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Exposure to mycotoxins from the consumption of corn-based breakfast cereals in the United Arab Emirates

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Corn-based breakfast cereals, known as cornflakes, have become a common breakfast choice worldwide, recognized for their convenience and versatility. However, mycotoxins can contaminate these products, adversely affecting human health. This study assessed the occurrence of major mycotoxins (AFB1, OTA, DON, ZEA, and FUM) in cornflake stock-keeping units (SKUs) marketed in the United Arab Emirates (UAE). It also evaluated the effect of different independent variables (country of origin, temperature on the production day, storage time, presence of chocolate, bran, and nut ingredients) and estimated the exposure levels of the UAE population to these mycotoxins and the associated risk factors. Seventy-six distinct cornflake SKUs were identified through a market screening and tested for mycotoxins using the Enzyme-Linked Immunosorbent Assay (ELISA) technique. AFB1, OTA, ZEA, FUM, and DON were detected in 23.7, 48.7, 27.6, 9.2 and 88.2% of the samples, respectively. The mean concentrations among positive samples were 2.0, 1.0, 10.14, 584.9, and 90.6 µg/kg, respectively. Except for AFB1, the average mycotoxin levels in samples were below the established limits by the European Union (EU). Among positive samples, none exceeded the US FDA limits for all mycotoxins, and only one exceeded the CODEX limit for FUM. On the other hand, four (5.3%), one (1.3%), one (1.3%), and one (1.3%) SKU exceeded EU limits for AFB1, OTA, FUM, and ZEA, respectively. The country of origin (developing vs. developed countries) exhibited a significant effect on AFB1 presence ($p < 0.0001$). Furthermore, higher temperature on the production day was associated with significantly higher AFB1 occurrence ($p = 0.009$). Moreover, the presence of chocolate ingredient had a borderline significant effect on AFB1 ($p = 0.05$) and a significant effect on OTA ($p = 0.002$), with higher percentages observed in SKUs containing chocolate. However, no significant effects were found for storage time or the presence of bran and nut ingredients in the cornflakes. On the other hand, the HQ values were below 1 for all mycotoxins, indicating low risk. MoE values exceeded 10,000 among regular cornflake consumers, except for FUM, suggesting minimal risk. Liver cancer risk was 0.0032 cases per 100,000 people per year. Weekly OTA exposure was 0.133 ng/kg BW, below PTWI (Provisional Tolerable Weekly Intake).

Keywords Cornflakes, Mycotoxins, ELISA, Risk assessment, UAE

Consumption of cereal-based food products is on the rise worldwide. Among these products are cornflakes, which serve as vital sources of energy and nutrients[1–3]. However, they are prone to fungal contamination, producing mycotoxins, including aflatoxins, ochratoxin A, trichothecenes, fumonisins, and zearalenone. These mycotoxins can occur at various stages, from field to storage. Temperature, water activity, humidity, pH, fungal strain, and substrate influence mycotoxin production[4–6]. Their toxicity (Table 1) poses significant health risks, highlighting the need for a comprehensive understanding and management of mycotoxins. In addition, the Food

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Mycotoxin	IARC classification	Fungal Species	Food commodity	Toxic effects/diseases	US FDA (μg/kg)	EU (EC 2006) (μg/kg)	CODEX (μg/kg)
AFB1, AFB2, AFG1, AFG2	Group 1: Carcinogenic to humans with sufficient evidence	*Aspergillus flavus, Aspergillus parasiticus*	Maize, wheat, rice, nuts	Carcinogenic, hepatotoxic, teratogenic, mutagenic immune suppressive effects, hepatitis, hepatocellular carcinoma	20 for total	2 for AFB1 20 for total Aflatoxins	10
OTA	Group 2B: possibly carcinogenic	*Aspergillus ochraceus, Penicillium verrucosum, Aspergillus carbonarius*	Cereals, coffee, beans, peas, wine, grape juice, dried vine fruit, cocoa	Carcinogenic, nephrotoxic, hepatotoxic, immunotoxicity, genotoxic, teratogenic, embryotoxic, Balkan Endemic Nephropathy	Not set	3	5
FB1, FB2, FB3	Group 2B: possibly carcinogenic	*Fusarium verticillioides, Fusarium proliferatum*	Maize, wheat, sorghum, asparagus	Encephalomalacia, pulmonary edema, carcinogenic, neurotoxic, liver /kidney damage, heart failure, esophageal cancer	2000–4000	200–1000	2000
DON	Group 3: not classifiable; not enough evidence to classify as a carcinogen	*Fusarium graminearum, Fusarium culmorum*	Maize, wheat, oats, legumes, fruits, vegetables	Nausea, vomiting, diarrhea, abdominal pain, headaches, dizziness, fever, immune suppression	1000	750	1000
ZEN	Group 3: not classifiable; not enough evidence to classify as a carcinogen	*Fusarium graminearum, Fusarium culmorum*	Maize, wheat, barley, oats, sorghum, rye	Carcinogenic, teratogenic, hormonal imbalance, estrogenic effect, reproductive disorders, infertility	Not set	50	-

Table 1. Major mycotoxins, their characteristics and limits (Yu & Pedroso, 2023).

and Agricultural Organization (FAO) reports that about 25% of global food crops are contaminated annually, resulting in substantial economic losses[7–9].

Ensuring food safety is a paramount priority for regulatory authorities in the UAE. Given its significant food imports, especially of long-stored corn-based cereals, strict food control standards are vital. The country's hot and humid climate, prevalent for about eight months annually, fosters microbial contamination, particularly mycotoxins, as noted in Regulation No. 6 (2010) on Food Hygiene[10]. This contamination poses risks to food reserves and public health. Legislative measures, including Food Law No. 2 (2008) and Regulation No. 6 (2010)[10], are crucial for enhancing food storage and consumption practices, ensuring safety standards, and boosting consumer confidence[10]. Cornflakes are increasingly popular in the UAE due to factors like urbanization, convenience, and changing dietary habits[11–14]. Effective marketing and perceived health benefits also contribute to their popularity[11,15,16].

Various methods have emerged for mycotoxin detection and quantification, addressing the need for accurate and efficient screening. Immunoassay-based techniques offer rapid and cost-effective detection[17], while chromatographic techniques like HPLC and LC–MS/MS provide high sensitivity and simultaneous detection of multiple mycotoxins[18]. Molecular methods, particularly PCR assays, enhance targeted surveillance efforts by enabling specific detection of mycotoxin-producing fungal species[19].

A plethora of studies tackled mycotoxins in cereal-based products, including in the Arab region, for example, in Lebanon[20–23] and Qatar[24]. Given that the UAE has a diverse population from over 200 nationalities, with varying food consumption patterns, and since until now, no study has been performed in the UAE to assess mycotoxins in the cornflakes marketed in the country and the associated exposure risks, our study aims to assess the mycotoxin contamination levels in all the cornflakes SKUs available in the UAE market and to evaluate the UAE population's exposure to these mycotoxins through the consumption of cornflakes.

Materials and methods

Sample collection and analysis

The biggest retail markets in the UAE were screened. Seventy-six different cornflake SKUs were identified and collected for analysis during December 2023. The sample preparation and analysis took place during February and March 2024. The cornflake samples were ground using a blender and thoroughly mixed before proceeding with the extraction process. Mycotoxin determination was carried out in triplicates using the Enzyme-Linked Immunosorbent Assay (ELISA) technique. Specifically, the RIDASCREEN AFB1 30/15 (R1211), OTA 30/15 (R1312), ZEA (R1401), FUM (R3401), and DON (R5906) test kits from R-biopharm, Germany, were utilized. Each test kit contains 96 wells, and the analysis was conducted following the step-by-step instructions outlined in the kit manuals. Detection limits indicated by the kit manufacturer for AFB1, OTA, ZEA, FUM, and DON were 1 μg/kg, 0.5 μg/kg, 1750 ng/kg, 25 μg/kg, and 18.5 μg/kg.

Exposure determination from the consumption of cornflakes

To estimate the exposure of UAE residents to mycotoxins from cornflake consumption, food frequency questionnaires (FFQs) were administered to a convenient sample of 400 adults. The FFQs assessed the consumption patterns of cornflakes. Ethical approvals were obtained from the Office of Research and Sponsored Program at Abu Dhabi University (approval no: CHS-0000014/2023). All research was performed in accordance with relevant guidelines/regulations. Informed consent was obtained from all participants.

Estimated Daily Intake (EDI) was determined using the following equation[25] (Eq. 1):

$$Estimated\ Daily\ Intake\ (EDI)\ (ng/kg\ bw/day) = \frac{Mean\ Concentration\,(MC)\,(ng/kg) * Daily\ Intake\ \ (DI)\,(kg/day)}{Average\ Body\ weight\,(kg)} \tag{1}$$

Mycotoxins	Tolerable daily intake (TDI) (µg/ kg/ bw/day)	Reference
AFB1	Not applicable since genotoxic	
OTA	0.018	EFSA, 2006
DON	1.0	EFSA, 2017
FUM	1.0	EFSA, 2018
ZEA	0.25	EFSA, 2014

Table 2. Tolerable daily intake of mycotoxins.

Mycotoxins	BMDL10 (µg/ kg/ bw/day)	Reference
AFB1	0.4	(EFSA, 2020)
OTA*	Critical neoplastic[1] effects: 14.5 Chronic non-neoplastic[2] effects: 4.73	(EFSA, 2020)
DON	210	(EFSA, 2017)
FUM	100	EFSA (2018); Zentai et.al (2019)

Table 3. BMDL10 of mycotoxins. [1]MOE below 200 indicates a public health concern for non-neoplastic effects. [2]MOE below 10,000 indicates a public health concern for neoplastic effects.

Risk assessment

Hazard quotient (HQ) calculation

The hazard quotient (HQ) represents the ratio of potential exposure to a substance (EDI) to the level at which no adverse effect is expected, such as the tolerable daily intake (TDI) or acute reference dose (ARfD) (Eq. 2)[26]. The TDI for the five mycotoxins are listed in Table 2:

$$HQ = \frac{EDI(ng/kgBW/day)}{TDI(ng/kgBW/day)} \tag{2}$$

A Hazard Quotient (HQ) below 1 indicates acceptable or tolerable exposure, implying little to no risk. Conversely, a value exceeding 1 suggests an unacceptable level of exposure, posing a potential health risk[25,26].

Margin of exposure (MoE) calculation

Considering the carcinogenic potential of various mycotoxins, the Margin of Exposure (MoE) was calculated for each mycotoxin as a ratio of the Benchmark Dose Lower Confidence Limit (BMDL10) to the level of exposure (EDI) (Eq. 3). The BMDL10 values for the different mycotoxins are presented in Table 3. The MoE serves as an indicator of risk level, where a MoE value greater than or equal to 10,000 suggests low public health concern, while a MoE value below 10,000 indicates high public health concern[25–29]:

$$MoE = \frac{BMDL10(ng/kgBW/day)}{EDI(ng/kgBW/day)} \tag{3}$$

Besides, as ZEA is categorized in Group 3 (not enough evidence to classify as a carcinogen), a threshold dose exists below which no adverse effects are observed, according to JECFA (2007) and[6]. Consequently, estimated ZEA intakes were compared with the provisional maximum tolerate daily intake (PMTDI) to assess potential health risks. Exceeding the tolerable intakes established by JECFA may indicate a health risk. Currently, the Joint Committee FAO/WHO has established a PMTDI for ZEA at 0.5 µg/kg of body weight[30]

Liver cancer risk from AFB1

The JECFA has indicated that even minimal exposure to AFB1, as low as 1 ng/kg body weight/day, can elevate the risk of liver cancer. Consequently, it is suggested that in non-European countries, the ingestion of 1 ng/kg body weight/day of AFB1 can lead to an incidence of 0.083 cases of liver cancer per year per 100,000 individuals[25,27].

Liver cancer risk was calculated as follows (JECFA, 2007) (Eq. 4):

$$Livercancerrisk from AFB1 = \frac{Exposure of AFB1(ng/kgbw/day) \times 0.083 cancercases/100,000 persons}{1(ng/kgbw/day)} \tag{4}$$

Weekly exposure to OTA

The weekly exposure to OTA was computed to assess the risk of kidney disease. It was compared to the provisional tolerable weekly intake (PTWI) established by JECFA at 100 ng/kg bw, which was considered in our analysis.

Statistical analysis

The mycotoxin concentration was determined as a mean of 3 replicate measures for all samples. The data was coded and entered into Excel before being transferred to STATA/SE 18.0 for subsequent analysis. Continuous variables are presented as means and standard deviations, whereas categorical variables are expressed as percentages. Fisher's Exact test was employed to explore the relationships between explanatory (independent) variables (including country of origin, temperature on production day, storage time, presence of bran, chocolate, and nut ingredients) and the presence of mycotoxins, which are treated as dependent variables. Fisher's exact test is well-suited for such scenarios, offering a robust answer for analyzing categorical data and detecting associations between variables, even in small datasets, particularly when dealing with cells containing low frequencies, which could compromise the reliability of traditional chi-square tests.

Results and discussion

Mycotoxin content in cornflake samples

The incidence of Aflatoxin B1 (AFB1), Ochratoxin A (OTA), Deoxynivalenol (DON), Fumonisin B1 (FB1), and Zearalenone (ZEA) in 76 samples of cornflakes are shown in Table 4. This study, AFB1 was detected in 18 out of 76 samples (23.7%) with a mean concentration of 2.0 ± 0.18 μg/kg. OTA was found in 37 samples (48.7%) with an average concentration of 1.0 ± 0.15 μg/kg, while ZEA was detected in 21 samples (27.6%) with an average concentration of 10.14 ± 0.76 μg/kg. FUM exhibited the lowest occurrence, detected in only seven samples (9.2%), with a mean concentration of 584.9 ± 38.00 μg/kg. Conversely, DON was the most prevalent mycotoxin in 67 samples (88.2%), with a mean concentration of 90.6 ± 14.15 μg/kg. A comparison between these concentrations and the regulatory limits revealed that a small percentage of positive samples exceeded EU limits: 5.3% for AFB1 and 1.3% for OTA, FUM, and ZEA each. Except for AFB1, the average levels of all mycotoxins in the cornflake samples remained below EU limits. However, the average concentration of AFB1 was 2 μg/kg. This finding could be concerning, given AFB1's classification as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC), unlike the other four mycotoxins. Furthermore, all mycotoxin averages were below the CODEX limits, with only one sample exceeding the limit for FUM. Additionally, they were all below the US FDA limits for mycotoxins.

The prevalence of DON observed in our study aligns with prior research on cereal products. For instance,[31] investigated the presence of various mycotoxins in 118 samples of Croatian cereals. They reported DON in 73.7% of Croatian cereal samples (vs.88.2% in our study). Another study by[20] aimed to assess mycotoxins in 35 cornflake SKUs marketed in Lebanon. Similar to our findings, the highest prevalence was observed for DON, with 60% of samples surpassing the EU limit. However, the average concentration of DON was 1206.7 μg/kg, much higher than the average concentration of DON found in our study (90.6 μg/kg). In addition, 17% of samples in the study of[20] exceeded the OTA limit (average contamination: 1.2 μg/kg), 9% exceeded the AFB1 limit (average contamination: 1.6 μg/kg), 14% exceeded the FUM limit (average contamination: 774.1 μg/kg), and 6% exceeded the ZEA limit (average contamination: 15.1 μg/kg). Except for AFB1, the average levels of OTA, FUM, and ZEA in the study of[20] were higher than those reported in our study. Yet, they were below the maximum permissible values, aligning with our findings. Notably, in the study of[20], the mean AFB1 level was below the EU limit, contrasting with our findings where it surpassed the established limit. This comparison underscores the variability in mycotoxin levels across different regions and highlights the importance of ongoing monitoring and regulatory efforts to meet food safety standards.

In another investigation by[32], the presence of mycotoxins was examined in wheat grains (n = 50), wheat flour (n = 50), and bread (n = 37) samples in Lebanon. Only 8% of the wheat flour samples tested positive for OTA (vs 48.7% in our study), with a concentration mean of 1.9 μg/kg, higher than the average in our findings (1 μg/kg). Furthermore, Alwan et al.[33] evaluated the levels of AFB1 in rice available in the UAE market. Using ELISA, the study detected AFB1 in 48 out of 128 rice samples, constituting a prevalence rate of 38%. Among the positive samples, the average contamination level of AFB1 was 1.66 μg/kg (vs. 2 μg/kg in our study). Notably, all samples exhibited contamination levels below the limit set by the Gulf Cooperation Council Standardization Organization (≤ 5 μg/kg), yet 10 (20.8%) out of the positive samples surpassed the EU limit (vs. 5.3% in our study). A comparable investigation involved 105 rice samples available in the Lebanese market[22]. While all samples tested positive for AFB1, the average concentration was 0.5 μg/kg (lower than the AFB1 concentration detected in study). Another study by[23] assessed OTA levels in 105 rice brands available in Lebanon and 127 rice brands from the UAE. Using ELISA, 53% and 58% of samples tested positive for OTA in Lebanon and the UAE, respectively. However, only 1% of samples in Lebanon and 1.6% in the UAE exceeded the EU limit, consistent with our findings. The average OTA concentrations were 1.29 and 1.40 μg/kg in Lebanon and the UAE, respectively, higher than our study's average OTA concentration in cornflakes.

Mycotoxin	Mean ± SD	Range	# of positive samples (%)	EU limit	Codex limit	US FDA limit	# of samples exceeding EU limit (%)	# of samples exceeding codex limit (%)	# of samples exceeding FDA limit (%)
AFB1 (μg/kg)	2.0 ± 0.18	1.0–9.6	18 (23.7)	2	10	20	4 (5.3%)	–	–
OTA (μg/kg)	1.0 ± 0.15	0.3–3.0	37 (48.7)	3	5	–	1 (1.3%)	–	–
DON (μg/kg)	90.6 ± 14.15	21.9–441.9	67 (88.2)	750	1000	1000	–	–	–
FB1 (μg/kg)	584.9 ± 38.00	27.0–2830.0	7 (9.2)	1000	2000	2000–4000	1 (1.3%)	1 (1.3%)	–
ZEA (μg/kg)	10.14 ± 0.76	1.757–68.37	21 (27.6)	50	–	–	1 (1.3%)	–	–

Table 4. Mean, range and limits for different mycotoxins.

Moreover, in a three-year comprehensive analysis, researchers conducted a global survey to assess the prevalence of mycotoxins in cereals. Among the 41 studies analyzed AFB1, ZEA, and DON exhibited the highest contamination rates[34]. A significant proportion of samples exceeded the EU limits, particularly for AFB1, where 87.5% surpassed the allowed levels, with levels reported as high as 188 µg/kg in Haiti, 76.2 µg/kg in Kenya, and 44 µg/kg in Serbia. Vietnam had the highest Ochratoxin A (OTA) levels at 1662 µg/kg, while Greece reported the lowest at 0.7 µg/kg. Additionally, Italy reported the highest levels of FUMs at 43,296 µg/kg. Given that corn serves as a primary ingredient in various food products, including popcorn, breakfast cereals, flour, and baby food, continuous monitoring of mycotoxin levels in corn is crucial due to potential hazards to both the food and feed chain[34]. Moreover, Iqbal et al.[35] and Alim et al.[36] reported comparable findings concerning assessing mycotoxins in cereal-derived products in Pakistan. For instance, Iqbal et al.[35] reported that 16% and 8% of the samples were above the EU limits for AFB1 (2 µg/kg) and total AFs (4 µg/kg), respectively, whereas[36] reported 22% and 12% for AFB1 and total AFs, respectively. Conversely, our study found 23.7% of SKUs positive for AFB1, aligning closely with[36]. Additionally, 48% and 50% of samples tested positive for OTA in[35,36] studies, respectively (compared to 48.7% in our study). Likewise, 53% and 56% of samples were positive for ZEA in the aforementioned studies (compared to 27.6% in our study), with 8% and 30% exceeding the maximum level, respectively (compared to 1.3% in our study).

Effect of different variables on mycotoxin presence in cornflakes

Effects of different variables on the presence of mycotoxins in cornflakes are presented in Table 5. All data are presented as the percentage of mycotoxin-positive samples for each variable category and the corresponding p-values. A p-value of less than 0.05 (denoted by "*") suggests a statistically significant association between each variable and the presence of each mycotoxin. As shown in Table 5, the country of origin (developing vs. developed countries), had a significant effect on AFB1 occurrence in cornflakes ($p < 0.0001$), with a notably higher proportion of positive SKUs detected in developing (77.78%) vs. in developed (16.42%). Likewise, there was a trend of higher percentages of positive samples for OTA, DON, and ZEA in developing countries, though statistical significance was not reached.

In contrast, Alwan et al.[33] found no significant impact of the country of origin on AFB1 exposure in rice in the UAE. Similarly, Hassan et al.[22] found no significant difference between rice brands packed in Lebanon and those packed in other countries, nor between rice from developing and developed countries. Moreover, Hassan et al.[23] also observed that rice from developing countries of origin (India, Pakistan, Thailand, China) exhibited higher OTA levels compared to those from developed countries (the United States, Italy). However, the difference was not statistically significant. Conversely, Hassan et al.[20], in their assessment of mycotoxin contamination in cornflakes sold in Lebanon, identified a significant effect of country of origin (Lebanon vs. others: Ukraine, France, Turkey, Poland, UK) on AFB1 and FUM levels, but not on OTA, ZEA, and DON.

Additionally, Yu and Pedroso[6] conducted a review to provide updated insights into the occurrence and co-occurrence of mycotoxins in cereal grains and cereal-derived food and feed products, along with their health impacts on humans, livestock animals, and pets. They highlighted that the prevalence and concentration of mycotoxins in finished cereal-based food products are higher in developing countries than in developed ones, which is consistent with our findings. Consequently, individuals in developing countries, such as Asia and Africa, face a greater risk of exposure to elevated levels of mycotoxins than those in developed countries. The

Variable		AFB1	OTA	DON	ZEA	FUM
Country of origin	P-value	< 0.001*	0.303	1	0.701	0.589
	Developing	77.78	66.67	88.89	33.33	0
	Developed	16.42	46.27	88.06	26.87	10.45
Temperature on production day	P-value	0.009*	0.186	1	0.717	0.584
	25–30	60	70	90	20	0
	Below 25	18.18	45.45	87.88	28.79	10.61
Storage time (months)	P-value	0.81	0.428	0.85	1	0.22
	< 5 months	33.33	50	100	33.33	0
	5–10 months	23.64	52.73	85.45	27.27	7.27
	> 10 months	20	33.33	93.33	26.67	20
Presence of bran ingredient	P-value	0.236	1	1	1	1
	Yes	50	50	100	25	0
	No	22.22	48.61	87.5	27.78	9.72
Presence of chocolate ingredient	P-value	0.05*	0.002*	1	1	0.037*
	Yes	35.48	70.97	87.1	29.03	0
	No	15.56	33.33	88.89	26.67	15.56
Presence of nuts ingredient	P-value	0.463	0.756	0.339	1	0.588
	Yes	33.33	41.67	100	25	0
	No	21.88	50	85.94	28.12	10.94

Table 5. Percentage distribution of mycotoxin occurrence according to various variables.

lower levels of mycotoxins observed in processed foods in developed countries can be attributed to the relatively lower mycotoxin contents in unprocessed cereal grains, more stringent control over storage conditions, and the implementation of regulatory measures. This disparity also explains why cases of human mycotoxicosis are comparatively more frequent in developing regions.

Moreover, a significant association was observed in our study between the temperature on the production day and AFB1 occurrence ($p = 0.009$). Data was obtained from weather websites to determine the temperature on the production day for each cornflakes SKU, considering the specific country of origin and the city where production took place. Subsequently, the averages of the recorded high and low temperatures were calculated to obtain a representative value. Specifically, a higher percentage of positive samples was noted when the temperature exceeded 25 °C (60% for temperatures ranging between 25 and 30 °C, compared to 18% for temperatures below 25 °C). Although a similar trend was observed for OTA and DON, statistical significance was not observed. This can be explained by the fact that higher temperatures can encourage the growth of toxigenic fungi, potentially increasing the risk of mycotoxin production in food products.

Similarly, Alwan et al.[33] noted that rice packed in UAE during the Spring/Summer seasons, characterized by higher temperatures, exhibited higher contamination levels of AFB1 compared to those packed during the Fall/Winter seasons, marked by cooler temperatures. However, this trend was not statistically significant. This observation may be attributed to the consistent implementation of appropriate storage measures, regardless of the season in which the products were packed. Indeed, the UAE's desert climate, characterized by warm temperatures, creates favorable conditions for the proliferation of aflatoxigenic fungi during storage, particularly in the dry and hot summers lasting from April to September. In addition, Hassan et al.[23] also investigated the seasonal impact of rice packing in Lebanon on AFB1 levels in rice. Despite Lebanon's recognized high temperature and humidity levels during the spring and summer seasons, which facilitate mold growth and, consequently, AFB1 contamination in food, no significant difference was found between rice brands packed in the fall and winter compared to those packed in the spring and summer.

Furthermore, the influence of storage duration from purchase until analysis was investigated. The results showed no significant effect across different storage periods. Notably, the cornflake samples underwent post-production storage in the UAE, followed by shipment to Lebanon and subsequent storage in the laboratory under refrigeration. This meticulous handling underscores the implementation of effective storage practices, which likely prevented the proliferation of mycotoxin-producing fungi and diminished the risk of mycotoxin contamination during storage and transportation processes. Investigations by[23,33] into the storage time between packing and purchasing revealed no significant impact on AFB1 levels in rice in the UAE and Lebanon, respectively, suggesting proper storage practices. However, Hassan et al.[22] observed higher OTA levels with increased storage time, although significance was only seen in the UAE samples. This was attributed to poor barrier properties of the rice packages and suboptimal storage conditions in some retailers.

The presence of the bran ingredient resulted in a higher percentage of positive samples for OTA, DON, and AFB1, yet these outcomes did not attain statistical significance. This trend aligns with previous research findings. Importantly, bran is an inherent component of all whole grains, which may contribute to the observed effects on mycotoxin levels. For instance, Gomes et al.[37] investigated the impact of flour type (white or whole-grain) and processing method (direct or par-baked) on the mycotoxin levels in bread in Spain. Industrial bread exhibited notably higher levels of DON than artisanal bread, with a threefold increase, consistent with our findings.

Additionally, a significant difference was evident in the levels of OTA, particularly in whole-grain bread and more prominent in industrial settings. Likewise, other research investigations have also indicated elevated levels of DON in the bran or outer layers of grains in contrast to white flour or whole-grain flours compared to their white counterparts[38–40]. A similar pattern was also noted for OTA concentrations[41]. The higher mycotoxin contamination observed in whole grain or bran compared to white flour can be attributed to several factors. First, mycotoxins tend to accumulate in the outer layers of grains, such as the bran, where they are more likely to be concentrated. Second, these outer layers are retained during the processing of whole grains, increasing the likelihood of mycotoxin presence in the final product. Third, bran, which contains higher levels of nutrients and moisture, can provide a favorable environment for fungal growth and mycotoxin production. As a result, whole grain or bran-based products may exhibit higher levels of mycotoxin contamination compared to those made from refined white flour[9,42].

Besides, the presence of mycotoxins may be influenced by including chocolate ingredients. In our study, chocolate showed a slight effect on AFB1 ($p = 0.05$) and a more pronounced and statistically significant effect on OTA ($p = 0.002$), with higher percentages observed in SKUs containing chocolate (35.5% vs 15.6% for AFB1 and 70.97% vs 33.3% for OTA). This observation is consistent with the findings of[43], who reported that 89% of breakfast cereals containing chocolate contained OTA. Moreover, in chocolate-containing breakfast cereals, DON and ZEA were detected in 62% and 73% of samples, respectively. This is particularly concerning as these products are predominantly targeted at children, who are known to be more susceptible to the adverse effects of mycotoxins. Chocolate products generally have a low water content, insufficient to support microbial growth and mycotoxin production. Thus, mycotoxins may have occurred due to the proliferation of toxigenic fungi in previous processing steps of the raw material[44].

As for nuts, their presence in the ingredients increased the percentage of positive samples for AFB1 and DON, although this result did not reach statistical significance. In a study by[45] from 2017 to 2021, the prevalence of aflatoxins in nuts and nut products imported into the UAE from 57 countries was examined. Their findings revealed aflatoxin levels exceeding Maximum Residue Limits (MRLs) in imports from developing and developed nations, indicating a widespread global risk. Approximately 8.6% of imported nut samples were rejected, with an overall mean aflatoxin level of 77.1. Non-conformity was observed in samples from 32 countries, with mean aflatoxin values ranging from 81.0 to 92.7 μg/kg in pistachios, peanuts, and mixed nuts. Notably, a significant difference ($p < 0.05$) was noted in mean aflatoxin levels between peanut butter samples (29.3 μg/kg) and other nut types.

Furthermore, processing methods significantly impacted aflatoxin levels, with ground samples exhibiting the highest mean level at 158.9 μg/kg. Additionally, packaging material played a role in AFB1 levels in nuts, with nuts packaged in fabric containers exhibiting the highest mean aflatoxin levels at 108.1 μg/kg, while nuts packaged in glass containers had the lowest mean level at 29.7 μg/kg. Hence, the incorporation of nuts in cereal products can introduce mycotoxins, such as AFB1, due to the nuts' potential contamination. Numerous studies have demonstrated that nuts, like other agricultural products, are susceptible to fungal contamination and subsequent mycotoxin production under certain conditions. If contaminated nuts are utilized as ingredients in cereal manufacturing processes, the mycotoxins present in the nuts can transfer to the cereal matrix, indirectly contributing to cereal contamination. This emphasizes the critical importance of ensuring the safety and quality of all ingredients used in cereal production to decrease the risk of mycotoxin contamination in the final product. A review by[46]) examining a decade of data from the Rapid Alert System for Food and Feed (RASFF) revealed increased mycotoxin contamination in nuts and nut products, particularly those destined for EU countries. From 2011 to 2021, 63% of mycotoxin-related RASFF notifications were linked to nuts, nut products, and seeds, with aflatoxins (AFs) responsible for 95% of these notifications. Ground nuts, notably from China, were the most frequently affected. These findings underscored the significant incidence of border rejections for contaminated nut products entering EU countries, advocating for enhanced quality control measures.

Exposure and risk assessment

The Estimated Daily Intake (EDI), Hazard Quotient (HQ), Margin of Exposure (MoE), as well as the risks of liver cancer associated with AFB1 consumption and kidney disease linked to OTA intake for both daily and regular consumers, and the general population, were calculated. The summarized findings from EDI, HQ, and MoE are presented in Table 6. According to our FFQ study, the average daily consumption of cornflakes in the UAE was 70 g/day for daily consumers, 1.5 g per day among regular consumers, and 0.25 g/day for the general population. On the other hand, the average body weight was 77 kg. Accordingly, EDIs of AFB1, OTA, DON, ZEN, and FUM for daily consumers were calculated at 1.8, 0.91, 82.36, 9.22, and 531.7 ng/kg BW/day, respectively. With an average daily intake of 1.5 g, regular consumers exhibited lower EDIs of 0.039, 0.019, 1.76, 0.2, and 11.39 ng/kg BW/day for AFB1, OTA, DON, ZEN, and FUM, respectively. Conversely, the general population, with an average daily intake of 0.25 g/day, had EDIs of 0.00649, 0.0032, 0.294, 0.0329, and 1.9 ng/kg BW/day for AFB1, OTA, DON, ZEN, and FUM, respectively. These findings suggest variations in mycotoxin exposure levels among different consumer groups, emphasizing the importance of monitoring dietary intake.

Besides, the HQ values for the exposure to all mycotoxins, encompassing daily consumers, regular consumers, and the general population, were below 1. This suggests that the exposure levels to these mycotoxins from the consumption of cornflakes are relatively low compared to their respective reference doses, indicating a low risk associated with this exposure. However, the Margin of Exposure (MoE) value for daily consumers of cornflakes was below 10,000 for AFB1, indicating a potentially elevated risk. Conversely, for regular consumers and for the general population, MoE values for AFB1 exceeded 10,000, suggesting a lower risk. As for OTA, the MOE neoplastic (MOE neo) and MOE non-neoplastic (MOE non-neo) values were above 10,000 and 200 respectively for all consumer groups, indicating a low health concern.. For the non-genotoxic mycotoxins, inclusing DON and FUM their estimated daily intake (EDI) were compared with their respective tolerable daily intake (TDI) values. The EDI values for these mycotoxins remained below their respective TDI values for all consumer groups, suggesting a minimal health risk (TDI for DON and FUM is 1.0 μg/kg). Regarding ZEA, also categorized as a non-genotoxic carcinogen, the EDI was compared to the provisional maximum tolerable daily intake (PMTDI) of 0.25 μg/kg BW, revealing that the EDI remained below this threshold for daily, regular, and general population consumption.

Furthermore, the liver cancer risk associated with AFB1 exposure from cornflake consumption in the UAE was assessed. The highest risk was observed among daily consumers, with 0.15 cases per 100,000 persons per year. The risk decreased to 0.0032 cases per 100,000 persons per year for regular consumers, and for the general population, it was even lower at 0.0005 cases per 100,000 persons per year. A comparison with the study by[25]

		AFB1	OTA	DON	ZEN	FUM
Daily consumers	EDI*	1.8	0.91	82.36	9.22	531.7
	HQ	0.02–0.11	0.05	0.082	0.037	0.53
	MoE	222.22	Neo: 15,934 non-neo: 5197.8	2549.8	–	188
Regular (not daily) consumers	EDI*	0.039	0.019	1.76	0.2	11.39
	HQ	0.0005–0.002	0.001	0.00176	0.0008	0.01139
	MoE	10,256.41	neo: 763,157.9 non-neo: 248,947.4	119,318	–	8779.63
General Population	EDI*	0.00649	0.0032	0.294	0.0329	1.9
	HQ	0.000079–0.00038	0.00018	0.000294	0.00013	0.0019
	MoE	61,633.3	neo: 4,531,250 non-neo: 1,478,125	714,286	–	52,632

Table 6. EDI, HQ and MoE for different mycotoxins. *EDI (ng/kg BW/day).

revealed that their findings indicated a total AFB1 exposure linked to 0.105 additional liver cancer cases per 100,000 people per year from the consumption of cereals and cereal products in Lebanon. This suggests a comparable risk for daily consumers, as observed in our investigation (0.15 cases per 100,000 persons per year). Other studies have examined the risk of liver cancer associated with AFB1 exposure. For example, Raad et al.[47] reported a risk of 0.053–0.055 additional liver cancer cases per 100,000 people per year for regular consumers based on a total diet study involving an adult urban Lebanese population. Daou et al.[21] also found a risk of 0.076 HCC/100,000 people/year associated with the consumption of heat and wheat products in Lebanon. In comparison to these studies, our findings revealed a lower risk of liver cancer associated with AFB1 exposure among regular consumers, with a rate of 0.0032 cases per 100,000 persons per year. Similarly, our results are also lower than those reported by[20] (0.35–0.41 HCC/100,000 people/year).Additionally, the weekly exposure to OTA in our study was 6.37 ng/kg bw for daily consumers, 0.133 ng/kg bw for regular consumers, and 0.022 ng/kg bw for the general population, all below the PTWI set by JECFA for OTA (100 ng/kg bw), indicating a low risk of kidney disease associated with OTA exposure from cornflakes consumption. Conversely, in the study by[25] in Lebanon, the overall weekly exposure to OTA was higher, at 28.68 ng/kg bw. Yet, it remained below the established PTWI for OTA across all food groups. These results also indicate a low risk of kidney disease associated with OTA exposure.

The study by[25] also investigated the dietary exposure of Lebanese adults to multi-mycotoxins (AFB1, AFM1, OTA, OTB, DON, T-2, and HT-2) and evaluated their associated health risks in cereals. Their findings revealed that pasta exhibited the lowest AFB1 concentration (0.005 µg/kg), while rice showed the highest (0.5 µg/kg). Moreover, within this food group, the total exposure to AFB1 was 0.86 ng/kg bw/day, with cornflakes contributing the least to exposure (0.0003 ng/kg bw/day) and rice contributing the most (0.48 ng/kg bw/day). Although their AFB1 exposure levels were lower than our findings for daily consumers (1.8 ng/kg bw/day), they exceeded those observed for our study's regular and general population (0.039 and 0.00649 ng/kg bw/day, respectively). As for the MoE, all values exceeding 10,000 were reported for most cereals except rice (827.90) and bulgur (4868.50). In contrast, our findings indicated that for daily consumers, the MoE for AFB1 was below 10,000 (MoE of 222). Regarding OTA, Hoteit et al.[25] reported total exposure of 3.29 ng/kg bw/day, with bread contributing the highest amount at 1.18 ng/kg bw/day, while cornflakes contributed the least at 0.0006 ng/kg bw/day. In our study, the OTA exposure from cornflake consumption was higher, at 0.91 ng/kg BW/day for daily consumers, 0.019 ng/kg BW/day for regular consumers, and 0.0032 ng/kg BW/day for the general population. Their findings indicated that all MOE non-neo and MOE neo values were above 200 and 10,000, respectively, which aligned with our results. As for DON, Hoteit et al.[25] reported an exposure of 0.11 ng/kg bw/day from cornflakes, 332.18 ng/kg bw/day from bread, and a total exposure of 347.05 ng/kg bw/day. In comparison, our study found exposure levels of 82.36 ng/kg bw/day for daily consumers, 1.76 ng/kg bw/day for regular consumers, and 0.294 ng/kg bw/day for the general population, all higher than those reported by[25] from cornflake consumption. Lastly, the Hazard Quotient (HQ) associated with the multi-mycotoxins analyzed in their study indicated that all cereal and cereal products examined had values below 1, aligning with our findings. Moreover, another study by[33] investigated AFB1 exposure from rice consumption in the UAE. They determined a daily exposure range of 0.52 to 13.6 ng/kg BW/day, with an average exposure level of 2.93 ng/kg BW/day. This average exposure exceeded the AFB1 exposure level from cornflake consumption detected in our study (1.8 ng/kg BW/day for daily consumers). Furthermore, Hassan et al.[23] observed that the average AFB1 exposure from rice consumption in Lebanon was 0.16 ng/kg BW/day, lower than the AFB1 exposure found in our study for daily cornflake consumers (1.8 ng/kg BW/day) but higher than the exposure for regular consumers and the general population (0.039 and 0.00649 ng/kg BW/day, respectively). However, Hassan et al.[22] reported OTA exposure levels of 1.27 in Lebanon and 1.42 in the UAE, both higher than the exposures found in our study for all consumer groups. Additionally, no health risks were detected for non-neoplastic effects such as kidney lesions, as indicated by MOE values exceeding 200 in both Lebanon and the UAE (3724 and 3330, respectively). Similarly, for neoplastic effects like kidney tumors, the MOE values of 11,417 and 10,211 (above 10,000) in Lebanon and the UAE, respectively, suggest no associated health risks. Besides, it is important to note that comparing the daily exposure to mycotoxins across different countries requires caution due to various influencing factors. Differences in methodologies used for assessing cereal contamination and variations in cereal consumption among populations can notably impact the results. Moreover, differences in consumption patterns, types of cereals studied, and environmental conditions in each country significantly contribute to determining population exposure levels.

Conclusion

In conclusion, cornflakes, a common breakfast staple, are susceptible to mycotoxin contamination, reflecting a broader issue in cereal products worldwide. This study investigated the presence of AFB1, OTA, DON, ZEA, and FUM in all cornflakes SKUs available in the UAE market. It also assessed the effects of various factors, estimated the exposure levels of the UAE population to these mycotoxins, and evaluated these risk characterization components (HQ, MOE, liver cancer cases, kidney disease risk). This study has many strengths. It is the first in the UAE to comprehensively analyze the levels of the five mycotoxins across all cornflake SKUs available in the country. Furthermore, it is the first study to evaluate the estimated daily exposure to AFB1, OTA, DON, ZEA, and FUM from cornflake consumption and assess the associated health risks, providing invaluable insights for public health interventions. Additionally, the study included a large sample size of 76 SKUs, with analyses conducted in triplicate, ensuring heightened accuracy and reliability of the findings. While our study offers valuable insights, it is essential to acknowledge that there are other dietary sources of mycotoxins, including wheat, rice, peanuts and other foods. Although the risks of mycotoxins for most consumers through cornflake consumption in UAE is acceptable, the aggregate exposure from the whole diet remains uncertain. Limitations of the study include the fact that the adults surveyed using the FFQ were chosen via convenient sampling, potentially limiting the representativeness of the consumption patterns and generalizability of the findings in the UAE. Additionally, the FFQ itself poses limitations, including self-reporting bias. Furthermore, it is worth noting that the FFQs were exclusively administered to adults over 18 years old, overlooking that children are among the highest consumers of cornflakes.

Data availability

Data availability All data generated or analysed during this study are included in this published article.

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Author contributions

HH, KZ and CI conducted the laboratory analysis; HH and MA conceptualized and oversaw the project; NA secured the funding; AC conducted the statistical analysis; all authors co-wrote and reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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