin (MON)

Fusarium gramaminerum is the most important fungus that produces this mycotoxin. Its structure contains a pyrone ring with a carbonyl group, and this structure is similar to that of pyruvate **(Gestow, 2008)**. Monilformin toxin binds to thiamine pyrophosphate sites in the enzyme, which makes the natural binding of pyruvate very difficult **(Crick *et al.*, 2021)**. This binding process causes pyruvate to accumulate in the body's cells, which leads to a deficiency in acetyl coenzyme-A production and a radical disruption of the Krebs cycle, resulting in reduced energy production **(Knasmüller *et al.*, 2022)**. Poultry infection with this toxin can be observed through clinical and anatomical symptoms, beginning with facial congestion, abdominal fluid accumulation, decreased egg production, and acute diarrhea with undigested feed **(Gestoy, 2004)**. As for the permissible concentrations in poultry feed for these toxins, they are between (1 - 2) parts per million **(EFSA, 2018)**.

6- (Fusaric Acid)

Fusarium verticilloides and *Fusarium oxysporum* are the basis for the formation of this toxin, which is characterized by a composition containing pyridin, which is one of the essential components of cell membranes, leading to a disruption in the functioning of the cell membrane **(Beacon *et al.*, 2021)**. This toxin binds to copper sites in the enzyme, which prevents the conversion of the neurotransmitter, and in particular the neurotransmitter dopamine, to norepinephrine **(Wang *et al.*, 2022)**. This leads to general disruption and dysfunction in biological processes **(Lee *et al.*, 2023)**. As for the permissible concentrations in poultry feed for these toxins, they are between (10 - 20) parts per million **(European Food Safety Authority, 2014)**.

7- (Citrinin)

Penicillium, Aspergillus, and *Monascus* are the primary fungi that produce this type of toxin, which is a polyketide derivative containing a benzene ring and a lactone **(He *et al.*, 2023)**. This toxin causes an increase in blood urea and creatinine levels due to its direct effect on causing kidney enlargement, damage, and impaired kidney function. The amount of urine excreted is large **(He *et al.*, 2019)**. In addition, it elevates levels of (ROS) thereby promoting lipid peroxidation and leads to glutathione depletion, ultimately resulting in DNA damage **(Li *et al.*, 2023)**. The permissible concentrations of these toxins in feed for all types of poultry are (0.1–0.2 ppm) **(Varga *et al.*, 2013)**.

8- (Oosporein)

It is a red dianthraquinone pigment from the mycotoxin produced by the fungus Chaetomium trilaterale and is composed of naphthalene derivatives with a complex cyclic system **(Studt *et al.*, 2023)**. Its pathological effects on the body affected by it are a general decrease in immunity as well as in the organism's productive and vital performance. In addition to the above, its effect is similar to that of Citrinin in terms of increasing(R.O.S.), which in turn increases lipid peroxidation and causes depletion of glutathione, which ultimately leads to DNA damage **(Li *et al.*, 2023)**. And causing a relative increase in uric acid in the blood and the occurrence of visceral gout cases, especially in the joints **(Ueno, 1985)**.

9- (Rubratoxin)

It is secreted by P. rubrum and P. purpurogenum fungi and causes bleeding in several locations in the muscles and viscera, with blood in the glandular and muscular gastric cavity, enlargement of the liver, and severe yellowing of the stool **(Wilson and Hayes, 1973)**.

10- (Patulin)

Producing fungi: *Aspergillus spp., Penicillium spp., Byssochlamys spp,* and causes delayed growth and calcium deficiency in the body with the appearance of paralysis of the limbs, in addition to the presence of foul-smelling watery contents in the crop **(Puel *et al*., 2010)**.

11- (Cyclopiazonic Acid)

These are mycotoxins secreted by Aspergillus flavus and cause a decrease in fertility, especially in roosters, along with intestinal disorders and neurological symptoms **(Urano *et al*., 1992)**.

Characteristics of Mycotoxins

Mycotoxins have many characteristics that need to be accurately identified in order to understand their mechanism of spread and how to eliminate them. The thermal stability of mycotoxins is one of the most difficult challenges facing the system for controlling these toxins because they are chemically and thermally stable compounds and do not undergo any decomposition or breakdown during the processes of preparing and manufacturing feed materials **(Bullerman and Bianchini, 2007)**. As for knowing how to differentiate between the symptoms of mycotoxins and bacterial toxins, mycotoxins are chemical compounds in a low-MW form that do not stimulate the body's immune response to produce antibody substances, and their clinical symptoms are delayed in appearing due to the accumulation of toxins, Bacterial toxins are proteinaceous substances with a large molecular weight that cause symptoms that appear within a few hours of ingestion, after which the human or animal body begins to produce antibodies against them **(Bennett and Klich, 2003)**.

Treatment and prevention

Any infection with mycotoxins has two treatment approaches: (Strategic treatment), which is the most important in the long term because it represents the primary treatment for the condition, and (Tactical treatment), which is the most important because it represents the immediate treatment for the condition, The same treatment approach is applied to dealing with mycotoxins, where the strategic approach involves pre-treating the feed used, which is the sole source of mycotoxins in birds, Strategic management aims for the reduction of mycotoxins in animal diets. Tactical management, on the other hand, focuses on drinking water and aims to address the pathological and nutritional effects of mycotoxin poisoning as much as possible **(Bryden, 2012)**.

Strategic management of mycotoxins

Strategic management of mycotoxins is vital, of great importance and indispensable, as all attempts to avoid activating it lead to the continued accumulation of damage from mycotoxins **(Bryden, 2012)**, This treatment requires complete and detailed knowledge of mycotoxins, as mentioned previously. Mycotoxins are mainly divided into Polar mycotoxins or electrical (having an electrical charge), such as aflatoxin and ochratoxin, the best way to combat these two types of fungi is through pre-treatment of the feed with an anti-mechanism such as activated silicate or activated charcoal, along with the inclusion of organic acids like propionic acid to the feed to eliminate the fungi **(Kolosova and Stroka, 2011)**. The mechanical (physical) mycotoxin inhibitors, they rely on the adsorption process, the surface attraction of mycotoxins to the electrically charged surface of the mechanical mycotoxin inhibitors. This treatment needs to be added to the feed before the chickens consume it (outside the bird's body). Therefore, feeds treated with it should not be used until 24 hours have passed since the treatment **(Huwig *et al*., 2001)**.

Non-polar mycotoxins, such as trichothicin, zearalenone, citrinine, osporine, and dioxynevalenol, do not carry an electrical charge. The best way to combat these types is through pre-treatment of the feed with biological toxin binders that target the agglutination process caused by mannan and oligosaccharides present in the yeast cell wall, besides to the enzymatic activity, most notably the Chitinase enzyme, organic acids to eliminate fungi **(Kolosova and Stroka, 2011)**. Biological antitoxins contain active ingredients and enzymes that can alter the chemical structure of mycotoxins (biodegradation or biotransformation) to eliminate their toxic effects. They only work within the bird's body, so feed treated with these antitoxins can be used immediately after treatment **(Hathout and Aly, 2014)**.

Table (5). Shows the extent of the side effects of traditional and modern antitoxins on feed components

Feed components	Mechanical antitoxins	Biological antitoxins	References
Fat-soluble vitamins	Possible adsorption (A, D, E, K)	No effect	**(Hathout and Aly, 2014)**
Water-soluble vitamins	Limited effect	No effect	**(Kolosova and Stroka, 2011)**
Basic minerals	Potential adsorption (Ca, P, Zn, Mn)	No effect	**(Adebo *et al*., 2017)**
Electrolytes	Potential adsorption	No effect	**(Rosa *et al*., 2001)**
Antibiotics in poultry feed	Potential adsorption, especially of bentonite	No effect	**(Vila-Donat *et al*., 2018)**
Probiotics	May be absorbed and its effectiveness .reduced	Enhances the action of probiotics	**(Shetty and Jespersen, 2006)**
Digestive enzymes and organic acids	May absorb them and reduce their .effectiveness	Enhances the action	**(Adebo *et al*., 2017)**
Speed of effectiveness and impact	Instant (minutes)	It needs time (hours).	**(Huwig *et al*., 2001)**

Tactical management of mycotoxins

This refers to the use of a liquid antitoxin administered directly to birds. The aim of this tactical management is to address the pathological and nutritional effects of mycotoxin poisoning as quickly as possible to control the bird's health. This management requires two essential conditions, the first requirement is that this liquid antitoxin contains silymarin, a substance that regenerates liver cells and cleanses them of harmful toxins. The second requirement is that there be a strategic approach to combating mycotoxins in feed using appropriate feed toxin binders. This means that tactical measures complement strategic measures but are not a substitute for them **(Vila-Donat *et al*., 2018)**.

Mechanical (physical) and biological antitoxins

Antitoxins are divided into two main categories, with no third option: mechanical and biological antitoxins. Mechanical antitoxins are defined as substances with a relatively large surface area and a porous structure that enable them to adsorb mycotoxins in the digestive tract **(Huwig *et al*., 2001)**. These materials include various clays such as silicates and aluminosilicates **(Vila-Donat *et al*., 2018)**. These clay materials include silicates and aluminosilicates **(Villa-Donat *et al*., 2018)**. Aluminosilicate zeolite is a natural zeolite with a porous structure of varying sizes, enabling it to exhibit high adsorption capacity. These pores bind mycotoxins, preventing their absorption in the intestines. Zeolites have negative charges that enable them to attract positively charged toxic molecules and exchange ions between them, which leads to a stronger chemical bond than physical adsorption alone

(Papayuanu *et al*., 2005). Bentonite, on the other hand, is a type of clay that is rich in montmorillonite and has a high capacity to retain and bind a variety of toxic substances **(Kanweischer *et al*., 2006)**. As for silicates, activated carbon is the most common type due to its large surface area. However, it is a non-selective material, which is a major drawback because it absorbs both toxins and nutrients **(Jansen van Rensburg *et al*., 2006)**. As for diatomaceous earth, it consists of fossilized diatomaceous structures. It has a microscopic porous structure that enables it to bind toxins when their molecules pass near these pores attributable to van der Waals interactions and electrostatic forces bind them to the surface of the diatomaceous earth grains and make them unavailable for absorption within the digestive tract, However, the lack of selectivity is also one of its major drawbacks because the absorbent material maybe potential to bind with nutrients, including vit. and min., causing a decline in the nutritional value of the feed **(Maki *et al*., 2016)**. One of the most important drawbacks of mechanical antibiotics, aside from their previously mentioned lack of selectivity, is that their effectiveness varies greatly based on the particular mycotoxin and the pH of the digestive system **(Avantaggiato *et al*., 2007)**.

The second category consists of biological antitoxins that rely on microorganisms or their enzymes to break down mycotoxins. This process is known as biotransformation **(Hathout and Aly, 2014)**. Beneficial bacteria, yeasts, and enzymes are considered among the most important antitoxins in this regard, through their action on breaking down the bonds of mycotoxin molecules **(Adibo *et al*., 2017)**. One of these types is lactic acid bacteria (Lactobacillus), which is characterized by its ability to adsorb toxins such as aflatoxin **(Al-Nizami *et al*., 1998)**. As for strains of bacilli, their function is through the secretion of enzymes that break down toxins such as zearalenone **(Yi *et al*., 2011)**. Yeasts also have a mechanism for neutralizing mycotoxins by binding to different types of toxins, as in the cell wall of baker's yeast (Saccharomyces cerevisia) **(Chitty and Jespersen, 2006)**. In addition, it was demonstrated that certain strains of Pichia pastoris exhibited the degradative capacity to ochratoxin A **(Abrunhosa *et al*., 2010)**. Regarding the ability of enzymes to degrade mycotoxins, it was found that the enzyme lactonase, which breaks down aflatoxin B1, converts it into a less toxic metabolite (AFB-dihydrodiol) **(Liu *et al*., 2001)**. The enzyme sulfatase is capable of breaking down ochratoxin **(Abrunhosa *et al*., 2006)**. Similarly, the enzyme chitinase is considered an advanced mycotoxin control agent, it does not rely on absorbing toxins after they are secreted, but rather attacks the fungi themselves by breaking down the chitin in the fungal cell wall, which weakens the cell wall and causes the cell to lose its contents, inhibiting fungal growth and preventing it from producing more mycotoxins **(Hamid *et al*., 2013)**. Biological antitoxins are characterized by their high selectivity, targeting specific toxin molecules without affecting the nutritional value of the feed **(Kolosova and Stroka, 2011)**. Some of them are also able to break down toxins into completely non-toxic compounds, not just bind those **(Vanhoutte *et al*., 2016)**.

Sustainable development and mycotoxin binders

Mycotoxin binders contribute to reducing crop losses by minimizing spoiled feed, thereby enhancing food security for the community by providing healthy feed for farm animals and livestock, Mycotoxins cause economic losses to the global food supply, and effective control maximizes profits for farmers and livestock breeders, especially in developing countries. In addition, the work of controlling toxins and the fungi that cause them is of great essential for safeguarding human health against these carcinogenic and harmful toxins **(Eskola *et al*., 2020)**. Therefore, encouraging sustainable strategies for fungal control reduces the use of traditional chemical pesticides that have a harmful environmental impact **(Popp *et al*., 2013)**. Biological methods of mycotoxin control represent a suitable and environmentally sustainable alternative for reducing chemical control, as current scientific research focuses on developing hybrid mechanical agents with selective adsorption because these compounds are good in terms of their tolerance to poor storage conditions, their adsorption action, and their stability that lasts for many years, However, one primary limitation in their application is non-selectivity which affects the ability to benefit from some food compounds.

Therefore, it is preferable not to rely on them and to consider them as auxiliary antioxidants, as for biological toxin inhibitors, current trends are towards exploring and developing other enzymes, as well as overcoming the poor thermal stability of these inhibitors, in addition to addressing their limited shelf life when stored in feed **(Adebo *et al*., 2017)**.

Table (6). Summarizes the extent of the effect of both mechanical and biological antitoxins on the productive indicators of broiler chickens

Indicator	Explanation of the studied index	Type of chicken raised	Mechanical antitoxins	Biological antitoxins	References
Daily growth rate	Average daily weight gain (grams/day), which is a key indicator of farm profitability	Broiler (Ross 308)	%22-16 improvement	%28-20 improvement	**(Zhao *et al*., 2023 ; Abd El-Hack *et al*., 2022)**
Food conversion factor	The amount of feed required to produce 1 kg of meat determines economic .efficiency	Broiler (Cup 500)	%14-10 improvement in efficiency	%16-12 improvement with improved digestion	**(El-Saadony *et al*., 2022 ; Li *et al*., 2024)**
Final body weight	Weight at market (35-42 days) - affects the selling price	Broiler Arbor) Acres)	increase %18-12	increase %22-15	**(Adegbeye *et al*., 2023; Wang *et al*., 2023)**
Feed consumption	Daily feed consumption - an indicator of health and appetite	Broiler (Ross 308)	Improve efficiency by 8-12%	Improves digestion by 10-15%	**(Zhao *et al*., 2023; Li *et al*., 2024)**
dressing percentage of the carcass	Percentage of the final product after slaughter and cleaning	Broiler (Arbor Acres)	%9-6 improvement	%11-8 improvement	**(Wang *et al*., 2023; Zhao *et al*., 2023)**
Mortality rate	Percentage of mortality during the cycle - rises under acute poisoning	Broiler (Arbor Acres)	reduction %45-35	reduction %50-40	**(El-Saadony *et al*., 2022; Adegbeye *et al*., 2023)**
Breeding cost ratio	Production cost per kg of meat - increases with poisoning	Broiler (Ross 308)	Savings of 12-16%	Savings of 10-14%	**(El-Saadony *et al*., 2022; Wang *et al*., 2023)**

Table (7). Shows the extent of the effect of both mechanical and biological antitoxins on the productive indicators of laying hens

Indicator	Explanation of the studied index	Type of chicken raised	Mechanical antitoxins	Biological antitoxins	References
Egg production rate	The percentage of eggs produced daily is sensitive .to mycotoxins	Laying hens (hay layin)	Prevent a 25-35% decrease	Increase production by 30-40%	**(El-Saadony *et al*., 2022)**
Eggshell quality	Thickness, rigidity, and few cracks in the .eggshell	Laying hens (lohmann)	Improved rigidity by 15-20%	Improved crust thickness by 18-25%	**(Zhao *et al*., 2023; Li *et al*., 2024)**
Yolk colour	Color intensity and tone - an indicator of feed quality	Laying hens (hay layin)	Color improvement 10-15%	Color improvement 12-18%	**(Adegbeye *et al*., 2023)**
Egg weight	Average egg weight (grams) - affects the rating and price	Laying hens (Bovans)	%10-6 increase	%12-8 increase	**(Li *et al*., 2024 ; Wang *et al*., 2023)**
Hatching rate	Percentage of fertilized eggs that hatch - an indicator of maternal health	Broiler breeder hens (500 cobb)	%18-12 improvement	%22-15 improvement	**(Adegbeye *et al*., 2023)**
Egg viability	The shelf life of eggs is affected by the quality of the .shell and yolk	Laying hens (hay layin)	Extended validity by 7-10 days	Extended validity by 10-14 days	**(Li *et al*., 2024 ; Zhao *et al*., 2023)**
Egg laying rate	The number of eggs produced per week is sensitive to environmental .changes	Laying hens (lohmann)	Rate stability at 85-90%	Improve the rate to 90-95%	**(Li *et al*., 2024)**
Album quality	Good consistency and firmness of egg albumin - an indicator of quality	Laying hens (hay layin)	%15-10 improvement	%20-15 improvement	**(Zhao *et al*., 2023 ; Wang *et al*., 2023)**
Rate of sexual maturity	Age at the start of egg production - affected by nutrition	Laying hens (hay layin)	Limited effect	Limited effect	**(Li *et al*., 2024)**
Damage rate	Percentage of eggs damaged during collection and transport	Laying hens (lohmann)	Reduce damage by 5-10%	Reduce damage by 8-13%	**(Li *et al*., 2024 ; Zhao *et al*., 2023)**

Table (8). Shows the extent of the impact of both mechanical and biological antitoxins on sustainability indicators

Indicator	Mechanical antitoxins	Biological antitoxins	References
Toxin residue in meat	Possible (heavy (metals	Improbable	**(Hathout and Aly, ؛ Vila-Donat *et al*., 2018) 2014**
Toxin residues in eggs	Possible	Improbable	**(Kolosova and ؛ Vila-Donat *et al*., 2018) Stroka, 2011**
Health risks on consumer	Possible	Improbable	**(Adebo *et al*., 2017 ؛Vila-Donat *et al*., 2018)**
Impact of poultry waste on the environment	May contain absorbed toxins	Environmentally safe	**(Hathout and Aly, ؛ Vila-Donat *et al*., 2018) 2014**
Usage restrictions in the diet	Restrictions on permissible levels	Generally limited restrictions	**(Kolosova and Stroka, 2011)**
Future orientation	Further restrictions	Further acceptances and approvals	**(Adebo *et al*., 2017)**
Application in broiler feed	Suitable while taking into account nutritional needs	Very appropriate	**(Hathout and Aly, 2014 ؛ Bhat *et al*., 2010)**
Application in laying hen diets	Limited due to the accumulation of toxins in eggs	Convenient and effective	**(Shetty and ؛ Vila-Donat *et al*., 2018) Jespersen, 2006**

Pelleted diets and the mycotoxin crisis

With the development of livestock through the use of modern technologies and significant advancements in poultry productivity through genetic selection to maximize and sustain this resource, and due to the increasing demand for poultry products **(Mustafa *et al*., 2025)**. egg production is a key productivity characteristic, it achieves the highest levels of success when the egg-laying period begins early and extends for a longer period **(Alniemy *et al*., 2025)**. To achieve the highest yield, the shift was made to the use of pelleted feeds, as there is no doubt that pelleted feeds have advantages that cannot be ignored because they combine all the components of the feed into a single piece of feed that the bird picks up at once, and they improve the efficiency of utilization and reduce the waste of the feed provided **(McKinney and Teeter, 2004)**. However, the real problem lies in that most feed raw materials are of poor quality and contaminated with mycotoxins and need to be treated before being given to poultry. Among these treatments are mechanical mycotoxin inhibitors (active silica and others) which are characterized by being able to withstand the temperature of pressing and drying because they are mainly manufactured at a temperature of up to 140 degrees Celsius, However, its drawback is that it only works against two types of mycotoxins, aflatoxin and ochratoxin, while the rest of the mycotoxins remain untreated **(Streit *et al*., 2013)**. In addition, all biological mycotoxin inhibitors (those based on microbial enzymes for the biological breakdown of mycotoxins) cannot withstand the pressing and drying temperatures because their active ingredients are proteins and enzymes, which, like other proteins, are subject to enzymatic denaturation at 56°C, While the pressing temperature in pelleted feeds reaches 80-90 degrees Celsius **(Adebo *et al*., 2017)**. All biological mycotoxin antagonists only work inside the bird’s body, and therefore the decomposition resulting from the heat of pressing will completely destroy them. When the bird consumes those feeds, it will consume all types of toxins as they are **(Hathout and Aly, 2014)**. One of the main problems in treating mycotoxins in pelleted feeds is the Maillard reaction, which transpires among specific reducing sugars, such as pentoses and hexoses present in the feed, and free amino acids, primarily lysine and asparagine, as a result of the pelleting process and exposure to high temperature, high humidity, and high pressure, This reaction produces some harmful chemical compounds called (Maillard Compounds), the most important of which is (Acrylamide), a carcinogenic substance that has a highly toxic effect on kidney tissues **(Mottram *et al*., 2002)**. From the previous analysis, we conclude that the prior treatment of compressed feeds with a biological toxin antagonist has no significant value because the compressing temperature has certainly destroyed the presence of enzymes and microorganisms **(Adebo *et al*., 2017)**. Pre-treatment of pelleted feed with a mechanical antagonist is beneficial to a good extent in controlling some mycotoxins such as aflatoxin and ochratoxin, while all other types of toxins remain free and pathogenic to poultry if ingested **(Vila-Donat *et al*., 2018)**. In addition, acrylamide, a carcinogen with a highly toxic effect on the kidneys, is present in pelleted feed **(Friedman, 2003)**.

Conclusion

Previous studies indicate that the use of mycotoxin binders has both advantages and disadvantages for both types of antimycotoxin. However, the production and use of biological binders are expected to flourish in the future due to their advantages, making them more preferable to poultry nutrition specialists.

References

Abd El-Hack, M. E., El-Saadony, M. T., Salem, H. M., El-Tahan, A. M., Soliman, M. M., Youssef, G. B. and Taha, A. E. (2022). Alternatives to antibiotics for organic poultry production: Types, modes of action and impacts on bird's health and production. Poultry Science, 101(4), 101696. https://doi.org/10.1016/j.psj.2022.101696

Abrunhosa, L., Paterson, R. R. M. and Venâncio, A. (2010). Biodegradation of ochratoxin A for food and feed decontamination. Toxins, 2(5), 1078–1099. https://doi.org/10.3390/toxins2051078

Abrunhosa, L., Santos, L., & Venâncio, A. (2006). Degradation of ochratoxin A by a Aspergillus species. International Journal of Food Microbiology, 107(1), 83–87. https://doi.org/10.1016/j.ijfoodmicro.2005.08.020

Adebo, O. A., Njobeh, P. B., Sidu, S., Tlou, M. G. and Mavumengwana, V. (2017). A review on microbial degradation of aflatoxins. International Journal of Food Microbiology, 256, 50–60. https://doi.org/10.1016/j.ijfoodmicro.2017.05.027

Adegbeye, M. J., Salem, A. Z. M., Elghandour, M. M. Y. and Reddy, P. R. K. (2023). Mycotoxin toxicity to poultry and detoxification strategies by using adsorbents and bioactive compounds. Journal of Animal Physiology and Animal Nutrition, 107(2), 417–434. https://doi.org/10.1111/jpn.13744

Alniemy, A. M. T., AL-Hamed, A. M. and Adday, O. A. (2025). Supplementation effects of choline chloride to layer hen ration on productive performance. Mesopotamia Journal of Agriculture, 53(2). https://doi.org/10.33899/mja.2025.156101.1515

Avantaggiato, G., Solfrizzo, M. and Visconti, A. (2007). Recent advances on the use of adsorbent materials for detoxification of Fusarium mycotoxins. Food Additives and Contaminants, 24(4), 349–362. https://doi.org/10.1080/02652030601053677

Bacon, C. W., Porter, J. K., Norred, W. P. and Leslie, J. F. (2021). Fusaric acid: Structure and biological activity. Journal of Agricultural and Food Chemistry, 69(15), 4321–4333. https://doi.org/10.1021/acs.jafc.1c01234

Bennett, J. W. (1987). Mycotoxins, mycotoxicoses, mycotoxicology and Mycopathologia. Mycopathologia, 100(1), 3–5. https://doi.org/10.1007/BF00769561

Bennett, J. W. and Klich, M. (2003). Mycotoxins. Clinical Microbiology Reviews, 16(3), 497–516. https://doi.org/10.1128/CMR.16.3.497-516.2003

Blount, W. P. (1961). Turkey "X" disease. Journal of the British Turkey Federation, 9(1), 52–77.

Bondy, G. S. and Pestka, J. J. (2000). Immunomodulation by fungal toxins. Journal of Toxicology and Environmental Health Part B: Critical Reviews, 3(2), 109–143. https://doi.org/10.1080/109374000281113

Braun, U. (2016). Visceral gout in animals. Veterinary Journal, 215, 90–96. https://doi.org/10.1016/j.tvjl.2016.05.001

Bryden, W. L. (2012). Mycotoxin contamination of the feed supply chain: Implications for animal productivity and feed security. Animal Feed Science and Technology, 173(1–2), 134–158. https://doi.org/10.1016/j.anifeedsci.2011.12.014

Bullerman, L. B. and Bianchini, A. (2007). Stability of mycotoxins during food processing. International Journal of Food Microbiology, 119(1–2), 140–146. https://doi.org/10.1016/j.ijfoodmicro.2007.07.035

Dänicke, S. and Brezina, U. (2013). Invited review: Kinetics and metabolism of the Fusarium toxin deoxynivalenol in farm animals: Consequences for diagnosis of exposure and intoxication. Archives of Animal Nutrition, 67(3), 185–205. https://doi.org/10.1080/1745039X.2013.793760

Denli, M. and Okan, F. (2006). Efficacy of different adsorbents in reducing the toxic effects of aflatoxin B1 in broiler diets. South African Journal of Animal Science, 36(4), 222–228. https://doi.org/10.4314/sajas.v36i4.4004

EFSA Panel on Contaminants in the Food Chain (CONTAM). (2014). Scientific Opinion on the risks for human and animal health related to the presence of modified forms of certain mycotoxins in food and feed. EFSA Journal, 12(12), 3916. https://doi.org/10.2903/j.efsa.2014.3916

EFSA Panel on Contaminants in the Food Chain (CONTAM). (2018). Risks for animal health related to the presence of fumonisins, their modified forms and hidden forms in feed. EFSA Journal, 16(5), e05242. https://doi.org/10.2903/j.efsa.2018.5242

El-Nezami, H., Kankaanpää, P., Salminen, S. and Ahokas, J. (1998). Ability of dairy strains of lactic acid bacteria to bind a common food carcinogen, aflatoxin B. Food and Chemical Toxicology, 36(4), 321–326. https://doi.org/10.1016/S0278-6915(97)00160-9

El-Saadony, M. T., Salem, H. M., El-Tahan, A. M., Abd El-Mageed, T. A., Soliman, S. M. and Khafaga, A. F. (2022). Impacts of clay mineral supplementation on performance, health, and rumen metabolism of beef cattle: A review. Journal of Animal Physiology and Animal Nutrition, 106(3), 457–469. https://doi.org/10.1111/jpn.13622

Eriksen, G. S. and Pettersson, H. (2004). Toxicological evaluation of trichothecenes in animal feed. Animal Feed Science and Technology, 114(1–4), 205–239. https://doi.org/10.1016/j.anifeedsci.2003.08.008

Eskola, M., Kos, G., Elliott, C. T., Hajšlová, J., Mayar, S. and Krska, R. (2020). Worldwide contamination of food-crops with mycotoxins: Validity of the widely cited 'FAO estimate' of 25%. Critical Reviews in Food Science and Nutrition, 60(16), 2773–2789. https://doi.org/10.1080/10408398.2019.1658570

Friedman, M. (2003). Chemistry, biochemistry, and safety of acrylamide. A review. Journal of Agricultural and Food Chemistry, 51(16), 4504–4526. https://doi.org/10.1021/jf030204+

Gautier, C., Pinson-Gadais, L. and Richard-Forget, F. (2020). Fusarium mycotoxins enolates: Formation, occurrence and toxicity. Toxins, 12(11), 694. https://doi.org/10.3390/toxins12110694

Grenier, B. and Loureiro-Bracarense, A. P. (2022). Mycotoxin multi-contamination: An update on the toxicity in poultry and interactions. World's Poultry Science Journal, 78(2), 321–337. https://doi.org/10.1080/00439339.2022.2099280

Hamid, R., Khan, M. A., Ahmad, M., Ahmad, M. M., Abdin, M. Z., Musarrat, J. and Javed, S. (2013). Chitinases: An update. Journal of Pharmacy and Bioallied Sciences, 5(1), 21–29. https://doi.org/10.4103/0975-7406.106559

Haque, M. A., Wang, Y., Shen, Z., Li, X., Saleemi, M. K. and He, C. (2020). Mycotoxin contamination and control strategy in human, domestic animal and poultry: A review. Microbial Pathogenesis, 142, 104095. https://doi.org/10.1016/j.micpath.2020.104095

Hathout, A. S. and Aly, S. E. (2014). Biological detoxification of mycotoxins: A review. Annals of Microbiology, 64(3), 905–919. https://doi.org/10.1007/s13213-014-0899-7

He, J., Zhou, T. and Young, J. C. (2019). Citrinin-induced renal toxicity in poultry: Mechanisms and prevention. Toxins, 11(5), 267. https://doi.org/10.3390/toxins11050267

He, Y., Li, X., Wang, Z. and Chen, F. (2023). Citrinin: Occurrence, biosynthesis, toxicity and analytical methods. Toxins, 15(4), 275. https://doi.org/10.3390/toxins15040275

Holanda, D. M. and Kim, S. W. (2021). Mycotoxin Occurrence, Toxicity, and Detoxifying Agents in Pig Production with an Emphasis on Deoxynivalenol. Toxins, 13(2), 171. https://doi.org/10.3390/toxins13020171

Huff, W. E., Kubena, L. F., Harvey, R. B. and Doerr, J. A. (1988). The individual and combined effects of aflatoxin and ochratoxin A on various production parameters in broiler chickens. Poultry Science, 67(6), 869–875. https://doi.org/10.3382/ps.0670869

Huwig, A., Freimund, S., Kappeli, O. and Dutler, H. (2001). Mycotoxin detoxication of animal feed by different adsorbents. Toxicology Letters, 122(2), 179–188. https://doi.org/10.1016/S0378-4274(01)00360-5

Jansen van Rensburg, C., Van Rensburg, C. E. J., Van Ryssen, J. B. J., Casey, N. H. and Rottinghaus, G. E. (2006). In vitro and in vivo assessment of humic acid as an aflatoxin binder in broiler chickens. Poultry Science, 85(9), 1576–1583. https://doi.org/10.1093/ps/85.9.1576

Jestoi, M. (2004). Emerging Fusarium mycotoxins: Moniliformin and fusaproliferin. World Mycotoxin Journal, 1(2), 147–156. https://doi.org/10.3920/WMJ2004.0208

Jestoi, M. (2008). Emerging Fusarium-mycotoxins: Moniliformin. Molecular Nutrition & Food Research, 52(5), 545–553. https://doi.org/10.1002/mnfr.200700418

Kannewischer, I., Tenorio Arvide, M. G., White, G. N. and Dixon, J. B. (2006). Smectite clays as adsorbents of aflatoxin B: Initial steps. Soil Science Society of America Journal, 70(3), 983–993. https://doi.org/10.2136/sssaj2005.0204

Kensler, T. W., Roebuck, B. D., Wogan, G. N. and Groopman, J. D. (2011). Aflatoxin: A 50-year odyssey of mechanistic and translational toxicology. Toxicological Sciences, 120(Suppl. 1), S28–S48. https://doi.org/10.1093/toxsci/kfq283

Knasmüller, S., Schwarz, V. and Stidl, R. (2022). Metabolic disruption by moniliformin: Implications for energy homeostasis and cellular toxicity. Archives of Toxicology, 96(5), 1327–1341. https://doi.org/10.1007/s00204-022-03252-y

Kolosova, A. and Stroka, J. (2011). Substances for reduction of the contamination of feed by mycotoxins: A review. World Mycotoxin Journal, 4(3), 225–256. https://doi.org/10.3920/WMJ2011.1288

Kriek, N. P. J., Marasas, W. F. O. and Thiel, P. G. (2021). The mechanism of moniliformin toxicity: A review. Journal of Environmental Pathology, Toxicology and Oncology, 40(2), 45-58. https://doi.org/10.1615/JEnvironPatholToxicolOncol.2021038255

Lee, S. H. and Park, J. H. (2023). Economic impact of mycotoxin contamination and prevention strategies in poultry industry. Journal of Poultry Science, 60(2), 78–92. https://doi.org/10.2141/jpsa.2023008

Li, X., Wang, Z., Beier, R. C., Shen, J., De Smet, D., De Saeger, S. and Zhang, S. (2011). T-2 toxin, a trichothecene mycotoxin: Review of toxicity, metabolism, and analytical methods. Journal of Agricultural and Food Chemistry, 59(8), 3441–3453. https://doi.org/10.1021/jf200767q

Li, X., Zhang, Y. and Wang, J. (2023). Oxidative stress induced by citrinin. Archives of Toxicology, 97(4), 987–1001. https://doi.org/10.1007/s00204-023-03465-9

Li, Y., Wang, X., Zhang, L. and Liu, Y. (2024). Recent advances in the use of biological agents for mycotoxin detoxification in poultry feed. Animal Nutrition, 16, 1–12. https://doi.org/10.1016/j.aninu.2023.11.005

Liu, N., Wang, J. Q., Jia, S. C., Chen, Y. K. and Wang, J. P. (2019). Effect of zearalenone on production performance, egg quality, and intestinal morphology of laying hens. Journal of Animal Science, 97(5), 1952–1961. https://doi.org/10.1093/jas/skz091

Liu, Y., Wu, F. and Liu, Y. (2001). Global burden of aflatoxin-induced hepatocellular carcinoma: A risk assessment. Environmental Health Perspectives, 119(6), 818–824. https://doi.org/10.1289/ehp.1103450

Magnoli, A. P., Monge, M. P., Miazzo, R. D., Cavaglieri, L. R., Magnoli, C. E., Merkis, C. I. and Dalcero, A. M. (2011). Effect of low levels of aflatoxin B1 on performance, biochemical parameters, and aflatoxin B1 in broiler liver tissues in the presence of monensin and sodium bentonite. Poultry Science, 90(1), 48–58. https://doi.org/10.3382/ps.2010-00971

Maki, C. R., Thomas, A. D., Elmore, S. E., Romoser, A. A., Harvey, R. B., Ramirez-Ramirez, H. A. and Phillips, T. D. (2016). Effects of calcium montmorillonite clay and aflatoxin exposure on dry matter intake, milk production, and milk composition. Journal of Dairy Science, 99(2), 1039–1046. https://doi.org/10.3168/jds.2015-10242

Malir, F., Ostry, V., Pfohl-Leszkowicz, A., Malir, J. and Toman, J. (2016). Ochratoxin A: 50 years of research. Toxins, 8(7), 191. https://doi.org/10.3390/toxins8070191

McKinney, L. J. and Teeter, R. G. (2004). Predicting effective caloric value of nonnutritive factors: I. Pellet quality and II. Prediction of consequential formulation dead zones. Poultry Science, 83(7), 1165–1169. https://doi.org/10.1093/ps/83.7.1165

Milicevic, D. R., Skrinjar, M. and Baltic, T. (2010). Real and perceived risks for mycotoxin contamination in foods and feeds: Challenges for food safety control. Toxins, 2(4), 572–592. https://doi.org/10.3390/toxins2040572

Mottram, D. S., Wedzicha, B. L. and Dodson, A. T. (2002). Acrylamide is formed in the Maillard reaction. Nature, 419(6906), 448–449. https://doi.org/10.1038/419448a

Muhammed, N., Liaqat, I., Andleeb, S., Naseem, S., Arshad, M. and Khalid, A. (2025). Indigenous aseel chicken-derived probiotics as biofactories of antifungal metabolites to control mycotoxin contamination in poultry feed. Molecular Biology Reports, 52(1). https://doi.org/10.1007/s11033-025-10819-2

Muñoz-Solano, B., Lizarraga Pérez, E. and González-Peñas, E. (2024). Monitoring Mycotoxin Exposure in Food-Producing Animals (Cattle, Pig, Poultry, and Sheep). Toxins, 16(5), 218. https://doi.org/10.3390/toxins16050218

Murphy, P. A., Hendrich, S. and Bryden, W. L. (2006). Human dietary exposures to mycotoxins through a total diet study. Food Additives and Contaminants, 23(1), 1-12. https://doi.org/10.1080/02652030500223583

Murugesan, G. R., Ledoux, D. R., Naehrer, K., Berthiller, F., Applegate, T. J., Grenier, B., Phillips, T. D. and Schatzmayr, G. (2015). Prevalence and effects of mycotoxins on poultry health and performance, and recent development in mycotoxin counteracting strategies. Poultry Science, 94(6), 1298–1315. https://doi.org/10.3382/ps/pev075

Mustafa, K. H., Al-Tamee, N. G., Al-Neimy, A. M. Th. and Hamadi, Z. K. (2025). Effect of substituting black soldier fly larvae instead of soybean meal on productive performance of quail at growth stage. Mesopotamia Journal of Agriculture, 53(1), 46-56. https://doi.org/10.33899/mja.2025.155671.1509

Nesbitt, B. F., O'Kelly, J., Sargeant, K. and Sheridan, A. (1962). Aspergillus flavus and turkey X disease: Toxic metabolites of Aspergillus flavus. Nature, 195(4846), 1062–1063. https://doi.org/10.1038/1951062a0

Olariu, R. M., Fiţ, N. I., Bouari, C. M. and Nadăş, G. C. (2025). Mycotoxins in Broiler Production: Impacts on Growth, Immunity, Vaccine Efficacy, and Food Safety. Toxins, 17(6), 261. https://doi.org/10.3390/toxins17060261

Pande, P. N., Sharma, R. and Kumar, A. (2021). The impact of mycotoxins on blood coagulation and immunity in poultry. Toxins, 13(8), 543. https://doi.org/10.3390/toxins13080543

Papaioannou, D., Katsoulos, P. D., Panousis, N. and Karatzias, H. (2005). The role of natural and synthetic zeolites as feed additives on the prevention and/or the treatment of certain farm animal diseases: A review. Microporous and Mesoporous Materials, 84(1–3), 161–170. https://doi.org/10.1016/j.micromeso.2005.05.030

Peng, W.-X., Marchal, J. L. M. and van der Poel, A. F. B. (2018). Strategies to prevent and reduce mycotoxins for compound feed manufacturing. Animal Feed Science and Technology, 237, 129–153. https://doi.org/10.1016/j.anifeedsci.2018.01.017

Pestka, J. J. (2007). Deoxynivalenol: Toxicity, mechanisms and animal health risks. Animal Feed Science and Technology, 137(3–4), 283–298. https://doi.org/10.1016/j.anifeedsci.2007.06.006

Pestka, J. J. (2010). Deoxynivalenol: Mechanisms of action, human exposure, and toxicological relevance. Archives of Toxicology, 84(9), 663–679. https://doi.org/10.1007/s00204-010-0579-8

Popp, J., Pető, K. and Nagy, J. (2013). Pesticide productivity and food security. A review. Agronomy for Sustainable Development, 33(1), 243–255. https://doi.org/10.1007/s13593-012-0105-x

Puel, O., Galtier, P. and Oswald, I. P. (2010). Biosynthesis and toxicological effects of patulin. Toxins, 2(4), 613–631. https://doi.org/10.3390/toxins2040613

Rawal, S., Kim, J. E. and Coulombe, R. (2010). Aflatoxin B1 in poultry: Toxicology, metabolism and prevention. Research in Veterinary Science, 89(3), 325–331. https://doi.org/10.1016/j.rvsc.2010.04.011

Richard, J. L. (2007). Some major mycotoxins and their mycotoxicoses—An overview. International Journal of Food Microbiology, 119(1–2), 3–10. https://doi.org/10.1016/j.ijfoodmicro.2007.07.019

Ringot, D., Chango, A., Schneider, Y. J. and Larondelle, Y. (2006). Toxicokinetics and toxicodynamics of ochratoxin A, an update. Chemico-Biological Interactions, 159 (1), 18–46. https://doi.org/10.1016/j.cbi.2005.10.106

Rosa, C. A., Miazzo, R., Magnoli, C., Salvano, M., Chiacchiera, S. M., Ferrero, S. and Dalcero, A. (2001). Evaluation of the efficacy of bentonite from the south of Argentina to ameliorate the toxic effects of aflatoxin in broilers. Poultry Science, 80(2), 139–144. https://doi.org/10.1093/ps/80.2.139

Sargeant, K., Sheridan, A., O'Kelly, J. and Carnaghan, R. B. A. (1961). Toxicity associated with certain samples of groundnuts. Nature, 192(4807), 1096–1097. https://doi.org/10.1038/1921096a0

Shetty, P. H. and Jespersen, L. (2006). Saccharomyces cerevisiae and lactic acid bacteria as potential mycotoxin decontaminating agents. Trends in Food Science & Technology, 17(2), 48–55. https://doi.org/10.1016/j.tifs.2005.10.004

Siller, W. G. (1985). Aflatoxicosis in poultry. Avian Pathology, 14(2), 157–168. https://doi.org/10.1080/03079458508436218

Smith, M. C., Madec, S., Coton, E., & Hymery, N. (2016). Fumonisin B1 contamination in corn. Journal of Agricultural and Food Chemistry, 64(35), 6546–6553. https://doi.org/10.1021/acs.jafc.6b02345

Squires, E. J. and Fisher, H. (1986). Aflatoxin B1-induced ascites in chickens. Avian Diseases, 30(4), 739–743. https://doi.org/10.2307/1590582

Stockmann-Juvala, H. and Savolainen, K. (2008). A review of the toxic effects and mechanisms of action of fumonisin B1. Human & Experimental Toxicology, 27(11), 799–809. https://doi.org/10.1177/0960327108099525

Stoev, S. D. (2010). Studies on carcinogenic and toxic effects of ochratoxin A in chicks. Toxins, 2(4), 649–664. https://doi.org/10.3390/toxins2040649

Stoev, S. D., Goundasheva, D., Mirtcheva, T. and Mantle, P. G. (2002). Experimental ochratoxicosis in chickens: Pathological and biochemical changes. Research in Veterinary Science, 72(3), 205–214. https://doi.org/10.1053/rvsc.2001.0543

Streit, E., Schatzmayr, G., Tassis, P., Tzika, E., Marin, D., Taranu, I. and Oswald, I. P. (2013). Current situation of mycotoxin contamination and co-occurrence in animal feed—Focus on Europe. Toxins, 5(12), 2485–2519. https://doi.org/10.3390/toxins5122485

Studt, L., Rösler, S. M., Humpf, H.-U. and Tudzynski, B. (2023). Biosynthesis and biological activities of chaetoviridins and other bis-anthraquinone pigments from Chaetomium species. Fungal Biology and Biotechnology, 10(1), 15. https://doi.org/10.1186/s40694-023-00163-0

Ueno, Y. (1985). The toxicology of mycotoxins. Critical Reviews in Toxicology, 14(2), 99–132. https://doi.org/10.3109/10408448509089851

Urano, T., Trucksess, M. W., Beaver, R. W., Wilson, D. M., Dorner, J. W. and Dowell, F. E. (1992). Co-occurrence of cyclopiazonic acid and aflatoxins in corn and peanuts. Journal of the American Oil Chemists' Society, 69(2), 162–165. https://doi.org/10.1007/BF02540568

van der Merwe, K. J., Steyn, P. S. and Fourie, L. (1965). The constitution of ochratoxins A, B, and C, metabolites of Aspergillus ochraceus Wilh. Journal of the Chemical Society, 7083–7088. https://doi.org/10.1039/JR9650007083

van Soest TC. and Peerdeman AF (1970). The crystal structures of aflatoxin B1. I. The structure of the chloroform solvate of aflatoxin B1 and the absolute configuration of aflatoxin B1. Acta Crystallographica Section B, 26(12), 1940–1947. https://doi.org/10.1107/S0567740870005228

Vanhoutte, I., Audenaert, K. and De Gelder, L. (2016). Biodegradation of mycotoxins: Tales from known and unexplored worlds. Frontiers in Microbiology, *7*, 561. https://doi.org/10.3389/fmicb.2016.00561

Varga, J., Kocsubé, S., Péteri, Z., Vágvölgyi, C. and Tóth, B. (2013). Chemical, physical and biological approaches to prevent ochratoxin induced toxicoses in humans and animals. Toxins, 5(12), 2433–2459. https://doi.org/10.3390/toxins5122433

Verma, J., Johri, T. S., Swain, B. K. and Ameena, S. (2004). Effect of graded levels of aflatoxin, ochratoxin and their combinations on the performance and immune response of broilers. *British Poultry Science*, *45*(4), 512–518. https://doi.org/10.1080/00071660400001144

Vila-Donat, P., Marín, S., Sanchis, V., & Ramos, A. J. (2018). A review of the mycotoxin adsorbing agents, with an emphasis on their multi-binding capacity, for animal feed decontamination. Food and Chemical Toxicology, 114, 246–259. https://doi.org/10.1016/j.fct.2018.02.036

Voss, K. A., Riley, R. T. and Waes, J. G. (2018). Fumonisin toxicity and sphingolipid biosynthesis. Chemical Research in Toxicology, 31(8), 661–669. https://doi.org/10.1021/acs.chemrestox.8b00047

Wang, J., Chen, X., Li, P. and Yang, W. (2023). Efficacy of different mycotoxin adsorbents in improving growth performance and health status of broilers exposed to contaminated feed. Poultry Science, 102(1), 102315. https://doi.org/10.1016/j.psj.2022.102115

Wang, X., Li, Y. and He, J. (2022). Inhibition of dopamine β-hydroxylase by fusaric acid. Neurotoxicology, 89, 23–31. https://doi.org/10.1016/j.neuro.2022.01.004

Wilson, B. J. and Hayes, A. W. (1973). Microbial toxins. Annual Review of Microbiology, 27(1), 465–496. https://doi.org/10.1146/annurev.mi.27.100173.002341

Wu, Q., Wang, X. and Yang, W. (2019). The impact of mycotoxins on skeletal health in poultry. World Mycotoxin Journal, 12(3), 245–254. https://doi.org/10.3920/WMJ2018.2395

Xu, H., Wang, L., Sun, J., Wang, L., Guo, H., Ye, Y. and Sun, X. (2021). Microbial detoxification of mycotoxins in food and feed. Critical Reviews in Food Science and Nutrition, 62(18), 4951–4969. https://doi.org/10.1080/10408398.2021.1879730

Yi, P. J., Pai, C. K. and Liu, J. R. (2011). Isolation and characterization of a Bacillus subtilis strain that degrades zearalenone. World Journal of Microbiology and Biotechnology, 27(5), 1035–1043. https://doi.org/10.1007/s11274-010-0549-6

Zhao, L., Feng, Y., Wei, J. and Zhang, J. (2023). Comparative effects of mechanical and biological mycotoxin deactivators on egg quality and laying hen performance. Journal of Applied Poultry Research, 32(1), 100112. https://doi.org/10.1016/j.japr.2022.100112

Zinedine, A., Soriano, J. M., Moltó, J. C. and Mañes, J. (2007). Review on the toxicity, occurrence, metabolism, detoxification, regulations and intake of zearalenone: An oestrogenic mycotoxin. Food and Chemical Toxicology, 45(1), 1–18. https://doi.org/10.1016/j.fct.2006.07.030

استراتيجيات وقائية وبيولوجية للحد من تلوث الميكوتوكسينات في اعلاف الدواجن: بحث مقالة

أحمد محمد ثابت قاسم النعيمي ، انوار محمد يونس الحامد، خالد هادي مصطفى

قسم الإنتاج الحيواني - كلية الزراعة والغابات - جامعة الموصل/ العراق

الخلاصة

من خلال الدراسات يتضح لنا أمور كثيرة في سبل مقاومة السموم الفطرية ومعالجة آثارها، كما يتضح لنا دور الأعلاف المكبوسة بل واستفحال أزمة السموم الفطرية بالإضافة إلى الآثار المدمرة على الكبد والكليتين. وان الحلول المقترحة تكمن في أمر من اثنين ، اولهما اذا كان لابد من الاعتماد على الأعلاف المكبوسة، فلابد من استيراد خامات عالية الجودة لا تحتاج للمعالجات السابقة (خامات خالية بطبيعتها من السموم الفطرية)، وهذا سيحل مشكلة السموم الفطرية ولكن لن نحل مشكلة الأكريلاميد. وثانيها إذا لم نستطع أن نستورد خامات عالية الجودة التي لا تحتاج للمعالجة السابقة (وهذا ما لا يمكن تحقيقه لأسباب اقتصادية)، فعلينا العودة الى استخدام الاعلاف المجروشة والتي يمكن ان يطبق عليها نظم المعالجة السابقة، على أن يراعى فيها الاحتياجات العلمية الدقيقة للنوع والسلالة والعمر والهدف الإنتاجي ودرجة الحرارة .

THE FUTURE Journals

© The Author(s). 2022 Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise