

DEMOCRATIC AND POPULARE REPUBLIC OF ALGERIA
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
MOHAMED BOUDIAF UNIVERSITY - M'SILA

FACULTY OF SCIENCE
DEPARTMENT OF MICROBIOLOGY
& BIOCHEMISTRY



FIELD: NATURAL AND LIFE SCIENCE
FIELD: FOOD SCIENCE
OPTION: NUTRITION AND FOOD
SCIENCE

N° :...../2024

**Thesis presented in partial fulfillment of the requirements
for the degree of academic master.**

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Title

**An In-Depth Analysis of Mycotoxin Research
and Publications in Algeria.**

Defended on 00/ 06/2024 in front of the jury composed of:

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Academic year: 2023/2024

Acknowledgements

First and foremost, we extend our deepest gratitude to Allah, who illuminates our paths and grants us the strength, will, and patience to complete this modest work.

This thesis represents the culmination of a long journey, and we owe thanks to several individuals who have supported us along the way:

Our heartfelt thanks go to our thesis advisor, **Dr. Yamina Ben Miri**, Professor at the University of Mohamed Boudiaf, M'sila. Her scientific expertise, human qualities, and meticulous proofreading have been invaluable in clarifying our objectives. We are profoundly grateful for her availability, hard work, and wise advice. Please accept this token of our deep respect and sincere thanks.

We are also deeply honored by the support of **Dr. Amine Belbahi**, Professor at the University of Mohamed Boudiaf, M'sila. We are sincerely grateful for his willingness to read our manuscript and for the honor of chairing the thesis jury. Please accept our heartfelt thanks for this significant contribution.

Our sincere gratitude extends to Dr. Mounira Ariech, Professor at the University of Mohamed Boudiaf, M'sila, for her interest in our work and her role as a judge. We deeply appreciate her thoughtful evaluation and respect her immensely.

Lastly, we thank all those who have accompanied and supported us throughout this endeavor. Your encouragement and assistance have been instrumental in the completion of this work.

Dedication

With profound gratitude and heartfelt words, we dedicate this modest work to our beloved parents, whose sacrifices and wise counsel have illuminated our path to success. We aspire to one day repay even a fraction of what they have done for us. May God bless them with happiness and long life.

Acknowledgements

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List of abbreviations

AF: Aflatoxin.

AFB1/G1: Aflatoxins B1+G1.

AFB1: Aflatoxin B1.

AFB2 : Aflatoxin B2.

AFG1: Aflatoxin G1.

AFG2: Aflatoxin G2.

AFM1: Aflatoxin M1.

AFT: Total aflatoxins.

ATA: Alimentary toxic aleukia.

BEA: Beauvericin.

BEN: Balkan Endemic Nephropathy.

CAC: Codex Alimentarius Commission.

DON: Deoxynivalenol.

EC: European Commission.

EFSA: European Food Safety Authority.

ELISA: Enzyme-Linked Immunosorbent Assay.

EN: Electronic nose.

ENNs: Enniatins.

EO: Essential Oil.

ERG: Ergot alkaloids.

EU: European Union.

FAO: Food and Agriculture Organization of the United Nations.

FCR: Fusarium Crown Rot.

FDA: Food and Drug Administration, United States of America.

FHB: *Fusarium* Head Blight.

FP: Fluorescence polarization

FUMB1: Fumonisin B1.

FUMB1/2: Fumonisin B1+B2.

FUMB1/2/3: Fumonisin B1+B2+B3.

HPLC: High-Performance Liquid Chromatography.

HPTLC: High-Performance Thin-Layer Chromatography.

HT-2: HT-2 toxin.

IAC: Immune-Affinity Columns.

List of abbreviations

IARC: International Agency for Research on Cancer .

LBSM: Laboratoire de Biologie des Systèmes Microbiens.

LC/MS/MS: Liquid Chromatography Coupled Mass Spectroscopy.

LEM: Leukoencephalomalacia.

MIC: Minimum Inhibitory Concentration.

OTA: Ochratoxin A.

PAT: Patulin.

PCR: Polymerase chain reaction.

Ppb: Parts Per Billion.

RISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

QPCR: Quantitative polymerase chain reaction.

QuEChERS: Quick, Easy, Cheap, Effective, Rugged, and Safe.

SPE: Solid-Phase Extraction.

STE: Sterigmatocystin.

T-2: T-2 toxin.

TCTC: Trichothecenes.

TLC: Thin-Layer Chromatography.

WHO: World Health Organization.

ZEN: Zearalenone.

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Abstract

This thesis reviewed mycotoxin research and publications in Algeria, offering insights into prevalent trends and future directions in the field. Despite limited resources, Algerian researchers have made significant progress in comprehending mycotoxin contamination and its effects on food safety and public health. The review focused on both the research accomplishments and the challenges faced in resource-constrained settings, along with the strategies used to overcome these challenges. Through analyzing existing literature, key themes emerged regarding mycotoxin identification, detection methods, mitigation strategies, and their implications. The significance of collaborative efforts between academia, industry, and government agencies is crucial in tackling mycotoxin-related challenges. Through this review, gaps in current research were identified, and recommendations for future investigation were proposed, providing a roadmap for advancing mycotoxin research in Algeria and beyond.

Key-words: mycotoxin, Algeria, publications, challenges, food safety, public health, collaborative efforts.

Résumé

Ce travail a passé en revue la recherche sur les mycotoxines et les publications en Algérie, offrant des perspectives sur les tendances prévalentes et les orientations futures dans le domaine. Malgré des ressources limitées, les chercheurs algériens ont réalisé des progrès significatifs dans la compréhension de la contamination par les mycotoxines et de ses effets sur la sécurité alimentaire et la santé publique. La revue s'est concentrée à la fois sur les réalisations de la recherche et les défis rencontrés dans des contextes où les ressources sont limitées, ainsi que sur les stratégies utilisées pour surmonter ces défis. En analysant la littérature existante, des thèmes clés sont apparus concernant l'identification des mycotoxines, les méthodes de détection, les stratégies d'atténuation et leurs implications. La pertinence des efforts de collaboration entre le milieu universitaire, l'industrie et les agences gouvernementales est cruciale pour relever les défis liés aux mycotoxines. À travers cette revue, des lacunes dans la recherche actuelle ont été identifiées, et des recommandations pour des investigations futures ont été proposées, offrant ainsi une feuille de route pour faire progresser la recherche sur les mycotoxines en Algérie et au-delà.

Mots-clés : mycotoxine, Algérie, publications, défis, sécurité alimentaire, santé publique, efforts collaboratifs.

ملخص:

قام هذا البحث بمراجعة البحوث والمنشورات حول السموم الفطرية في الجزائر، مقدماً رؤى حول الاتجاهات السائدة والاتجاهات المستقبلية في هذا المجال. على الرغم من القيود المحدودة للموارد، فقد قام الباحثون الجزائريون بتحقيق تقدم كبير في فهم التلوث بالسموم الفطرية وتأثيراته على سلامة الغذاء والصحة العامة. ركزت المراجعة على الإنجازات البحثية والتحديات التي تواجهها في إعدادات ذات موارد محدودة، بالإضافة إلى الاستراتيجيات المستخدمة للتغلب على هذه التحديات. من خلال تحليل الأدب الحالي، ظهرت مواضيع رئيسية تتعلق بتحديد السموم الفطرية وطرق الكشف عنها واستراتيجيات التخفيف وتداعياتها. يعد أهمية الجهود التعاونية بين الأكاديميين والصناعة والجهات الحكومية حاسمة في التصدي للتحديات المتعلقة بالسموم الفطرية. من خلال هذه المراجعة، تم التعرف على الفجوات في البحث الحالي، وتم اقتراح توصيات للتحقيقات المستقبلية، وتوفير خريطة طريق لتعزيز البحث حول السموم الفطرية في الجزائر وخارجها.

الكلمات الرئيسية: سموم فطرية، الجزائر، منشورات، تحديات، سلامة الغذاء، الصحة العامة، الجهود التعاونية

Introduction

In the intricate web of global food safety, mycotoxins emerge as potent challengers, stealthily infiltrating agricultural environments and food systems with persistent threat. These hazardous compounds, born from fungal metabolism, cast a looming shadow over every facet of the food supply chain, from cultivation to consumption. They not only imperil agricultural yields but also present significant risks to the health of consumers worldwide (**Ben Miri et al., 2024**).

Across diverse geographical regions and agricultural practices, mycotoxins exert a surreptitious influence, erecting substantial barriers to food safety. Whether in the temperate climes of Europe, the sprawling landscapes of North America, or the arid expanses of Africa, these imperceptible contaminants persist, menacing the quality and safety of food products (**Zebiri et al., 2020**).

Within this global context of mycotoxin contamination, Algeria emerges as a distinctive focal point, shaped by its diverse agricultural heritage, climatic variations, and cultural richness. From the verdant oases of the Sahara to the fertile valleys of the Tell Atlas Mountains, Algeria's varied terrain provides fertile ground for both agricultural abundance and mycotoxin proliferation. Moreover, the country's vibrant cultural tapestry, woven from Arab and Mediterranean traditions, adds layers of complexity to the intricate interplay between agricultural methods, food production, and mycotoxin exposure (**Badji et al., 2023; Ben Miri et al., 2023**).

Indeed, within the dynamic context of Algeria, the prevalence and distribution of mycotoxins are not solely determined by environmental factors but are deeply intertwined with socio-economic dynamics, agricultural policies, and cultural practices (**Belasli et al., 2023**). These multifaceted influences converge to shape the landscape of research and scholarly inquiry dedicated to understanding and mitigating the impact of mycotoxins within the country. Academic institutions and among other stakeholders, are actively engaged in unraveling the mysteries of mycotoxin contamination and developing strategies to safeguard public health and food security.

A thorough investigation into mycotoxin research and publications in Algeria is of great importance, as it reveals the specific challenges and opportunities in addressing these

contaminants. Through an in-depth analysis of scholarly discussions, one can uncover patterns, evaluate methodologies, and pinpoint areas needing further research to strengthen the resilience of Algerian food systems and public health.

This work conducts a comprehensive investigation into mycotoxin research and publications within Algeria, with the goal of shedding light on the current knowledge landscape regarding mycotoxin contamination in Algerian food systems. It involves a detailed examination of existing literature to identify prevalent trends, evaluate methodologies, and identify areas where understanding is lacking. Through synthesizing this information, it reveals pathways for targeted intervention and innovation, providing concrete strategies for addressing the complex dynamics underlying mycotoxin contamination in Algerian food systems.

The ultimate aim of this research is to advance food safety and public health, not only within Algeria but also on a broader scale. By leveraging the insights generated from this comprehensive review, stakeholders can collaboratively work towards mitigating mycotoxin risks, safeguarding consumer well-being, and fostering resilient food systems that benefit Algerian communities and beyond.

The review covers several objectives, including examining research advancements and identifying obstacles and resource constraints. It aims to assess progress made in mycotoxin research within Algeria, elucidating key findings, methodologies employed, and emerging trends. Despite the growing recognition of mycotoxin contamination as a pressing concern, researchers often encounter various obstacles and resource constraints that hinder their efforts. Through an in-depth analysis, this review aims to identify challenges such as limited funding, infrastructure deficiencies, and regulatory gaps in Algeria, thereby paving the way for targeted interventions and capacity-building initiatives.

Bibliographic Synthesis

I. Research methodology

The methodological approach employed to conduct the study, including literature review, search strategy, inclusion criteria, data collection methods, and analysis processes (**Figure 1**).

I.1. Literature review

- A structured approach inspired by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines was employed to ensure a systematic exploration and transparent reporting of mycotoxin research and publications specifically related to Algeria.

I.2. Search strategy

- Relevant keywords such as mycotoxin, Algeria, food safety, agricultural practices, mitigation, detection, health implications, and regulatory measures were carefully selected.
- An extensive search was conducted using academic databases like PubMed, Scopus, and Web of Science to ensure comprehensive coverage.
- Only articles available in English or French were considered to cover a wider range of publications relevant to the Algerian context.

I.3. Inclusion criteria

- Articles available in English were prioritized to ensure relevance to the Algerian context.
- Non-peer-reviewed sources such as government reports, dissertations, and conference abstracts were also included if they provided valuable insights into mycotoxin research in Algeria.

I.4. Data collection

- After screening the search results, relevant information was systematically extracted from the selected articles, covering a comprehensive range of variables such as:
 - Mycotoxin occurrence, prevalence, and levels in different Algerian agricultural products.
 - Research methodologies employed in mycotoxin analysis, including sampling techniques, analytical methods, and validation procedures.
 - Health implications of mycotoxin contamination in Algerian populations, including epidemiological data and clinical outcomes.

- Regulatory frameworks governing mycotoxin levels in Algeria, including legal standards, monitoring programs, and enforcement mechanisms.
- Publication characteristics such as publication year, journal of publication, author affiliations, and citation metrics.
- Collaboration patterns among Algerian researchers and with international collaborators, including co-authorship networks and joint publications.
- Funding sources for mycotoxin research in Algeria, including governmental, institutional, and external funding agencies.

I.5. Analysis process

- The selected articles underwent thorough analysis to identify prevalent mycotoxins, research methodologies, Geographic distribution of studies, collaboration patterns, and emerging trends within the Algerian context.
- Findings were synthesized to provide insights into the current state of mycotoxin research in Algeria and potential avenues for future investigation.

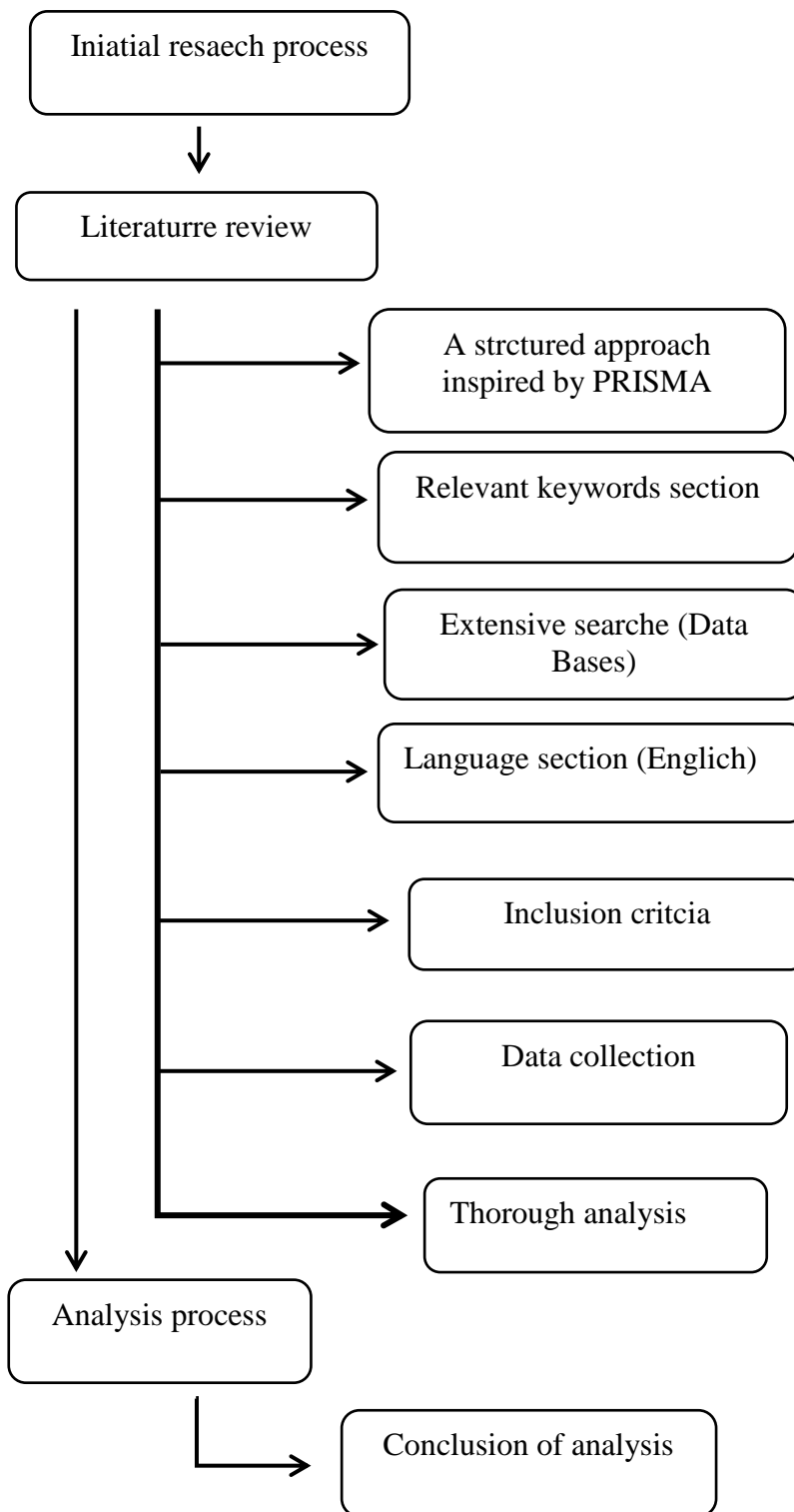


Figure 1. Comprehensive research methodology.

II. Occurrence and toxicity of major mycotoxins

Mycotoxins, naturally produced by *fungi* species, can elicit toxic reactions when contaminated food is ingested by animals or humans. These substances have garnered global attention owing to their significant economic implications, stemming from their adverse effects on human health, animal productivity, and international food trade (**González-Curbelo & Kabak, 2023; Mukhtar *et al.*, 2023**). Mycotoxins constitute a diverse group of approximately 400 fungal toxins, characterized by their non-proteinaceous nature, low molecular weight (<1000 Daltons), and limited volatility. Primarily localized within the mycelium and spores of *fungi species*, their widespread presence in the environment raises substantial concerns for food safety (**Nguyen *et al.*, 2017**). The Figure 2 depicts The structures of the most common mycotoxins.

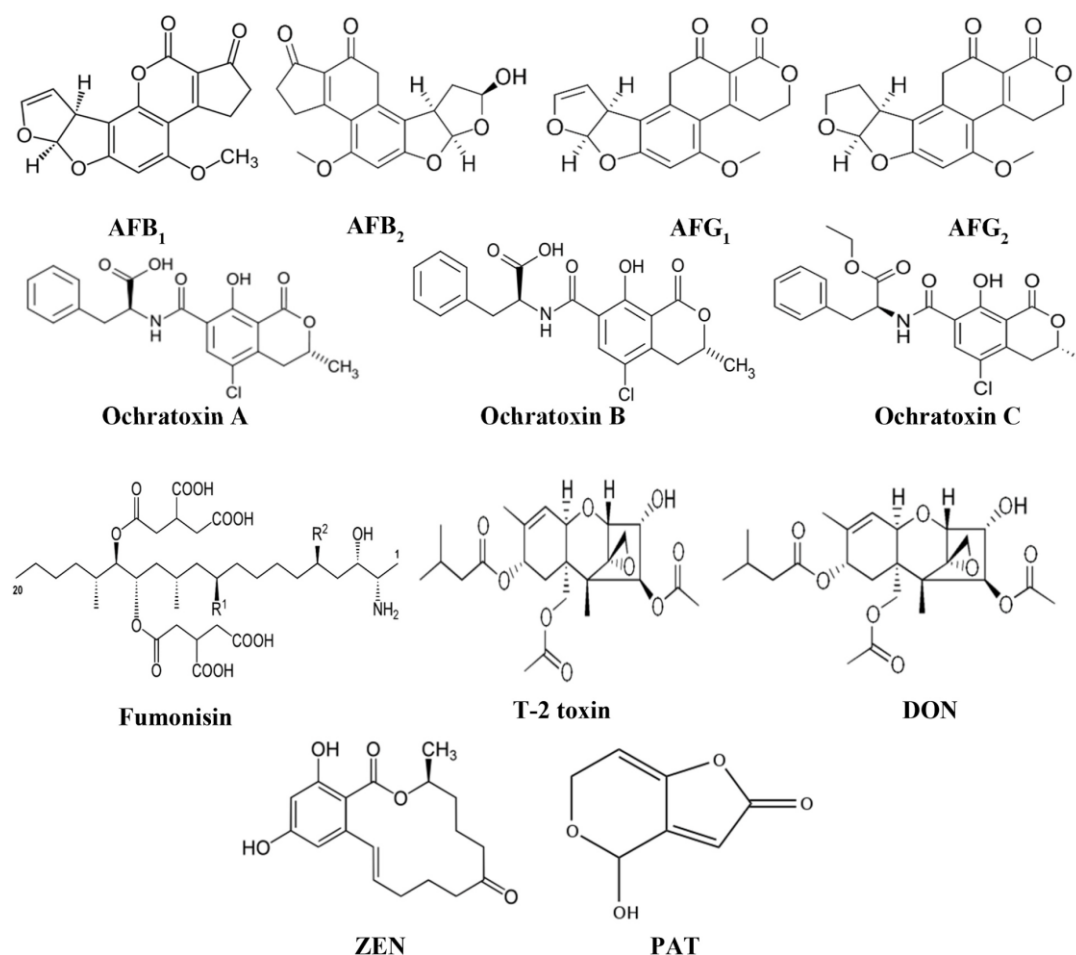


Figure 2. The structures of the most common mycotoxins (**Ndiaye *et al.*, 2022**).

The presence and harmful effects of major mycotoxins can occur either before or after harvesting, during various stages of food production and storage, including processing,

packaging, distribution, and storage (**Pereira *et al.*, 2014; Bhatnagar *et al.*, 2006**). Inadequate storage conditions, characterized by high temperatures and humidity, can lead to mold growth and subsequent mycotoxin contamination in a wide range of crops and cereals (**Bottalico & Perrone, 2002**). Among these, maize is particularly vulnerable to mycotoxin contamination, while rice tends to be less affected.

Most mycotoxins remain chemically and thermally stable throughout food processing methods such as cooking, boiling, baking, frying, roasting, and pasteurization. Additionally, mycotoxins can find their way into human consumption through animal products like meat, eggs, and milk if the animals consume contaminated feed (**Sobrova *et al.*, 2010; Kaushik, 2015**).

Numerous national and international health and regulatory authorities, including the US Food and Drug Administration (FDA), the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the European Food Safety Authority (EFSA), are actively addressing the global issue of mycotoxin contamination in both food and feed through stringent regulatory measures.

The guidelines for major mycotoxin categories in both food and feed have been established (**Yazar & Omurtag, 2008**). Presently, approximately 100 countries have set thresholds for the allowable presence of major mycotoxins in food and feed (**Moretti *et al.*, 2017**). Table 1 outlines the key toxins, primary producers, and frequently contaminated food items, along with the regulatory limits imposed by the US FDA and EU for mycotoxin levels in both food and animal feed.

Table 1. Major mycotoxins and US and EU limits on food and animal feed levels.

Mycotoxin	Fungal Species	Food Commodity	US FDA (µg/kg)	EU (EC 2006) (µg/kg)
Aflatoxins B1, B2, G1, G2	<i>Aspergillus flavus</i> , <i>A. parasiticus</i>	Maize, wheat, rice, peanut, sorghum, pistachio, almond, ground nuts, tree nuts, figs, cottonseed, spices	20 for total,	2–12 for B1, 4–15 for total
Aflatoxin M1	Metabolite aflatoxin B1	of Milk, milk products	0.5	0.05 in milk, 0.025 in infant formulae and infant milk
Ochratoxin A	<i>A.ochraceus</i> , <i>Penicillium verrucosum</i> , <i>A.carbonarius</i>	Cereals, dried vine fruit, wine, grapes, coffee, cocoa, cheese	Not set	2–10
Fumonisin B1, B2, B3	<i>Fusarium verticillioides</i> , <i>proliferatum</i>	Maize, maize products, sorghum, asparagus	2000–4000	200–1000
Zearalenone	<i>F.graminearum</i> , <i>F.culmorum</i>	Cereals, cereal products, maize, wheat, barley	Not set	20–100
Deoxynivalenol	<i>F. graminearum</i> , <i>F. culmorum</i>	Cereals, cereal products	1000	200–50
Patulin	<i>P. expansum</i>	Apples, apple juice, and concentrate	50	10–50

II.1. Aflatoxin

Aflatoxins constitute a group of closely related toxic secondary metabolites primarily produced by *A. flavus* and *A. parasiticus* fungi, which are typically found in soil and various organic substrates (Marin *et al.*, 2013; Wilson *et al.*, 2002). While *A. flavus* strains synthesize aflatoxins B1 (AFB1) and B2 (AFB2), *A. parasiticus* strains are capable of producing AFB1, AFB2, G1 (AFG1), and G2 (AFG2) (Bennett & Klich, 2003). These toxins gained significant attention following their identification as the causative agents of Turkey X disease, which resulted in the deaths of 100,000 young turkeys in Great Britain in 1960, marking the beginning of extensive research on aflatoxins (Richard, 2007).

The initial human outbreak of aflatoxicosis, reported in India, resulted in the deaths of 100 individuals (Krishnamachari *et al.*, 1975). Aflatoxin-producing fungi can contaminate a

wide array of food items such as cereals (maize, rice, barley, oats, and sorghum), peanuts, groundnuts, pistachio nuts, almonds, walnuts, and cottonseeds (**Boevre *et al.*, 2012; Tanaka *et al.*, 1988**). Additionally, aflatoxin M1 (AFM1), a primary hydroxylated metabolite of AFB1, can contaminate milk when cows ingest feed contaminated with AFB1, as it is biotransformed in their livers by microsomal cytochrome P450 enzymes (**Prandini *et al.*, 2009; Govaris *et al.*, 2001**). AFM1 can be detected in milk within 12–24 hours after cows consume AFB1-contaminated feed, and its concentration correlates with the levels of AFB1 in the consumed feed materials (**Prandini *et al.*, 2009**). AFM1 may also be present in certain dairy products like cheese at concentrations higher than those found in raw milk due to its heat stability, strong binding to casein, and resistance to the cheese-making process (**Prandini *et al.*, 2009; Barbiroli *et al.*, 2007**).

Aflatoxins exhibit carcinogenic, teratogenic, hepatotoxic, mutagenic, and immunosuppressive properties, with the liver being the primary target organ (**Hussein & Brasel, 2001**). They are linked to both acute toxicity and chronic carcinogenicity in both human and animal populations (**Hussein & Brasel, 2001**). AFB1 is classified by the International Agency for Research on Cancer (IARC) as a Group 1 carcinogen, posing a high risk for hepatocellular carcinoma (HCC) in individuals exposed to aflatoxins, whereas AFM1 is categorized as Group 2B (possibly carcinogenic to humans) (**Ostry *et al.*, 2017**). Although acute toxicosis is typically rare in developed countries, it remains prevalent in certain regions.

In developing countries, notably in Africa, acute aflatoxicosis is a significant concern, whereas chronic carcinogenicity poses a global issue (**Stoev, 2013**). The LD50 values vary between 0.5–10 mg/kg body weight across different animal species (**Pitt, 2000**). In humans, acute aflatoxicosis manifests as symptoms such as vomiting, abdominal pain, pulmonary and cerebral edema, coma, convulsions, and in severe cases, death (**Mwanda *et al.*, 2005**). Animals affected by aflatoxin poisoning exhibit symptoms like gastrointestinal disturbances, reduced reproductive capability, diminished feed conversion efficiency, decreased milk and egg production, and anemia (**Pier, 1992**). The adverse effects of AFB1 primarily stem from the binding of bio activated AFB1-8,9-epoxide to cellular macromolecules, particularly mitochondrial and nuclear nucleic acids and nucleoproteins, leading to general cytotoxic effects (**Yazar & Omurtag, 2008**).

Due to the substantial concerns surrounding aflatoxin contamination in both food and feed and its detrimental impacts on public health and economics, the FDA has closely regulated

aflatoxins since 1969. Among all mycotoxins, aflatoxins are the sole ones subject to established FDA action levels, while others are only subject to advisory levels.

II.2. Ochratoxins

Discovered in 1965 in South Africa, ochratoxins comprise a group of closely related compounds synthesized by *A. ochraceus*, *P. verrucosum*, and various other *Penicillium* species (Pitt & Miller, 2016). The primary toxin within this group is ochratoxin A (Pitt & Miller, 2016). Typically, *P. verrucosum* produces OTA in cool-temperate climates, whereas *A. ochraceus* thrives in hot-tropical regions (Magnoli *et al.*, 2007). Ochratoxins have been detected in a diverse range of agricultural products including corn, wheat, barley, flour, coffee, rice, oats, rye, beans, peas, and mixed animal feeds (Magnoli *et al.*, 2007). They are particularly prevalent in wine, grape juice, and dried vine fruits (Scudamore, 2005). Ochratoxins can also contaminate animal-derived products such as meat and milk, and they have been found in human breast milk (Magnoli *et al.*, 2007). Among the various sources of OTA exposure, coffee and wine are recognized as significant contributors to OTA intake (Stoev & Paskalev, 2002).

Notably, OTA exhibits high stability in acidic environments and can withstand high-temperature processing. Consequently, OTA can persist in cereal products, beer, and roasted coffee, proving challenging to eliminate from food through conventional cooking methods (Scudamore, 2005; Duarte *et al.*, 2010). OTA is categorized by the International Agency for Research on Cancer (IARC) as Group 2B, indicating it is a potential human carcinogen, and there have been suspicions of its involvement in Balkan Endemic Nephropathy (BEN), a chronic tubulointerstitial disease affecting populations in southeastern Europe (Ostry *et al.*, 2017). OTA demonstrates acute nephrotoxic and hepatotoxic effects, with oral LD50 values ranging from 3 to 20 mg/kg across different animal species (Stoev & Paskalev, 2002). Additionally, OTA is known to induce immunotoxicity, genotoxicity, neurotoxicity, teratogenicity, and embryotoxicity in both humans and animals (Heussner & Bingle, 2015). It adversely affects the productivity of livestock by reducing feed conversion efficiency, inhibiting body weight gain, and potentially decreasing egg production in poultry (Scudamore, 2005). Being fat-soluble, OTA tends to accumulate in animal tissues, particularly in pigs (Magnoli *et al.*, 2007). Due to its structural similarity to the essential amino acid phenylalanine, OTA interferes with phenylalanine hydroxylase activity in the kidney and liver, thereby hindering proper protein synthesis. Furthermore, OTA inhibits RNA and DNA synthesis (Magnoli *et al.*, 2007). As of now, the US FDA has not established any regulatory guidelines for OTA. However, the EU has set limits for

OTA in various food items, typically ranging from 5 to 50 parts per billion (ppb) according to Regulations (EC) No. 1881/2006 (**Stroka & Maragos, 2016**).

II.3. Zearalenone

Zearalenone is a macrocyclic resorcylic acid lactone produced primarily by *Fusarium* species, notably *F. graminearum* and *F. semitectum* (**Yazar & Omurtag, 2008; Rheeder et al., 2002**). Due to its structural resemblance to naturally occurring estrogens, ZEA is more accurately described as an estrogenic mycotoxin, eliciting evident estrogenic effects in both humans and animals (**Bennett & Klich, 2003; Kowalska et al., 2016**). ZEA is commonly detected in corn, wheat, barley, sorghum, and rye. In the United States and Canada, corn and wheat are more frequently contaminated with ZEA, while in European countries, wheat, rye, and oats are the primary sources of ZEA contamination (**Lee & Ryu, 2017; Bennett & Klich, 2003**). Conditions of high humidity and low temperature favor the production of ZEA. ZEA contamination often occurs concurrently with deoxynivalenol (DON) and less frequently with aflatoxins (**Reddy et al., 2010**). ZEA exhibits stability under typical cooking temperatures but is partially eliminated when subjected to high temperatures (**Kowalska et al., 2016**).

Zearalenone (ZEA) is categorized as a Group 3 carcinogen by the International Agency for Research on Cancer (IARC) (**Ostry et al., 2017; Moake et al., 2005**). Public health concerns regarding ZEA primarily stem from its potent estrogenic activity. ZEA competitively binds to estrogen receptors (ER α and ER β) in various *in vitro* and *in vivo* models across different animal species, leading to alterations and lesions in the female reproductive system (**Kowalska et al., 2016**). ZEA and its derivatives displace estradiol from its uterine binding protein, triggering estrogenic responses. ZEA induces significant changes in the reproductive tract of laboratory and domestic animals, including infertility, uterine and vulval swelling, increased embryolethal resorptions, and ovarian atrophy observed in mice, rats, guinea pigs, and rabbits (**Bennett & Klich, 2003**). In cattle, consumption of feed contaminated with high levels of ZEA may directly contribute to infertility, reduced milk production, and hyperestrogenism. Currently, there are no advisory levels for ZEA established by the US FDA. However, the European committee has regulated maximum ZEA levels ranging between 20–100 ppb in various food commodities (**Kaushik, 2015**).

II.4. Fumonisin

Fumonisin are hydrophilic mycotoxins, differing structurally from most others that are soluble in organic solvents. Initially isolated from corn associated with an outbreak of leukoencephalomalacia (LEM) in equines in South Africa in 1970, fumonisin also led to pulmonary edema in pigs when contaminated corn was consumed (**Bennett and Klich, 2003**). They are primarily produced by *Fusarium verticillioides*, with some contribution from *F. proliferatum*. Currently, more than 28 fumonisin have been isolated and categorized into four groups (A, B, C, and P) (**Yazar and Omurtag, 2008**). Fumonisin B1 (FB1) is the most prevalent, constituting 70–80% of the total fumonisin family, commonly contaminating maize kernels. Besides maize, fumonisin can also be found in sorghum, wheat, barley, soybean, asparagus, figs, black tea, and medicinal plants. In the US, *F. verticillioides* contaminates around 80% of harvested corn (**Bennett and Klich, 2003**). In China, FB1, FB2, and FB3 were detected in 98.1% of corn product samples collected from Shandong.

Structurally resembling sphinganine, FB1 exerts its toxic effects by disrupting sphingolipid metabolism. Fumonisin primarily target the liver and kidneys, causing severe toxicity in experimental animals. Due to their hydrophilicity, fumonisin do not carry over into cattle milk, and only minimal FB1 accumulates in edible tissues (**Hussein and Brasel, 2001**). The World Health Organization (WHO) has set the provisional maximum tolerable daily intake at 2 µg/kg body weight (**Ostry et al., 2017**). The FDA has recommended maximum levels of 2–4 ppm for fumonisin in human foods like corn and processed corn-based products, and 5–100 ppm in various animal feeds, which it believes can be achieved through good agricultural and manufacturing practices. In 2007, the EU updated legislation on maximum fumonisin levels in maize and maize-based products to 4 ppm in unprocessed maize and 1 ppm in maize intended for direct human consumption (**Ostry et al., 2017**).

II.5. Trichothecenes

Trichothecenes (TCTC) were identified as the cause of alimentary toxic aleukia (ATA) toxicosis in the USSR in 1932. Although over 150 TCTC variants have been identified to date, only a few are agriculturally significant. Among TCTC, deoxynivalenol (DON) is the most prevalent and extensively studied, despite being among the least toxic. TCTC are primarily produced by *Fusarium* species fungi, with additional capability observed in *Acremonium* (*Cephalosporium*), *Cylindrocarpon*, *Dendrodochium*, *Myrothecium*, *Trichoderma*,

Trichothecium, and *Stachybotrys* species. *Fusarium* species typically infect and produce TCTC in crop plants in the field (**Bottalico & Perrone, 2002**). Economically, the most significant TCTC producers are *F. graminearum* and *F. culmorum*, responsible for *Fusarium* Head Blight (FHB), a detrimental disease affecting cereal grain crops globally (**Bottalico & Perrone, 2002**). TCTC predominantly contaminate cereals such as wheat, barley, oats, rye, maize, and rice. They may also be present in soybeans, potatoes, sunflower seeds, peanuts, bananas, and certain processed foods derived from cereals like bread, breakfast cereals, noodles, and beer (**Bennett & Klich, 2003**).

II.6. Patulin

Patulin is a polyketide mycotoxin discovered in 1943, primarily produced by certain species of *Penicillium*, *Aspergillus*, and *Byssoschlamys*, with *P. expansum* being the primary producer (**Drusch & Ragab, 2003**). While it is commonly found in apples, apple juice, and apple products, other fruits like pears, peaches, and grapes may also be susceptible to patulin contamination (**Abnet, 2007; Van Emon, 2010**). Initially investigated as a potential antibiotic, subsequent research revealed human toxicities including nausea, vomiting, ulceration, and hemorrhage (**Yang et al., 2014**). In rodents, the oral LD50 of patulin ranges from 29–55 mg/kg body weight. Despite the International Agency for Research on Cancer (IARC) expressing concerns about its potential carcinogenicity, patulin is classified in carcinogenicity Group 3 (**Moake et al., 2005**). The US FDA sets an action level of 50 ppb for patulin in food for human consumption. The EU committee established maximum levels of 50 ppb for fruit juices and concentrated fruit juices, 25 ppb for solid apple products, and 10 ppb for juices and foods consumed by babies and infants.

II.7. Mycotoxin analytical methods

Given the complex composition of food and the typically minute presence of mycotoxins, some form of sample processing is usually necessary before testing food samples. Sample preparation is a critical and demanding phase in the entire analytical procedure, and the approach can vary depending on the specific food matrix (**Figure 3**).

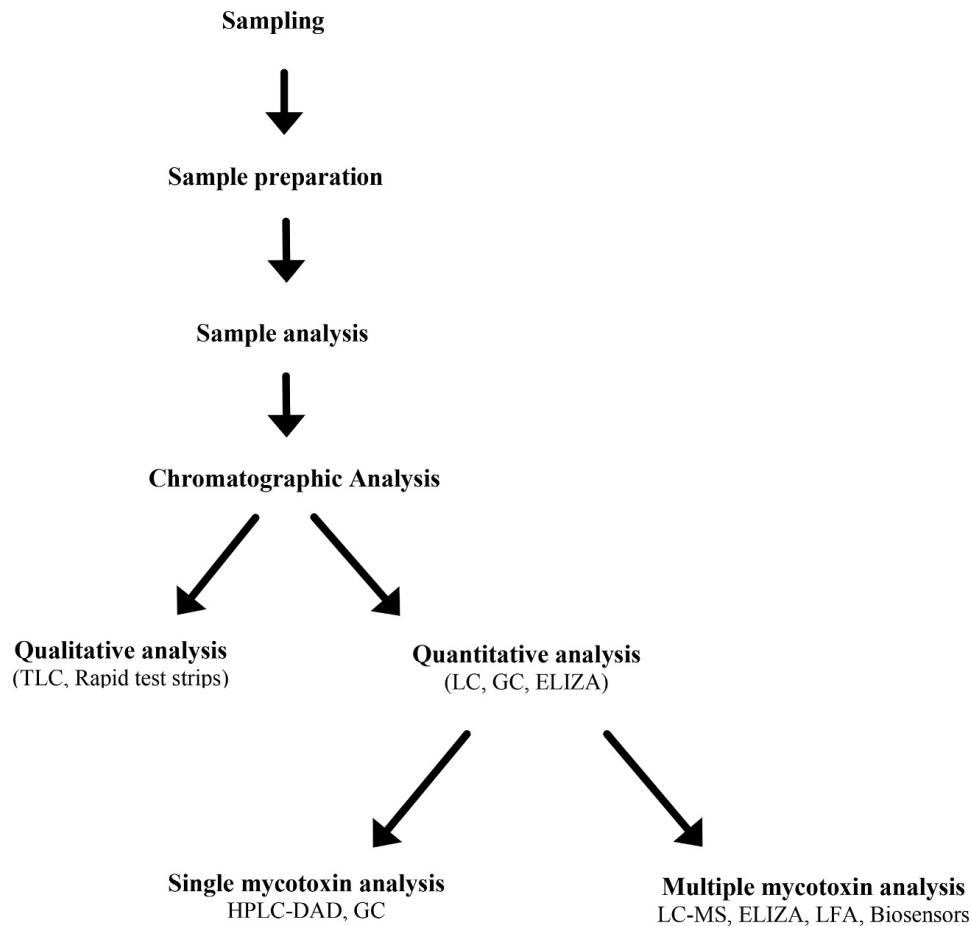


Figure 3. Flowchart of common steps involved in mycotoxins analysis.

Sampling strategies are pivotal when analyzing mycotoxins in food, including mycotoxins, as they significantly influence the reliability of results and determine whether a food batch meets safety standards. Carefully designed sampling plans are essential to ensure representativeness and accuracy (Ridgway, 2012; Shephard, 2016).

Sample preparation for mycotoxin analysis in food involves isolating mycotoxins from the food matrix to enhance detection sensitivity and specificity (Krska & Schubert-Ullrich, 2008; Shephard, 2008). This process is influenced by the chemical properties of the mycotoxin, the nature of the food matrix, and the chosen detection method (Ridgway, 2012). Mycotoxins, including mycotoxins, are typically extracted using organic solvents such as methanol, acetonitrile, or acetone, sometimes with water or an acidic buffer to improve efficiency (Turner, 2009).

Cleaning up the extract is crucial to enhance specificity and sensitivity, thereby improving accuracy and precision (**Rahmani et al., 2009**). Cleanup methods include liquid-liquid partitioning, solid-phase extraction (SPE), immune-affinity columns (IAC), among others. SPE involves the specific partitioning of the analyte between a solid adsorbent and an organic solvent, while IAC utilizes antibodies to selectively bind mycotoxins (**Hu et al., 2016**). The QuEChERS method (Quick, Easy, Cheap, Effective, Rugged, and Safe) simplifies extraction and cleanup using acetonitrile, salts, and dispersive-SPE, offering a fast and cost-effective option with minimal solvent usage (**Koesukwiwat et al., 2014**).

Various food products such as cereals, coffee, chocolate, wine, beer, and dried fruits can be tested for the presence of mycotoxins using different methods:

II.7.1. Chromatographic methods

- *Thin-layer chromatography (TLC)*: A rapid screening method for mycotoxins where a thin layer of a stationary phase is used to separate mycotoxins based on their properties (**Teixeira et al., 2011**).
- *High-Performance Liquid Chromatography (HPLC)*: Employed in unique ways in different studies, often preceded by immunoaffinity column purification to remove impurities, ensuring accurate mycotoxin analysis (**Heperkan et al., 2023**).
- *High-Performance Thin-Layer Chromatography (HPTLC)*: An advanced analytical technology derived from TLC, known for its accuracy and efficiency (**Heperkan et al., 2023**).
- *Liquid Chromatography Coupled Mass Spectroscopy (LC/MS/MS)*: Highly sensitive and accurate for mycotoxin analysis, including mycotoxins detection in various food and feed samples (**Meerpoel et al., 2018**).
- *PCR (polymerase chain reaction) and Quantitative Real-Time PCR (qPCR)*: Quantitatively measure DNA or RNA in a sample, primarily focusing on detecting the initial amount of DNA. These methods can employ various fluorescent compounds for detection and may detect mycotoxins earlier by monitoring gene expression associated with mycotoxin production (**Moh et al., 2017; Rahman et al., 2020**).

II.7.2. Immunochemical methods

- *Enzyme-Linked Immunosorbent Assay (ELISA)*: Widely used for mycotoxins detection, with new, highly sensitive mycotoxins ELISA formats developed using monoclonal antibodies (**Zhang *et al.*, 2019**).
- *Immunosensors*: Effective tools for sensitive mycotoxins detection, including electrochemical and optical types (**Mazaafrianto *et al.*, 2018**).
- *Nanoparticles in detection assays*: Utilized in various diagnostic assays, coupled with molecular recognition components to amplify detection signals and improve the precision and sensitivity of mycotoxin detection (**Clemons *et al.*, 2019**).

II.7.3. Other detection methods

- *Infrared spectroscopy*: Uses infrared light to detect mycotoxins without sample preparation, although it faces challenges with heterogeneous food matrices (**Pettersson & Aberg, 2003**).
- *Fluorescence polarization (FP)*: Measures the rate of rotation of a fluorophore and is used for detecting low molecular weight materials like mycotoxins in solution (**Wendy & Anton, 2011**).
- *Electronic nose (EN)*: Mimics the human olfactory system and detects volatile compounds, although it is still in development for mycotoxins analysis and faces challenges with non-volatile mycotoxins (**Keshri & Magan, 2000**).

II.8. Preventive and control strategies for mycotoxins

Preventing and managing mycotoxin contamination involves both pre-harvest and post-harvest actions (**Figure 4**). Before harvesting, farmers implement preventative measures such as timely harvesting to prevent over-ripening and avoiding harvest during high moisture periods to reduce fungal growth risk. Additionally, crops with high moisture content are dried before storage to inhibit fungal proliferation and mycotoxin production. Modern agricultural practices prioritize quality and safety, employing advanced technologies like filtration, air sterilization, and disinfection to maintain sterile conditions during food production, minimizing fungal presence and mycotoxin contamination (**Zhang *et al.*, 2019**).

Challenges in managing fungal contamination include preventing seed and fruit superinfection from soil and contaminated equipment, which can facilitate fungal penetration and mycotoxin production (**Kumar *et al.*, 2017**). Effective strategies entail preventing fungal spore germination and hyphae development through optimal storage conditions, sanitation practices, and judicious fungicide use when needed (**Awuchi *et al.*, 2021**).

In cases where mycotoxins are already present, controlling their adverse effects on human health becomes imperative. Decontamination methods such as physical, chemical, or biological approaches can be utilized during food processing, although they may not entirely eliminate mycotoxins (**Ostry *et al.*, 2013**; **Marc, 2022**).

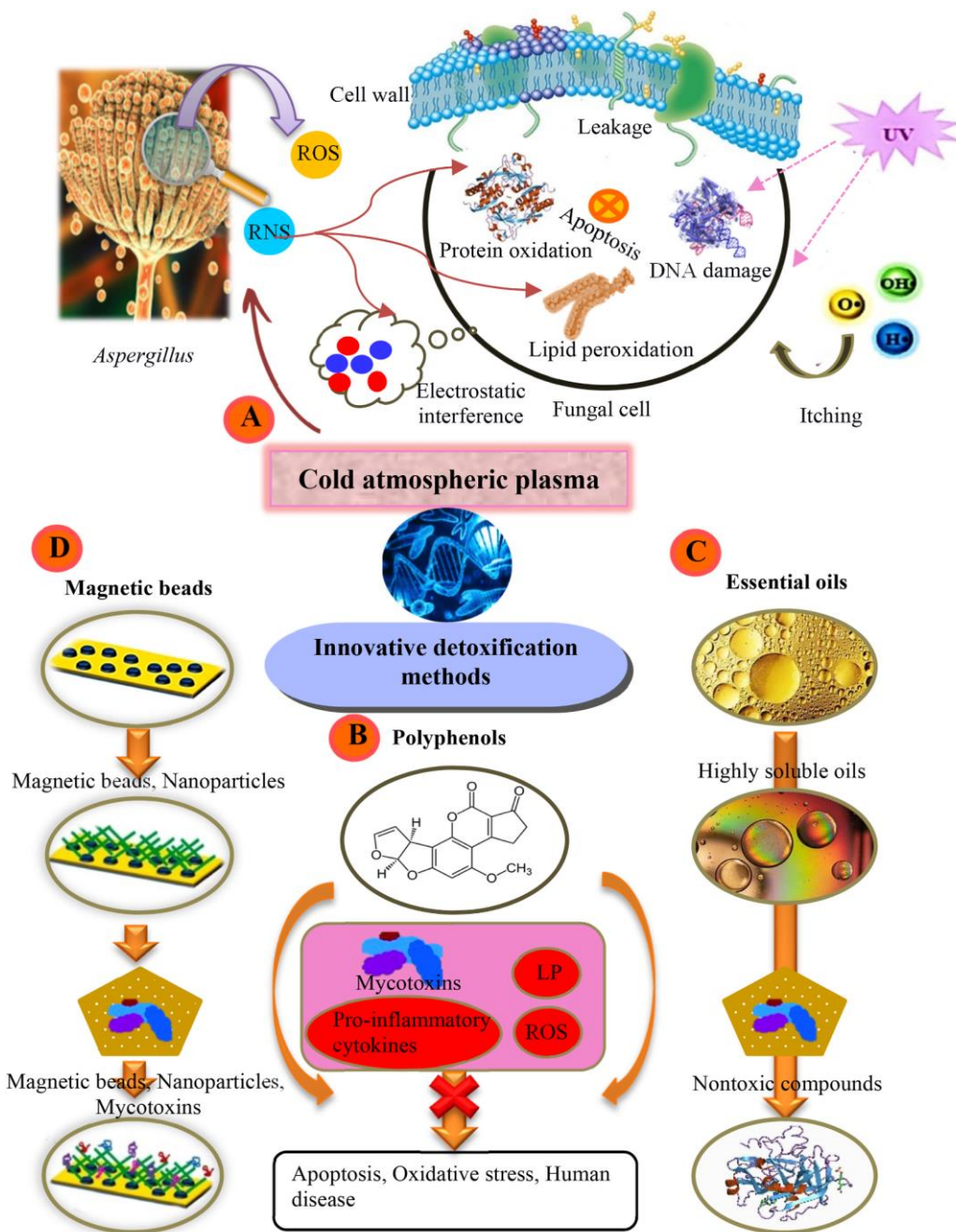


Figure 4. Methods for controlling mycotoxin contamination: (A) cold atmospheric plasma method, (B) polyphenols, (C) natural essential oils, and (D) magnetic materials and nanoparticles (Khan *et al.*, 2024).

III. Historical evolution of mycotoxin research in Algeria

Mycotoxin contamination presents a significant challenge to food safety and public health globally, particularly in Algeria, a country with a rich agricultural heritage. Over the past few decades, concerted efforts by researchers, policymakers, and industry stakeholders have aimed to

address this issue, leading to advancements in scientific inquiry, technology, regulation, and collaborative efforts across sectors. By tracing the historical progression of mycotoxin research in Algeria, this review sheds light on the challenges, opportunities, and progress made in mitigating mycotoxin contamination and ensuring the safety and quality of Algerian agricultural products (Figure 5).

III.1. Foundation phase (2008-2010)

During this phase, Algeria embarked on crucial efforts to confront mycotoxin contamination in agricultural produce, particularly staple crops like wheat. This period marked the recognition of mycotoxin's detrimental impact on food safety and public health, prompting the formation of specialized research groups and the development of fundamental methodologies for mycotoxin detection and analysis tailored to Algerian agricultural products.

A significant milestone during this phase was the establishment of the first research group on mycotoxins at the Laboratoire de Biologie des Systèmes Microbiens (LBSM) at the Ecole Normale Supérieure de Kouba, Alger, led by Professor Sabaou and Amar Riba. Situated within a prestigious educational institution, the LBSM brought expertise in microbiology and molecular biology to the study of mycotoxins, contributing to innovative methods for mycotoxin detection, characterization, and mitigation.

During the late 2000s and early 2010s, pioneering studies led by **Riba *et al.*** marked a crucial turning point in the historical trajectory of mycotoxin research in Algeria, particularly concerning wheat contamination. These groundbreaking investigations represented some of the earliest systematic efforts to understand and address mycotoxin contamination in Algerian agricultural products.

In 2008, **Riba *et al.*** conducted a comprehensive study focusing on OTA contamination in Algerian wheat. Their research highlighted the prevalence of OTA-producing molds and revealed alarming levels of OTA contamination in wheat samples from different regions and production phases across Algeria. This study emphasized the urgent need for enhanced monitoring and regulatory measures to mitigate mycotoxin risks in Algerian wheat, a staple food for the population.

Building upon their 2008 study, **Riba *et al.*** continued their investigations in 2010, this time focusing on aflatoxin contamination in Algerian wheat. By analyzing a wide range of wheat

samples collected at various production stages, they provided critical insights into the prevalence and levels of AF contamination, particularly attributed to *Aspergillus* section *Flavi* populations. Their findings highlighted the significant risk posed by aflatoxin contamination in Algerian wheat, emphasizing the importance of ongoing research and intervention efforts to ensure food safety and public health.

These pioneering studies by **Riba *et al.*** expanded our understanding of mycotoxin contamination in Algerian wheat and laid the groundwork for subsequent research and regulatory initiatives in the country. Their meticulous investigations, coupled with the development of refined methodologies for mycotoxin detection and analysis, have played a crucial role in shaping the trajectory of mycotoxin research and management in Algeria, setting the stage for continued advancements in the field.

III.2 Expansion phase (2011-2015)

During Algeria's expansion phase in mycotoxin research, there was a significant surge in efforts to understand and mitigate mycotoxin contamination in agricultural products. This period saw a proliferation of research across diverse institutions and disciplines, fostering a nuanced understanding of mycotoxin interactions and driving the adoption of advanced analytical techniques like LC-MS and ELISA. Collaboration, both domestically and internationally, played a pivotal role in accelerating progress, enabling knowledge exchange and the development of standardized protocols. Overall, this phase marked a crucial step forward in safeguarding food safety and public health in Algeria.

The study by **Yang *et al.* (2011)** sheds light on the significant issue of internal fruit rot in sweet pepper cultivation within Canadian greenhouses. This ailment, caused by *Fusarium* species, not only threatens crop yield but also poses food safety concerns due to mycotoxin production by these fungi. Through meticulous examination, the researchers revealed that all tested *Fusarium* isolates were capable of producing beauvericin (BEA), highlighting the pervasive nature of mycotoxin contamination in affected crops. Their findings underscore the complexity of the issue and emphasize the need for comprehensive strategies to mitigate mycotoxin risks in sweet pepper cultivation. In contrast, the pivotal study led by **Guezlane-Tebibel *et al.* (2012)** focused on the natural mycobiota present in Chinese peanuts sold in Algiers, with a particular emphasis on *Aspergillus* section *Flavi* species known for their potential to produce aflatoxins. The study revealed alarming levels of aflatoxin contamination in peanut

samples, with all tested *Aspergillus* section *Flavi* isolates found to be aflatoxigenic. These findings highlight the significant risk of aflatoxin contamination in peanuts sold in Algiers and underscore the importance of stringent monitoring and regulatory measures to safeguard food safety and public health. In 2013, **Riba & colleagues** conducted a pioneering investigation into aflatoxin contamination in various nuts available in the Algerian market. Their study revealed the widespread presence of aflatoxigenic fungi, particularly within the *Aspergillus* genus, in nuts such as almonds, pistachios, and peanuts. Impressively, advanced analytical techniques such as HPLC detected aflatoxins in 90% of the nut samples, with concentrations varying widely. These findings underscored the urgent need for robust monitoring and regulatory measures to mitigate the risks posed by aflatoxins in nuts consumed by the Algerian population. The study conducted by **Redouane-Salah and colleagues in 2015** focused on the presence of AFM1, a metabolite of aflatoxin, in milk consumed in Algeria. Their investigation uncovered AFM1 contamination in a significant proportion of raw and imported milk samples, with concentrations exceeding European regulations in some cases. This highlights the potential health risks associated with the consumption of contaminated dairy products and emphasizes the importance of ongoing surveillance and regulatory measures to ensure food safety in Algeria's dairy industry. Additionally, **Yekkour et al.** conducted two studies in 2015 focusing on *F. culmorum* isolates collected from cereal-growing regions in North Algeria. These studies elucidated the trichothecene-producing ability of these isolates, particularly their production of DON, a mycotoxin with significant implications for agricultural and public health. Their findings underscored the risk posed by *F. culmorum* contamination in cereal crops and emphasized the critical importance of understanding and managing fungal diseases to ensure food safety and security in Algeria. **Yekkour et al.'s 2015** study on the impact of DON sheds light on the intricate mechanisms underlying programmed cell death (PCD) induced by this mycotoxin in plant cells, particularly in *Nicotiana tabacum* BY2 cells. Unlike observations in animal cells, the study suggests that DON-induced PCD in plants may involve transcription and translation processes, highlighting the complexity of mycotoxin-mediated responses. The research uncovers multiple pathways triggered by DON, revealing its involvement in the generation of reactive oxygen species (ROS) and mitochondrial dysfunction, as well as its regulation of ion channel activities leading to cell shrinkage, a characteristic feature of PCD. The identification of these interconnected pathways deepens our understanding of how mycotoxins impact cellular processes in plants.

III.3. Consolidation phase (2016-2020)

Significant attention was directed towards regulating mycotoxin levels in agricultural products, aiming to ensure food safety and quality. This involved developing regulatory frameworks and standards, with emphasis on robust enforcement and adaptability to scientific advancements. Collaboration with industry stakeholders was crucial, fostering knowledge exchange and innovation in mycotoxin management. Investments in capacity building were prioritized, empowering local expertise to address mycotoxin contamination effectively. Continuous collaboration among academia, industry, and government entities amplified the impact of regulatory efforts, fostering a safer and more resilient food system prioritizing consumer health. **Azzoune et al. (2016)** conducted a comprehensive assessment of aflatoxigenic fungi and AFB1 contamination in spices available in Algerian markets. Their study highlighted the prevalence of *Aspergillus* species in the spices, particularly *Aspergillus* section *Flavi*, which was found to produce aflatoxins. AFB1 contamination was detected in a significant proportion of the spice samples, with some exceeding regulatory limits. This study provided valuable insights into the potential health risks associated with spice consumption and emphasized the importance of monitoring and regulatory measures to ensure food safety. **Touati-Hattab et al. (2016)** investigated *Fusarium* head blight (FHB), a significant wheat disease previously unexplored in Algeria. They identified *F. culmorum* as the predominant pathogen responsible for FHB and *Fusarium* root rot in Algerian wheat crops. Their research also explored mycotoxin production and pathogenic potential across different *F. culmorum* isolates, providing insights into disease management strategies and varietal susceptibility among wheat cultivars. **Bouras et al. (2016)** focused on *Pyrenophora tritici-repentis*, a fungus known to cause tan spot and red smudge on wheat leaves and kernels. Their study investigated the impact of nitrogen sources on the growth and mycotoxin production of *P. tritici-repentis* isolates. They found that different nitrogen sources influenced mycelial growth and mycotoxin production differently among the isolates. This research provided valuable insights into the factors affecting mycotoxin synthesis in this pathogenic fungus, contributing to our understanding of tan spot and red smudge diseases in wheat. **Hadjout et al. (2017)** focused on FHB resistance in durum wheat, a critical concern due to mycotoxin contamination. Their research identified promising breeding lines with enhanced resistance to FHB, which exhibited reduced susceptibility to initial fungal infection, disease spread, and mycotoxin contamination. This study sheds light on the potential of breeding strategies to mitigate the impact of FHB on durum wheat crops, offering insights for future breeding programs aimed at enhancing resistance to this damaging fungal disease. **Lahoum et al.**

(2017) investigated the potential of actinobacterial strains in reducing AFB1 contamination in food products. Their study revealed the efficacy of certain actinobacterial strains, particularly those from the *Streptomyces* and *Saccharothrix* genera, in significantly reducing AFB1 levels. This research provides valuable insights for developing effective strategies to address the health risks associated with AFB1 in food supply chains, highlighting the potential of biocontrol agents in mycotoxin mitigation. In **Laraba et al. (2017)**, *F. culmorum* strains were identified as causal agents of crown rot (FCR) and FHB in Algerian wheat, emphasizing the significance of these diseases. The study uncovered intriguing findings regarding the genetic diversity and population dynamics of *F. culmorum* strains associated with FCR and FHB across different geographic regions. This research contributes to our understanding of the epidemiology and genetic variability of *F. culmorum*, providing insights into disease management strategies. **Ait Mimoun et al. (2018)** investigated the presence of *Aspergillus* section Flavi and aflatoxin contamination in peanuts, almonds, and dried figs in Algeria. Their study revealed widespread contamination of these commodities with aflatoxins, with some samples exceeding regulatory limits. This research underscores the importance of monitoring and controlling aflatoxin contamination in various food products to ensure food safety and compliance with regulatory standards. **Zebiri et al. (2018)** investigated OTA contamination in wheat and wheat-derived products, revealing significant levels of contamination in the samples collected from different regions of Algeria. Their findings underscore the potential public health concern associated with OTA contamination in wheat-based products, highlighting the importance of monitoring and controlling mycotoxin levels in food commodities. **Ben Miri et al. (2018)** explored the inhibitory effects of essential oils (EOs) from *Citrus limon* and *Citrus sinensis* on the growth of *A. flavus* and AFB1 production. Their study demonstrated the efficacy of *Citrus* EOs in inhibiting fungal growth and mycotoxin production, suggesting their potential as natural agents for food preservation and protection against fungal contamination. **Ben Miri & Djenane (2019)** investigated the antifungal properties of *Thymus capitatus* EO against *A. flavus* and its ability to inhibit AFB1 production. Their findings indicated significant inhibition of fungal growth and mycotoxin production by *T. capitatus* EO, highlighting its potential as a safe alternative for food protection. **Mazru et al. (2019)** conducted a study on OTA contamination in grapes in the Mediterranean basin, employing chromatographic techniques for detection and quantification. Their findings indicated low levels of OTA contamination in the sampled grapes, suggesting minimal health risks associated with OTA exposure in this commodity. **Mahdjoubi et al. (2020)** conducted a comprehensive survey on mycotoxin contamination in cereal samples obtained from Algerian markets. Their study revealed widespread contamination of cereals with various

mycotoxins, including fumonisins, deoxynivalenol, zearalenone, and others, highlighting the urgent need for mycotoxin control measures and regulatory standards in Algeria to ensure food safety.

III.4. Diversification phase (2021-2024)

During the Diversification phase, mycotoxin research in Algeria expanded its focus to include mitigation strategies and health impact assessment, reflecting a maturation within the scientific community. Innovative technologies, such as chromatography-mass spectrometry, revolutionized detection methodologies, while advancements in data analytics and remote sensing facilitated comprehensive surveillance. Advocacy initiatives aimed at raising awareness and promoting evidence-based interventions will ultimately safeguarding consumer welfare and agricultural sustainability in Algeria and beyond.

Moussaoui *et al.* (2021) focused on mycotoxin contamination in coffee samples from various locations in Algeria. Their study revealed significant contamination of coffee samples by *Aspergillus* species, indicating potential issues with hygiene during coffee processing and storage. Additionally, the presence of mycotoxins such as AFB1, AFG1, and OTA in coffee samples highlights the importance of monitoring mycotoxin levels to ensure food safety and protect consumer health. **Carbonell-Rozas *et al.* (2021)** investigated the natural occurrence of ergot alkaloids in cereal samples from Algeria, emphasizing the prevalence of ergot alkaloid contamination in barley and wheat samples. Their findings underscore the need for monitoring and controlling ergot alkaloid levels to mitigate potential health risks associated with their consumption. **Boulanouar *et al.* (2021)** explored the potential of vegetable tars extracted from wood or bark as sources of biofungicides. Their study demonstrated significant antifungal activity of acetate extracts from vegetable tars against fungal phytopathogens, particularly *Fusarium* species. These findings suggest the potential utility of vegetable tar extracts as biofungicides for crop protection, highlighting the importance of further research in this area for the development of effective biofungicidal products. **Bouti *et al.* (2022)** investigated the presence of fungi and AFB1 in animal feed samples collected from various sources across Algeria. Their findings highlighted significant contamination of feed samples with aflatoxigenic strains belonging to *Aspergillus* section Flavi, with maize and ground poultry feed being particularly prone to contamination. The detection of AFB1 in a considerable proportion of samples underscores the potential health risks associated with aflatoxin contamination in animal feed and emphasizes the need for regulatory measures to ensure feed safety. **Saber *et al.* (2022)**

focused on characterizing fungal isolates from animal feeds in southwestern Algeria, with a specific emphasis on *A. flavus*. Through morphological and molecular assays, they successfully identified *A. flavus* isolates and confirmed their genetic variability. Their study highlights the importance of understanding the diversity and characteristics of fungal contaminants to mitigate aflatoxin contamination risks effectively. **Belabed et al. (2022)** evaluated the efficacy of commercially available fungicides against Fusarium head blight in durum wheat, a significant disease affecting wheat crops in Algeria. Their findings demonstrated varying effectiveness of fungicides in inhibiting the mycelial growth of *Fusarium* strains, with triazoles and specific combinations showing notable efficacy. This study provides valuable insights into the potential use of fungicides for controlling *Fusarium* head blight and mitigating yield losses in wheat crops. **Medjdoub et al. (2023)** conducted a comprehensive assessment of traditionally manufactured foods, including couscous and *Capsicum annuum* spice, sold in Bechar city. Their study revealed significant fungal contamination in these food items, with *Aspergillus* and *Penicillium* being the dominant genera. Moreover, high proportions of *Aspergillus* isolates were found to produce AFB1 and AFG1, while *A. ochraceus* and *Penicillium* species were identified as OTA producers. The detection of aflatoxins in a considerable proportion of samples highlights the potential health risks associated with mycotoxin contamination in traditional Algerian foods, emphasizing the need for effective control measures to ensure food safety. **Redouane-Salah et al. (2023)** focused on assessing AFB1 levels in coffee samples sold in Constantine province, Algeria. Their findings revealed widespread contamination of coffee samples with AFB1, indicating potential exposure to aflatoxins through coffee consumption. The highest concentrations of AFB1 were observed in roasted coffee bean samples, suggesting that processing methods may influence aflatoxin levels in coffee products. The study underscores the importance of ongoing surveillance of mycotoxins in agricultural products and the implementation of stringent regulations to protect consumer health and ensure food quality and safety. **Ben Miri et al. (2023 a)** conducted two separate studies focusing on the efficacy of menthol, eugenol, and their combination against different fungal species, aiming to provide insights into their potential use as preservatives in food commodities. In the first study, **Ben Miri et al. (2023b)** investigated the effectiveness of menthol, eugenol, and their combination against *A. ochraceus* and *A. niger*. The researchers evaluated both contact and fumigation toxicity of these compounds and found that they significantly reduced mycelial growth and spore germination in a dose-dependent manner. The minimum inhibitory concentration (MIC) values against both fungal species were determined, highlighting the antifungal potency of these compounds. Additionally, the combination of menthol and eugenol exhibited synergistic effects

against both fungi, demonstrating potential as natural antifungal agents for controlling fungal contamination and mycotoxin production in food commodities, particularly stored cereal grains. In the second study, **Ben Miri *et al.* (2023c)** focused on assessing the efficacy of menthol and eugenol against *A. parasiticus*, a fungus commonly associated with mycotoxin contamination in green coffee beans during long-term storage. The researchers found that both menthol and eugenol exhibited significant antifungal activity against *A. parasiticus*, with MIC values indicating their effectiveness in inhibiting fungal growth. Furthermore, when used as fumigants during storage, menthol and eugenol demonstrated efficacy in reducing *A. parasiticus* contamination in green coffee beans, thereby suggesting their potential as preservatives for mitigating fungal infections and preserving the quality of coffee beans.

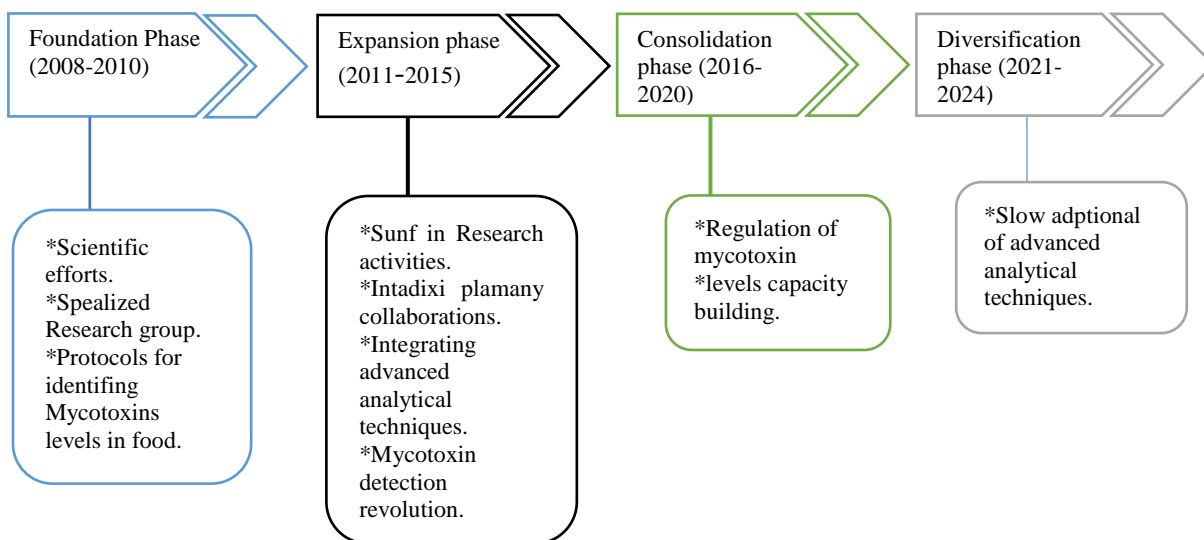


Figure 5. A Timeline chart illustrating key milestones and developments in mycotoxin Research in Algeria over the years.

IV. Mycotoxin contamination in Algerian agrifood and challenges in its analysis

Mycotoxin contamination poses a significant threat to Algerian agriculture and its food supply chain due to the country's diverse climatic regions, which are prone to infestations by mycotoxin-producing fungi in staple crops like wheat, maize, barley, and nuts. These toxins, produced by fungi such as *Aspergillus*, *Penicillium*, and *Fusarium*, not only compromise agricultural yields but also endanger human and animal health when contaminated food products

are consumed. Given that agriculture is a vital sector in Algeria, employing a significant portion of the population and serving as a cornerstone of the economy, addressing mycotoxin contamination is crucial for ensuring food security and public health. Detection techniques for mycotoxins play a crucial role in safeguarding public health by enabling accurate assessment and effective mitigation strategies to comply with regulatory standards. In Algeria, the use of efficient and cost-effective screening methods is essential. Chromatographic techniques, especially when coupled with mass spectrometry, offer precise identification. However, Algerian researchers encounter challenges such as sample preparation intricacies and issues of sensitivity and validation. Optimizing sample preparation is critical, considering factors like matrix effects and analyte stability. Precision is paramount for sensitivity, as minor variations in parameters can significantly impact outcomes. Rigorous validation protocols are necessary to ensure credibility and reproducibility. Limited access to cutting-edge techniques and standards presents a barrier to progress, necessitating collaboration with foreign institutions. Investment in domestic infrastructure and capacity-building programs is vital to enhance Algeria's mycotoxin detection capabilities. Collaborations also play a crucial role in fostering local expertise and research capabilities, contributing to long-term improvements in addressing mycotoxin contamination.

Riba et al. (2008) investigated OTA-producing molds and contamination in wheat two regions in Algeria (Tizi Ouzou and Setif) during preharvest, storage in silos, and after processing. Analysis revealed *Aspergillus* as the dominant genus, particularly *A. flavus*, *A. niger*, and *A. versicolor*, with other species like *A. ochraceus*, *A. alliaceus*, *A. carbonarius*, and *Penicillium* spp. also identified. Silo storage showed high *Aspergillus* levels, notably *A. flavus*. HPLC analysis detected OTA in 40% of wheat samples, with concentrations ranging from 0.21 to 41.55 µg/kg. Of the isolates analyzed, 32.3% were ochratoxigenic, with varying OTA production. Later, **Riba et al. (2010)** explored AFs-producing molds and contamination in Algerian wheat, spanning production stages. Field and silo samplings were from Mitidja and Sétif regions, alongside durum wheat samples from silos in the same regions. An additional samples were procured from flour and semolina mills, including soft wheat, durum wheat from mill bins, clean wheat, flour, semolina, and bran, ensuring a comprehensive assessment of wheat quality and safety. Analysis of the isolated *Aspergillus* species underscored the prevalence of those belonging to section Flavi, with strains identified as *A. flavus* and 6 as *A. tamarii*. The findings revealed significant proportions of *A. flavus* strains capable of producing AFs (72%) and CPA (10%). AFB1 were in 56.6% of the wheat samples and derived products (flour, semolina, and bran) using HPLC. The contamination levels ranged from 0.13 to 37.42 µg/kg, highlighting the

presence of AFs in the wheat supply chain and associated products. **Zebiri *et al.* (2019)** conducted a study to determine the concentrations of OTA in wheat and its derivatives in various regions of Algeria. The study employed HPLC coupled with a fluorescence detector for the extraction, quantification, and validation of OTA levels in the samples. A total of 81 samples were collected, including durum wheat, common wheat, semolina, and flour. The results revealed that a significant portion of the samples were contaminated with OTA, with 62 out of 81 samples (76.54%) showing contamination. The levels of OTA ranged from 0.84 to 34.75 mg/kg. Specifically, 69.23% of wheat grains were found to be contaminated with ochratoxin A, with concentrations ranging from 0.21 to 27.31 mg/kg. Moreover, OTA was detected in both semolina and flour samples, with concentrations ranging from 0.16 to 34.75 mg/kg. **Mahdjoubi *et al.* (2023)** conducted a survey on 120 cereal samples (including barley, maize, rice, and wheat) sourced from Algerian markets to assess the presence of mycotoxins employing UHPLC-MS/MS for quantification. Results revealed that 78 cereal samples (65%) were contaminated with at least one toxin, with 50% of samples containing three to nine mycotoxins. The most commonly detected mycotoxins were T-2 toxin, citrinin, beauvericin, and deoxynivalenol, with frequencies of 50%, 41.6%, 40.8%, and 33.3%, respectively. High concentrations of FB1 + FB2, ENB and B1, DON, and ZEN were observed, ranging from 289 to 48,878 µg/kg, 1.2 to 5,288 µg/kg, 15 to 4,569 µg/kg, 48 to 2,055 µg/kg, and 10.4 to 579 µg/kg, respectively. In their 2021 study, **Carbonell-Rozas *et al.*** investigated the occurrence of six major ergot alkaloids, including ergometrine, ergosine, ergotamine, ergocornine, ergokryptine, and ergocristine, along with their corresponding epimers, in 60 cereal samples collected from Algeria, specifically Aint Temouchent, Oran, and Tiaret using UHPLC-MS/MS. Their findings revealed that 12 out of 60 samples (20%) were contaminated with ergot alkaloids, with wheat showing a higher incidence of contamination at 26.7% (8 out of 30 samples). The concentration of total ergot alkaloids ranged between 17.8 and 53.9 µg/kg for barley samples and between 3.66 and 76.0 µg/kg for wheat samples. **Fernane *et al.* (2010)** focused on evaluating fungal contamination and the presence of AF and OT in Algerian pistachios with HPLC. The research faced challenges due to the scarcity of pistachios in the Algerian market including Constantine and Jijel. The findings revealed prevalent fungal contamination in the samples, with *Penicillium* spp. (38%), *Aspergillus* section *Nigri* (30%), and *A. flavus* (22%) being the most commonly encountered fungi. Of particular concern was the mycotoxigenic capacity of *A. flavus* isolates, with 56.5% capable of producing carcinogenic aflatoxins AFB1 and AFB2. Interestingly, while no OTA-producing isolates were found in *Aspergillus* section *Nigri*, 33.3% of biserial isolates displayed OTA production capability. Despite the high incidence of mycotoxin-producing fungi, the actual

occurrence of AFs and OTA in the samples was relatively low. Only two samples contained AFs, both below the EU maximum tolerable level, and only one sample exhibited OTA contamination. **Belasli et al. (2023)** conducted an investigation into the occurrences and levels of AFs, OTA, DON, and ZEA using HPLC-FLD in 198 samples of nuts, dried fruits, and cereal products commercialized in Algeria. AFs were detected in 26.2% of the nut samples (specifically in peanuts and almonds, but not in walnuts), 38.7% of the dried fruit samples (including dried figs, dates, and bradj pastries), and 47.9% of the cereal-based products (such as rechta noodles and metlou bread, but not in couscous). The mean concentrations of aflatoxins ranged from 0.03 to 0.49 $\mu\text{g}/\text{kg}$. OTA occurred in 16.9% of the cereal-based samples, with an average concentration of 0.15 $\mu\text{g}/\text{kg}$, while it was not detected in nuts or dried fruits. DON was prevalent in cereal-based products, with an average incidence of 85.9% and mean concentrations ranging from 90 to 123 $\mu\text{g}/\text{kg}$. However, ZEA mycotoxin was not detected in any of the samples. The study carried out by **Guezlane-Tebibel et al. (2012)** investigated the fungal contamination in peanuts sold in Algiers. *Aspergillus* section Flavi were identified as aflatoxigenic, with 65 isolates (79.27%) demonstrating high aflatoxin production, synthesizing four types of AFs at varying levels. Through advanced analytical techniques like HPLC, AFs were detected in four analyzed samples, with concentrations ranging from 0.71 to 25.50 $\mu\text{g}/\text{kg}$. **Riba et al. (2013)** investigated the presence of aflatoxigenic fungi and AF contamination in nut samples sourced from the Algerian market using HPLC. Their analysis revealed a diverse array of molds, with *Aspergillus* species, particularly those from the sections *Nigri* and *Flavi*, being most prevalent. *A. flavus* was identified as the predominant aflatoxigenic strain. AFs were detected in 90% of the nut samples, with concentrations ranging widely from 0.2 to 25.82 $\mu\text{g}/\text{kg}$. Peanuts, pistachios, and walnuts exhibited the highest levels of contamination. **Ait Mimoune et al. (2018)** conducted an investigation into the presence of *Aspergillus* section Flavi and AF contamination in 112 samples of peanuts, almonds, and dried figs collected in Algeria. The HPLC findings revealed detectable levels of AFS in 28 samples of peanuts, 16 samples of almonds, and 26 samples of dried figs. Among these, a total of 69 samples (61.6%) were contaminated with AFB₁, with concentrations ranging from the limit of quantification to 174 $\mu\text{g kg}^{-1}$. AFB₂ was detected in 12 samples (10.7%), with levels varying from 0.18 to 193 $\mu\text{g kg}^{-1}$. Additionally, seven samples showed AF concentrations below the limit of quantification. Notably, eleven peanut samples and fourteen dried fig samples exceeded the European maximum limits for AFB₁. **Redouane et al. (2015)** assessed the presence of AFM₁ in various milk samples included raw milk collected from 11 dairy farms representative of Algerian production conditions around Constantine city, as well as reconstituted and powdered milk purchased from local supermarkets using liquid

chromatography-fluorescence detection (LC-FLD) following immunoaffinity purification. The results revealed AFM1 contamination in 5 out of 47 samples (11%), with levels ranging from 9 to 103 ng/L. One sample exceeded the European regulations limit of 50 ng/L. Additionally, traces of AFM1 (less than 8 ng/L) were found in 11 other samples. Importantly, the incidence of AFM1 contamination was higher in imported powdered milk (29%) compared to raw milk (5%). In their study, **Mohammedi-Ameur *et al.* (2020)** delved into the presence of AFM1 within raw cow milk across diverse Algerian regions such as Constantine, Mila, Medea, Tipaza, Djelfa, Chlef, Tlemcen, and Mascara, encapsulating all four seasons for a comprehensive assessment using ELISA. The outcomes were telling; AFM1 was detected in a significant 46.43% of the samples ranging from 95.59 to 557.22 ng/L. While the majority of samples remained below the FDA's stipulated maximum tolerance level of 500 ng/L, only a solitary sample (1.19%) transgressed this threshold. Statistical scrutiny unearthed noteworthy disparities in AFM1 levels between samples procured during spring and autumn. Specifically, spring-harvested samples boasted markedly higher mean AFM1 levels compared to their autumn counterparts. This study illuminates the prevalence of AFM1 contamination in Algerian raw cow milk, accentuating the exigency for vigilant monitoring and stringent management of aflatoxin levels in dairy products to safeguard public well-being. In **Jedidi *et al.*'s 2023** study, the focus was on determining the level of AFM1 in raw camel milk, raw cow milk, and powdered milk Biskra, Constantine, and Taref regions using a competitive ELISA. The findings revealed that 14.63% of all analyzed samples tested positive for AFM1, with an average concentration of 17.92 ng/L and a range spanning from 5.5 ng/L to 42.5 ng/L. one sample (4.76%) of cow's milk tested positive for AFM1, while all samples of camel's milk (100%) were free from AFM1 contamination. The highest incidence and concentration of AFM1 (38.46%) were observed in powdered milk, with an average concentration of 20.34 ng/L. However, none of the analyzed samples exceeded the limit set by European regulations, which is 50 ng/L. **Azzoune *et al.* (2016)** delved into the prevalence of aflatoxigenic fungi and AFB1 contamination in various spices samples found collected from four Algerian markets located in Algiers, Batna, Biskra, and Oran, with each spice type represented by four samples. Their findings unveiled a rich fungal diversity, with *Aspergillus* species being the most prevalent (56.4%), followed by *Penicillium* (25.1%), *Mucor* (12.8%), and *Eurotium* (5.7%). Regarding AF production, 38.4% of the examined isolates from *Aspergillus* section Flavi were found to produce AFs. The study identified two primary chemotypes, with 84% of isolates capable of producing both AFB and cyclopiazonic acid, followed by those producing only AFB. In terms of AFB1 contamination, 63.9% of the spice samples were found to contain AFB1, with concentrations ranging from 0.10 to 26.50 µg/kg

using HPLC. Notably, two saffron samples and two sweet cumin samples exceeded the Algerian regulatory limit of 10 µg/kg. **Moussaoui et al. (2023)** focused on couscous and *Capsicum annuum* spice (sweet hror), marketed in Bechar. Mycotoxicological analysis revealed that 78.55% of *Aspergillus* isolates (flavus-parasiticus group) produced AFB1 and AFG1, while 86.66% of *A. ochraceus* isolates and 40% of *Penicillium* species produced OTA. At the sample level, 63.63% of couscous samples and 78.57% of sweet hror samples were contaminated with mycotoxins. Employing HPLC, AFB1 was detected in one sweet hror sample, with a contamination level of 21.75 µg/kg. **Mazou et al. (2019)** examined the presence of OTA in grapes, with a specific focus on the Algerian Cinsault variety and *Vitis vinifera* species. The HPLC findings revealed that the contamination level of OTA in grapes was lower than 30 ng/L, significantly below the regulatory limit set by the European Commission (EC) of 2µg/L. **Laouni et al. (2023)** focused on detecting enniatins (ENNs) and beauvericin (BEA), in poultry feed and eggs sourced from various locations in Algeria. UHPLC-MS/MS analysis of 10 chicken feed samples and 35 egg samples revealed that ENN B1 was the most prevalent mycotoxin, detected in 9 samples, with contamination levels ranging from 3.6 to 41.5 µg/kg with UHPLC-MS/MS. BEA was found in only one sample at a level of 12 µg/kg. However, eggs were not contaminated with any mycotoxin at the detection limit levels. **Redouane-Salah et al. (2023)** evaluate the presence of AFs in coffee. They analyzed 43 samples of both green and roasted coffee sourced from local markets and coffee shops in Constantine. Their findings revealed contamination with AFB1 in all coffee samples, with concentrations ranging from 1.004 ng/g to 1.167 ng/ g with ELISA. Roasted coffee bean samples showed the highest levels of contamination. In their research, **Bouti et al. (2022)** examined 101 animal feed samples sourced randomly from various vendors and factories in Algeria to determine the presence of fungi and AFB1. The study identified *Aspergillus*, *Penicillium*, and *Fusarium* as the main genera of fungi isolated from the samples. Additionally, they screened 459 strains of *Aspergillus* section Flavi to assess their ability to produce aflatoxins and cyclopiazonic acid, finding that 49% of the strains were capable of producing AFB1. The investigation highlighted the highest incidence of aflatoxigenic strains in maize (61%) and ground poultry feed (60%). AFB1 was found in 36.6% of the samples were contaminated within a range of 0.34 to 171.06 µg/kg using HPLC.

In Algeria, the lack of solid regulations and insufficient consideration of economic losses, health risks, and food security implications regarding mycotoxin contamination in agricultural products exacerbates several pressing issues. Algerian farmers face significant economic losses when their crops are contaminated with mycotoxins, leading to financial strain on those reliant

on agriculture for their livelihoods. Furthermore, rejection of Algerian agricultural exports due to mycotoxin contamination can result in substantial revenue losses for the country (**Belasli *et al.*, 2023**).

Mycotoxin-contaminated crops pose serious health risks to Algerian consumers. Inadequate regulations and oversight mean that contaminated food products may enter the market, exposing consumers to toxins that can cause liver damage, cancer, and other illnesses. The lack of awareness about mycotoxin contamination among the general population further compounds these health risks, particularly for vulnerable groups such as children and pregnant women (**Mendes *et al.*, 2023**).

Moreover, mycotoxin contamination undermines food security in Algeria by reducing the availability of safe and nutritious food. Contaminated crops may be unfit for human consumption, leading to potential shortages and exacerbating food insecurity, especially in rural areas where agriculture plays a significant role in food production. The absence of potential regulatory measures further weakens the integrity of the food supply chain, heightening the risk of widespread contamination and foodborne illnesses. Additionally, improper disposal of mycotoxin-contaminated crops can have adverse environmental consequences, leaching toxins into the soil and water, thus contaminating local ecosystems and posing long-term risks to environmental and agricultural sustainability.

Given the lack of solid regulations, public awareness and education are critical components of addressing mycotoxin contamination in Algeria. Efforts to educate farmers, food producers, and consumers about the risks of mycotoxin exposure and best practices for prevention and mitigation are essential for safeguarding public health and enhancing food safety standards. Building awareness about the economic, health, and food security implications of mycotoxin contamination can also mobilize support for policy reforms and regulatory interventions.

Furthermore, Algeria's regulatory landscape has made strides in addressing mycotoxin contamination by establishing specific limits for aflatoxin (AF) levels in certain food items. For instance, the regulation mandates that AFB1 should not exceed 10 µg/kg in peanuts, nuts, and cereals, while a broader spectrum of AFs, including B1, B2, G1, and G2, are regulated with a threshold of 20 µg/kg for these products (**FAO, 2004**). Similarly, for cattle feed, adherence to RASFF guidelines dictates that AFB1 content must not exceed 20 µg/kg

(<https://www.mycotoxins.info/regulations/regulations-for-africa>; accessed on 26 April 2024).

Moreover, evaluating Algeria's mycotoxin regulations within the framework of international standards not only ensures compliance but also fosters continuous improvement.

Additionally, analyses of food and feed commodities from Algeria have revealed instances where mycotoxin levels surpassed EU standards. While this underscores progress, it emphasizes the necessity of maintaining vigilant monitoring and regulatory measures to ensure consistent compliance and protect public health. Thus, a critical aspect of this analysis involves comparing Algeria's regulatory regime against internationally recognized benchmarks, particularly those established by entities such as the Codex Alimentarius Commission and the FDA (Redouane-Salah *et al.*, 2023).

V. Algerian researchers and publications on the global stage

Given that in Algeria we do not have enough means to carry out comprehensive studies on mycotoxins, most studies in this subject are done through collaboration with foreign researchers. Many studies were conducted in cooperation with foreign researchers with the aim of eliminating many of the possible obstacles that were published in international journals (**Table 2**).

Table 2. A table listing notable research publications from Algerian researchers in the mycotoxin field, including authors, publication dates, and key findings.

Title of the publication	Authors	Journal	Dates
- Contamination of common spices by aflatoxigenic fungi and aflatoxin B1 in Algeria.	N. Azzoune, S. Mokrane, A. Riba, N. Bouras, C. Verheecke, N. Sabaou and F. Mathieu.	Quality Assurance and Safety of Crops & Foods	2016
- Investigations on aflatoxigenic fungi and aflatoxins contamination in some nuts sampled in Algeria.	A.Riba, A.Matmoura, S. Mokrane, F. Mathieu and N. Sabaou.	African Journal of Microbiology Research.	2013
	K. Bouti, C.	Hal Open Science	2021

Title of the publication	Authors	Journal	Dates
-Polyphasic characterizatin of Aspergillus section Flavi Isolated From Animal feeds In Algeria.	Verheecke-vaessen, S.Mokrane, A.Meklat, N.Djemouai, N. Sabaou, F. Mathieu, A. Riba.		
Detection And Preliminary Identification Of Ochratoxins And Aflatoxins Produced By Aspergillus Species Isolated From Coffee	M.Mohammed , Z. Mohammed , B. Olfa ,Y.Wassim and M. Adellah	Plant Archives	2021
Multi-Mycotoxin Occurrence and ExposureAssessment Approach in Foodstuffs from Algeria	C. Khelifa Mahdjoubi , N. Arroyo-Manzanares , N. Hamini-Kadar , M. García-Campaña , K.Mebrouk and L.Gámiz-Gracia	Toxins	2020
Antifungal, antitoxigenic, and antioxidant activities of the essential oil from laurel (<i>Laurus nobilis</i> L.): Potential use as wheat preservative	A. Belasli, Y. Ben Miri, M. Aboudaou, L. Aït Ouahioune ,L.M. A. Ariño, D. Djenane	Food science And nutrition	2020
-Zootechnical, bacteriological, and histometrical effects of a combination mycotoxin binder-acidifier in broiler chickens	N. Mimoune, C. Houari, C. Ammari, R. Hammouni, N. Ait Issad and D. Khelef	Food Additives and Contaminants: Part B	2018

Title of the publication	Authors	Journal	Dates
-Deoxynivalenol producing ability of <i>Fusarium culmorum</i> strains and their impact on infecting barley in Algeria.	A. Yekkour, O. Toumatia, A.Meklat, C.Verheecke, N. Sabaou, A. Zitouni, F. Mathieu.	World Journal of Microbiology and Biotechnology	2015
Antioxidant And Antifungal Activities <i>In Vitro</i> Of Essential Oils And Extracts Of Twelve Algerian Species Of <i>Thymus</i> Against Some Mycotoxigenic <i>Aspergillus</i> Genera	Y. Ben Miri, A. Taoudiat, M.Mahdid	Journal of Biological Research	2022
Comprehensive Insights into Ochratoxin A: Occurrence, Analysis, and Control Strategies	Y. Ben Miri , A. Benabdallah , I.Chentir , D. Djenane , A. Luvisi and L.De Bellis ,	Foods	2024

VI. Analyzing the board when resources for researching mycotoxins are unavailable.

In Algeria, conducting comprehensive research on mycotoxins often encounters challenges stemming from limited access to essential resources. Despite these obstacles, thorough analysis remains pivotal for understanding the prevalence and impact of mycotoxins on agricultural produce and human health in the region. Article reviews serve as foundational pillars in research efforts, allowing Algerian researchers to transcend resource limitations and make significant contributions to fields like mycotoxin research. These reviews involve strategic extraction of insights, data, and methodologies from published studies, academic journals, and relevant databases. Through synthesizing existing knowledge, researchers identify gaps in the literature,

discern research trends, and shape their study designs. Advanced literature mining techniques, including text analysis algorithms, further aid in extracting nuanced information and refining research approaches. For instance, **Ben Miri et al. (2024)** demonstrated the importance of literature reviews by examining OTA-related studies. Similarly, **Riba and colleagues** conducted a comprehensive review in 2018, focusing on toxigenic fungi and mycotoxin occurrence in Northern Africa, providing valuable insights into mycotoxin prevalence across the region.

Collaboration extends beyond ideational exchange to encompass the sharing of physical resources, facilitated by formal agreements. This collaborative effort enables access to diverse sample sets, fostering transparency and reproducibility in research. For example, Algerian urine samples collected from workers were shared with laboratories in Portugal, revealing the presence of multiple mycotoxins and highlighting public health concerns (**Mendes et al., 2023**) .

Capacity building initiatives play a crucial role in advancing scientific knowledge and expertise among Algerian researchers in the realm of mycotoxins. These initiatives encompass comprehensive training programs covering essential skills such as laboratory techniques, data analysis, and quality assurance protocols, tailored to meet researchers' specific needs. In securing external funding through grant applications, Algerian researchers articulate the significance and feasibility of their projects, aligning proposals with funding agency priorities. Successful grants not only provide financial support but also validate research endeavors, attracting additional collaborators and resources. For instance, scholarships and grants from various entities have enabled researchers to pursue mycotoxin-related studies, despite resource constraints.

VII. Bridging the gap: Future research directions

Algeria finds itself at a critical juncture in mycotoxin research, marked by notable achievements intertwined with significant challenges. As scientists delve into comprehending the complexities of mycotoxin occurrence, detection methods, and their implications on food safety and public health, they confront hurdles ranging from resource limitations to the necessity for innovative, context-specific solutions. Despite these obstacles, Algerian researchers exhibit resilience and creativity, laying the groundwork for future advancements in the field. Through the exploration of indigenous remedies, bolstering surveillance systems, and nurturing interdisciplinary cooperation, Algeria not only stands to surmount existing barriers but also holds the potential to wield substantial global influence in mitigating mycotoxin contamination :

- a. **Exploring indigenous solutions:** This endeavor involves delving into traditional Algerian methods of preserving food and natural substances believed to counteract mycotoxins. By studying age-old practices passed down through generations, researchers aim to discover effective, culturally relevant, and sustainable ways to tackle mycotoxin contamination.
- b. **Strengthened surveillance and monitoring:** Building robust surveillance systems entails implementing continuous monitoring methods for mycotoxin levels across various Algerian agricultural products and regions. This proactive approach allows for early detection of contamination areas, facilitating swift intervention strategies.
- c. **Innovations in detection technologies:** Research is focused on creating mycotoxin detection technologies that are cost-effective, portable, and easy to use. Adapting these technologies to meet the specific needs of Algerian farmers and food producers is crucial for widespread adoption. Integrating rapid testing methods with smartphone applications aims to streamline data collection and analysis, improving efficiency and accessibility.
- d. **Cross-disciplinary collaboration:** By encouraging collaboration among experts from fields such as agriculture, food science, microbiology, and public health, Algerian researchers aim to develop comprehensive solutions to mycotoxin contamination. Drawing on diverse areas of expertise enables a deeper understanding of the complex factors contributing to contamination, paving the way for holistic approaches to address them.
- e. **International partnerships and resource sharing:** Engaging with international institutions, industry stakeholders, and governmental organizations provides opportunities to access funding, expertise, and advanced technologies. Through shared resources and knowledge exchange, Algerian researchers can overcome the limitations of limited resources, accelerating research and development efforts.
- f. **Building capacity through training programs:** Implementing training programs and workshops is crucial for enhancing the skills and knowledge of local researchers, extension workers, and professionals in the food industry. Investing in human capital strengthens Algeria's research ecosystem and establishes a sustainable framework for addressing mycotoxin contamination in the long term.
- g. **Risk assessment and management strategies:** Comprehensive risk assessments help identify situations with high mycotoxin exposure risks and vulnerable population groups. Developing targeted management strategies, such as implementing good agricultural

practices and regulatory measures, is vital for effectively mitigating these risks and upholding food safe standards.

Conclusion

The review on mycotoxin research and publications in Algeria has uncovered a complex landscape characterized by both notable achievements and significant challenges in the field. Algerian researchers have demonstrated commendable progress in comprehending various aspects of mycotoxins, including their occurrence, detection techniques, and effects on food safety and public health. Through rigorous investigations, valuable insights into the prevalent mycotoxins found in diverse foodstuffs have been garnered, contributing substantially to the development of enhanced management strategies.

However, the field of mycotoxin research in Algeria is not devoid of hurdles. The scarcity of resources poses a formidable challenge, including limitations in funding and access to advanced technology. Such constraints impede the optimal advancement of research endeavors and hinder the realization of their full potential. Nevertheless, Algerian researchers have demonstrated commendable resilience in the face of these challenges. Embracing innovation and creativity, they have pioneered the development of cost-effective detection methods and employed interdisciplinary methodologies to surmount resource limitations. Moreover, through strategic partnerships with international collaborators, external expertise and resources have been leveraged to augment research capabilities.

Algerian mycotoxin research holds promise for global impact, notwithstanding the prevailing resource limitations. The country's diverse environmental conditions provide a rich tapestry for studying mycotoxin dynamics, offering unique opportunities for scientific exploration and discovery. Prioritizing localized solutions enables Algerian researchers to devise interventions with broader relevance for analogous regions worldwide.

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