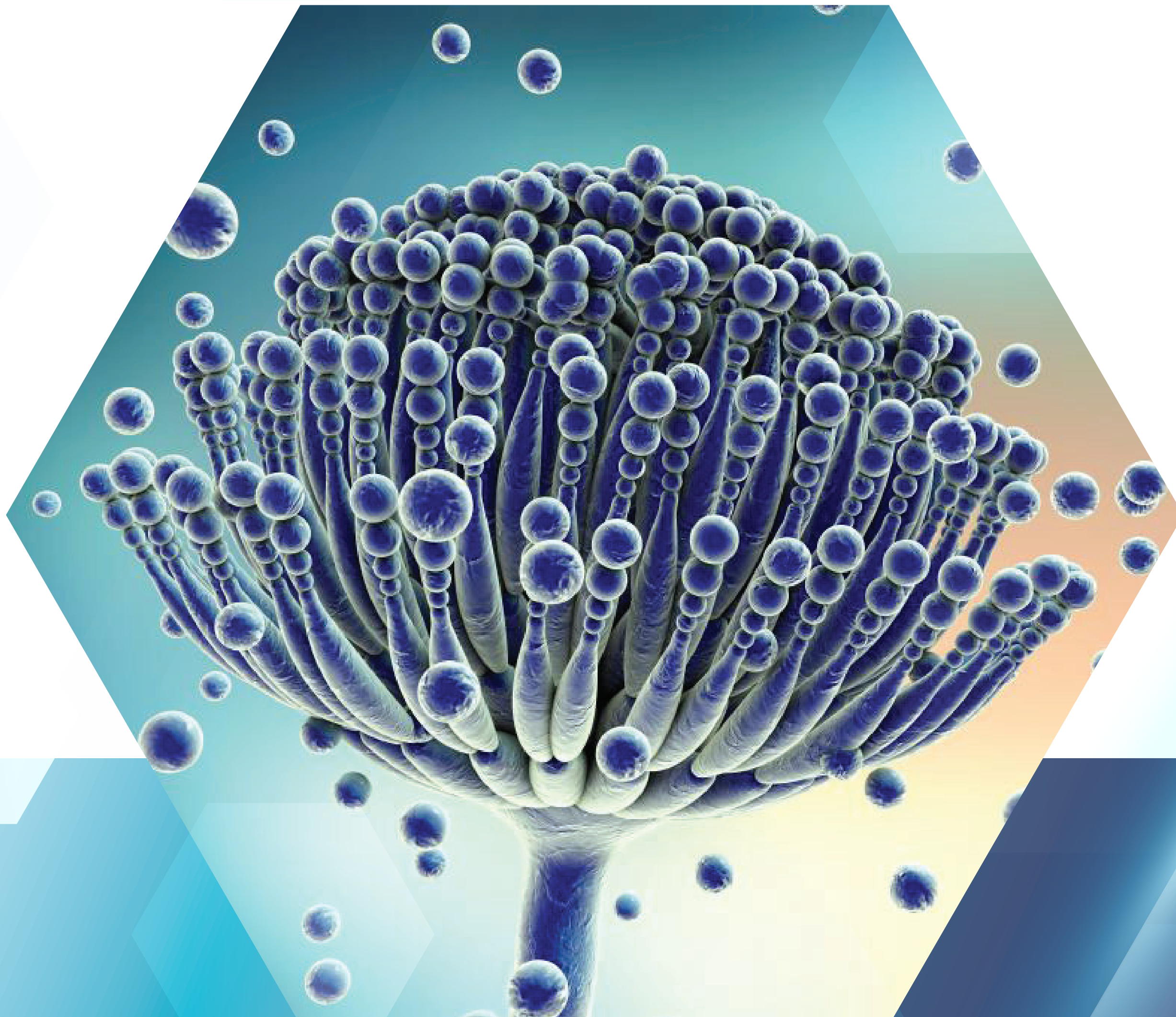
MYCOTOXINS

IN LEBANESE FOOD BASKET



DATABASE ON OCCURRENCE AND EXPOSURE

Editors

André El Khoury, Rouaa Daou, Ali Atoui and Maha Hoteit

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EDITORS

Andre EL KHOURY holds a PhD in Environmental and Process Engineering, section Microbial Engineering, from the Polytechnic National Institute of Toulouse (INP), France and a PhD in Chemistry from the Saint-Joseph University of Beirut, Lebanon. He also holds an Agriculture Engineering diploma from the Lebanese University, a Master degree in Food Chemistry and a Master's in Animal Physiology from the Faculty of Sciences of the Saint-Joseph University of Beirut. Currently, he is an Associate Professor filling a full time Faculty position (teaching and research), within the Life and Earth Sciences - Biochemistry Department, at the Faculty of Sciences of Saint-Joseph University of Beirut. He acts as chair of the master Program "Food Chemistry" since 2010 and since 2014 as head of the research laboratory of "Mycotoxicology and Food Safety", within the same faculty. He covers different courses related to the Food Toxicology, Mycotoxicology, Good hygiene and manufacturing practices (GMP/GHP), Industrial Toxicology, Food Biochemistry, Food Additives, Environmental Health, Biosafety & Biosecurity, Parasitology, Mycology and professional risks management. His research interests focus on Mycotoxicology, Environmental impact of filamentous fungi and their related mycotoxins, Bioaerosols, Antimicrobial resistance, Biofilms, Food Control, Food Toxicology, Food Microbiology, Food Contaminants and Food Analysis topics. Dr. El Khoury mentored 11 PhD students and around 40 Master students with various scientific backgrounds. Altogether, these activities led to a large and rich scientific production including 2 patents, 1 book chapter, 40 publications in prestigious scientific journals and an intense participation to national and international conferences. In addition, he is guest editor at Frontiers in Nutrition and Frontiers in Fungal Biology journals, as well as reviewer for many scientific journals. Dr. El Khoury is member of the International Network of Biotechnology (INB) and member of the project 18 of the Chemical, Biological, Radiological and Nuclear (CBRN) Unit, working under the Umbrella of The United Nations Interregional Crime and Justice Research Institute (UNICRI) and covering subject areas of Biosafety, Biosecurity, Bioethics and responsible Life Sciences. He is also a member of the Food Safety committee founded by the Lebanese ministry of Public health in 2021 and member of the expert committee designated to evaluate the health impact due to the moldy and fermented grains of the Lebanese silos after the explosion of the port of Beirut in 2020. He followed various trainings on an international level covering different scientific disciplines and collaborated with the UNICRI as a trainer on the malicious use of social media during the COVID-19 pandemic.

Rouaa Daou holds a Ph.D in Life Sciences from Saint-Joseph University of Beirut, Lebanon, and a Ph.D. in Public Health from the Lebanese University. She also holds a M.S. degree in Food Technology and a B.S. degree in Nutrition and Dietetics from the American University of Beirut. Her Ph.D. studies concentrated on quantifying the concentrations of aflatoxin B_1, aflatoxin M_1, and ochratoxin A in a selected Lebanese food basket including milk and dairy products, wheat and derived products, spices, herbs, nuts, etc. Her work also included quantifying the exposure to those mycotoxins in the Lebanese population and their related health risks. Currently, Dr. Daou is a part-time instructor at the Notre Dame University-Louaize where she teaches Basic Human Nutrition and Food Security and Sustainability courses. She is also responsible for mentoring M.S. students in research studies in areas of food mycology, public health, and microbiology at the Saint Joseph University. Dr. Daou had different national and international participations in many conferences. She was able to achieve first position in poster competition at the 13th Dubai International Food Safety Conference on her study entitled, "Assessment of aflatoxin M_1 in cow's milk and dairy products and its effect on liver cancer in Lebanon". Dr. Daou has published several articles in prestigious scientific journals including review and research articles on food contamination with mycotoxins in Lebanon. She is also a licensed dietitian since 2011 and a member of the Lebanese Academy for Nutrition and Dietetics.

Ali Atoui received his Diploma in Agriculture Engineering (specialization in Agri-Food Industries) from the Lebanese University in 2001. He then obtained his M.Sc. Degree in 2003 in Food Quality Management from the Mediterranean Agronomic Institute of Chania (MAICh), Crete- Greece. In 2006, he completed his PhD, specializing in molecular and physiological studies of the mycotoxin producing fungi, from the Institut National Polytechnique de Toulouse, France where he received the 2007 Léopold Escande Prize awarded for the most innovative PhD from the Institut National Polytechnique de Toulouse. From 2007 to 2008 he has been Faculty Research Associate in the Department of Biological Science at the Northern Illinois University, Dekalb, Illinois, U.S.A and worked there on the molecular regulation of Secondary metabolites biosynthesis in filamentous fungi. In June 2008 he worked at the Lebanese Atomic Energy commission where he served as Scientific researcher and head of the laboratory of Microorganisms and Food Irradiation. In 2014 he was appointed Professor of Microbiology in the Department of Life & Earth Sciences at Faculty of Sciences of the Lebanese University. He is teaching General Microbiology, General Microbiology Laboratory, Food Microbiology, Laboratory Management and Biosafety. His research interests focus on the genetics and physiology of mycotoxin biosynthesis by filamentous fungi, molecular identification of mycotoxigenic species, mycotoxin detection and control. He has (co-) supervised 8 PhD students and more than 30 MSc students. He has more than 40 scientific papers in and has participated in many international conferences. In the field of Biosafety and Biosecurity Ali Atoui is a member of scientific committee for the Annual International Symposium on Biosecurity and Biosafety: Future Trends and Solutions since 2010 and has many conferences participation on this area. He also served as a potential expert in the realization of the Project 18 "International Network of Universities and Institutes for Raising Awareness on Dual-Use Concerns in Bio-Technology" (2013-2014) and since 2017, he is member of the International Network of Biotechnology (INB) of UNICRI.

Maha Hoteit, holding a PhD in Nutritional Sciences and Nutrigenomics, is the Director of the Master Program in Clinical and Public Health Nutrition and Head of Department of Nutrition and Dietetics at the Faculty of Public Health-Section I at the Lebanese University. Pr. Hoteit is the founder of the public health Nutrition program of Lebanon (PHENOL) and her research interests lie in the area of public health nutrition, ranging from surveys, food composition data, to clinical trials than to policies implementation. In recent years, she has focused on studying the effect of nutritional interventions on health community's outcomes by spreading the term "Public Health Nutrition". More than 33 publications observed lights between 2014 and 2021 aiming to improve the quality of life of communities living in Lebanon and the Eastern Mediterranean region. Main outcomes and topics were non-Communicable diseases, fruits and vegetables intake, Mediterranean diet, smoking and body weight, physical activity and body markers, autism and nutrition, body image and healthy lifestyle, inflammatory bowel disease and nutrition, Vitamin D and Calcium supplementation in elderly, food composition tables for traditional dishes, food security, breastfeeding and pregnancy amid the COVID-19 pandemic. Some of the research projects were achieved in collaboration with the regional office of the World Health Organization.

FOREWORD

Fungal attack is a natural phenomenon that affects agricultural lands worldwide leading to the production of toxic secondary metabolites known as mycotoxins on crops either on-field or during storage. In Lebanon, several studies have reported the occurrence of mycotoxins in either locally produced or imported food-stuffs. Based on its geographical location, Lebanon, has a diverse climate that promotes mycotoxin production due to the prevalence of humid to sub-humid conditions in the winter that shifts to sub-tropical with high temperatures and humidity in the summer. Added to that, the prevalence of multiple issues including poor agricultural, storage, and food safety control practices, lead to further contamination with mycotoxins. Mycotoxin's exposure threatens public health, especially upon prolonged chronic exposure due to the continuous presence of carcinogenic mycotoxins at different concentrations in major staple Lebanese food. Therefore, this database serves to present a brief explanation on the issue of mycotoxins in food, their promoting factors, control methods, health, and economic effects, etc. In addition to that, it mainly aims to present a summary of all studies conducted in Lebanon that reports the occurrence of mycotoxins in foodstuff present in the national markets and the exposure of Lebanese population to them. At the end of this report, future trends in mycotoxin research and recommendations to decrease contamination in Lebanon are also presented. This database was prepared by the Laboratory of mycology and food safety at the Faculty of Sciences of the Saint Joseph University of Beirut, the Faculty of Public Health and the Lebanese Food Drugs and Chemical Administration (LFDCA) at the Lebanese University for its dissemination to policy makers, food safety organizations and specialists, and food mycology researchers in Lebanon.

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Editors are grateful to Mr. Ibrahim kheireddine for his assistance in designing this database.

ACRONYMS

AFB1	Aflatoxin B_1
AFB2	Aflatoxin B_2
AFG1	Aflatoxin G_1
AFG2	Aflatoxin G_2
AFM1	Aflatoxin M_1
AFT	Total aflatoxins
ALT	Altenuene
AME	Alternariol monomethyl ether
AOH	Alternariol
a_w	Water activity
DON	Deoxynivalenol
EC	European Commission
ELISA	Enzyme-linked immunosorbent assay
FB1	Fumonisin B_1
FB2	Fumonisin B_2
FFQ	Food Frequency Questionnaire
HPLC-FLD	High Performance Liquid Chromatography coupled with a fluorescence detector
IAC	Immunoaffinity column
IARC	International Agency for Research on Cancer
LIBNOR	The Lebanese Standards Institution
MCT	Mycotoxin
MTL	Maximum Tolerable Limit
NIV	Nivalenol
OTA	Ochratoxin A
TeA	Tenuazonic acid
TTX	Tentoxin
UPLC/MS-MS	Ultra-performance liquid chromatography-tandem mass spectrometry
ZEA	Zearalenone

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BACKGROUND

Mycotoxins are secondary metabolites of filamentous fungi that can attack crops on-field or during storage. Fungal attacks are unavoidable and are part of a natural occurrence that is affected by environmental conditions including temperature and humidity. Fungi can contaminate vast types of crops including food products and feedstuff and can tolerate diverse circumstances allowing them to produce mycotoxins under different sets of conditions. Contamination with fungi can happen at any stage of the food production chain making it an additive process that may start in the field and increase with subsequent steps. Identified in 1962 due to the aftermath of a veterinary crisis in London where 100,000 turkey poults died in what was known as a mysterious turkey X disease attributed later to aflatoxin contamination in peanut meal, mycotoxins have emerged since then as a risk to public health and food security (Bennett & Klich 2003). Currently, more than 300 mycotoxins are known that range from simple C4 molecules to complex ones and that differ in fungal origins, structure, function, and effects. Mycotoxins are generally low molecular weight compounds and as their production does not seem to affect fungal growth, they may have developed to play a defensive role against external intruders (Reverberi et al. 2010; Zain 2011).

Table 1: Major mycotoxins, their producing fungi, and affected food types (Pitt 2000; Bennett & Klich 2003; Magan & Olsen 2004; Marin et al. 2013; Milani 2013; Daou et al. 2021)

Mycotoxin	Producing Fungi	Affected Foodstuff
Aflatoxin B_1, B_2, G_1, and G_2	*Aspergillus flavus* *Aspergillus parasiticus* *Aspergillus nomius*	Wheat, maize, rice, peanuts, nuts, spices, oilseeds, and cottonseed
Aflatoxin M_1	Metabolite of aflatoxin B_1	Milk and dairy products
Ochratoxin A	*Aspergillus carbonarius* *Aspergillus niger* *Aspergillus ochraceus* *Penicillium verrucosum* *Penicillium nordicum* *Penicillium cyclopium*	Wheat, barley, oats, cocoa beans, coffee beans, fruits and fruit juice, dried fruits, and wine
Patulin	*Penicillium expansum* *Byssochlamys nivea* *Aspergillus clavatus*	Fruit and fruit juices, cheese, and wheat
Trichothecenes	*Fusarium sporotrichiodes* *Fusarium langsethiae* *Fusarium graminearum* *Fusarium culmorum* *Fusarium cerealis*	Maize, wheat, barley, oats, grains, and animal feed
Zearalenone	*Fusarium graminearum* *Fusarium culmorum* *Fusarium cerealis* *Fusarium equiseti*	Maize, wheat, barley, rye and animal feed
Fumonisin B_1, B_2, B_3	*Fusarium verticillioides* *Fusarium proliferatum*	Maize, rice, wheat, sorghum, barley, and oats

Mycotoxin promoting conditions

Climate conditions are the main determining factors of fungal attacks and mycotoxin production as they affect their incidence, survival, and distribution (Richard et al. 2003). Fungi, being diverse, require different conditions to grow, germinate, and produce mycotoxins. For example, on-field, *Fusarium spp.* dominate, while during storage *Aspergillus spp.* and *Penicillium spp.* become more relevant since they thrive at lower relative humidity that is usually found in storage (Mannaa & Kim 2017). However, fungal contamination does not necessarily mean subsequent mycotoxin contamination since only restricted specific conditions of temperature, water activity, and pH promote mycotoxin production. Generally conditions considered favorable for fungal growth and mycotoxin production are a temperature range of 25-30°C, a_w higher than 0.78, and a relative humidity range between 88% and 95% (Thanushree et al. 2019). pH also affects mycotoxin production and generally fungi can modulate the surrounding pH by secreting acids or alkali giving it a better survival chance (Vylkova 2017). However, usually, an acidic medium surrounding the fungi leads to more mycotoxin production. Fungal strains affect mycotoxins production as well and sometimes different strains of the same species require different conditions to produce different types of mycotoxins. For example, *Aspergillus flavus* and *Aspergillus carbonarius* can grow at different temperatures and while the first can produce AFB1, the second has the ability to produce OTA (Mannaa & Kim 2017). Substrate type also plays an important role in determining the dynamics of fungal growth and mycotoxin production. As molds can be found on almost all kinds of food since most of them contain carbon and nitrogen that are essential for fungal growth, those species cannot definitely produce mycotoxins on all crop types (Kokkonen et al. 2005). More complex interactions govern this process in the substrate including that of temperature, pH, water activity, and composition and in the absence of one single factor fungal growth might be affected and mycotoxin production stopped (Özćelik & Özćelik 2004). On the other hand, substrates with simple sugars mostly supports mycotoxins production (Hamad et al. 2015).

Mycotoxin control

Mycotoxins that are naturally produced in food are to a large extent unavoidable and their stable nature makes them resistant to decontamination and processing methods. Their presence in the food chain, therefore, might lead to induced crops destruction as a method to reduce global contamination of food with mycotoxins causing therefore, an increase in food waste and economic losses. Hence, the best strategy to control mycotoxin contamination in the final food product is to apply integrated quality control measures from the beginning of the food chain until the end, particularly since fungal attack and mycotoxin production can take place at any stage of the food chain. So, proper practices must be applied on-field during pre-harvest, as well as, during the later stages of harvest, drying, storage, and processing (Lopez-Garcia et al. 1999).

1. Proper agricultural practices

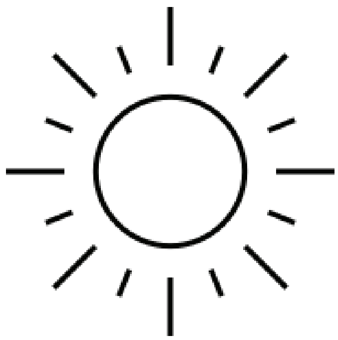
Good agricultural practices on-field are crucial as a first step in the control of fungal attacks and mycotoxin contamination since most fungi are phytopathogens that can invade crops. As it is mostly impossible to totally prevent mycotoxin contamination on planted crops, it is possible to reduce it through proper strategies. On-field it is extremely important to get rid of any debris plant material from previous crops that can act as perfect media for fungal attacks, growth, and germination through applying deep plowing, tiling, and yearly crop rotation (Food and Agriculture Organization 2007; Munkvold 2014; Rose 2019). It is also important to time the production cycle to avoid early maturing of the plant and harvest during a time of rainfall or high relative humidity (Food and Agriculture Organization 2007; Rose 2019). It is also crucial to prevent pest, weed, insect, and rodent attacks that can spread fungi and cause harm to the plant integrity making it more prone and less resistant to fungal attacks. Using proper practices such as proper irrigation that prevents splashing and spread of fungi, in addition to the usage of fertilizers and fungicides in recommended limits is also important to control on-field contamination (Food and Agriculture Organization 2007).

Proper field practices

- Deep plowing and tiling
- Crop rotation
- Timing the production cycle
- Use of high-quality seeds
- Use of fertilizers
- Applying appropriate irrigation methods
- Weed and insect control
- Use of fungicides in recommended quantities

Proper harvest practices

- Start after a period of dry weather
- Harvest in a rapid way
- Avoid mechanical damage to crops especially when using heavy machinery
- Visually examine the crops for any symptoms of fungal disease
- Separate contaminated crops from healthy ones Ensure the cleanliness and hygiene of harvest equipment to avoid fungal cross-contamination



Proper drying practices

- Perform drying directly after harvest
- Perform drying at the fastest rate possible
- Transfer crops upon completion directly to controlled storage
- Place a barrier or platform between the soils and crops in case of sun drying

2. Proper storage practices

Storage is a crucial period when control measures can be applied and several techniques could be done to limit fungal infection, growth, germination, and mycotoxin production. However, if executed in improper ways, uncontrolled arbitrary storage creates an optimal condition for fungi to germinate and create internal contamination pockets. Generally, it is very important to control temperature and relative humidity and maintain them at levels below 10˚C and 70%, respectively. However, if storage conditions become uncontrolled, for example, if the storage facility was not well sealed and proofed against weather conditions and insect, rodent, and pest attacks and in the particular presence of low temperatures in the outer atmosphere, evaporation might occur followed by condensation that increases water activity in the stored crops leading to fungal growth and mycotoxin contamination and the formation of internal pockets of contamination (Figure 1) (Richard et al. 2003).

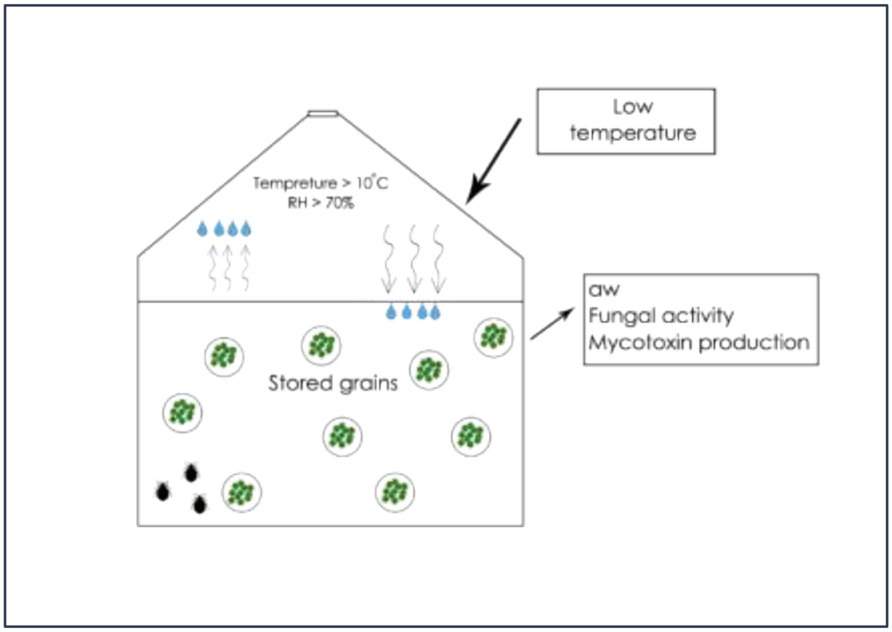


Figure 1: Uncontrolled storage and its effect on contamination.

Proper storage practices

- Check grains' physical condition before storage including moisture content and signs of fungal infection
- Check soundness of storage warehouse
- Weatherproof warehouse and seal any holes or damages
- Sanitize building and equipment before storage, remove any previous crop debris, and apply insecticide
- Install moisture barriers on the floor of impermeable nature
- Install temperature and moisture sensors and calibrate them frequently
- Continuously monitor pest infestation, physical crop damage, and fungal infection signs during storage
- Perform periodic quality analysis during storage including microbiological and chemical assessments Keep data records and test results

3. Detoxification, decontamination, and processing methods

Quality control methods application through the food chain is the best approach for reducing contamination, however, in many cases, any single deviation from control procedures could lead to the frequency of mycotoxins in the foodstuff (Hojnik et al. 2017; Pankaj et al. 2018). Therefore, some decontamination and detoxification methods have been developed to minimize mycotoxin contamination in the final product (Magan & Olsen 2004). Methods developed were either physical that includes procedures like sorting, cleaning, washing, cooking, etc., or chemical that relies on organic acids, alkalis, reducing and oxidizing agents, or biological that concentrates on using microorganisms such as bacteria, yeasts, molds, and algae for decontamination (Karlovsky et al. 2016; Hojnik et al. 2017; Pankaj et al. 2018; Pleadin et al. 2019; Deng et al. 2021).

Nonetheless, no single method has proved to be significantly effective against the various mycotoxins and several ones were found to be inapplicable due to their impracticality on large industrial scales.

On the other hand, processing techniques that aims to increase the stability and shelf-life of any food product are not particularly effective against mycotoxins due to their high resistance (Bullerman & Bianchini 2007). Generally, based on the nature of the mycotoxin some processing techniques have been shown to either increase or slightly decrease their concentration. For example, during cheese making AFM1 becomes more concentrated in the final product while in cereal production OTA may decrease due to the complex nature of processing methods. Therefore, on a general note, processing is not highly effective in removing mycotoxins from food.

4. Role of legislation in mycotoxin control

Mycotoxin total exclusion from foods is practically impossible so the last step of control that safeguards markets from mycotoxin contamination is the application of legislation and regulations. Usually regulatory agencies in different countries set legislations in the form of tolerances, guideline levels, residue levels, and maximum admissible levels for mycotoxins in different food commodities (Magan & Olsen 2004). Countries tend to test samples of the food upon import to ensure acceptable levels of mycotoxins before admission. Generally, contamination vary significantly worldwide and this creates a condition of imbalance and disparities. Strict regulations may also lead to food safety problems in non-developed countries that may have abundance of mycotoxin contaminated foods in their markets due to border rejection in developed ones (Magan & Olsen 2004; Barkai-Golan & Paster 2008). To ensure appropriate application of regulations proper sampling and analysis methods should also be used since sampling can introduce a lot of bias and the usage of improper analysis methods can lead to inaccurate results hence, compromising the health of the consumers and the benefits of the trader and the buyer as well. Analytical procedures usually start with cleanup and extraction steps using mostly solid-phase extraction such as the usage of immunoaffinity columns, then afterwards, different chromatographic methods could be used for quantification including high performance liquid chromatography (HPLC), mass spectrometry (MS), etc. However, those methods could be time-consuming, so instead enzyme-linked immunosorbent assay (ELISA) might be used, since it is rapid, simple, and cost-effective. Nonetheless, it remains a less reliable method due to the high risk of false-positive or false-negative results (Sakamoto et al. 2018). The following figure sums up the factors that affect mycotoxin production and the control methods.

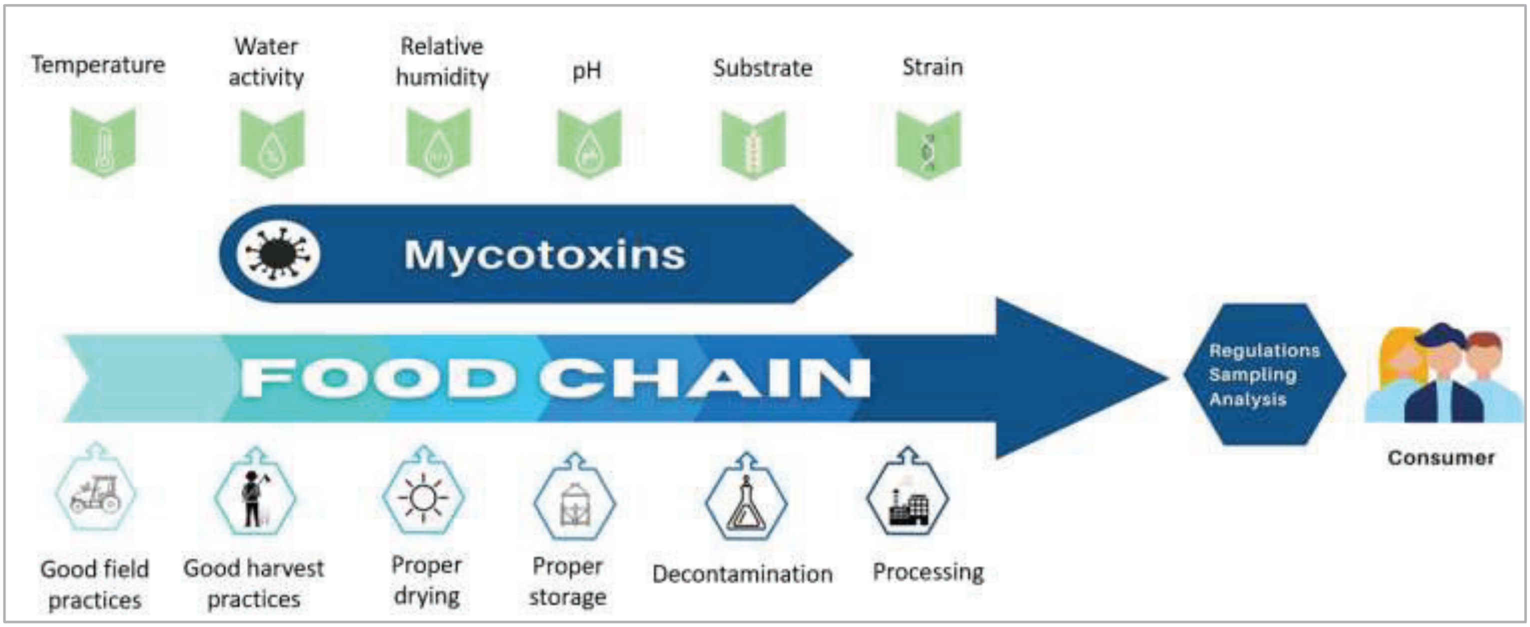


Figure 2: Conditions affecting mycotoxin production and control methods (Daou et al. 2021).

Table 2: Maximum tolerable limits (MTL) for different mycotoxins in some food commodities (European Commission 2006).

Food Commodity	**Mycotoxin**	
	AFB1 (µg/kg)	AFT (µg/kg)
All cereals and all products derived from cereals	2.0	4.0
Maize and rice to be subjected to sorting or other physical treatment before human consumption	5.0	10.0
Groundnuts (peanuts) and other oilseeds and processed products intended for direct human consumption or as an ingredient in food	2.0	4.0
Almonds and pistachios for direct human consumption or use as an ingredient in foodstuff	8.0	10.0
Other tree nuts for direct human consumption or use as an ingredient in foodstuff	2.0	4.0
Processed cereal-based foods and baby foods for infants and young children	0.10	-
Spices	5.0	10.0
	AFM1 (µg/kg)	
Raw milk, heat-treated milk and milk for the manufacture of milk-based products	0.050	
Infant formula	0.025	
	OTA (µg/kg)	

Food Commodity	Mycotoxin
Unprocessed cereals	5.0
Cereals intended for direct human consumption	3.0
Processes cereal-based foods and baby foods for infants and young children	0.5
Roasted coffee beans and ground roasted coffee	5.0
Soluble coffee	10.0
Wine	2.0
Spices	15.0
	DON (µg/kg)
Cereals intended for direct human consumption	750
Pasta (dry)	750
Bread, pastries, biscuits, cereal snacks, and breakfast cereals	500
	ZEA (µg/kg)
Cereals intended for direct human consumption	75
Bread, pastries, biscuits, cereal snacks and breakfast cereals excluding maize-based snacks and maize-based breakfast cereals	50
Maize intended for direct human consumption, maize-based snacks and maize-based breakfast cereals	100
	Sum FB_1 & FB_2 (µg/kg)
Maize intended for direct human consumption	1000
Maize-based breakfast and maize-based snacks	800

5. Impacts of mycotoxins

5.1. Economic effects

Mycotoxins presence in food chain can have economic consequences and it has been estimated by the Food and Agriculture Organization (FAO) that approximately 25% of cereals produced worldwide are contaminated with mycotoxins leading to huge losses (Richard et al. 2003). This contamination can also lead to the disruption of trade balance and leads to increased food waste specifically in developing countries where food security is already a problem. Mycotoxins also add significant costs due to the price of sampling, analysis, control methods, and subsequent health costs.

5.2. Health effects

Exposure to mycotoxins is mostly significant through the ingestion of contaminated food. Naturally, this exposure would be to a group of mycotoxins rather than a single one and it could be direct through consuming contaminated plant-based foods or indirect through the consumption of carry-over mycotoxins and their metabolites in animal products such as milk, meat, and eggs (Bosco & Mollea 1983).

Exposure to high levels of mycotoxins during a short period could induce acute toxicity known as mycotoxicosis that include several symptoms such as liver damage, kidney damage, immune-suppression, nausea, vomiting, diarrhea, and skin irritations. Those symptoms could also be aggravated in the presence of other factors such as malnutrition, vitamin deficiency, infections, and disease and is impacted by age, health, and gender of the affected person, as well (Richard et al. 2003; Bennett & Klich 2003).

On the other hand, exposure to low levels of mycotoxins and their metabolites over an extended period may result in chronic toxicity and irreversible health effects due to their accumulation along with their metabolites in different body organs (Richard et al. 2003). Many studies have established the carcinogenic properties of several mycotoxins as they were proved to be hepatotoxic, genotoxic, immunosuppressive, estrogenic, nephrotoxic, and teratogenic (Smith et al. 2016). Accordingly, the International Agency for Research on Cancer have classified mycotoxins as carcinogenic to humans or potentially carcinogenic **(Table 3)**. Mycotoxins could also be neurotoxic and cause developmental effects during pregnancy (Leslie et al. 2008).

Aflatoxins (B_1, B_2, G_1, G_2, and M_1)

Ochratoxin A
Sterigmatocystin
Fumonisin B_1

Deoxynivalenol
Patulin
T-2 toxin
Zearalenone

Figure 3: IARC classification of different mycotoxins (International Agency for Research on Cancer 2002; International Agency for Research on Cancer 2010; Ostry et al. 2017).

6. Conditions affecting mycotoxin contamination in Lebanon

In Lebanon, several factors affect fungal attack incidence and mycotoxin contamination in local and imported foodstuff. Those factors are mainly: the Lebanese weather and climate, poor agricultural practices, poor storage practices, and the weakness of the food safety system. In Lebanon, the weather is humid to sub-humid in the winter and shifts to sub-tropical with high temperatures and humidity in dry seasons (Karam 2002). This weather is considered favorable for fungal attacks and could lead to the contamination of locally planted crops with fungi and mycotoxins. Additionally, poor agricultural practices on the field further aggravate this problem and in fact, a previous study reported the contamination of Lebanese durum wheat samples collected from field where AFB1 and OTA were found in 71.8% and 84.6%, with 35.2% and 23.7% of samples with contamination levels exceeding the limits, respectively (Joubrane et al. 2011). Add to that, poor storage practices in warehouses and in food production outlets lead to more contamination especially since many warehouses in Lebanon were found to lack control over storage conditions including temperature and humidity, in addition to, haphazard storage leading to more pest and rodent attacks. Also, a previous study reported the contamination of stored wheat from the Ministry of Economy and Trade warehouses where AFB1 and OTA were found both in 48.3% of samples with 24.3% and 27% of samples with contamination levels exceeding the limits, respectively (Joubrane et al. 2020). Finally, the Lebanese food sector has been faced for long with a major challenge represented in the weakness of the national food safety system. The system that had been governed by a series of out-of-date laws and decrees since the 1961 Ministry of Public Health law, had for long followed a multidisciplinary approach through which nine different agencies were responsible for food safety namely; the Ministry of Agriculture (MOA), Ministry of Public Health (MOPH), Ministry of Economy and Trade (MOET), Ministry of Finance, Ministry of Interior, Ministry of Tourism, Ministry of Industry, National Council for Scientific Research (CNRS), and the Lebanese Standards Institution (LIBNOR) (El-Jardali et al. 2014). The presence of all those authorities that possessed overlapping functions contributed negatively to the application of food safety measures, increased bureaucracy, and led to job duplication and fragmentation. Furthermore, the absence of coordination, monitoring, and accountability among one another led to more regression in the food safety situation (El-Jardali et al. 2014). Even inspection programs were deficient, and according to El Jardali et al., "it was almost non-existent for both local and imported foods, and most products supplied to markets lacked any type of quality control" (El-Jardali et al. 2014). Monitoring and surveillance programs were also deficient which led to underreporting of food safety hazards and the lack of accountability measures such as sanctions imposed on violators. This scheme led eventually to the deterioration of the food control system and the dominance of wrong and fraudulent practices in the food sector in a way that threatened public health in Lebanon. Recently, in November 2015, a

Food Safety Law was endorsed by the Lebanese Parliament following a huge food safety scandal that involved many food establishments including restaurants, supermarkets, and food industries. The recent law aimed at controlling and enhancing the food safety system through imposing strict regulatory actions, monitoring and surveillance programs, and firm corrective measures. It also included the establishment of the Food Safety Lebanese Commission (FSLC) that is responsible directly for enforcing the new law through several activities including: setting food safety regulations, coordinating between different authorities, monitoring food safety practices, conducting national studies and compiling statistical data, directing traceability measures, collecting samples from food establishments, performing risk analysis, and receiving food safety complaints from Lebanese citizens, etc…(Lebanese Parliment 2015; Cortas 2018). Nevertheless, since then, slow progress was made and the FSLC has not been put yet into action due to political instability which unfortunately led to the further perpetuation of the previous food safety system. This mentioned weakness of the food safety system was reflected through many aspects including the prevalence of mycotoxins in Lebanese foods. Some studies that assessed the level of contamination in Lebanese food products with different mycotoxins such as AFs, AFM1, OTA, deoxynivalenol… showed moderate to high levels of contamination and recommended the continuous monitoring of mycotoxin levels in Lebanese food through further studies. The prevalence of mycotoxins in Lebanese food could be related to many factors including the fact that mycotoxin monitoring is almost absent in food establishments and mycotoxin analysis is performed solely for food samples at ports of entry into the country where imported food is supposedly admitted or rejected according to its conformity with the Lebanese regulations, nonetheless, many violations are also expected to be taking place in such proximities leading to the wrongful admission of contaminated samples. In addition to that, sampling procedures may not be always executed in proper ways, therefore, introducing bias into analysis.

OBJECTIVES

Many studies on mycotoxins were conducted in Lebanon, each study has adopted a different approach, analysis method, and data representation form.

The main objective of this database is to make the occurrence data of different mycotoxins readily available and accessible in a uniform way of presentation. It also aims at summarizing each study's method, objectives, analysis methods, etc. The database aims as well to present a summary of exposure data presented in the studies of different mycotoxins in the Lebanese population.

Finally, a main objective behind this database is to facilitate the work of academics, policymakers, food safety organizations and specialists, and food mycology researchers in Lebanon.

METHODOLOGY

Different studies done in Lebanon were obtained. In total, 21 studies were found that discuss mycotoxin contamination ranging from 2004 till 2021. Mycotoxin data were reported in the form of positive samples, samples exceeding the limit set by the European Commission that is applied in Lebanon by LIBNOR, and the range of contamination. Additionally, wherever reported exposure to mycotoxins was also included. Then different tested commodities were distributed according to the Lebanese Cedar Food Guide specified in the Food-Based Dietary Guidelines in Lebanon (Hwalla et al. 2013), into 4 main groups namely:

Group 1: Cereals
Group 2: Meats, eggs, legumes, nuts, and seeds
Group 3: Milk and dairy products
Group 4: Solid fats, oils, sugar, and salt

Three other groups were added to include the foods tested in the different studies namely:

Group 5: Traditional dishes, cultural food, and other dishes
Group 6: Beverages
Group 7: Seasonings

Work Flow-Chart

A systematic search of available databases was conducted to review and extract required published articles of mycotoxin research in Lebanon and under-review articles were requested from different authors

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Occurrence and exposure data were extracted from the studies

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Data was organized in the form of positive samples, samples exceeding the limit set by the European Commission that is applied in Lebanon by LIBNOR, and the range of contamination

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Data was organized according to mycotoxins occurrence in commodities distributed according to four different food groups from the Lebanese Cedar Food Guide in the Food-Based Dietary Guidlines in Lebanon. Three other food groups were added to include other food items.

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In total:

Number of studies: 21

Types of Mycotoxins tested: AFB1, AFB2, AFG1, AFG2, AFM1, OTA, DON, NIV, FB1, FB2, HT-2, T2, ZEA, TeA, AOH, AME, ALT, and TTX

PRESENTATION OF DATA

1. **PRESENTATION OF STUDIES REPORTING MYCOTOXIN'S CONTAMINATION IN LEBANON**

Table 3: Summary of studies that reports mycotoxin contamination in Lebanon

Year	Published data in Lebanon
2004	Authors: Hind Assaf, Anne-Marie Betbeder, Edmond E Creppy, Marc Pallardy, and Hayat Azouri Title: Ochratoxin A levels in human plasma and foods in Lebanon Tested mycotoxin(s): OTA Description: OTA was tested in wheat, burghul, beans, lentils, maize, rice, and beer. OTA was also tested in plasma samples obtained from healthy individuals Analysis method: HPLC-FLD Ref: (Assaf et al. 2004)
2006	Authors: André El Khoury, Toufic Rizk, Roger Lteif, Hayat Azouri, Marie-Line Delia, and Ahmed Lebhiri Title: Occurrence of ochratoxin A and aflatoxin B1 producing fungi in Lebanese grapes and ochratoxin A content in musts and finished wines during 2006 Tested mycotoxin(s): OTA Description: This study tests the occurrence of filamentous fungi isolated from Lebanese wine-grapes and their ability to produce AFB1 and OTA. Occurrence of OTA was also tested in handmade grape musts and finished red wine samples. Analysis method: IAC + HPLC-FLD Ref: (El Khoury et al. 2006)
2008	Authors: André El Khoury, Toufic Rizk, Roger Lteif, Hayat Azouri, Marie-Line Delia, and Ahmed Lebhiri Title: Fungal contamination and aflatoxin B1 and ochratoxin A in Lebanese wine-grapes and musts Tested mycotoxin(s): AFB1 & OTA Description: Fungal strains were isolated from Lebanese grapes during 2005. In this study, the occurrence of OTA and AFB1 in handmade grape musts was also reported Analysis method: IAC + HPLC-FLD Ref: (El Khoury et al. 2008)
2009	Authors: Lama Soubra, Dolla Sarkis, Christo Hilan, and Philippe Verger

Year	Published data in Lebanon
	Title: Occurrence of total aflatoxins, ochratoxin A and deoxynivalenol in foodstuffs available on the Lebanese market and their impact on dietary exposure of children and teenagers in Beirut Tested mycotoxin(s): AFB1, OTA, & DON Description: In this study, mean levels of mycotoxins were calculated for different food items obtained from major retail outlets throughout Lebanon. Food consumption data was also obtained to calculate mycotoxins exposure. Analysis method: - Ref: (Soubra et al. 2009) Note: Data reported in this database for mean contamination in this study were data calculated on the lower bound estimate, i.e. the undetected values were replaced by zero
2011	Authors: Assem Elkak, Mohamad Abbas, and Oula El Atat Title: A survey on the occurrence of aflatoxin M1 in raw and processed milk samples Tested mycotoxin(s): AFM1 Description: This study reported the occurrence of AFM1 in cow and goat milk samples obtained either from loal small farms or markets. Analysis method: ELISA Ref: (Elkak et al. 2011)
2011	Authors: Assem Elkak, Mohamad Abbas, and Oula El Atat Title: Occurrence of aflatoxin M1 in cheese processed and marketed in Lebanon Tested mycotoxin(s): AFM1 Description: This study investigated the level of AFM1 in various locally produced and imported cheese available on the Lebanese markets. Analysis method: ELISA Ref: (Elkak et al. 2011)
2011	Authors: André El Khoury, Ali Atoui, and Joseph Yaghi Title: Analysis of aflatoxin M1 in milk and yogurt and AFM1 reduction by lactic acid bacteria used in Lebanese industry Tested mycotoxin(s): AFM1 Description: The study reported the presence and levels of AFM1 in locally produced liquid milk, powdered milk, and yogurt. Additionally, lactic acid bacteria used in the Lebanese traditional dairy industry were tested for their ability to reduce AFM1 levels. Analysis method: ELISA

Year	Published data in Lebanon
	Ref: (El Khoury et al. 2011)
2011	Authors: Karine Joubrane, André El Khoury, Roger Lteif, Toufic Rizk, Mireille Kallassy, Christo Hilan, and Richard Maroun Title: Occurrence of aflatoxin B1 and ochratoxin A in Lebanese cultivated wheat Tested mycotoxin(s): AFB1 & OTA Description: In this study, fungal species were isolated from Lebanese cultivated wheat collected at pre-harvest stage from different locations in Bekaa area and studied for their capacity to produce aflatoxins and ochratoxin A. Additionally, wheat samples were analyzed for the levels of AFB1 and OTA. Analysis method: HPLC-FLD Ref: (Joubrane et al. 2011)
2014	Authors: Hussein F. Hassan and Zeina Kassaify Title: The risks associated with aflatoxins M1 occurrence in Lebanese dairy products Tested mycotoxin(s): AFM1 Description: Milk and dairy products collected from the Bekaa region were studied for the occurrence of AFM1 in different seasons of fall and spring. FFQs were used in this study to obtain data on milk and dairy consumption. Analysis method: ELISA Ref: (Hassan & Kassaify 2014)
2014	Authors: F. Raad, Lara Nasreddine, Christo Hilan, M. Bartosik, and Dominique Parent Massin Title: Dietary exposure to aflatoxins, ochratoxin A and deoxynivalenol from a total diet study in an adult urban Lebanese population Tested mycotoxin(s): AFM1 Description: This study aimed at evaluating the dietary exposure of an adult Lebanese urban population to mycotoxins by the means of total diet study approach. Composite sampling approach was applied in this study and the results were reported for each composite food group rather than for every single sample. Additionally, FFQs were used to obtain data on the consumption of particular food products. Analysis method: IAC + HPLC-FLD Ref: (Raad et al. 2014)
2018	Authors: Nada El Darra, Lucia Gambacorta, and Michele Solfrizzo Title: Multimycotoxins occurrence in spices and herbs commercialized in Lebanon

Year	Published data in Lebanon
	Tested mycotoxin(s): AFB1, AFB2, AFG1, AFG2, OTA, FB1, FB2, HT-2, T-2, ZEA, DON, and NIV Description: Spices and herbs samples that originate from 15 different countries were collected from Lebanese markets and studied for multi-mycotoxin occurrence. The samples collected were either pre-packaged or collected as samples from large unpackaged batches. Analysis method: UPLC-MS/MS Ref: (Darra et al. 2018)
2019	Authors: Jomana Elaridi, Hani Dimassi, and Hussein Hassan Title: Aflatoxin M1 and ochratoxin A in baby formulae marketed in Lebanon: occurrence and safety evaluation Tested mycotoxin(s): AFM1 & OTA Description: Infant formulae samples were collected from the Lebanese market and analyzed over two production dates for every brand. Analysis method: ELISA Ref: (Elaridi et al. 2019)
2019	Authors: Jomana Elaridi, Osama Yamani, Amira Al Matari, Saada Dakroub, and Zouhair Attieh Title: Determination of ochratoxin A (OTA), ochratoxin B (OTB), T-2 and HT-2 toxins in wheat grains, wheat flour, and bread in Lebanon by LC-MS/MS Tested mycotoxin(s): OTA, OTB, T-2, and HT-2 Description: This study tested the occurrence of mycotoxins in wheat grains, wheat flour, and bread collected from the main mills in Lebanon. Analysis method: LC-MS/MS Ref: (Elaridi et al. 2019)
2019	Authors: Lucia Gambacorta, Nada El Darra, Rajaa Fakhoury, Antonio F. Logrieco, and Michele Solfrizzo Title: Incidence and levels of alternaria mycotoxins in spices and herbs produced worldwide and commercialized in Lebanon Tested mycotoxin(s): TeA, AOH, AME, ALT, & TTX Description: Spices and herbs samples that originate from 15 different countries were collected from Lebanese markets and studied for alternaria mycotoxins occurrence. The samples collected were either pre-packaged or collected as samples from large unpackaged batches. Analysis method: LC-MS/MS

Year	Published data in Lebanon
	Ref: (Gambacorta et al. 2019)
2020	Authors: Rouaa Daou, Charbel Afif, Karine Joubrane, Lydia Rabbaa Khabbaz, Richard Maroun, Ali Ismail, and André El Khoury Title: Occurrence of aflatoxin M1 in raw, pasteurized, and UHT cows' milk, and dairy products in Lebanon Tested mycotoxin(s): AFM1 Description: In this study occurrence of AFM1 was studied in raw cows' milk samples collected from farms, collection centers, cooperatives, and peddlers in seven Lebanese governorates. Additionally, AFM1 occurrence was reported in dairy products collected from dairy industry and supermarkets in Lebanon. FFQs were also used to obtain data on consumption of milk and dairy products among the Lebanese population. Analysis method: IAC + HPLC-FLD Ref: (Daou et al. 2020)
2020	Authors: Karine Joubrane, Dima Mnayer, André El Khoury, Anthony El Khoury, and Elie Awad Title: Co-occurrence of aflatoxin B1 and ochratoxin A in Lebanese stored wheat Tested mycotoxin(s): AFB1 & OTA Description: This study reported the occurrence of AFB1 and OTA in stored Lebanese durum wheat collected over a range of six periods of time from two official warehouses in Lebanon. Analysis method: IAC + HPLC-FLD Ref: (Joubrane et al. 2020)
2021	Authors: Rouaa Daou, Karine Joubrane, Lydia Rabbaa Khabbaz, Richard G. Maroun, Ali Ismail, and André El Khoury Title: Aflatoxin B1 and ochratoxin A in imported and Lebanese wheat and-products Tested mycotoxin(s): AFB1 & OTA Description: In this study occurrence of mycotoxins were reported in wheat samples collected from port shipments, silos, and mills and supermarkets in Lebanon. Wheat products collected from supermarkets, bakeries, and mills were also analyzed for mycotoxin contamination. Additionally, FFQs were used to obtain data on the consumption of wheat and wheat-derived products in Lebanon. Analysis method: IAC + HPLC-FLD Ref: (Daou et al. 2021)

Year	Published data in Lebanon
2022	Authors: Rouaa Daou, Karine Joubrane, Lydia Rabbaa Khabbaz, Richard G. Maroun, Ali Ismail, and André El Khoury Title: Occurrence and exposure assessment of aflatoxin M1, aflatoxin B1, and ochratoxin A in different food items selected from the Lebanese food basket: a summary Tested mycotoxin(s): AFB1, AFM1, & OTA Description: In this study, summary of occurrence of mycotoxins was reported in different foodstuff including milk, dairy products, wheat and wheat products, spices, herbs, nuts, and beer. Additionally, FFQs were used to obtain data on the consumption of different food products in Lebanon. Analysis method: IAC + HPLC-FLD Ref: (Daou et al., 2022a)
2022	Authors: Rouaa Daou, Maha Hoteit, Sahar Nahle, Ayoub Al-Jawaldeh, Mohamad Koubar, Samah Doumiati, and André El Khoury Title: Occurrence of AFB1 in infants and young children's food products, and prevalence of AFM1 and its dietary exposure through baby formula in Lebanon Tested mycotoxin(s): AFB1 & AFM1 Description: Occurrence of AFM1 in infant formula and of AFB1 in infant and children food samples was reported in this study. AFM1 exposure in infants through formula was also reported. Analysis method: ELISA Ref: (Daou et al., 2022b)
2022	Authors: Hussein F. Hassan, Rita Kordahi, Hani Dimassi, André El Khoury, Rouaa Daou, Nisreen Alwan, Samar Merhi, Joyce Haddad, and Layal Karam Title: Aflatoxin B1 in rice: effects of storage, duration, grain type and size, production site and season Tested mycotoxin(s): AFB1 Description: Occurrence of AFB1 in packed rice marketed in Lebanon was reported in addition to its exposure from rice consumption. The effects of storage duration, grain type and size, production site and season were also evaluated. Analysis method: ELISA Ref: (Hassan et al. 2022)

Year	Published data in Lebanon
2022	Authors: Hussein F. Hassan, Alissar Abou Ghaida, Abeer Charara, Hani Dimassi, Hussein Faour, Rayan Nahouli, Layal Karam, Nisreen Alwan Title: Exposure to ochratoxin A from rice consumption in Lebanon and United Arab Emirates: a comparative study Tested mycotoxin(s): OTA Description: Occurrence of OTA was reported in this study in packed rice marketed in Lebanon and United Arab Emirates. Additionally, exposure to this toxin from rice consumption was evaluated. The effects of storage duration, grain type and size, production site and season were also evaluated. Analysis method: ELISA Ref: (Hassan et al., 2022b)

2. Presentation of data on mycotoxin's contamination according to food groups

Table 4: Mycotoxin's contamination reported in cereals group

Group 1: cereals									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard Deviation (±)**	**Range (µg/kg)**	**Reference**
2004	Wheat	OTA	32	12	0	0.15	0.03	N.A.	(Assaf et al. 2004)
	Burghul		13	61	0	0.21	0.21	N.A.	
	Maize		9	0	0	0	0	0	
	Rice		13	0	0	0	0	0	
2009	Bread	AFT	80	170	0	0.2-0.61	N.A.	0.50-1.30	(Soubra et al. 2009)*
		OTA	40	40	0	0.55-0.83	N.A.	0.50-2.00	
		DON	40	55	10	176	N.A.	80-700	
	Cornflakes	AFT	30	0	0	0-0.5	N.A.	0	
		OTA	10	20	0	0.22-0.56	N.A.	1	
		DON	20	70	0	58	N.A.	60-100	
		AFT	40	20	0	0.22-0.62	N.A.	0.50-1.30	

Group 1: cereals									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard Deviation (±)**	**Range (µg/kg)**	**Reference**
	Kaak Asrounieh	OTA	20	40	0	0.46-0.76	N.A.	0.50-2.10	
		DON	20	50	0	50	N.A.	75-130	
	Kaak tea	AFT	40	20	0	0.29-0.69	N.A.	0.50-2.10	
		OTA	20	40	0	0.48-0.78	N.A.	0.90-2.00	
		DON	20	50	0	70	N.A.	70-220	
	Toast	AFT	40	28	0	0.38-0.75	N.A.	0.50-2.00	
		OTA	20	30	0	0.50-0.80	N.A.	1.00-2.00	
		DON	20	50	0	52	N.A.	90-120	
	Rice (steamed)	OTA	13	0	0	0-0.25	N.A.	0	
2008	Lebanese Cultivated wheat (collected from fields in Bekaa)	AFB1	78	71.8	29.5	0.89	N.A.	N.A.	(Joubrane et al. 2011)
		OTA		84.6	28.2	1.30	N.A.	N.A.	
2009		AFB1	78	80.7	41	1.4	N.A.	N.A	
		OTA		79.5	19.2	1.3	N.A.	N.A.	
2014	Bread and toast	AFB1	N.A.	N.A.	N.A.	0.24 – 0.28	N.A.	N.A.	(Raad et al. 2014)*
		OTA	N.A.	N.A.	N.A.	0.30	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	524.17	N.A.	N.A.	
	Pasta and other cereals	AFB1	N.A.	N.A.	N.A.	0 – 0.01	N.A.	N.A.	
		OTA	N.A.	N.A.	N.A.	0.18	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	62.5	N.A.	N.A.	
	Rice and rice-based products	AFB1	N.A.	N.A.	N.A.	0 – 0.01	N.A.	N.A.	
		OTA	N.A.	N.A.	N.A.	0.68	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	322	N.A.	N.A.	
	Pizza and pies	AFB1	N.A.	N.A.	N.A.	0.043-0.048	N.A.	N.A.	
		OTA	N.A.	N.A.	N.A.	0.22	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	121.16	N.A.	N.A.	
2019	Wheat grains	OTA	50	0	0	0	0	0	(Elaridi et al. 2019)
		OTB		0	0	0	0	0	
		T-2		0	0	0	0	0	
		HT-2		0	0	0	0	0	

Group 1: cereals									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard Deviation (±)**	**Range (µg/kg)**	**Reference**
	Wheat flour	OTA	50	8	2	1.9	0.20	0.60-3.40	
		OTB		0	0	0	0	0	
		T-2		0	0	0	0	0	
		HT-2		0	0	0	0	0	
	Bread	OTA	37	0	0	0	0	0	
		OTB		0	0	0	0	0	
		T-2		0	0	0	0	0	
		HT-2		0	0	0	0	0	
2020	Durum wheat (warehouse A)	AFB1	150	58.7	23.3	2.54	N.A.	1.05-7.36	(Joubrane et al. 2020)
		OTA		52	28.6	2.81	N.A.	0.51-5.11	
	Durum wheat (warehouse B)	AFB1	150	38	25.3	2.32	N.A.	1.09-5.11	
		OTA		44.6	25.3	2.93	N.A.	1.01-7.31	
2021	Wheat (port)	AFB1	59	35.6	0	0.11	0.15	0.20-0.44	(Daou et al. 2021)
		OTA		100	33.9	4.68	7.34	0.07-27.30	
	Wheat (silos)	AFB1	9	33.3	0	0.04	0.08	0.05-0.24	
		OTA		100	0	0.25	0.10	0.20-0.53	
	Wheat (supermarkets and mills)	AFB1	16	93.8	0	0.30	0.22	0.13-0.81	
		OTA		100	0	0.26	0.40	0.07-1.72	
	Bulgur	AFB1	38	65.8	2.6	0.32	1.00	0.04-6.21	
		OTA		100	18.4	4.62	13.0	0.02-63.3	
	Flour	AFB1	28	100	0	0.19	0.07	0.10-0.37	
		OTA		100	7.10	0.74	2.03	0.06-8.18	
	Pita Bread	AFB1	45	4.4	0	0.01	0.03	0.07-0.16	
		OTA		100	6.7	1.18	1.89	0.22-11.90	
	Baguette	AFB1	16	75	0	0.20	0.15	0.15-0.44	
		OTA		100	0	0.20	0.13	0.07-0.47	
	Toast	AFB1	16	87.5	0	0.28	0.20	0.007-0.57	
		OTA		100	62.5	4.11	3.22	0.08-8.86	

Group 1: cereals									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard Deviation (±)**	**Range (µg/kg)**	**Reference**
	Breakfast cereals	AFB1	10	100	0	0.16	0.01	0.14-0.17	
		OTA		100	0	0.27	0.13	0.08-0.44	
	Kaak	AFB1	26	100	0	0.46	0.36	0.09-1.66	
		OTA		100	30.80	2.03	2.65	0.07-6.97	
2022	Cereal-based complementary baby and child food	AFB1	42	0	0	0	0	0	(Daou et al., 2022b)
2022	Packed rice	AFB1	105	100	1	0.50	0.30	0.06-2.08	(Hassan et al., 2022)
2022	Packed rice	OTA	105	100	1	0.42	0.09	0.02-4.98	(Hassan et al., 2022b)

N.A.: data not available in the study

* Means reported in the table according to two values are based on lower bound calculation (the undetected values were replaced by zero while the unquantified were replaced by limit of detection) and upper bound calculation (the undetected values were replaced by limit of detection while the unquantified were replaced by limit of quantification)

Table 5: Mycotoxin contamination reported in meats, eggs, legumes, nuts, and seeds group in different studies

Group 2: Meats, eggs, legumes, nuts, and seeds									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard Deviation**	**Range (µg/kg)**	**Reference**
2004	Beans	OTA	9	0	0	0	0	0	(Assaf et al. 2004)
	Lentil		13	7.6	0	0.11	N.A.	N.A.	
	Peas		13	0	0	0	0	0	
2009	Beans (cooked)	AFT	100	0	0	0-0.42	N.A.	0	(Soubra et al. 2009)*
		OTA	13	0	0	0-0.04	N.A.	0	
	Chickpeas (cooked)	AFT	100	0	0	0-0.25	N.A.	0	
		OTA	14	0	0	0-0.03	N.A.	0	
	Lentils (cooked)	AFT	130	0	0	0-0.25	N.A.	0.50-2.10	
		OTA	13	16	0	0.08-0.12	N.A.	N.A.	

Group 2: Meats, eggs, legumes, nuts, and seeds									
Year	Type	MCT	Number of samples	Positive samples (%)	Samples exceeding limit (%)	Mean (µg/kg)	Standard Deviation	Range (µg/kg)	Reference
	Nuts	AFT	200	40	8	1-1.33	N.A.	0.50-8.00	
		OTA	20	0	0	0-0.50	N.A.	0	
	Peas (cooked)	OTA	12	0	0	0-0.04	N.A.	0	
2014	Pulse	AFB1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	(Raad et al. 2014)*
		OTA	N.A.	N.A.	N.A.	0	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	31.25	N.A.	N.A.	
	Nuts, seeds, olives, and dried dates	AFB1	N.A.	N.A.	N.A.	0.18 – 0.26	N.A.	N.A.	
		OTA	N.A.	N.A.	N.A.	0.08	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	62.5	N.A.	N.A.	
2022	Nuts	AFB1	71	98.6	0	0.40	0.296	0.056-1.780	(Daou et al., 2022a)

* Means reported in the table according to two values are based on lower bound calculation (the undetected values were replaced by zero while the unquantified were replaced by limit of detection) and upper bound calculation (the undetected values were replaced by limit of detection while the unquantified were replaced by limit of quantification)

Table 6: Mycotoxin contamination reported in milk and dairy products group in different studies

Group 3: Milk and dairy products									
Year	Type	MCT	Number of samples	Positive samples (%)	Samples exceeding limit (%)	Mean (µg/kg)	Standard deviation	Range (µg/kg)	Reference
2011	Raw cow milk	AFM1	35	N.A.	60.7	N.A.	N.A.	0.00263-0.126	(Elkak et al. 2011)
	Raw goat milk		3	N.A.	0	N.A.	N.A.	0	
	Local pasteurized cow milk		14	N.A.	5.9	N.A.	N.A.	0.00518-0.0553	

Group 3: Milk and dairy products									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard deviation**	**Range (µg/kg)**	**Reference**
	Imported pasteurized cow milk		11	N.A.	17.6	N.A.	N.A.	0.00327-0.0844	
	Powdered cow milk		13	N.A.	0	N.A.	N.A.	0.00918-0.0165	
	Powdered goat milk		1	N.A.	0	N.A.	N.A.	0	
	Total raw milk		38	73.6	44.7		N.A.	0.00263-0.126	
	Total pasteurized milk		25	68	16		N.A.	0.00327-0.0844	
	Total powdered milk		14	35.7	0		N.A.	0.00918-0.0165	
2011	Cheese from local farms	AFM1	53	71.7	49	0.13	N.A.	0.00561-0.315	(Elkak et al. 2011)
	Cheese from dairy industry		38	55.2	47.6	0.05	N.A.	0.00157-0.077	
	Imported cheese		20	80	0	0.003	N.A.	0.00126-0.00395	
	Total cheese kinds		111	68	32.4	N.A.	N.A.	0.00561-0.315	
	Halloum		31	67.7	38	N.A.	N.A.	N.A.	
	Naboulsi		7	71.4	20	N.A.	N.A.	N.A.	
	Feta		4	75	33.3	N.A.	N.A.	N.A.	
	Baladi		5	80	25	N.A.	N.A.	N.A.	
	Akkawi (low salt)		23	60.8	14.2	N.A.	N.A.	N.A.	
2011	Milk	AFM1	64	40.6	17.2	N.A.	N.A.	N.A.	(El Khoury et al. 2011)
	Yogurt		64	32.8	6.3	N.A.	N.A.	N.A.	
2013	Raw milk (April data)	AFM1	12	N.A.	N.A.	0.01074	0.00201	N.A.	(Hassan & Kassaify 2014)
	Pasteurized milk (April data)		23	N.A.	N.A.	0.00965	0.00201	N.A.	

Group 3: Milk and dairy products									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard deviation**	**Range (µg/kg)**	**Reference**
	Sheep milk (April data)		8	N.A.	N.A.	0.00272	0.09×10^{-3}	N.A.	
	Goat milk (April data)		8	N.A.	N.A.	0.00570	0.15×10^{-3}	N.A.	
	Cow milk (April data)		19	N.A.	N.A.	0.02218	0.0058	N.A.	
	Cow's raw milk (total)		60	N.A.	N.A.	0.02239	0.0029	N.A.	
	Cow's pasteurized milk (total)		60	N.A.	N.A.	0.01951	0.0029	N.A.	
	Akkawi (total)		64	48	39	0.05256	0.00281	N.A.	
	Halloum (total)		64	56	31	0.03540	0.00281	N.A.	
	Yogurt (total)		68	72	14	0.02455	0.00272	N.A.	
	Shanklish (total)		64	56	41	0.04378	0.00281	N.A.	
	Karishe (total)		68	84	9	0.02643	0.00272	N.A.	
	Ashta (total)		60	75	24	0.03723	0.00290	N.A.	
	Total cow's milk and dairy		508	N.A.	N.A.	0.04028	0.00197	N.A.	
	Dairy products (fall)		224	11.8	11.8	0.02516	0.00197	N.A.	
	Dairy products (spring)		195	27.8	27.8	0.04028	0.00197	N.A.	
2014	Milk and milk-based beverages	N.A.	N.A.	N.A.	N.A.	0.11-0.18	N.A.	N.A.	(Raad et al. 2014)*
	Cheese	N.A.	N.A.	N.A.	N.A.	0-0.05	N.A.	N.A.	
	Yogurt and yogurt-based product	N.A.	N.A.	N.A.	N.A.	0-0.05	N.A.	N.A.	
2019	Infant formula	AFM1	84	88	31	0.2001	0.0013	0-0.0481	(Elaridi et al. 2019)
		OTA		95	33	0.37	0.0001	0-0.96	

Group 3: Milk and dairy products									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard deviation**	**Range (µg/kg)**	**Reference**
2020	Raw cow milk	AFM1	701	58.8	28	0.04	0.051	0.011-0.440	(Daou et al. 2020)
	Pasteurized and UHT cow milk		11	90.9	54.5	0.07	0.068	0.013-0.219	
	Yogurt		28	64.3	35.7	0.09	0.152	0.015-0.545	
	Strained yogurt (Labneh)		27	88.9	81.5	0.20	0.348	0.037-1.843	
	Ayran yogurt		9	88.9	44.4	0.24	0.425	0.020-0.315	
	Favored yogurts and milkshakes		10	70	30	0.08	0.137	0.018-0.397	
	Halloum		26	65.4	42.3	0.05	0.054	0.019-0.175	
	Akkawi		20	60	50	0.06	0.081	0.044-0.300	
	Double Cream		23	52.2	34.8	0.15	0.424	0.019-1.984	
	Bulgarian and Chanklish		3	33.3	33.3	0.03	0.053	N.A.	
	Ashta		4	25	0	0.05	0.010	N.A.	
	Karishe		6	50	33.3	1.63	2.961	0.033-7.350	
	Total dairy products		156	66	45.5	0.17	0.659	0.015-7.350	
2022	Infant formula	AFM1	42	9.5	9.5	0.00572	0.014 $\times 10^{-3}$	0.02954 – 0.14016	(Daou et al., 2022b)

[*] Means reported in the table according to two values are based on lower bound calculation (the undetected values were replaced by zero while the unquantified were replaced by limit of detection) and upper bound calculation (the undetected values were replaced by limit of detection while the unquantified were replaced by limit of quantification)

Table 7: Mycotoxin contamination reported in solid fats, oils, sugar, and salt group in different studies

Group 4: solid fats, oils, sugar, and salt									
Year	Type	MCT	Number of samples	Positive samples (%)	Samples exceeding limit (%)	Mean (µg/kg)	Standard deviation	Range (µg/kg)	Reference
2009	Biscuits	AFT	70	10	0	0.11-0.56	N.A.	0.50-2.00	(Soubra et al. 2009)*
		OTA	20	20	2	0.55-0.87	N.A.	1.00-5.00	
		DON	20	50	0	31	N.A.	60-70	
	Cakes	AFT	30	10	0	0.11-0.56	N.A.	0.50-1.40	
		OTA	20	30	0	0.27-0.64	N.A.	0.50-1.25	
		DON	20	75	0	60	N.A.	60-100	
	Croissant	AFT	30	10	0	0.11-0.56	N.A.	0.90-1.20	
		OTA	20	30	0	0.33-0.68	N.A.	1.00-1.30	
		DON	20	50	0	50	N.A.	70-120	
	Doughnuts	AFT	30	17	0	0.19-0.62	N.A.	0.90-1.50	
		OTA	20	20	0	0.18-0.50	N.A.	0.50-1.00	
		DON	20	60	0	60	N.A.	80-130	
	Chocolate	AFT	30	10	3	0.43-0.88	N.A.	1.00-6.00	
		OTA	7	0	0	0-0.05	N.A.	0	
2014	Olive oil, sesame oil, and other oils	AFB1	N.A.	N.A.	N.A.	0	N.A.	N.A.	(Raad et al. 2014)*
	Biscuit and croissant	AFB1	N.A.	N.A.	N.A.	0-0.01	N.A.	N.A.	
		OTA	N.A.	N.A.	N.A.	2.84	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	340.33	N.A.	N.A.	
	Cakes and pastries	AFB1	N.A.	N.A.	N.A.	0.105-0.115	N.A.	N.A.	
		OTA	N.A.	N.A.	N.A.	0.15	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	109.67	N.A.	N.A.	
	Milk based ice-cream and pudding	AFM1	N.A.	N.A.	N.A.	0-0.05	N.A.	N.A.	

* Means reported in the table according to two values are based on lower bound calculation (the undetected values were replaced by zero while the unquantified were replaced by limit of detection) and upper bound calculation (the undetected values were replaced by limit of detection while the unquantified were replaced by limit of quantification)

Table 8: Mycotoxin contamination reported in traditional dishes, cultural food, and other dishes group in different studies

Group 5: Traditional dishes, cultural food, and other dishes									
Year	Type	MCT	Number of samples	Positive samples (%)	Samples exceeding limit (%)	Mean (µg/kg)	Standard Deviation	Range (µg/kg)	Reference
2009	Lahm bi ajin	AFT	40	20	0	0.19-0.60	N.A.	0.50-1.10	(Soubra et al. 2009)*
		OTA	20	25	0	0.25-0.77	N.A.	1	
		DON	20	55	0	88	N.A.	90-240	
	Manakeesh	AFT	40	20	0	0.20-0.60	N.A.	0.90-1.00	
		OTA	20	25	0	0.26-0.63	N.A.	0.90-1.15	
		DON	20	50	0	88	N.A.	100-300	
	Pizza	AFT	20	20	0	0.24-0.66	N.A.	0.90-1.50	
		OTA	20	25	0	0.27-0.75	N.A.	1.00-1.50	
		DON	20	50	0	85	N.A.	100-200	
	Chickpeas (moutabal)	AFT	100	0	0	0-0.37	N.A.	0	
		OTA	14	0	0	0-0.04	N.A.	0	
	Falafel	AFT	100	0	0	0-0.23	N.A.	0	
		OTA	14	0	0	0-0.02	N.A.	0	
	Meat Kibbeh	AFT	40	0	0	0-0.05	N.A.	0	
		OTA	13	39	0	0.02-0.03	N.A.	0.50-1.00	
	Pasta in red sauce	AFT	70	0	0	0-0.35	N.A.	0	
		OTA	4	0	0	0-0.37	N.A.	0	
	Rice with meat	OTA	13	0	0	0-0.18	N.A.	0	
2021	Kishik	AFB1	49	100	2	0.83	0.44	0.11-2.02	(Daou et al. 2021)
		OTA		100	10.2	1.14	1.69	0.02-7.66	

* Means reported in the table according to two values are based on lower bound calculation (the undetected values were replaced by zero while the unquantified were replaced by limit of detection) and upper bound calculation (the undetected values were replaced by limit of detection while the unquantified were replaced by limit of quantification)

Table 9: Mycotoxin contamination reported in beverages group in different studies

Group 6: Beverages									
Year	Type	MCT	Number of samples	Positive samples (%)	Samples exceeding limit (%)	Mean (µg/kg)	Standard deviation	Range (µg/kg)	Reference
2004	Beer	OTA	11	82	0	0.19	0.12	N.A.	(Assaf et al. 2004)
2006	Red wine	OTA	70	60	0	N.A.	N.A.	0.012-0.126	(El Khoury et al. 2006)
	Handmade grapes must		47	57.4	0	N.A.	N.A.	0.011-0.221	
2008	Handmade grapes must	AFB1	47	40	0	N.A.	N.A.	0.010-0.460	(El Khoury et al. 2008)
		OTA		0	0	0	N.A.	0	
2014	Caffeinated beverages	OTA	N.A.	N.A.	N.A.	0.51	N.A.	N.A.	(Raad et al. 2014)
	Alcoholic beverages	OTA	N.A.	N.A.	N.A.	1.47	N.A.	N.A.	
		DON	N.A.	N.A.	N.A.	52.08	N.A.	N.A.	
2022	Beer (alcoholic)	OTA	11	45.5	N.A.	0.36	0.508	0.291-1.367	(Daou et al., 2022a)
	Beer (non-alcoholic)	OTA	11	90.9	N.A.	0.55	0.380	0.176-1.084	

Table 10: Mycotoxin contamination reported in seasonings group in different studies

Group 7: Seasonings									
Year	**Type**	**MCT**	**Number of samples**	**Positive samples (%)**	**Samples exceeding limit (%)**	**Mean (µg/kg)**	**Standard deviation**	**Range (µg/kg)**	**Reference**
2018[1]	Spices	AFB1	94	16	14	193.4	N.A.	2.20-1118.3	(Darra et al. 2018)
		AFT		19	15	168.1	N.A.	2.20-1118.3	
		OTA		30	3	7.1	N.A.	2.00-34.00	
		FB1		64	N.A.	6432.3	N.A.	18.2-113474.5	
		FB2		35	N.A.	230.2	N.A.	15.10-1757.4	
		HT-2		4	N.A.	10	N.A.	6.40-16.7	
		T-2		3	N.A.	7.3	N.A.	3.80-11.9	
		ZEA		30	N.A.	30.6	N.A.	0.40-305.4	
		DON		12	N.A.	1751.4	N.A.	76.5-6850.6	
		NIV		0	N.A.	0	N.A.	0	
	Herbs	AFB1	38	8	8	36.1	N.A.	8.70-62.7	
		AFT		8	5	36.1	N.A.	8.70-62.7	
		OTA		11	0	7	N.A.	4.20-9.8	
		FB1		55	N.A.	2826.4	N.A.	16.1-12410.3	
		FB2		18	N.A.	75.2	N.A.	19.8-214.9	
		HT-2		5	N.A.	18.7	N.A.	0.90-36.6	
		T-2		3	N.A.	4.4	N.A.	4.4	
		ZEA		3	N.A.	0	N.A.	2.8	
		DON		3	N.A.	0	N.A.	589.7	
		NIV		0	0	0	N.A.	0	
2019	Spices	TeA	94	77	N.A.	3311.1	N.A.	N.A.	(Gambacorta et al. 2019)
		AOH		40	N.A.	45.0	N.A.	N.A.	
		AME		44	N.A.	16.3	N.A.	N.A.	
		ALT		7	N.A.	2.1	N.A.	N.A.	
		TTX		40	N.A.	16.8	N.A.	N.A.	
	Herbs	TeA	38	73	N.A.	273.4	N.A.	N.A.	
		AOH		19	N.A.	9.7	N.A.	N.A.	
		AME		51	N.A.	19.1	N.A.	N.A.	
		ALT		0	N.A.	1.3	N.A.	N.A.	
		TTX		30	N.A.	9.8	N.A.	N.A.	
2022	Spices	AFB1	73	100	2.7	0.97	2.679	0.132-18.354	

Group 7: Seasonings									
Year	Type	MCT	Number of samples	Positive samples (%)	Samples exceeding limit (%)	Mean (µg/kg)	Standard deviation	Range (µg/kg)	Reference
		OTA		100	30.1	38.77	80.505	0.017-452.461	(Daou et al., 2022a)
	Herbs	AFB1	54	20.4	0	0.27	0.763	0.069-4.874	
		OTA		44.4	3.7	1.81	4.784	0.020-23.822	

[1] Mean contamination reported in this study is only for positive samples

Exposure data

Exposure to mycotoxins was not evaluated in all studies done, however, where reported exposure was calculated according to different three methods as follows:

Method 1: Mycotoxin analyzed in the plasma of healthy individuals and daily intake of the targeted mycotoxin was estimated through an equation from the mean concentration in all plasma samples.

Method 2: Food consumption data was obtained through FFQ and combined with mean contamination levels. The obtained value was then used to calculate average daily exposure based on average body weight.

Method 3: This method was used for studies on infant formula in which recommended formula intake for infants was used to calculate exposure

Table 11: Exposure of Lebanese population to mycotoxins reported in different studies

Year	Type of food(s) studied	Exposure analysis	MCT	Exposure (ng/ kg bw/d)	Reference
2004	Wheat - Burghul – Beans – Lentil – Maize – Pea – Rice - Beer	Method 1	OTA	**0.23**	(Assaf et al. 2004)
2009	Biscuits - Bread - Cakes - Cornflakes - Doughnats - Kaak assrounieh - Kaak tea - Lahm bi ajin - Manakeesh - Pizza - Toast - Beans cooked - Chickpeas moutabal - Chickpeas cooked - Chocolate - Falafel - Lentils cooked - Meat kibbeh - Nuts - Pasta in red sauce - Peas cooked - Rice steamed - Rice with meat	Method 2	AFT (children)	**1.48-4.37**	(Soubra et al. 2009)
			AFT (teenagers)	**1.26-3.77**	
			OTA (children)	**17.57-38.57**	
			OTA (teenagers)	**14.84-28.77**	
			DON (children)	**545**	
			DON (teenagers)	**409**	
2013	Milk and dairy products	Method 2	AFM1	**0.14**	(Hassan & Kassaify 2014)
2014	Bread and toast Biscuit and Croissant Cakes and pastries Pasta and other cereals Rice and rice-based products Pulses Pizza and pies Olive oil, sesame oil, and other oils Nuts, seeds, olives, and dried fruits Caffeinated beverages Alcoholic beverages Milk and milk-based beverages Cheese Yogurt and yogurt-based products Milk-based ice cream pudding	Method 2	AFB1	**L.B.[1]: 0.63-0.66** **U.B.[2]: 1.40-1.46**	(Raad et al. 2014)
			AFM1	**0.22-0.31**	
			OTA	**4.28**	
			DON	**1560**	
2019	Infant formula	Method 3	AFM1	**0.47**	(Elaridi et al. 2019)
			OTA	**8.70**	
2020	Cows' milk and dairy products	Method 2	AFM1	**0.495**	(Daou et al. 2020)
2021	Wheat and wheat products	Method 2	AFB1	**0.92**	(Daou et al. 2021)
			OTA	**7.6**	

Year	Type of food(s) studied	Exposure analysis	MCT	Exposure (ng/ kg bw/d)	Reference
2022	Spices, herbs, and nuts	Method 2	AFB1	**0.20**	(Daou et al., 2022a)
	Spices and herbs		OTA	**5.04**	
	Beer		OTA	**1.82**	
2022	Infant formula	Method 3	AFM1	**0.67**	(Daou et al, 2022b)
2022	Rice	Method 2	AFB1	**0.1-2**	(Hassan et al., 2022)
2022	Rice	Method 2	OTA	**0.07**	(Hassan et al., 2022b)

[1]L.B.: Lower bound calculation for regular consumers

[2]U.B.: Upper bound calculation for excessive consumers

Future considerations in mycotoxin studies

Previous studies presented in this document have shown that mycotoxin contamination was frequent in Lebanese locally produced food and imported ones. Therefore, future strategies must concentrate on controlling fungal and mycotoxin contamination from the beginning of the food chain until the final stages before food reaches the consumer. The synergistic toxic effects of mycotoxins occurring simultaneously in food products must be considered in future studies, in addition, to the possibility of the occurrence of masked mycotoxins.

It is also very important to assess the effects of the ongoing financial crisis in Lebanon through continuous surveillance studies that reports the occurrence of mycotoxins in different food products, especially since many were not previously found in the Lebanese market before the crisis and that are recently being imported from unknown sources due to their low prices.

Additionally, continuous consumption studies and risk assessments must be performed to verify the suitability of the European regulations on the Lebanese context in what mostly suits and protects the local consumer from mycotoxins' health effects.

Finally, Lebanon is expected to be affected by climate change due to its geographical location on the eastern part of the Mediterranean that has been reported to be warming 20% faster than the global average by the "Mediterranean Action Plan Barcelona Convention" of the UN environment program (UN environment program 2016). Those changes will be evident with an expected increase in the frequency and intensity of droughts, decrease in precipitation, and increase in temperature by 2 to 3˚C (Haddad et al. 2014). This change will shift the dynamics of fungal attacks and eventually Lebanese crops will be more prone to attacks by *Aspergillus spp.* and subsequent aflatoxins contamination. Therefore, it is very important to adopt proactive strategies to mitigate climate change effects on food safety and mycotoxin contamination.

Recommendations for mycotoxin control

To minimize mycotoxin contamination and protect Lebanese consumers from related health effects, there is an urgent need to apply strict food safety measures. Accordingly, several recommendations at different levels of the food chain could be suggested:

- Lebanese borders: strengthen food safety control on the borders to ensure the safety of imported foods and feed through providing border control centers with the essential equipment and training for proper sampling and inspection.
- Laboratories: support official laboratories where food analysis is performed with the equipment, machines, chemical products, etc. Periodic calibration of machines should be performed as well as proficiency tests. Periodical training must also be delivered to laboratory staff.
- Farms: ensure the safety of cultivated Lebanese wheat through training farmers on the proper application of GAP, GHP, and GDP. High-quality resistant seeds should be provided to farmers along with pesticides, fungicides, and fertilizers with clear detailed usage instructions that ensures regulated application according to specific safety guidelines. Inspections

and analysis of cultivated wheat for fungal and/or mycotoxin contamination should be performed before storage in MOET warehouses.

- Storage sites: provide safe storage for both foods and feed through ensuring their safety before storage, improving the infrastructure of storage sites, installing humidity and temperature sensors, and applying GSP. Guidance must be provided as well by the authorities and continuous inspections on different storage sites should be performed.
- Dairy farms: support small dairy farms by providing technical guidance and training to farmers especially in rural areas. Periodic visits and inspections must be implemented and raw milk samples should be collected frequently and analyzed to ensure their safety.
- Dairy industries: ensure safe production through enforcing AFM1 testing of raw milk and powdered milk in cooperatives, collection centers, and dairy industries before processing or storage. Periodic visits and inspections must be performed, as well, and samples of dairy products should be collected frequently and analyzed to ensure their safety.
- Food safety system: strengthen the whole food safety control system by establishing a national food monitoring program, performing periodic inspections, reinforcing strict measures on food safety violators, increasing cooperation between food safety responsible authorities, providing guidance for all food production sectors, and implementing corrective actions in case of deviance.
- Control plans: programs like HACCP can be established and followed for several food chains such as wheat, animal feed, milk, etc. to ensure the safety of food and keep records of all activities.
- Monitor mycotoxin contamination through conducting continuous studies on Lebanese food.

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