Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Monitoring Fumonisins Contamination in Corn Snacks in 2020-2024 and Assessments of Dietary Exposure

Cavidan DEMİR GÖKIŞIK

cavidan.gokisik@giresun.edu.tr

Giresun University: Giresun Universitesi https://orcid.org/0000-0001-7273-3156

Mehmet Kahtalı

Giresun Üniversitesi: Giresun Universitesi

Research Article

Keywords: Fumonisins, corn, corn-based products, exposure assessment, food safety

Posted Date: November 19th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-7921707/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Abstract

The presence of fumonisins in corn and corn-based products is a global public health problem. This study aimed to assess the contamination level of fumonisins (FBs: FB1 and FB2) in corn snacks and the tolerable daily intakes of consumers. A total of 96 corn snack samples were analyzed over four years. In this study, 30 corn snack samples with different contents purchased from supermarkets in Giresun in 2020 were examined to assess the presence, amount, and public health risk of FB_1 and FB_2. The same products with fumonisin levels above 200 ng/g in the 30 analyzed corn snack samples were purchased from the same supermarkets in 2021, 2023, and 2024, and FB_1 and FB_2 levels were monitored. Fumonisin occurrence rates in 2020, 2021, 2023, and 2024 were 90%, 95.5%, 59%, and 50%, respectively, with concentrations ranging from 79 to 4126 ng/g, 18 to 5055 ng/g, 20 to 1035 ng/g, and 20 to 1360 ng/g. High fumonisin levels were detected in 2020 and 2021, and lower levels in 2023 and 2024. Fumonisin exposure was determined as the average probable daily intake (APDI) and maximum probable daily intake (MPDI) for adults. APDI and MPDI values ranged from 0.2 to 0.7 µg/kg body weight/day and 0.6 to 2.8 µg/kg bw/day, respectively. In 2021, a maximum intake of 2.8 µg/kg bw/day was observed, exceeding the PMTDI of 2 µg/kg bw/day set by JECFA. To protect public health and ensure food safety, stricter enforcement and controls, and increased monitoring of corn snacks, are needed.

Introduction

Corn, or maize (Zea mays L.), is one of the most important agricultural crops globally, ranking second only to wheat in production, consumption, and trade. Maize is of increasing importance in global agri-food systems. Global maize production has increased rapidly over the past few decades, driven by a combination of rising demand and technological advances, increasing yields, and area expansion. Maize is currently the leading cereal in terms of volume production and yield diversity and is projected to be among the most grown and traded crops by the 2030s (Ernest et al. 2022). Maize is a versatile, multipurpose industrial grain used in over 500 different product formulations, including feed, food, and beverages. Beyond its industrial value, maize is particularly important as a staple food in regions of the Global South such as Sub-Saharan Africa, China, India, Indonesia, and Latin America (Scussel et al. 2014; Li et al. 2015; Ekwonadu et al. 2020). However, the frequent contamination of maize with mycotoxins is a global problem. The global reliance on maize elevates concerns regarding mycotoxin contamination, which poses serious risks to food safety, public health, and international trade (Reinhold et al. 2024).

Mycotoxins are toxic and carcinogenic secondary metabolites produced by fungi such as Aspergillus, Fusarium, and Penicillium, commonly found in grains during field production and post-harvest storage (Gomes et al. 2024; Anumudu et al. 2025). Major mycotoxins detected in maize include aflatoxins, fumonisins, zearalenone, deoxynivalenol, and ochratoxins, which frequently co-occur (Chen et al. 2018). Among these, fumonisins are the most prevalent mycotoxins in maize globally (Song et al. 2025). Fumonisins are a group of mycotoxins produced in cereals by fungi of the genus Fusarium, particularly *Fusarium verticillioides* and *Fusarium proliferatum*, and found at high levels in corn grains worldwide.

Other fungi, such as *Aspergillus niger* and Alternaria sp., also produce fumonisins at lower levels (Yli-Mattila & Sundheim, 2022). Fumonisins are one of the most important classes of mycotoxins globally due to their widespread occurrence, significant health risks to humans and animals, and significant economic impact (Ekwonadu et al. 2020). The chemical structure of fumonisins was isolated by Gelderblom et al. in 1988 following outbreaks of equine leukoencephalo-malacia (ELEM) and porcine pulmonary edema (PPE) linked to consumption of *F. verticillioides* contaminated maize (Gelderblom et al. 1988). Since the discovery of fumonisins, their toxicity has been extensively studied worldwide, and numerous toxic effects, including ELEM, PPE, liver cancer, kidney lesions, infertility, and immune system impairment, have been reported (Yang et al. 2024). Fumonisins are known to exhibit neurotoxic, hepatotoxic, nephrotoxic and carcinogenic properties in experimental animals. Epidemiological studies have reported an association between long-term exposure to fumonisins and esophageal cancer, particularly in regions where maize is a staple food, such as South China (Xue et al. 2019), Italy (Girolamo et al. 2010) and Sub-Saharan Africa (Yli-Mattila & Sundheim, 2022). Notably, studies have indicated potential links between fumonisin exposure and neural tube defects in newborns, as well as growth impairment in children consuming fumonisin-contaminated maize products (Chen et al. 2018; Reinhold et al. 2024). To date, more than 30 fumonisin analogs have been identified and classified into four main groups: series A, B, C, and P. Group B fumonisins (FBs), particularly fumonisins B_1 (FB_1), B_2 (FB_2), B_3 (FB_3), and B_4 (FB_4), are the most frequently detected in corn and corn-based products (Scussel et al. 2014; Song et al. 2025). Of these, FB_1 and FB_2 are the most abundant and toxic analog, typically constituting 70–80% of total fumonisin content, followed by FB_2 (15–25%), FB_3 (3–8%), and FB_4 (less than 5%) (Redeer et al. 2002). FB_1, the most toxic and highest found in corn and corn products, is considered potentially carcinogenic to humans and is classified as Group 2B (IARC 2002). Structurally, fumonisins are long-chain aliphatic amines with methyl and hydroxyl groups that resemble sphingolipids such as sphinganine and sphingosine. FBs disrupt sphingolipid metabolism by altering endogenous sphingolipids, thus inhibiting ceramide biosynthesis and sphingolipid metabolism (Torres et al. 2015; Vanhoutte et al., 2016), leading to cellular and organ dysfunction (Anumudu et al. 2025**).** Acute fumonisin exposure can result in liver damage, nausea, vomiting, diarrhea, edema, impaired consciousness, and, in severe cases, death (James & Zikankuba, 2018). Chronic exposure has been associated with esophageal cancer, hepatocellular carcinoma, immune suppression, renal toxicity, reproductive disorders, and growth impairment in children (Chen et al. 2018; Reinhold et al. 2024; Anumudu et al. 2025). In animals, acute fumonisin intoxication leads to liver and kidney damage, neurological disorders, respiratory issues, anorexia, abortion, and often mortality (James & Zikankuba, 2018). Importantly, Fumonisins, like other mycotoxins, are chemically stable and heat-stable, and not effectively eliminated during conventional food processing, posing a persistent risk in corn-based products (Bryla et al. 2016; Matos et al. 2024; Soraia et al. 2025). Currently, the European Commission has established maximum allowable fumonisin levels in maize and maize-based products: 4000 µg/kg for unprocessed maize, 2000 µg/kg for maize flour, 1000 µg/kg for maize intended for direct human consumption, 800 µg/kg for maize-based snacks, and 200 µg/kg for baby foods (ECR, 2007). Duo to the health risks mentioned above, the provisional maximum tolerable daily intake (PMTDI) for fumonisins was set as 2 µg/kg body weight/day by the Joint FAO/WHO Expert Committee on Food Additives

(JECFA, 2017). Türkiye adheres to the same regulatory limits as the European Union. Despite extensive research and the implementation of good agricultural practices, fumonisin contamination remains a public health and global food safety problem.

Study Objective

The first objective of this study was to determine the presence of fumonisins B1 and B2 in commonly consumed corn-based snacks. For this purpose, our 2020 study found that fumonisin levels in some corn snacks were significantly above the limit value (800 µg/kg). This study aimed to monitor fumonisin contamination levels in corn snacks on an annual basis and determine daily exposure.

Materials and Methods

Collection of Corn snack Samples

In November 2020, a total of 30 different corn snack samples were purchased from all varieties sold in the market, with different production contents (spicy, salty, sugary, cheese, etc.), and analyzed for the presence of FBs (FB_1 and FB_2). Of the 30 corn snacks samples, 18 were purchased from institutional economy supermarkets and 12 were purchased from other institutional supermarkets. Of the 30 corn snacks analyzed in 2020, 22 corn snacks varieties with total fumonisin levels above 200 µg/kg were purchased from the same supermarkets in January 2021, 2023, and 2024, and their fumonisin levels were monitored for 3 years. In 2022, the study could not be carried out because the chemical materials required for analysis could not be supplied.

Chemicals and Reagents

The chemicals used were of HPLC quality and grade. Acetonitrile (ACN) and Methanol (MeOH) were sourced from Merck KGaA. 2-Mercaptoethanol (MCE) and o-Phthaldialdehyde (OPA) were obtained from Sigma. Sodium dihydrogen phosphate ($NaH_2PO_42H_2O$) and sodium tetraborate ($Na_2B_4O_510H_2O$) were acquired from Merck. The certified standard of FB1 + FB2 (50 µg/mL) was purchased from Romer Labs Diagnostic GmbH (Austria). BiopureTM MIX 3 contains 50 µg/mL each of FB_1 and FB_2 in an acetonitrile-water mixture (5050, v/v). All standard solutions were prepared in acetonitrile-water (50:50). o-Phthaldialdehyde solution (OPA), 40 mg of OPA was dissolved in 1 ml methan ol, then 5 ml of sodium tetraborate solution (0.1 M $Na_2B_4O_5$) was added, and then 50 µl of MCE was added and vortexed. Extraction dissolvent, acetonitrile-methanol-water (25:25:50, v/v/v). Preparation of fumonisin B_1 + B_2 calibration stock standard, 500 µL of fumonisin standard (FB_1 + FB_2, 50 µg/mL) was taken and pipetted into a 5 ml vial. 5 ng/g working stock standard was prepared by completing 5 ml with acetonitrile /water (50:50, v/v). Mobile phase solution, methanol and sodium dihydrogen phosphate solution ($NaH_2PO_4.2H_2O$) (77:23, v/v), adjusted to pH 3.35 with orthophosphoric acid (Merck) (H_3PO_4). Then,

Mobile phase was filtered with 0.45 µm membrane. Solvent solutions; water -acetonitrile (50 + 50, v/v) and methanol -acetik acit (1 + 99, v/v).

Apparatus and Enstruments

High-Performance Liquid Chromatography (HPLC) was performed using the Agilent 1100 system. The system includes a quaternary pump, automatic sampler, solvent degasser, column heater, and fluorescence detector (Agilent, Germany). Filter papers are of the Whatman No. 4 brand (Millipore Corp., Bedford, MA). The HPLC column is a 150 × 4.6 mm internal diameter, 5 µm C18 reverse-phase column, supplied by GL Sciences Inc. (Tokyo). Solid-phase extraction (SPE) columns, provided by Welchrom (Austria), are of P-SAX, 2 g/10 mL, and C18 types.

Chromatographic Conditions

This study was conducted according to the AOAC Official Method 2001.04, as reported by Visconti et al. (2001). SPE column was used in 2020 and 2021 and immunoaffinity column was used in 2023 and 2024. The HPLC pump was set to deliver a constant flow rate of 1 mL/min, and the injection system was calibrated to deliver 20 µL. HPLC column: 150 × 4.6 mm, GL Sciences 5C_{18}, 5 µm; mobile phase: methanol/0.1 M NaH2PO4 (77/23, v/v), adjusted to pH 3.35 with H3PO4; flow rate: 1.0 mL/min; fluorescence detector: excitation at 335 nm and emission at 440 nm.

Samlpe Extraction and HPLC Analysis

The extraction of samples was performed according to the method of Visconti et al. (2001). Corn snacks were ground using a coffee grinder. A 20 g portion of the ground samples was weighed into a 250 mL bottle, and 50 mL of a methanol: acetonitrile: water (25:25:50, v/v/v) mixture was added. The mixture was homogenized by shaking on an orbital shaker for 60 minutes and then centrifuged at 2500 x g for 10 minutes. The supernatant obtained after centrifugation was filtered through filter paper (Whatman No. 4). The remaining solid was then re-extracted with an additional 50 mL of extraction solvent and centrifuged again at 2500 x g for 10 minutes; the supernatant was filtered through the same filter paper. Both filtrates were combined in a single container, homogenized by vortexing for 5 minutes, and then 10 mL of the filtered extract was cleaned up using a pre-conditioned SPE column. The SPE column was conditioned with 5 mL of methanol and 5 mL of a methanol-water (3:1) solution, respectively. After conditioning the column, 10 mL of the filtered sample extract was passed through the SPE column, and the extract was further cleaned with 5 mL of a methanol-water (3:1, v/v) solution and then washed with 3 mL of methanol. The fumonisin elution was performed at a flow rate of 1 mL/min using 10 mL of an acetic acid/methanol (1:99, v/v) solution. The eluate was collected in a 20 mL capacity collection flask and dried under nitrogen gas at 60°C. A 10 mL filtrate was allowed to flow through the FumoniTest™ immunoaffinity column at a rate of approximately 1–2 drops/second. The loaded immunoaffinity column was then washed with 10 mL of PBS at a rate of 1–2 drops/second until air was removed from the

column. The column was eluted with 1.5 mL of methanol at a rate of 1 drop/second, and fumonisins were transferred to a vial. The methanol was removed under nitrogen gas. The dried residue was stored at 4˚C until analysis.

The dried eluates were dissolved by adding 200 µL of acetonitrile/water (50:50, v/v) and vortexed. Then, 50 µL aliquots of the extract were transferred into 1 mL test tubes, and 50 µL of OPA reagent was added. The derivatized solution was vortexed, and 20 µL was injected into the LC system. FBs (FB_1 and FB_2) were quantified based on their expected retention times: 8.05 min for FB_1 and 15.53 min for FB_2.

Consumption Frequency

Daily intake of corn snacks, consumption frequency was assessed based on sales volumes in the supermarkets where corn snack samples were purchased. A 3-month registration form was kept in the supermarkets where samples were collected to assess consumption frequency. The age, weight, consumption frequency, and packaging quantities of corn snack purchasers were recorded over a 3-month period. Consumption volume was calculated based on the most frequent consumers. Due to school closures during the Covid-19 pandemic, the consumption frequency was found to be very low in 2020 (20 g/day) and 2021 (40 g/day). The highest consumption frequency was found in 2023 and 2024 in people aged 19–30 weighing 55–84 kg (average 70 kg), with the highest consumption frequencies being 60 g/day and 50 g/day, respectively. In Türkiye, children are not allowed to consume snacks and chips by their parents. Children were not evaluated because their consumption is very low. In this study, average probable daily intake (APDI) and maximum probable daily intake (MPDI) for young adults in Giresun province were evaluated according to the PMTDI of 2 µg/kg body weight/day determined by the Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2017).

Method Performance

Method performance was carried out on linearity, selectivity, sensitivity, accuracy, reproducibility and precision. (In 2020 and 2021) The linearity was performed by constructing a calibration curve for FB_1 + FB_2 ranging from 0.05 to 4.00 µg/kg (0.05, 0.25, 1.00 and 4.00) and the retention times of FB_1 and FB_2 were 8.05 min ± 0.5 and 15.54 min ± 0.5, respectively. The coefficients of correlation (R^2) were 0.9999 and 0.9996 for FB_1 and FB_2, respectively. The sensitivity of the method was determined using the limit of detection (LOD) and limit of quantificication (LOQ). The LOD (3:1) and LOQ (10:1) were based on signal-to-noise (S/N) and the LODs were 4.5 and 6 µg kg^{-1} for FB_1 and FB_2 respectively, and the LOQs 15 and 20 µg kg^{-1} for FB_1 and the FB_2, respectively. The accuracy was confirmed through recovery experiments. The recoveries were determined with spiked samples at concentrations of 0.25, 0.50 and 1.00 ng/µL for each and analyse them in triplicate on the same day. The average recoveries were 88% for FB_1 and 81% for FB_2 in corn snacks. Relative standard deviations (RSDs) ranged from 2.40% to 6.84%, averaging 3.81%. (In 2023 and 2024) The analytical performance was studied by taking the average of 6 replicates

of samples spiked at 2 levels (750 and 1500 ng/g) on different days by two different analysts. The linearity was performed by constructing a calibration curve for FB_1 + FB_2 ranging from 0.05 to 10.000 µg/kg (0.05, 0.25, 0.50, 5.00 and 10.00 µg/kg). The coefficients of correlation (R^2) were 0.9999 and 0.9998 for FB_1 and FB_2, respectively. The average recoveries were 93% for FB_1 and 85% for FB_2. The LOD and LOQ values were calculated from the standard deviation and means taken after 8 readings of samples inoculated with 300 µg/kg fumonisin. The LODs were 2.68 µg/kg for FB_1 and 7.38 µg/kg for FB_2, and the LOQs were 55 µg/kg for FB_1 and 60 µg/kg for FB_2. The RSDs were 1.93% and 2.07% for FB_1 and FB_2, respectively. Analytical performance results are provided in Table 1.

Table 1
Performance of the analytical method

Year	Fumonisins	Recovery	LOQ - LOD	RSD (%)	R^2	Regression equation
[2020	FB_1	88%	15 - 4,5	2.84	1.000	y = 32.175x + 1.0236
2021]	FB_2	81%	20 - 6,0	5.12	0.9996	y = 23.816x + 0.5153
[2023	FB_1	93%	55 - 17	2.10	0.99999	y = 10.0126 + 0.0876
2024]	FB_2	86%	60 - 18	2.68	0.99998	y = 12.276x + 0.184

These results indicate that the analytical method is applicable for the detection of FB_1 and FB_2 in corn snack samples. These results suggest that the chosen analytical method exhibits good accuracy and precision for the detection of FB_1 and FB_2 in corn snacks.

Statistical Analysis

In this study, all statistical analyses were performed using the SPSS 23 version. In the experimental study, the data were collected in 4 groups as 2020,2021, 2023 ve 2024.

Results and Discussion

Occurrence of Fumonisins in Corn snacks

In this study, 22 corn snack samples with different additives and production methods were monitored for fumonisin contamination levels over a four-year period (2020, 2021, 2023, and 2024), and the results are presented in Table 2. FB_1 and FB_2 analysis was performed on a total of 96 corn snack samples in four years. Of the 30 corn snack samples purchased from supermarkets in 2020, 27 (90%) contained FB_1 at concentrations ranging from 63 ng/g to 3958 ng/g, and 18 contained FB_2 at concentrations ranging from 20 to 168 ng/g. Total fumonisins (FBs: FB_1 + FB_2) ranged from 79 to 4126 ng/g, with the mean of positive samples being 1042 ± 905 ng/g. As for 2021, 22 corn snacks with high fumonisin levels (200 ng/g) were analyzed in 2020, and 21 (95.5%) were found to be contaminated with fumonisins ranging

from 18 to 5055 ng/g. FB_1 ranged from 18 to 4313 ng/g in 21 samples, and FB_2 ranged from 20 to 742 ng/g in 17 samples. The mean of positive samples was calculated as 1296 ± 1280 ng/g. In contrast, these levels were much lower in 2023 and 2024, with total fumonisins being 1041 ng/g and 932 ng/g, respectively. The mean of positive samples was 449 to 334 and 319 to 308 ng/g. Eleven samples in 2020, 12 in 2021, 2 in 2023, and 3 in 2024 were found to be above the maximum limit (800 ng/g). The results revealed that FB contamination levels in corn snacks varied significantly between years, with average concentrations ranging from 1042 ng/g in 2020 to 319 ng/g in 2024. The high fumonisin levels in 2020 and 2021 may have been due to raw material supply shortages.

Table 2
Fumonisin B_1 and Fumonisin B_2 levels in corn snacks (ng/g)

	Fumonisin B_1 (ng/g)		**Fumonisin B_2 (ng/g)**		**Total fumonisin (FB_1 + FB_2, ng/g)**
Taken year of Samples	Positive/total samples (%)	Range	Positive/total samples	Range	Range Average
2020	27/30 (90)	63-3958	8/30	20–168	79- 4126 1042 ± 905
2021	21/22 (95.5)	18-4313	17/22	20–742	18-5055 1296 ± 1280
2023	13/22 (59)	20–823	9/22	20–218	20-1041 449 ± 334
2024	11/22 (50)	32–730	11/22	20–236	32–932 319 ± 308
The mean of positive samples was taken. There is a significant difference (P ⍰ 0.05) between years and corn snacks.					

In 2023, 13 out of 22 samples (59%) were contaminated with fumonisins ranging from ≤ LOQ (20 ng/g) to 1041 ng/g. FB_1 ranged from 20 ng/g to 823 ng/g in 13 samples, and FB_2 ranged from 20 to 218 ng/g in 9 samples. The mean of positive samples was 449 ± 334 ng/g. 3 örnek limiti aştı. In 2024, Fifteen out of 22 samples (68%) were found to be contaminated with fumonisins at levels ranging from 32 to 932 ng. The mean of positive samples was 319 ± 308 ng/g. FB_1 ranged from 32 to 730 ng/g in 15 samples, and FB_2 ranged from 20 ng/g to 236 ng/g in 11 samples. In 2020, 40% of samples, 40.9% in 2021, 13% in 2023, and 9% in 2024 were above the maximum standard of 800 ng/g. In this study, samples were not collected randomly, and corn snack samples with high fumonisin contamination levels from 2020 (in 2021, 2023 and 2024) were monitored.

In this study, we monitored and evaluated FB_1 and FB_2 contamination levels in corn snacks between 2020 and 2024. We observed high levels of fumonisin in corn snacks in 2020 and 2021, with maximum total fumonisin levels of 4126 ng/g and 5055 ng/g, respectively. The levels were much lower in 2023 and

2024, at 1041 ng/g and 932 ng/g, respectively. However, more than half of the samples contaminated with fumonisins in all four years. Similarly, Bordin et al. (2014; 2015) found FB_1 1208 µg/kg in corn flakes samples in 2014 and 170 µg/kg in 2015, but it was lower than the results of this study.

In this study, the fumonisin contamination rate found in corn snack samples varied from year to year. Eleven samples in 2020, nine samples in 2021, two samples in 2023, and three samples in 2024 were found to be above the maximum allowable limit (800 ng/g) in corn snacks. Based on these results, it is considered possible that moldy corn was processed in 2020 and 2021. The observed annual variation in fumonisin levels may be influenced by multiple factors, including climatic conditions during corn cultivation, fungal infection pressure, and storage or processing practices (Logrieco et al., 2018). In particular, the highest mean and maximum concentrations in 2020 and 2021 coincided with the COVID-19 pandemic years, suggesting that older corn may have been used due to corn grain scarcity in these years. In contrast, 2023 and 2024 showed relatively lower contamination, likely reflecting improvements in feedstock selection, storage practices, or climate differences. These fluctuations are consistent with previous findings that fumonisin levels are highly dependent on annual environmental conditions and maize harvest quality (James and Zikankuba, 2018). Since fumonisins are not much affected by heat processing and food processing stages, the fumonisins found in corn are also carried over to their products. Traditional food processing methods often fall short in eliminating these toxins due to their remarkable heat stability (Karlovsky et al. 2016; Wan et al. 2020).

There are few studies on the presence of fumonisins in corn and corn-based products in Türkiye. In previous studies conducted in Türkiye, Omurtag (2001) reported 2660 ng/g FB_1 in corn-bades products, Bakırcı (2014) reported 132.4 to 9589.4 ng/g FB_1 in corn and corn-based products. When our results were compared with previous studies conducted in Turkey, they were found to be higher than those reported by Omurtag (2001) and lower than those reported by Bakırcı (2014). Fumonisins are one of the most concerning mycotoxins affecting corn and its derivatives worldwide, particularly for populations with high maize consumption. Their presence varies significantly by region, influenced by climatic conditions, agricultural practices, storage methods, and regulatory regulations.

Fumonisins are carcinogenic mycotoxins known to cause a variety of toxic effects on human and animal health (IARC 2002). Maksimum limitler are intended to be health protective and to ensure that fumonisin exposure is below the PMTDI of 2 µg/kg body weight/day established by JECFA. However, in many parts of the world, authors have reported that corn-based products consumed with fumonisin contamination above maximum limits. High levels of fumonisins in corn and corn-based products from different countries around the world are shown in Table 3.

Tablo 3. High levels of fumonisin levels in corn and corn-based products from different countries/regions of the world.

Country	Products	Total Fumonisin	Incidence	References
USA	Corn products	2679 µg/kg	65%	Gutema et al. 2000
Honduras	Corn tortilla	0.63-12.04 mg/kg	100%	Cabrera-Meraz et al. 2021
Argentina	Corn puff	1649 µg/kg	95%	Federico et al. 2010
	Infant cereals	992 µg/kg	84.2%	Cendoya et al. 2025
Brazil	Corn	9033 µg/kg	46.6%	Scussel et al. (2014)
	Popcorn	3213; 2158 µg/kg	100%	Andrade et al. 2018;2020
	Corn products	2908.2 µg/kg	100%	Matos et al. 2024
	Popcorn	3338.5		Gomes et al. 2024
	Corn meal	6920	96.6%	Savi et al. 2016
Mexico	Tortillas	689.3 µg/kg	90%	Wall- Martinez et al. 2019
	Tortillas	1579 µg/kg	98%	Gilbert Sandoval et al. 2020
Italya	Corn products	6.790 µg/kg	100%	Doko and Visconti, 1994
	Corn	11.100 µg/kg	100%	Berardo et al. 2011
	Corn meal	961 µg/kg	95%	Espito et al. 2016
Portugal	Breakfast cereals	295 µg/kg	17%	Soria et al. 2024
	Popcorn	1381 µg/kg/	11%	Martins et al. 2012
	Cornflakes	991 µg/kg	88%	
	Breakfast cereals	67 µg/kg	81%	Martins et al. 2018
			58%	
Poland	Corn snacks	6342 µg/kg		Pokrzywa and Surma 2022
	Corn snacks	7331 µg/kg	77%	Bryla et al. 2016
	Popcorn	7000 µg/kg	28%	
	Corn flour	6342 µg/kg	45%	Kowalska et al. 2017
	Popcorn	763 µg/kg	61.5%	
Slovenia	Maize and its products	27.483 µg/kg	23.5%	Kirinic et al. 2015

Hungary	Corn grits	2540 µg/kg	41.9%	Zentai et al. 2019
	Cornflakes	70 µg/kg	28%	
Serbian	Corn flakes	579.4 µg/kg	73.3%	Torovic, 2017
Iran	Cookie samples	2300 µg/kg	93.4%	Azizi IG, Rouhi S 2013
Japan	Corn snacks	2551µg/kg	86.7%	Sugita-Konisha et al., 2013
	Corn snacks	1850 µg/kg	100%	Yoshinari et al. 2020
China	Corn meal	5046 µg/kg	100%	Li et al. 2015,
	Cornflakes	171 µg/kg	100%	
	Corn products	6209 µg/kg	89.5%	Song et al. 2025
			95.8%	Zhang et al. 2021
Indonesia	Maize snacks	400 µg/kg	100%	Shantika et al. 2024
Lebanon	Cornflakes	6285 µg/kg	87.5%	Hasan et al., 2023
South Africa	Maize	11.347 µg/kg	100%	Meyer et al. 2019
	Maize	14.347 µg/kg	100%	Ekwonadu et al. 2020
Malawi	Corn flour	10.306 µg/kg	100%	Reinhold et al. 2024
Nigeria	Maize products	11.552	77%	Chilaca et al. 2016
Tanzania	Corn	11.048 µg/kg	52%	Chen et al.2018
Zimbabwe	Corn	432.32 µg/kg	100%	Murashiki et al. 2017
Guatemala	Maize	17.100 µg/kg	100%	Torres et al.2015

In comparison, the 2020 and 2021 maximum values in the presented study (4126 and 5052 µg/kg) are lower than the maximum values in Brazil and Honduras, but higher than the results in Argentina and Mexico. The 2023 result (1041 µg/kg) and 2024 result (932 µg/kg) are lower than most South American findings, indicating a relative improvement. In China, levels of up to 6209 µg/kg in corn products (Song et al. 2025) and 5046 µg/kg in corn flour (Li et al. 2015) with a 100% contamination rate have been reported. Similarly, in Japan, Sugita-Konisha et al. (2013) and Yoshinari et al. (2020) reported contamination levels of 2551 µg/kg and 1850 µg/kg in corn snacks, respectively, whereas Indonesia, on the contrary, reported a relatively lower level of 400 µg/kg of fumonisin in corn-based products (Shantika et al., 2024). The 2020 result (4126 µg/kg) and 2021 result (5052 mg/kg) from the current study closely match the values seen in China and Japan, but are still lower than the results reported in China. The 2024 level (932 µg/kg) is more similar to the results from India but more than double the values reported in Indonesia. In South America, fumonisin contamination in corn and corn products is widely and highly

reported. In Brazil, various products, including popcorn, corn flour, and breakfast cereals, contained fumonisin at levels ranging from 81 µg/kg to 6920 µg/kg (Savi et al., 2016; Matos et al., 2024), with prevalence often at or near 100%. Argentina reported 1649 µg/kg in corn flakes and 992 µg/kg in baby cereals (Federico et al., 2010; Cendoya et al., 2025). In Honduras, corn tortillas showed levels between 6300 µg/kg and 12,040 µg/kg (Cabrera-Meraz et al., 2021), while Mexico reported 1579 µg/kg in tortillas (Gilbert-Sandoval et al., 2020). European countries generally report lower fumonisin levels due to stricter regulations and well-developed food safety infrastructure. However, there are exceptions. An extremely high value of 27.483 µg/kg was reported in corn products in Slovenia (Kirinic et al., 2015), while in Poland, 7331 µg/kg (Bryla et al., 2016) and 6342 mg/kg (Pokrzywa and Surma, 2022) were reported in corn snacks. These findings were higher than the findings of our study. Other European countries, such as Italy, Portugal, Spain, and Hungary, reported more moderate levels, ranging from 961 µg/kg (Espito et al., 2016) to 2,540 µg/kg (Zentai et al., 2019). Additionally, Zinedin et al. (2005) measured contamination levels at 5844 µg/kg in Morocco. These findings demonstrate that fumonisin contamination is a widespread problem worldwide, and that various environmental factors, agricultural practices, and storage conditions play a significant role in these contamination levels, with fumonisin contamination varying from year to year.

Assessing the Risk of Exposure to Fumonisins

The FBs exposure, APDI and MPDI were calculated using the average levels of fumonisins and the maximum concentrations found in the samples and divided by 70 kg body weight (Bordin et al. 2015; Song et al. 2025). Adults aged 19–30 years were the largest consumers of corn snacks in Giresun, and the fumonisin exposure assessment was based on this group. In Türkiye, children under 15 years of age are not permitted to consume snacks and chips by their parents. Therefore, snack and chip consumption rates in children under 15 are low. Children primarily consume breakfast cereals designed for children. APDI and MPDI values are given in Table 4. APDI and MPDI in adults ranged from 0.227 µg/kg bw/day to 0.741 µg/kg bw/day and 0.665 to 2.8 µg/kg bw/day, respectively. APDI for adults was lower than the PMTDI of 2 µg/kg bw/day recommended by JECFA. However, the MPDI (2.8 µg/kg bw/day) value in 2021 was found to be higher than the PMTDI value of 2 mg/kg body weight/day. The MPDI was found to be 1.47 µg/kg in 2020, 0.892 µg/kg in 2023, and 0.665 µg/kg bw/day in 2024. These values were lower than the PMTDI value. These values were lower than the PMTDI value.

Table 4. The average tolerable daily intake (APDI) and maximum tolerable daily intake (MPDI) for adults

Years	Total FBs (ng/g) Mean ± SD	Median	Consumption (g/day)	ATDI (µg/kg bw/day) 18 ≤ Adults PMTDI%	MTDI (µg/kg bw/day) 18 ≤ Adults PMTDI %
2020	1042 ± 905	807	25	0.372 18.6%	1.473 74.6%
2021	1296 ± 1280	981	40	0.741 37%	2.888 144%
2023	449 ± 334	354	60	0.384 19%	0.892 44.6%
2024	319 ± 308	188	50	0.228 11.4%	0.665 33%

MDI (Mean Daily Intake) estimates were calculated from the mean. Body weight 70 for adults. PMTDI of 2 µg/kg body weight/day for fumonisins (WHO 2002).

Recent worldwide research has focused on human exposure to mycotoxins (Sspuuya et al. 2018; Shephard et al. 2019; Yoshinarı et al. 2020; Soraia et al. 2024; Song et al. 2025). A study by Soraia et al. (2024) in Poland reported the highest FB_1 levels in breakfast cereals as 4051.22 µg/kg bw/day for infants and 1011.25 µg/kg bw/day for children. In Turkey, products made from corn flour are not used in child nutrition. Therefore, exposure to corn-based products in infants and children is almost negligible. In Honduras, Cabrera-Meraz et al. (2021) estimated dietary exposure to FBs between 6.16 and 151.98 µg/kg bw/day. In Brazil, Andrade et al. (2018) found the maximum consumption of popcorn with maximum (MPDI) of the mycotoxin concentrations led to an FBs intake of 26.78 µg/kg bw/day (13 times greater than PMTDI) and for consuming cornflakes was 0.027µg/kg bw/ day. In the study conducted in China, Song et al. (2025) found that the 95th and 99th FB exposures for children and adolescents were estimated at 2.18 to 3.46 µg/kg body weight/day, exceeding the PMTDI of 2 µg/kg bw/day. Probabilistic analysis also showed that the 99th exposures for all age groups were 2.06 to 3.08 µg/kg bw/day. The results presented above are higher than the maximum result of this study (2.8 µg/kg bw/day) and pose a higher health risk. In addition, Martins et al. (2012) determined the APDI and MPDI for Brazilians as 120.58 and 256.04 ng/kg bw/day, Savi et al. (2016) estimated the mean probable daily intake as 133.9 ng/kg bw/day and the maximum probable daily intake as 340.9 ng/kg bw/day for the population of the state of Santa Catarina (Brazil), similar to the results of this study. There are studies that are well below the PMTDI limit and do not pose a risk of exposure. Yoshinarı et al. (2020) reported that the mean intake of free fumonisin in the Japanese population was 3.9 ng/kg, and the mean intake of total fumonisin (free + hidden fumonisin) ranged from 3.3 to 12.5 ng/kg bw/day, which was much lower than in this study. In studies in China, Li et al. (2015) and Liu et al. (2017) estimated daily exposure as 0.08 µg/kg bw/day and 0.12 µg/kg bw/day, respectively, and Bordin et al. (2019) estimated the total probable daily intake (PDI) of fumonisins in Brazil as 96.9 ng/kg bw/day. Pokrzywa et al. (2022) found PMTDI in the range of 0.50–0.92% and 0.05–0.42% in corn flour and corn semolina, respectively. They observed the highest values in corn flakes (0.14–1.84% PMTDI), with the highest value found in the 4–6 age group. Kirimker et al (2020) found mean fumonisin exposures for infants and toddlers to be 0.093 and 0.068 µg/kg bw/day, respectively, while P95 exposure estimates were 0.079 and 0.058 µg/kg bw/day. In Türkiye, children's foods and breakfast cereals do not pose a health risk from fumonisins (Gökışık & Kahtalı, 2023). However, the same cannot be said for cereal snacks, as they do pose a risk.

Conclusions

This study focused on commercially available corn-based snacks collected from supermarkets in a single province (Giresun, Turkey). Broader surveillance across multiple regions and product categories would provide a more comprehensive understanding of fumonisin contamination in Türkiye. This study was showed the occurrence of fumonisins (FB1 + FB2) in corn-based snacks consumed in Türkiye between 2020 and 2024, with mean levels ranging from 319 to 1296 ng/g. Although overall contamination levels were comparable to reports from other regions of the world, occasional exceedances of international safety thresholds highlight the need for continued monitoring. The annual variation in fumonisin levels highlights the influence of climatic, agricultural, and processing factors on contamination. While most products meet current European regulatory standards, consumption of such snacks by children and young adults raises concerns about potential chronic exposure. Strengthening good agricultural and production practices, and expanding surveillance and public awareness efforts are crucial to minimize health risks and ensure food safety in Türkiye. As a result of intensive studies conducted since the isolation of fumonisin from corn (1988), the presence of high levels of fumonisin in corn and corn products continues to be a global health and economic problem. The presence of health-threatening levels of fumonisin in corn and corn products is also a significant public health concern in Türkiye and may require close monitoring. Contamination of corn and corn products with fumonisins poses a health risk in Türkiye, as has been reported in many countries worldwide.

Declarations

Acknowledgements

This study was supported by the Giresun University Scientific Research Foundation (grant number BAP-C-281119-80) in 2020 and 2021. The 2020 and 2021 data for this study are part of a master's thesis conducted at the Department of Bioprocess Engineering at Giresun University. We thank the Giresun University Scientific Research Projects (BAP) Commission for their support. The studies conducted in 2023 and 2024 were conducted with the authors' own funds and efforts.

Declaration of Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

Cavidan Demir Gökışık: Formal analysis, Writing - Original Draft, Conceptualization, Methodology, Validation, Investigation, Data Curation, Writing- Review& Editing, Supervision, Project administration, Daily consumption records, Funding acquisition **Mehmet Kahtalı**: Resources, Funding acquisition, Investigation, sample collection

References

1. Andrade GCRM, Pimpinato RF, Francisco JG, Monteiro SH, Calori- Domingues MA, Tornisielo VL (2018) Evaluation of mycotoxins and their estimated daily intake in popcorn and cornflakes using LC-MS techniques. Lebensm Wiss Technol 95:240–246. https://doi.org/10.1016/j.lwt.2018.04.073
2. Andrade PD, Dias JV, Souza DM, Brito AP, van Donkersgoed G, Pizzutti IR, Caldas ED (2020) Mycotoxins in cereals and cereal-based products: incidence and probabilistic dietary risk assessment for the Brazilian population. Food Chem Toxicol 143:111572 Epub 2020/07/17. https://doi:10.1016/j.fct.2020.111572
3. Andrade PD (2023) Dietary risk assessment for fumonisins: challenges and prospects, Current Opinion in Food Science, 54, 2023, 101080, ISSN 2214–7993. https://doi.org/10.1016/j.cofs.2023.101080
4. Azizi IG, Rouhi S (2013) The comparison of total fumonisin and total aflatoxin levels in biscuit and cookie samples in Babol City, Northern Iran. Iran J Public Health 42(4):422–427 PMID: 23785683; PMCID: PMC3684730
5. Bakırcı GT (2014) Investigation of Cereal and Cereal Products in Terms of Aflatoxin, Ochratoxin A, Zearalenone, Fumonisin and Deoxynivalenol Mycotoxins. Acad Food J 12(2):46–56
6. Berardo N, Lanzanova C, Locatelli S, Laganà P, Verderio A, Motto M (2011) Levels of total fumonisins in maize samples from Italy during 2006–2008. Food Addit Contam Part B 4:116–124. https://doi.org/10.1080/19393210.2011.564313
7. Bryła M, Roszko M, Szymczyk K, Jedrzejczak R, Obiedzi´nski MW (2016) Fumonisins and their masked forms in maize products. Food Control 59:619–627. https://doi.org/10.1016/j.foodcont.2015.06.032
8. Cabrera-Meraz J, Maldonado L, Bianchini A, Espinal R (2021) Incidence of aflatoxins and fumonisins in grain, masa and corn tortillas in four municipalities in the department of Lempira. Honduras Heliyon 7(12) Article e08506. https://doi.org/10.1016/j.heliyon.2021.e08506
9. Cendoya E, María J, Nichea, Cindy J, Romero Donato, Vanessa GL Zachetti María del Pilar Monge & María L. Ramirez (2025) Fumonisins in infant cereals marketed as complementary food in Argentina. Food Addit Contaminants: Part B, 18:1, 48–54. https://doi.org/10.1080/19393210.2024.2411278
10. Chen C, Mitchell NJ, Gratz J, Houpt ER, Gong Y, Egner PA, Wu F (2018) Exposure to aflatoxin and fumonisin in children at risk for growth impairment in rural Tanzania. Environ Int 115:29–37. https://doi.org/10. 1016/j. envint. 2018. 03. 001
11. Chilaka CA, De Boevre M, Atanda OO, De Saeger S (2016) Occurrence of Fusarium Mycotoxins in Cereal Crops and Processed Products (Ogi) from Nigeria. Toxins 8(11):342. https://doi.org/10.3390/toxins8110342
12. ECR (European Community Regulation) (2007) Commission regulation (EC) N 1126/2007. 28 September 2007. Amending regulation (EC) N 1881/2006 setting maximum levels for certain

contaminants in foodstuffs as regards toxins in maize and maize products. Official J Eur Communities L 255:14–17

13. Ekwomadu TI, Gopane RE, Mwanza M (2018) Occurrence of filamentous fungi in maize destined for human consumption in South Africa. Food Sci Nutr 6:884–890. https://doi.org/10.1002/fsn3.561
14. Esposito F, Fasano E, Scognamiglio G, Nardone A, Triassi M, Cirillo T (2016) Exposure assessment to fumonisins B1, B2 and B3 through consumption of gluten- free foodstuffs intended for people affected by celiac disease. Food Chem Toxicol 97:395–401. https://doi.org/10.1016/j.fct.2016.10.013
15. Farhadi A, Fakhri Y, Kachuei R, Vasseghian Y, Huseyn E, Mousavi Khaneghah A (2021) Prevalence and concentration of fumonisins in cereal-based foods: a global systematic review and meta-analysis study. Environ Sci Pollut Res Int 28(17):20998–21008. https://doi.oprg/10.1007/s11356-021-12671-w
16. Federico FJ, Funes GJ, Salas MP, Resnik SL (2010) Natural occurence of fumonisins i, n corn and corn puff in Argentina. Mycotoxin Res 26:273–278. https://doi.org/10.1007/s12550-010-0066-3
17. Gelderblom WCA, Jaskiewicz K, Marasas WFO, Thiel PG, Horak MJ, Vleggaar R, Kriek NPJ (1988) Fumonisins—novel mycotoxins with cancer-promoting activity produced by Fusarium moniliforme. Appl Environ Microbiol 54:1806–1811 Crossref. PubMed. https://doi.org/10.1128/aem.54.7.1806-1811
18. Gilbert-Sandoval I, Wesseling S, Rietjens IMCM (2020) Occurrence and Probabilistic Risk Assessment of Fumonisin B1, Fumonisin B2 and Deoxynivalenol in Nixtamalized Maize in Mexico City. Toxins 12(10):644. https://doi.org/10.3390/toxins12100644
19. Gomes AL, Sousa RLM, das Neves LAV, EM, da Gloria MFC, Burbarelli LdeO, Seno RR, Petrus AM (2024) Fernandes,Occurrence and Co-exposure of aflatoxins and fumonisins in conventional and organic corn,Food Control,Volume 165, 110628, ISSN 0956–7135. https://doi.org/10.1016/j.foodcont.2024.110628
20. Gutema T, Munimbazi C, Bullerman LB (2000) Occurrence of fumonisins and moniliformin in corn and corn-based food products of US origin. J Food Prot 63:1732–1737. https://doi.org/10.4315/0362-028X-63.12.1732
21. Hassan HF, Awada F, Dimassi H, El Ahmadieh C, Hassan NB, El Khatib S, Alwan N, Abiad MG, Serhan M, Darra NEl (2023) Assessment of mycotoxins in cornflakes marketed in Lebanon. Sci Rep 13(1):20944. https://doi.org/10.1038/s41598-023-48172-8
22. International Agency for Research on Cancer. Fumonisin B1. In: Some traditional herbal medicines, some mycotoxins, naphthalene and styrene. WHO IARC monographs on the evaluation of carcinogenic risks to humans, Vol. 82, IARC, Lyon IARC (2002) France (2002), pp. 301–366. https://doi.org/10.1016
23. JECFA, Joint FAO/WHO Expert Committee on Food Additives, the Joint FAO/WHO Expert Committee on Food Additives (2017) World Health Organization & : Evaluation of certain contaminants in food:

eighty- third report of 83rd, WHO Technical Report Series. World Health Organization; 2017 1002, 2017 https://apps.who.int/iris/handle/10665/254893

24. Juan C, Raiola A, Mañes J et al (2014) Presence of mycotoxin in commercial infant formulas and baby foods from Italian market. Food Control 39:227–236. https://doi.org/10.1016/j.foodcont.2013.10.036
25. Kirimker SE, Turksoy S, Kabak B (2020) Assessment of dietary exposure to deoxynivalenol and fumonisin in the population of infants and toddlers in Turkey. Food Chem Toxicol 140(111304):0278–6915. https://doi.org/10.1016/j.fct.2020.111304
26. Kirinčič S, Škrjanc B, Nataša Kos B, Kozolc N, Pirnat G, Tavčar-Kalcher (2015) Mycotoxins in cereals and cereal products in Slovenia – Official control of foods in the years 2008–2012, Food Control, Volume 50,2015, Pages 157–165, SSN 0956–7135. https://doi.org/10.1016/j.foodcont.2014.08.034
27. Kowalska A, Hajok I, Piekut A (2017) Assessment of the contamination level by fumonisins B 1 and B 2 of the corn food products available on polish consumer market. Pol J Environ Stud 26(6):2595–2601. https://doi.org/10.15244/pjoes/70386
28. Li F, Jiang D, Zheng F, Chen J, Li W (2015) Fumonisins B_1, B_2 and B_3 in corn products, wheat flour and corn oil marketed in Shandong province of China. Food Addit Contam Part B Surveill 8:169–174. https://doi.org/10.1080/19393210.2015.1028480
29. Martins FA, Ferreira FMD, Ferreira FD, Bando E, Nerilo SB, Hirooka EY, Machinski M Jr (2012) Daily intake estimates of fumonisins in corn-based food products in the population of Parana. Brazil Food Control 26:614–618. https://doi.org/10.1016/j.foodcont.2012.02.019
30. Martins C, Ricardo Assunção SC, Cunha JoséO, Fernandes A, Jager CA, Oliveira P, Alvito (2018) Assessment of multiple mycotoxins in breakfast cereals available in the Portuguese market, Food Chemistry, 239, 2018, 132–140, 0308–8146. https://doi.org/10.1016/j.foodchem. 2017.06.088
31. Matos Nínive Alves Vieira de André Victor Sartori, Eloiza Rodrigues Pimentel de Sá Soilo, Maria Heloísa Paulino de Moraes, Silvana do Couto Jacob (2024) A survey on free and hidden fumonisins in Brazilian corn and corn-based products. Food Control, 156, 110135, ISSN 0956–7135. https://doi.org/10.1016/j.foodcont. 2023.110135
32. Meyer H, Skhosana ZD, Motlanthe M, Louw W, Rohwer E (2019) Long term monitoring (2014–2018) of multi-mycotoxins in South African commercial Maize and wheat with a locally developed and validated LC-MS/MS method. Toxins 11:E271. https://doi.org/10.3390/toxins11050271
33. Murashiki TC, Chidewe C, Benhura MA, Maringe DT, Dembedza MP, Manema LR, Mvumi BM, Nyanga LK 82017) Levels and daily intake estimates of aflatoxin B1 and fumonisin B1 in maize consumed by rural households in Shamva and Makoni districts of Zimbabwe. Food Control, 72, 105–109. http://dx.doi.org/10.1016/j. foodcont.2016.07.040
34. Omurtag GZ (2001) Determination of fumonisin B1 and B2 in corn and corn-based products in Turkey by high performance liguid chromatography. J Food Protec 64:1072–1075. https://doi.org/10.4315/0362-028X-64.7.1072

35. Pokrzywa P, Cieslik E, Surma M (2019) Effect of storage conditions on the formation of type A and B trichothecenes in cereal products. Ann Agric Environ Med 26:260–265. https://doi.org/10.26444/aaem/103398
36. Reinhold A, Gessner AL, Scherlach K, Borkowetz WNS, Mothes A, Hertweck AR, Mothes C (2024) H Maize Flour Processing Determines the Fumonisin Intake of South Malawi Residents, Journal of Food Processing and Preservation, 2024, 8785591, 9 pages. https://doi.org/10.1155/jfpp/8785591
37. Rheeder JP, Marasas WFO, Wismer HF (2002) Production of Fumonisin Analogs by Fusarium Species. Appl Environ Microbiol 68(5):2101–2105. https://doi.org/10.1128/AEM.68.5.2101-2105.2002
38. Savi GD, Piacentini KC, Marchi D, Scussel VM (2016) Fumonisins B1 and B2 in the corn-milling process and corn-based products, and evaluation of estimated daily intake. Food Addit Contaminants: Part A 33(2):339–345. https://doi.org/10.1080/19440049.2015.1124459
39. Scussel VM, Geovana D, Savi LLFC, José Junior Mendonça Xavier, Daniel Manfio, Bittencourt KO, Aguiar K, Stephanie M, Stein (2014) Fumonisins in corn (Zea mays L.) from Southern Brazil, Food Additives & Contaminants: Part B, 7:2, 151–155. https://doi.org/10.1080/19393210.2013.862745
40. Shantika ZR, Rahayu WP, Lioe HN (2024) Co-occurrence and exposure assessment of deoxynivalenol and fumonisins from maize and maize-based products in Indonesia. Food Res 8(2):413–426. https://doi.org/10.26656/fr.2017
41. Song X, Song Y, Gu J, Zhang M, Zhang L, Zheng X, Liu X (2025) Fumonisins in maize and its products from Dalian region, China, and risk assessment by deterministic and probabilistic approaches. Food Addit Contaminants: Part B 1–7. https://doi.org/10.1080/19393210.2024.2446799
42. Soraia VM, de Sá, Fernandes JO, Faria MA, Sara C Cunha (2025) Assessment of Mycotoxins in Infants and Children Cereal-Based Foods: Dietary Exposure and Potential Health Risks. Expo Health 17:425–444. https://doi.org/10.1007/s12403-024-00668-y
43. Sugita-Konish Y, Kamata T, Sato T, Yoshinari, Saito S (2013) Exposure and risk assessment for ochratoxin A and fumonisins in Japan. Food Addit Contaminants: Part A 30(8):1392–1401. https://doi.org/10.1080/19440049.2012. 743190
44. Torović L (2018) Fusarium toxins in corn food products: a survey of the Serbian retail market. Food Addit Contaminants: Part A 35(8):1596–1609. https://doi.org/10.1080/19440049.2017.1419581
45. Torres O, Matute J, Gelineau-van Waes J, Maddox J, Gregory SG, Ashley-Koch AE, Showker JL, Voss KA, Riley RT (2015) Human health implications from co-exposure to aflatoxins and fumonisins in maize-based foods in Latin America: Guatemala as a case study. World Mycotoxin Journal 8: 143–159. https://doi
46. Visconti A, Solfrizzo M, De Girolamo A (2001) Determination of fumonisins B1 and B2 in corn and corn flakes by liquid chromatography with immunoaffinity column cleanup: Collaborative study. J AOAC Int. https://doi.org/10.1093/jaoac/84.6.1828
47. Wall-Martínez HA, Ramírez-Martínez A, Wesolek N, Brabet C, Durand N, Rodríguez-Jimenes GC, García-Alvarado MA, Salgado-Cervantes MA, Robles- Olvera VJ, Roudot AC (2019) Risk assessment

of exposure to mycotoxins (aflatoxins and fumonisins) through corn tortilla intake in veracruz city (Mexico). Food Addit Contam 36(6):929–939. https://doi.org/10.1080/19440049.2019.1588997

48. Xue KS, Tang L, Sun G, Wang S, Hu X, Wang JS (2019) Mycotoxin exposure is associated with increased risk of esophageal squamous cell carcinoma in Huaian area, China. BMC Canc 19(1):1218. https://doi.org/10.1186/s12885-019-6439-x
49. Yli-Mattila T, Sundheim L (2022) Fumonisins in African Countries. Toxins 14:419. https://doi.org/10.3390/toxins14060419
50. Yoshinari T, Maiko W, Takahiro O, Yukiko H-K (2020) Assessment of Modified Forms of Fumonisins in Corn-Based Products Retailed in Japan by an Alkaline Hydrolysis Method. Food Hyg Saf Sci 61:119–125. 4https://doi.org/10.3358/shokueishi. 61.119
51. Zentai A, Szeitzn´e-Szab´o M, Mihucz G, Szeli N, Szab´o A, Kov´acs M (2019) Occurrence and Risk Assessment of Fumonisin B1 and B2 Mycotoxins in Maize-Based Food Products in Hungary. Toxins (Basel) 11:709. https://doi.org/10.3390/toxins11120709
52. Zhang S, Zhou S, Lyu B, Qiu1 N, Li J, Zhao Y, Wu Y (2021) Dietary exposure to fumonisins and health risk assessment in the sixth China total diet study — China, 2015–2020 Vol. 3, 627–632. China CDC Weekly. 16;3(29):627–631. https://doi.org/10.46234/ccdcw2021.136

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Highlights.docx