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Public health risk due to aflatoxin and fumonisin contamination in rice in the Mekong Delta, Vietnam

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Abstract

Mycotoxin contamination in rice can lead to a health risk for consumers. In this study, the health risk among different age groups of Vietnamese population in the Mekong Delta, Vietnam was evaluated through rice consumption. Total aflatoxins (AFs) and fumonisins (FBs) in raw rice samples ($n=50$) were analyzed using an ELISA method. A survey ($n=155$) was used to collect data on rice consumption and consumer practices for the evaluation of mycotoxin exposure. Results showed that the frequency of AFs and FBs contamination was 60 and 74% with the average concentrations in raw rice ranging from 1.88–4.00 ng/g and 227–290 ng/g from the lower bound (LB) to the upper bound (UB), respectively. The average AFs exposure due to rice consumption was estimated from 0.81 to 2.44 ng/kg bw/day at scenarios LB – UB with the medium bound (MB) of 2.10, 1.60, 1.92 and 1.23 ng/kg bw/day for children, adolescents, adults and elderly, respectively. These values ranged from 343 to 724 ng/kg bw/day with respect to FBs (scenarios LB - UB), which are below the provisional maximum tolerable daily intakes (PMTDI) value (2000 ng/kg bw/day). The margin of exposure (MoE) to AFs ranged from 160 to 1585,179-2669,149–2175 and 206–3480 for children, adolescent, adults and elderly, respectively from UB - LB, indicating a high health risk for this carcinogenic hazard since the values are so lower than 10,000 (safe limit). However, for FBs, MoE value ranged from 105 to 575 (UB-LB) for all groups, which are higher compared to 100 (safe limit), indicating no risk for public health. The mean cancer risk due to estimated AFs exposure at LB - UB was 0.05–0.13 cases/year/100,000 individuals with MB of 0.08–0.13 cases/year/100,000 people for all four age groups. This study provides new insights into probabilistic risk assessment and potential health impact of mycotoxins in rice in the Mekong Delta, Vietnam.

Keywords Rice consumption, Liver cancer risk, Margin of exposure, Total aflatoxins and fumonisins, Mekong Delta

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Introduction

Mycotoxins are toxic secondary metabolites produced primarily by fungi. Of those, aflatoxins (AFs) that are produced mainly by *Aspergillus flavus* and *A. parasiticus* were frequently found in agricultural products in pre-and post-harvest (Gonçalves et al. 2019). AFs are considered as Group 1 Carcinogens by the International Agency for Research on Cancer (IARC 2002), causing 5–28% of all global hepatocellular carcinoma (HCC) cases (Liu and Wu 2010). More than 80% of the HCC occurred in poor countries, where people have a high-risk source of dietary exposure to AFs, chronic hepatitis B and hepatitis C viral infection (HBV and HCV) (Majeed et al. 2018). Fumonisins (FBs) produced by *Fusarium proliferatum* and *F. vertillioides* were also prevalently detected in farming products (Gonçalves et al. 2019). FBs are categorized to group 2B, possibly carcinogenic to humans (IARC 2002).

Rice (*Oryza sativa* L.) is the staple food for 50% of the Asian population (Devi and Ponnarasi 2009). Also, rice is a main staple food in Vietnam. The average annual rice consumption was 218 kg/capita in 2017 surveyed by Food and Agriculture Organization Statistics in 2020 (FAOSTAT 2020). Rice is grown in the Summer-Autumn and Autumn-Winter crop seasons (General Statistics Office of Vietnam 2020, Phan et al. 2021a, b), in which frequent and heavy rainfalls occur, especially during harvest, leading to the rice crop prone to fungal infection (Reddy et al. 2008). Several reports have indicated the presence of aflatoxin B1 (AFB1) and fumonisin B1 (FB1) in rice or cereals in the Mekong Delta, northern and central regions of Vietnam (Phan et al. 2021a, Huong et al. 2016b; Nguyen et al. 2007; Thieu et al. 2008; Trung et al. 2001). However, these studies did not contain enough data to indicate a comprehensive understanding of mycotoxin presence in the Mekong Delta rice linked to public health risk, where more than 50% of Vietnam's rice production was produced.

Risk assessment involves hazard identification, hazard characterization, exposure assessment and risk characterization (Borchers et al. 2010). Regarding carcinogenic mycotoxins (e.g., AFs), it is overall assumed that there is no cut off dose below leading to no cancer induction. That means, there is no tolerable daily intake for AFs since such toxins are genotoxic and carcinogenic contributing to tumor growth while regarding FBs, PMTDI has been established at 2000 ng/kg bw/day (EFSA 2014). If daily consumption is below the proposed PMTDI value, no adverse human health impacts would appear over a lifetime. Mycotoxin exposure assessment depends on the mycotoxin levels in food as well as food consumption. The risk is usually evaluated based on the MoE for both AFs and FBs (EFSA 2005). In addition to MoE, in terms of AFs, risk is also assessed based on HCC risk (JECFA 1999).

In recent years, the application of probabilistic methods to estimate exposure to mycotoxins in food has been increased (Panrapee et al. 2016; Meerpoel et al. 2021; Udovicki et al. 2021). Based on the approaches, proper statistical descriptions were employed to assess the data and to describe the range of consumer exposures (EFSA 2011). Thus, the aim of this study was (i) to estimate total aflatoxins and fumonisins contamination in rice, (ii) to estimate dietary exposure via rice consumption and (iii) to assess human health risks for different age group categories of Vietnamese population in the Mekong Delta (i.e., Can Tho, Dong Thap and An Giang provinces) using the probabilistic Monte Carlo simulation as potential input for further risk management.

Materials and methods

Sampling of raw rice

Fifty raw rice samples were collected from farmers' households in July 2019, in Can Tho ($n = 17$), Dong Thap ($n = 16$) and An Giang ($n = 17$) provinces of the Mekong Delta (Fig. 1). Each sample was collected about 0.5–1.0 kg from farmers'containers or bags which contained 20-50 kg raw rice. The collected samples were kept in plastic bags, transported to Ho Chi Minh city University of Food Industry's laboratory and stored at -20 °C before mycotoxins analysis.

Rice consumption data

The consumption survey dedicated to rice was performed in July 2019 in three provinces, namely Can Tho, Dong Thap and An Giang in the Mekong Delta, Vietnam (Fig. 1). One hundred and fifty-five participants from 50 families (1–6 persons/family) were interviewed face to face to avoid uncertain answers. During the survey, also raw rice samples from interviewed families were collected (as mentioned in section 2.1). The participants consisted of children (6–9.9 years, 3%), adolescents (10–17.9 years, 14%), adults (18–64.9 years, 77%) and elderly (> 65 years, 6%). The survey was carried out in participants' houses at lunch-time or dinner-time to verify participants' answers. The respondents in this survey were farmers, housewives, workers and their children who always consumed rice prepared by their families. Moreover, children did not consume rice in their schools or school canteens. In terms of rice consumption, the number of rice bowls consumed by each individual per day was recorded (range: 1–12 bowls/day). Besides, grams of rice in each bowl (range: 105–218 g) used by respondents were measured using the study organizer's scale (Kitchen scale, Max 5000 g, CH 303A-1, China). Afterward, the total grams of rice consumed (g) per day per person was calculated based on the following equation (Eq. 1).

$$\text{Rice consumption}\ (\text{g/day/person}) = \text{the total number of rice bowls x gram of rice in each bowl} \tag{1}$$

Additionally, participants' body-weight were measured by the study organizer's scale (Nhon Hoa, Vietnam). Other information was also collected including washing,

Fig. 1 Sampling and interviewing locations such as An Giang, Can Tho and Dong Thap provinces of the Mekong Delta (red buttons), Vietnam

cooking method, etc. The survey data were analyzed by @RISK (version 8.1, Palisade Corporation, USA).

Determination of aflatoxins and fumonisins in raw rice by enzyme-link immunosorbent assay (ELISA)

Fifty samples (range: 0.5–1.0 kg) were individually ground using a laboratory blender (Phuong Thanh, Vietnam) for 30 seconds and stored at -20 °C before mycotoxin determination. The total aflatoxins and fumonisins were analyzed by ELISA (AgraQuant®, Romer, USA). The limit of detection (LOD) and limit of quantification (LOQ) were 3 ng/g and 4 ng/g, respectively for AFs and these values were 200 ng/g and 250 ng/g, respectively in regard to FBs. The method was conducted according to the manufacturer's instructions. Briefly, the samples (25 g raw rice powder) were homogenized and mixed with 100 mL methanol (Merck, German)/water (70/30 v/v) for 2 min to extract mycotoxins. The mixture was centrifuged for 10 min at 4000 rpm. The supernatant was collected for toxin detection. Optical density was measured using a microtiter plate reader at 405 nm (Chromatic Reader, USA). The concentration of AFs and FBs were calculated on a dry weight basis according to the specifications of the manufacturer.

Mycotoxin reduction rates in rice during processing based on literature

Raw rice is usually processed before consumption. Many processing methods are applied such as normal cooking in boiling water, pressure cooking, etc.. Washing and cooking methods, leading to a reduction in mycotoxin levels, were mentioned by several studies and screened in a literature search (Table 1). Key words 'effect of cooking or washing' and 'reduction of mycotoxins in rice or cereals' were applied to search literatures published on

Table 1 Reduction of aflatoxins and fumonisins level in rice using different cooking and washing methods, reported in literature studies

Washing/cooking methods	Reduction (%)	Mycotoxins	Mycotoxin analysis methods	References
Washing (raw rice-white rice was washed by drinking water three times, afterwards soaked in drinking water/20mins or not and then removed water)	14 ± 1.1–15 ± 1.1	AFs	LC-MS/MS	Majeed et al. 2018
	20–24	AFB1	HPLC-FD	Park et al. 2005
Normal cooking (washed rice was added drinking water and cooked from 10 to 30 mins in electric cooker or pot)	32–38	AFB1	HPLC-FD	Park et al. 2005
	31–36	AFB1	HPLC-FD	Park and Kim 2006
	17.5–24.80	AFs	Elisa	Sani et al. 2014
	7–18	AFs	HPLC-FD	Sakuma et al. 2013
	84	AFs	HPLC-FD	Hussain and Luttfullah 2009
Pressure cooking (pressure cooker)	78–88	AFB1	HPLC-FD	Park and Kim 2006
Washing and cooking (maize added boiled water and then cooked in 20 min)	23–48	FBs	VICAM method	Shephard et al. 2002

Web of Science, PubMed and Google Scholar from 2000 to 2021. The reported mycotoxin reduction ranged from 7 to 88%, depending on cooking methods (Table 1). The highest AFs reduction was found when rice was cooked by pressure cooking (78–88%) followed by normal cooking (7–84%) while 23–48% of FBs were removed by a combination of washing and cooking approaches. AFs reduction through washing methods was lower (14–24%), compared to a cooking process. Based upon our questionnaire on the Vietnamese households' practices, raw rice was washed (procedure is similar to methods reported by Majeed et al. (2018), Park et al. (2005)) before cooking, and most respondents cooked rice using normal cooking procedure (96%) the same as methods of Park and Kim (2006), Sani et al. (2014), Sakuma et al. (2013) and Hussain and Luttfullah (2009). Few families used the pressure cooking approach (4%), which was more popular in families having high incomes or/and living in big cities (i.e., Ho Chi Minh, Ha Noi, etc.). Moreover, Nguyen et al. (2007) analyzed mycotoxin in raw rice and estimated them in rice based on the reduction rate during processing mentioned in previous researches and then calculated exposure based on rice consumption data. Thus, based on this information, a range of reduction rates from 7 to 88% (normal cooking – pressure cooking) and 14–24% (washing) with respect to AFs and 23–48% (combination of washing and cooking) for FBs was applied.

Dietary exposure assessment related to aflatoxins and fumonisins due to rice consumption

A probabilistic approach was used to evaluate AFs and FBs exposure due to rice consumption in the Mekong Delta based on raw rice-contamination data, reduction factors to rice preparation, cooking and rice consumption data. The mycotoxins concentration in rice was calculated by multiplying the best fit distribution of mycotoxin contamination in raw rice (ng/g) with the best fit distribution of the mycotoxin reduction (%) in washing and cooking processes (Table 1). Thus, dietary exposure was calculated as follows:

$$\begin{aligned}\text{Dietary exposure}\left(\text{ng/kg bw/day}\right) = {} & \text{Distribution of mycotoxin in raw rice}\left(\text{ng/g}\right)\\ & \text{x distribution of mycotoxin reduction }(\%)\\ & \text{x distribution of rice consumption}\left(\text{g/kg bw/day}\right)\end{aligned} \tag{2}$$

However, mycotoxins levels in some samples were low; therefore, no probability method could be performed. Hence, in the current work, AFs and FBs exposure was evaluated integrated three scenarios analysis (LB, MB and UB) with the calculation of such toxins contamination data of the non-detects (NDs) and below the limit of quantification (<LOQ) (Vinci et al. 2012). Management of the left-censored contamination data is considered as the main factor of uncertain exposure. Replacement of the ND values by zero (0) and by the limit of detection (LOD) value for the LB and UB, respectively was the most frequent approach in mycotoxins risk assessment studies (EFSA, European Food Safety Authority 2010). Thus, ND values were replaced by zero, half of the LOD (1/2 LOD) and LOD, while <LOQ values were replaced by half of the LOD (1/2 LOD), LOD and LOQ for the LB, MB and UB, respectively.

The probabilistic exposure assessment was also used to consider the variances and uncertainties related to the mycotoxins intake determinants. The fractions of the ND, <LOQ and > LOQ values were calculated. The fractions of >LOQ, <LOD and > LOQ, <LOQ and > LOQ were calculated by an "if" function of the Microsoft excel at LB, MB and UB, respectively with regard to the risk output calculations (Yogendrarajah et al. 2014). Best fit distributions were observed at the three scenarios of the AFs and FBs content data based on the Chi square statistics. Also, the probability/probability and quantile/quantile plots were evaluated to identify the best fit distribution for both cooked rice consumption and mycotoxins concentration data. For consumption data, best fit distribution functions such as Log-logistic were used to calculate raw rice consumption distribution. Regarding reduction rates during processing, a uniform distribution function (min-max) was used ranging from 14 to 24% (washing), 7 to 88% (cooking) for AFs and 23–48% (washing and cooking) for FBs (based on the data in Table 1). Monte Carlo simulations were performed at 100,000 iterations with the add-in @RISK (version 8.1, Palisade Corporation, USA). Based on these input data, a best fit distribution was performed with @RISK (Table 2).

Risk characterization

The calculated exposure values were compared with the proposed PMTDI value to assess the risk of the exposure for FBs. AFs are genotoxic carcinogens, leading to unsafe at any level of exposure. Risk characterization was performed by two approaches namely MoE (EFSA 2005) and HCC associated risk (JECFA 1999) for AFs while in terms of FBs, such evaluation was based on MoE. Regarding the MoE, this parameter is calculated as the ratio between a toxicological reference point (a dose, causing a low measurable response) and the estimated exposure. EFSA recommends to use the benchmark dose lower confidence limit 10% ($BMDL_{10}$) (the lowest dose, causing no more than a 10% of cancer incidence in rodents or human) (EFSA 2007). In this study, a $BMDL_{10}$ of 870 ng/kg bw/day for AFs (EFSA 2018) and 150,000 ng/kg bw/day for FBs (Bondy et al. 2012) was used. If the MoE value is less than 10,000 (EFSA 2005) and 100 (ChemSafetyPro 2022), the exposure is considered as a public health concern with respect to AFs and FBs, respectively. In this study, it is assumed that AFs and FBs contained 100% of the AFB1 (Manizan et al. 2018; Majeed et al. 2018) and FB1, respectively.

The HCC risk approach is based on the carcinogenic potency of AFB1, resulting from synergistic

Table 2 Best fit distribution for the mycotoxin levels (ng/g) in raw rice, rice consumption (ng/kg bw/day) and reduction of mycotoxins during processing in the Mekong Delta applied for the probabilistic exposure assessment

Input mycotoxin exposure	Best distribution function
Mycotoxin concentration (ng/g) in raw rice	
AFs (data > LOQ)	RiskGamma(0,53,238;17,035;RiskShift(4,06)
FBs (data > LOQ)	RiskLognorm(262,73;67,821;RiskShift(69,088)
IF-function for fit AFs or FBs concentration at three scenarios[a]	
LB	RiskMakeInput (IF (Random< Fraction of ND data; 0; IF (Random < (Fraction of <LOD data + Fraction of <LOQ); LOD/2; Fit Gamma distribution AFs/Lognorm distribution FBs concentration data > LOQ)
MB	RiskMakeInput (IF (Random < Fraction of ND data; LOD/2; IF(Random < (Fraction of LOD data + Fraction of <LOQ); LOD; Fit Gamma distribution AFs/Lognorm distribution FBs concentration data > LOQ)
UB	RiskMakeInput (IF (Random < Fraction of ND data; LOD; IF(Random < (Fraction of <LOD data + Fraction of <LOQ); LOQ; Fit Gamma distribution AFs/Lognorm distribution FBs concentration data > LOQ)
Rice consumption (g/kg bw/day)	
Population (all age groups)	RiskExtvalue(48,117;23,961)
Children	RiskLaplace(70,012;15,138)
Adolescents	RiskPert(0,61,803;40,727;14,726)
Adults	RiskLoglogistic(−66,691;12,684;78,772)
Elderly	RiskExpon(27,133;RiskShift(15368))
Reduction of mycotoxin (washing/cooking) (fraction) – derived from Table 1	
AFs (washing)	RiskUniform(14/100;24/100)
AFs (cooking)	RiskUniform(7/100;88/100)
FBs (washing and cooking)	RiskUniform(23/100;48/100)

[a] AFs (30 samples > LOD (3 ng/g) and LOQ (4 ng/g)); FBs (37 samples >LOD (200 ng/g) and LOQ (250 ng/g)); *ND* not detected = < LOD; 28% (*n* = 14/50) and 66% (*n* = 32/50) of samples > LOQ (AFs = 4 ng/g) and LOQ (FBs = 250 ng/g)

hepato-carcinogenic effects of AFB1 and hepatitis B virus infection. In hepatitis B surface antigen-positive individuals ($HBsAg^{+}$), the AFB1 carcinogenic potency is estimated at 0.3 cases/year/100,000 individuals. In hepatitis B surface antigen-negative individuals ($HBsAg^{-}$), the AFB1 carcinogenic potency is estimated at 0.01 cases/year/100,000 individuals. In terms of the incidence of $HBsAg^{+}$ individuals in a certain population, the hepatitis B-positive prevalence (%) of the Vietnamese rural population was 18.4 ± 5.0% and 18.8 ± 3.1% for children and adults, respectively (David et al. 2003, Huong et al. 2016a & Huong et al. 2020) used in this study. The HCC risk (cases/year/100,000 individuals) due to hepatitis B was obtained by multiplying dietary exposure with the average potency (Majeed et al. 2018; Do et al. 2020; Huong et al. 2016a & Huong et al. 2020) presented in Eqs. 3 & 4.

$$\text{HCC risk} = \text{Exposure} \times \text{average potency} \tag{3}$$

$$\text{Average potency} = 0.3 \times \text{prevalence of B} - \text{positive hepatitis}\ (\%) + 0.01 \times (1 - \text{prevalence of B} - \text{positive hepatitis}\ (\%)) \tag{4}$$

Results and discussions

Distribution of aflatoxins and fumonisins in raw rice and rice

Best fit distribution functions used in this study are related to mycotoxins contents in raw rice, IF-function for fitting of AFs and FBs levels at three scenarios (LB, MB and UB) and mycotoxin reduction during processing (Table 2). These data were fitted to best fit distributions according to the @RISK (version 8.1, Palisade Corporation, USA).

The estimated distribution of AFs and FBs contamination in raw rice and rice is presented in Table 3. In terms of mycotoxins contamination in raw rice, the prevalence of contaminated samples by AFs was 60% ($n = 30/50$) and the estimated average levels of AFs concentration in raw rice ranged from 1.88 to 4.0 ng/g from LB-UB with the mean MB of 2.98 ng/g (Table 3). AFs contents at all levels were lower than the Vietnamese regulation limit for food (15 ng/g) (Vietnamese Ministry of Health 2011). Moreover, AFs concentrations from percentile 75 (P_{75}) to percentile 95 (P_{95}) at three scenarios were also lower than the European maximum limit for unprocessed rice (10 ng/g) (EC 2006). The prevalence of contaminated samples with FBs was 74% ($n = 37/50$), with the average content at LB, MB and UB of 277, 261 and 290 ng/g, respectively in raw rice. These mycotoxins contents were lower than Vietnamese regulation limit for corn (1000 ng/g) (Vietnamese Ministry of Health 2007). In general, both AFs and FBs contents were lower than Vietnam and European maximum limit for food and unprocessed rice, respectively even at P_{95} of MB or/and UB (5.64 ng/g for AFs and 433 ng/g for FBs). However, rice is an important staple food and a key exported product in Vietnam, hence contents of these toxins should be as low as possible, especially AFs.

Furthermore, raw rice is washed and cooked during processing before consumption by Vietnamese people. Table 3 shows that the mean contents of AFs were 0.18 ng/g, 0.27 ng/g and 0.35 ng/g and these FBs values were 81 ng/g, 93 ng/g and 103 ng/g at LB, MB and UB, respectively when the processing factors were used to shift from raw rice to rice.

The result of this study is in good agreement with previous reports in Vietnam and Malaysia. For instance, the

Table 3 Distribution of aflatoxins and fumonisins contamination in raw rice and rice with applied reduction of washing 14–24% and cooking 7–88% of the raw rice contamination in the Mekong Delta (ng/g)

Mycotoxins	Scenarios	Rice (raw rice) (ng/g)				
		Mean	P_{50}	P_{75}	P_{90}	P_{95}
Aflatoxins	Data>LOQ for raw rice	4.97	4.50	5.27	6.48	7.45
	LB	0.18 (1.88)	0.09 (1.5)	0.23 (4.07)	0.53 (4.86)	0.7 (5.64)
	MB	0.27 (2.98)	0.21 (3.0)	0.38 (4.07)	0.55 (4.86)	0.68 (5.64)
	UB	0.35 (4.0)	0.33 (4.0)	0.49 (4.07)	0.61 (4.86)	0.7 (5.64)
Fumonisins	Data>LOQ for raw rice	332	323	371	421	455
	LB	81 (227)	92 (279)	124 (343)	152 (400)	172 (433)
	MB	93 (261)	92 (280)	124 (343)	152 (400)	172 (433)
	UB	103 (290)	95 (280)	124 (342)	152 (400)	172 (433)

The distribution mycotoxins in rice = the distribution of mycotoxins raw rice x distribution of washing reduction x distribution of cooking reduction at LB, MB and UB; *LB* Lower Bound, *MB* Medium Bound, and *UB* Upper Bound based on the best fit distributions presented in Table 3; *P50* Percentile 50%, *P75* Percentile 75%, *P90* Percentile 90%, *P95* Percentile 95%; $n = 20$ (<LOD); $n = 16$ (>LOD and < LOQ) and $n = 14$ (>LOQ) for AFs, for FBs $n = 13$ (<LOD); $n = 4$ (>LOD and < LOQ) and $n = 33$ (>LOQ);

mean of AFB1 was 3.31 ng/g in raw rice of five provinces in central Vietnam (Nguyen et al. 2007), 2.99 ng/g (MB) and 2.4–3.0 ng/g (LB-UB) in Lao Cai rice (Huong et al. 2020) and 0.68–3.79 ng/g (AFs) in Malaysia (Reddy et al. 2011). However, the levels of AFs in rice in this study were higher than those of AFB1 reported in Thailand (range: 0.05–1.66 ng/g) (Panrapee et al. 2016). In contrast, higher values were detected in rice in Philippines (range:1–2546 ng/g) (Sales and Yoshizawa 2005), Pakistan (mean of AFs: 7.75 ng/g) (Majeed et al. 2018), Turkey (range: 0.05–21.4 ng/g) (Aydin et al. 2011). Regarding FBs, FB1 concentration was found lower in Lao Cai (Huong et al. 2016a) and Nigerian rice (Makun et al. 2011) than FBs content in our results. This difference may be associated with weather conditions (humidity, temperature and rainfall) and traditional agricultural practices (Phan et al. 2021a, b; Tran et al. 2021a, b; Reddy et al. 2011).

Consumption of rice in the Mekong Delta

The information of 155 participants belonging to 50 families interviewed in this survey is presented in Table 4. According to the survey, the average of rice consumption for the overall population was estimated at 6.20 g/kg bw/day. The mean of rice intake was highest (7.00 g/kg bw/day) for children and then adults (6.43 g/kg bw/day), adolescents (5.27 g/kg bw/day) and elderly (4.25 g/kg bw/day).

This seems to accord with general findings on the global consumption of rice for different population groups (Udovicki et al. 2021; Majeed et al. 2018). Typically, children and adults ate more rice per unit bodyweight than adolescents and elderly (Udovicki et al. 2021; Majeed et al. 2018). Because adults and children usually consumed rice at breakfast, lunch and dinner, prepared by their family, and they rarely ate other food outside. Moreover, adults must work hard on their farm requiring more energy; thus, they consumed a lot of rice. In contrast, adolescents who are secondary and high school students ate variety of food replacing for rice such as milk, milk-tea, soup, corn, sweet potato, bread, instant noodle, etc. at school canteens or street food markets. Similarly, the elderly usually consumed soup, rice noodle, sweet potato, etc. instead of rice prepared by their family. Moreover, elderly worked less than adults; therefore, they did not consume a lot of food. Thus, adolescents and elderly consumed less rice than children and adults due to a different consumption pattern.

As regard rice consumption, the mean of daily rice intake per capita in this study (341 g/day/capita) calculated by multiplying daily intake (g) per body weight (kg) (6.20 g/kg bw/day) with the mean body weight of 55 kg is quite higher than the results surveyed in northern Vietnam namely Ha Giang, Ha Noi and Thanh Hoa provinces in Vietnam, which ranged from 244 to 301 g/day/adult (Do et al. 2020), China (183 g/day/person), Japan (157 g/day/capita) (Abdullah et al. 2006), Pakistan (108 g/day/people) (Majeed et al. 2018) and Iran (107 g/day/individual) (Yazdanpanah et al. 2012). However, rice consumption in this work is lower than that reported in other Asian countries namely Thailand (377 g/day/capita). The difference could be related to the characteristics of participants (ages, profession etc.) and regions surveyed. Indeed, most participants in this survey were farmers (adults, 77%) who consumed rice higher than the people working in the offices, adolescents (14%) and elderly (6%) (Table 4), which maybe result in higher consumption data than other studies. Also, rice is the main staple food in Vietnam; therefore, Vietnamese farmers have consumed a large amount of rice per day, leading to higher rice intake data in the current study, compared to that in other countries.

Estimated aflatoxins and fumonisins exposure related to rice consumption

The calculated exposure related to AFs and FBs in rice is presented in Table 5. The mean levels of AFs intake based on rice consumption were estimated to be 1.30 to 2.44 ng/kg bw/day for children and adults, whereas for elderly and adolescents, these values were slightly lower of 0.81 to 2.04 ng/kg bw/day from LB to UB. Regarding FBs, the values for the LB-UB were estimated from 517 to 724 ng/kg bw/day for children and adults, while these

Table 4 Distribution of rice household consumption in different age groups in Mekong Delta (g/kg bw/day) obtained from the survey in 2019 using best distribution functions presented in Table 2

Statistical description	Daily intake (g)/kg body weight in age group ($n = 155$)				Daily intake(g)/kg body weight overall population
	Children ($n = 5$)	Adolescents ($n = 21$)	Adults ($n = 120$)	Elderly ($n = 9$)	
Mean	7.00	5.27	6.43	4.25	6.20
P50	7.00	4.99	6.03	3.42	5.69
P75	7.74	6.97	7.92	5.30	7.80
P90	8.72	8.80	10.14	7.78	10.20
P95	9.47	9.84	11.87	9.67	11.93

Table 5 Estimated distribution of exposure due to rice consumption associated with aflatoxins and fumonisins in the Mekong Delta (ng/kg bw/day)

Mycotoxins	Statistical description	Children			Adolescents			Adults			Elderly		
		LB	MB	UB	LB	MB	UB	LB	MB	UB	LB	MB	UB
AFs	Mean	1.42	2.10	2.04	1.09	1.60	2.04	1.30	1.92	2.44	0.81	1.23	1.58
	P_{50}	0.55	1.41	2.18	0.33	0.96	1.43	0.40	1.18	1.78	0.25	0.73	1.07
	P_{75}	1.60	2.50	3.30	1.17	1.83	2.52	1.41	2.22	3.00	0.89	1.40	1.90
	P_{90}	3.55	3.88	4.51	2.59	3.14	3.84	3.16	3.74	4.51	2.04	2.52	3.16
	P_{95}	4.90	4.97	5.42	3.95	4.25	4.86	4.69	5.07	5.83	3.12	3.55	4.22
FBs	Mean	564	649	724	425	489	546	517	595	664	343	394	440
	P_{50}	603	620	670	352	395	474	457	501	578	260	293	338
	P_{75}	874	875	886	665	676	713	790	802	840	483	502	546
	P_{90}	1123	1123	1126	980	981	994	1140	1146	1166	800	808	845
	P_{95}	1290	1291	1292	1191	1191	1195	1401	1405	1422	1058	1065	1092

P50 Percentile 50%, *P75* Percentile 75%, *P90* Percentile 90%, *P95* Percentile 95%

values were lower ranging from 343 to 546 ng/kg bw/day for adolescents and elderly.

The results indicated that although AFs intake were low due to rice consumption, this may be harmful to human health because these toxins are genotoxic and carcinogenic compounds (JECFA 1999), which exposure above zero level is harmful. Moreover, the Mekong Delta population consumed a big amount of rice, leading to a risk for human health (Table 3).

The mean AFs intake for rice is lower than AFs or/and AFB1 exposure in Pakistani children (4.12–7.58 ng/kg bw/day at LB-UB), Pakistani adults (4.07–7.31 ng/kg bw/day at LB-UB) (Majeed et al. 2018), Nigeria (5.2 ng/kg bw/day) (Abdus-Salaam et al. 2016) and Brazil (6.5–6.6 ng/kg bw/day) (Andrade et al. 2013). However, the mean of AFs exposure in the current data was quite higher than the average of AFB1 exposure by rice consumption in Japan (1.20–1.78 ng/kg bw/day) at the 95th percentile level (Sakuma et al. 2013), Morocco (0.033 ng/kg bw/day) (Serrano et al. 2012), France (<LOD—0.035 ng/kg bw/day) (Sirot et al. 2013), Lebanon (0.63–0.66 ng/kg bw/day) (Raad et al. 2014) or/and brown rice and color rice consumption in Thailand (0.1 and 2.37 ng/kg bw/day) (Panrapee et al. 2016). By contrast, estimated AFs exposure values linked to rice intake in the current study were quite lower than the mean of AFB1 exposure values for Northern Vietnamese adults (21.7 ng/kg bw/day), children (33.7 ng/kg bw/day) (Huong et al. 2016b) and Lao Cai adults (22.2 ng/kg bw/day) (Huong et al. 2016a) and Chinese population (5.8–76 ng/kg bw/day (LB-UB)) (Ding et al. 2012).

For FBs, the estimated mean of FBs exposure values due to rice consumption in this work is slight lower than that in other studies in Vietnam. For instance, a lower average of FB1 exposure (536 ng/kg bw/day and 1019 ng/kg bw/day) was found in Northern Vietnamese adults and children in Vietnam, respectively (Huong et al. 2016b). Our results are also lower than those observed in Ha Giang children (851–1199 ng/kg bw/day) and adults (1106–1325 ng/kg bw/day) (Do et al. 2020). In contrast, the results in the present work are higher than Thanh Hoa, Ha Noi children (6.5–256 ng/kg bw/day), adults (127–209 ng/kg bw/day) (Do et al. 2020), Nigerian population (19.13 ng/kg bw/day) (Abdus-Salaam et al. 2016), Pakistani children (31.2–64.2 ng/kg bw/day (LB-UB)) and adults (30.8–61.9 ng/kg bw/day (LB-UB)) (Majeed et al. 2018). This difference may be associated with sampling, levels of mycotoxins contamination in rice, processing method, consumption data, etc..

Risk characterization of aflatoxins and fumonisins related to rice consumption

Increase risk associated with the MoE

Concerning MoE associated with AFs exposure, the mean of MoE ranged from 160 to 1585, 179–2669, 149–2175 and 206–3480 for children, adolescents, adults and elderly, respectively (Fig. 2). These MoE values were lower when compared to 10,000, leading to a public health concern. However, the average of MoE related to FBs was higher than 100, ranging from 105 to 575 for all groups. Moreover, FBs exposure values were lower than tolerable daily intake and PMTDI established by the European Union Scientific Committee for Food and JECFA (2000 ng/kg of body weight) (International agency for research on cancer (IARC) and world health organization (WHO) 2012; EFSA 2014). Therefore, it is safe for human health due to rice intake regarding FBs.

Based on these results, the intake of contaminated rice was considered as a great public health concern with respect to AFs for the Vietnamese population. The

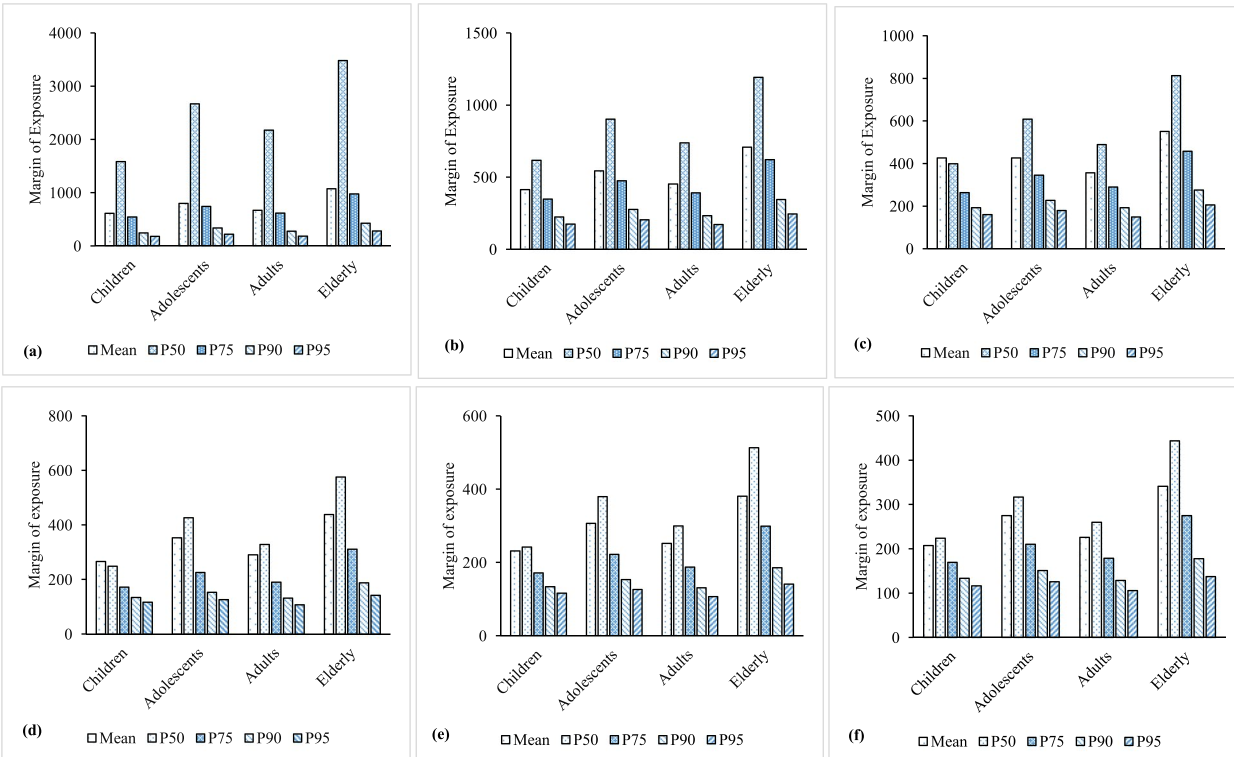

Fig. 2 Margin of exposure using the probabilistic exposure values at mean and percentiles of AFs (**a**) and FBs (**b**) at three scenarios LB, MB and UB due to rice intake by different age groups in the Mekong Delta, Vietnam

estimated mean of MoE based on AFs intake for rice consumption was compared to those of previous studies. For instance, the mean of MoE to AFB1 intake due to rice consumption in Brazil (Andrade et al. 2013), Malaysia (Chin et al. 2012), China (Ding et al. 2012), Northern Vietnam (Huong et al. 2020; Do et al. 2020), Pakistan (Majeed et al. 2018), Gambia (Shephard 2008) and Japan (Sakuma et al. 2013) was lower than that in the present study. However, the MoE through AFB1 intake in Serbian rice (Udovicki et al. 2021) was higher than this value in our study. This could be related to mycotoxin contamination contents in rice, consumption levels, type of $BMDL_{10}$ (for human or rodent), etc.. as mentioned above.

Prevalence of liver cancer risk or HCC associated with AFs contamination in rice

AFB1 is considered the most biologically active and abundant in the AFs. The risk of liver cancer in people exposed to both chronic HBV infection and AFs was 30 times higher than the risk in people exposed to AFs only (Groopman et al. 2014). The burden of AFs induced HCC has been recently evaluated in different countries (Liu and Wu 2010).

The risk characterization based on AFs exposure through rice consumption was estimated using the liver cancer risk approach (Table 6). The mean of HCC risk at three scenarios (LB, MB and UB) ranged from 0.05 to

Table 6 Distribution of HCC risk due to rice consumption associated with AFs in the Mekong Delta (cases/year/100,000 individuals) (assumption AFs = AFB1 contamination)

Statistical description	Children			Adolescents			Adults			Elderly		
	LB	MB	UB	LB	MB	UB	LB	MB	UB	LB	MB	UB
Mean	0.09	0.13	0.13	0.07	0.1	0.13	0.08	0.12	0.15	0.05	0.08	0.1
P_{50}	0.03	0.09	0.14	0.02	0.06	0.09	0.03	0.07	0.11	0.02	0.05	0.07
P_{75}	0.1	0.16	0.21	0.07	0.12	0.16	0.09	0.14	0.19	0.06	0.09	0.12
P_{90}	0.22	0.24	0.28	0.16	0.20	0.24	0.20	0.24	0.28	0.13	0.16	0.2
P_{95}	0.31	0.31	0.34	0.25	0.27	0.31	0.30	0.32	0.37	0.20	0.22	0.27

LB Lower Bound, *MB* Medium Bound, and *UB* Upper Bound; *P50*, *P75*, *P90* and *P95*, Percentile 50, 75, 90 and 95%

0.13 cases/year/100,000 individuals for children, adolescents, adults and elderly.

The average liver cancer risk due to AFs in this study was slight higher than that due to AFB1 intake through colored and brown rice in all age groups of Thailand (0.010–0.039 cases/year/100,000 individuals) (Panrapee et al. 2016), Brazil (0.0753 cases/year/100,000 individuals) (Andrade et al. 2013) and Malaysia (0.01 cases/year/100,000 individuals) (Chin et al. 2012). In contrast, the cancer risk because of AFB1 intake through rice consumption in Chinese population (0.2–2.65 (UB-LB) cases/year/100,000 individuals) (Ding et al. 2012), Lao Cai Children (4.2–5.4 cases/year/100,000 individuals) (Huong et al. 2020) and Gambia population (1.1 cases/year/100,000 individuals) (Shephard 2008) was higher when compared to those found in the present study. Such difference could be related to the prevalence rate of HBV (i.e., Huong et al. 2020 used a prevalence rate of 20% for HBV to evaluate cancer risk in children while Chin et al. 2012 applied a 0.2–2.1% HBV incidence to calculate HCC risk), mycotoxins contamination data in rice, as well as consumption data as explained above.

In order to reduce the risk of cancer, improvements in HBV vaccination and methods to eliminate AF contamination of rice (i.e., remove off residue crops and spray bio-decomposer to decompose residue crops, use disease-resistant paddy varieties, inorganic fertilizers, biocontrol in pre-harvest, and hygienic storage containers, essential oil, milling and polishing in post- harvest (Phan et al. 2021a, b)) should be promptly implemented as risk mitigation strategies. The risk characterization of AF and FB from rice consumption (Majeed et al. 2018; Park et al. 2005 & Park and Kim 2006) is helpful in establishing priority control approaches for mycotoxins.

Uncertainty analysis

Regarding rice consumption surveys, under or over (−/+) reporting of consumption data, misreporting of consumed rice and the erroneous estimation of consumed quantities (based on portion sizes) could contribute to an underestimation or overestimation of rice consumption (−/+), affecting the exposure assessment (Vinci et al. 2012). Moreover, consumption data that were used in this study were surveyed by 155 people in three provinces of Mekong Delta, in which only 3 and 6% of respondents were children and elderly, respectively, and consuming habits may have been different from other provinces in this Delta, leading to lower or higher rice consumption (−/+). This made overestimation or underestimation (+/−). In terms of sampling, collecting samples and/or the number of samples (50 samples) in this study could result in underestimation or overestimation (−/+) in mycotoxin intake evaluation. For mycotoxins analysis method, in this study using an ELISA method to analyze mycotoxins in raw rice may have a limitation because of the possibility of matrix effect and cross-reactivity, leading to a certain level of uncertainty in exposure assessment (−/+) (Udovicki et al. 2021).

In addition to problems such as consumption surveys, sampling and mycotoxins analysis method as mentioned above, the distribution fitting to literature input data for reduction of mycotoxins during processing as cooking and washing could lead to high mean reductions of mycotoxins in comparison to actual practices (+). Because washing and cooking were only performed in small sizes (100 g rice and 200 mL drinking water in laboratory for washing and cooking). Moreover, AFs and FBs are stable and hard to destroy them during cooking (normal cooking) or/and mycotoxins could transfer to other structures which could be toxic or not, and they were not identified during mycotoxins analysis or mycotoxins reduction could be related to other factors. Moreover, we do not have clear and original data from literatures as a result in under or over estimation (−/+) in exposure assessment. Also, this study assumed that AFs and FBs containing 100% of AFB1 and FB1, respectively used to evaluate MoE and HCC may result in overestimation (+).

The bioavailability of mycotoxin in target organs in humans depends on factors as bio-accessibility, percentage of mycotoxin released (partially or totally) from the matrix during digestion in the gastrointestinal tract, bio-accessible fraction transported across the intestinal epithelium as well as metabolism (Meca et al. 2012; González-Arias et al. 2013; Bordin et al. 2017; Van et al. 2020, Tran et al., 2020). In our study, these factors are not included; thus, this study could make overestimation in exposure and risk assessment (+).

Conclusions

This study is the first report on probabilistic risk assessment related to AFs and FBs exposure in rice for the Mekong Delta, Vietnam population. The dietary exposure to aflatoxins and fumonisins through rice consumption was higher for children and adults than adolescents and elderly, due to the high consumption of adults (farmers needed high energy input) and children (high consumption compared to lower body weight). The MoE related to aflatoxins exposure was remarkably lower than the recommended safe limit, leading to a health concern when consuming the Mekong Delta rice. In addition, there is a potential risk due to rice consumption, associated with aflatoxin-induced HCC. Thus, AF contamination in such commodity should be decreased to ensure food safety. This work highlights the need to establish risk management strategies and set (regulatory) guidelines for the rice cultivation (pre and post-harvest) in the Mekong Delta rice to prevent contamination, followed by a regular monitoring of highly consumed foodstuff, especially rice. Also, a cumulative risk assessment from the exposure of multi-mycotoxins, especially in the HBV and HCV-positive population should be studied in the future to estimate the full burden on human health due to mycotoxins.

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Authors' contributions
L.T. K.P.: Conceptualization, Formal Analysis, Writing—Original draft; M.E.: Supervision, Reviewing and editing; S.D.S.: Supervision, Reviewing and Editing, L.J.: Supervision, Conceptualization, Reviewing and Editing. The author(s) read and approved the final manuscript.

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References

Abdullah, Alias Bin, Ito, Shoichi, & Adhana, Kelali. (2006). Estimate of rice consumption in Asian countries and the world towards 2050. Paper presented at the Proceedings for Workshop and Conference on Rice in the World at Stake

Abdus-Salaam, Rofiat B, Atanda, Olusegun O, Fanelli, Francesca, Sulyok, Michael, Cozzi, Giuseppe, Bavaro, Simona, Antonio, Logerico F, Kimanya, Martin E, Krska, Rudolf, & Chilaka, Cynthia A. (2016). Dietary exposure to mycotoxins by adult consumers of locally processed rice from Nigeria. Paper presented at the 8th International Toxicology Symposium in Africa

Andrade PD, de Mello MH, França JA, Caldas ED (2013) Aflatoxins in food products consumed in Brazil: a preliminary dietary risk assessment. Food Addit Contam: Part A 30(1):127–136. https://doi.org/10.1080/19440049.2012.720037

Aydin A, Aksu H, Gunsen U (2011) Mycotoxin levels and incidence of mould in Turkish rice. Environ Monit Assess 178(1):271–280

Bondy G, Mehta R, Caldwell D, Coady L, Armstrong C, Savard M, Miller JD, Chomyshyn E, Bronson R, Zitomer N (2012) Effects of long term exposure to the mycotoxin fumonisin B1 in p53 heterozygous and p53 homozygous transgenic mice. Food Chem Toxicol 50(10):3604–3613. https://doi.org/10.1016/j.fct.2012.07.024

Borchers A, Teuber SS, Keen CL, Gershwin ME (2010) Food safety. Clin Rev Allergy Immunol 39(2):95–141. https://doi.org/10.1007/s12016-009-8176-4

Bordin K, Saladino F, Fernández-Blanco C, Ruiz MJ, Mañes J, Fernández-Franzón M, Meca G, Luciano FB (2017) Reaction of zearalenone and zearalenol with allyl isothiocyanate, characterization of reaction products, their bioaccessibility and bioavailability in vitro. Food Chem 217:648–654. https://doi.org/10.1016/j.foodchem.2016.09.044

ChemSafetyPro. (2022). What are margin of exposure (MoE) and margin of safety (MoS) and how to calculate. Retrived Accessed: 09/12/2022, from https://www.chemsafetypro.com/Topics/CRA/margin_of_safety_MOS_margin_of_exposure_MOE_difference_chemical_risk_assessment.html

Chin CK, Abdullah A, Sugita-Konishi Y (2012) Dietary intake of aflatoxins in the adult Malaysian population–an assessment of risk. Food Addit Contam: Part B 5(4):286–294. https://doi.org/10.1080/19393210.2012.713028

David BH, Van NT, Huong VM, Long HT, Dat DT, Trung TN, Jolley D, Maynard JE, Biggs BA (2003) Hepatitis B infection in rural Vietnam and the implication for a national programme of infant immunization. Am J Trop Med Hyg 69:288–294

Devi KS, Ponnarasi T (2009) An economic analysis of modern rice production technology and its adoption behaviour in Tamil Nadu. Agric Econ Res Rev 22(347-2016-16872):341–348. https://doi.org/10.22004/ag.econ.57473

Ding X, Li P, Bai Y, Zhou H (2012) Aflatoxin B1 in post-harvest peanuts and dietary risk in China. Food Control 23(1):143–148. https://doi.org/10.1016/j.foodcont.2011.06.026

Do TH, Tran SC, Le CD, Nguyen H-BT, Le P-TT, Le H-HT, Le TD, Thai-Nguyen H-T (2020) Dietary exposure and health risk characterization of aflatoxin B1, ochratoxin A, fumonisin B1, and zearalenone in food from different provinces in northern Vietnam. Food Control 112:107108. https://doi.org/10.1016/j.foodcont.2020.107108

EC (2006) Commission regulation (EC) no 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Off J Eur Union 364(1):5–24

EFSA (2005) Opinion of the scientific committee on a request from EFSA related to a harmonised approach for risk assessment of substances which are both genotoxic and carcinogenic. EFSA J 3(10):282

EFSA (2007) Opinion of the scientific panel on contaminants in the food chain [CONTAM] related to the potential increase of consumer health risk by a possible increase of the existing maximum levels for aflatoxins in almonds, hazelnuts and pistachios and derived products. EFSA J 5(3):446

EFSA. (2011). Towards a harmonised total diet study approach: a guidance document: joint guidance of EFSA, FAO and WHO

EFSA (2014) Scientific opinion on the risks for human and animal health related to the presence of modified forms of certain mycotoxins in food and feed. EFSA J 12(12):3916

EFSA, European Food Safety Authority (2010) Management of left-censored data in dietary exposure assessment of chemical substances. EFSA J 8(3):1557

EFSA (2018). Effect on public health of a possible increase of the maximum level for 'aflatoxin total' from 4 to 10 µg/kg in peanuts and processed products thereof, intended for direct human co... EFSA J 16(2):e05175. https://doi.org/10.2903/j.efsa.2018.5175

FAOSTAT. (2020). Rice consumption per capita in Vietnam. Retrieved Accessed: 10/1/2021, 2020, from https://www.helgilibrary.com/indicators/rice-consumption-per-capita/vietnam

General Statistics Office of Vietnam. (2020). Retrieved Accessed: 16 June 2021, from https://www.gso.gov.vn/en/px-web/?pxid=E0612&theme=Agriculture%2C%20Forestry%20and%20Fishing

Gonçalves A, Gkrillas A, Dorne JL, Dall'Asta C, Palumbo R, Lima N, Battilani P, Venâncio A, Giorni P (2019) Pre-and postharvest strategies to minimize mycotoxin contamination in the rice food chain. Compr Rev Food Sci Food Saf 18(2):441–454. https://doi.org/10.1111/1541-4337.12420

González-Arias CA, Marín S, Sanchis V, Ramos AJ (2013) Mycotoxin bioaccessibility/absorption assessment using in vitro digestion models. World Mycotoxin J 6:167–184. https://doi.org/10.3920/WMJ2012.1521

Groopman JD, Egner PA, Schulze KJ, Wu LS-F, Merrill R, Mehra S, Shamim AA, Ali H, Shaikh S, Gernand A (2014) Aflatoxin exposure during the first 1000 days of life in rural South Asia assessed by aflatoxin B1-lysine albumin biomarkers. Food Chem Toxicol 74:184–189. https://doi.org/10.1016/j.fct.2014.09.016

Huong BTM, Brimer L, Dalsgaard A (2016a) Dietary exposure to aflatoxin B1, ochratoxin A and fuminisins of adults in Lao Cai province, Viet Nam: a total dietary study approach. Food Chem Toxicol 98:127–133. https://doi.org/10.1016/j.fct.2016.10.012

Huong BT, Mai D, Thanh T, Madsen H, Brimer L, Dalsgaard A (2016b) Aflatoxins and fumonisins in rice and maize staple cereals in northern Vietnam and dietary exposure in different ethnic groups. Food Control 70:191–200. https://doi.org/10.1016/j.foodcont.2016.05.052
Huong BT, Mai LD, Tuyen HM, Brimer L, Friis H, Dalsgaard A (2020) Total dietary intake and health risks associated with Fuminisins exposure of children to aflatoxin in Lao B1, Ochratoxin A and Cai Province, Vietnam. Mycotoxin Exposure Relat Dis 19. https://doi.org/10.3390/toxins11110638
Hussain A, Luttfullah G (2009) Reduction of aflatoxin-beta/sub 1/and ochratoxin-A levels in polished basmati rice (oryza sativa Linn.) by different cooking methods. J Chem Soc Pak 31(6):911–915
IARC (2002) Working Group on the Evaluation of Carcinogenic Risks to Humans. Some traditional herbal medicines, some mycotoxins, naphthalene and styrene. 82: World Health Organization.
International agency for research on cancer (IARC) and world health organization (WHO) (2012) In: Pitt J, Wild C, Baan R, Gelderblom W, Miller J, Riley R, Wu F (eds) Improving public health through mycotoxin control, vol 158. International Agency for Research on Cancer (IARC), Lyon, p 2012
JECFA (1999) Evaluation of certain food additives and contaminants: forty-ninth report of the Joint FAO/WHO Expert Committee on Food Additives: World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/42378/WHO_TRS_896.pdf
Liu Y, Wu F (2010) Global burden of aflatoxin-induced hepatocellular carcinoma: a risk assessment. Environ Health Perspect 118(6):818–824. https://doi.org/10.1289/ehp.0901388
Majeed S, De Boevre M, De Saeger S, Rauf W, Tawab A, Rahman M, Iqbal M (2018) Multiple mycotoxins in rice: occurrence and health risk assessment in children and adults of Punjab, Pakistan. Toxins 10(2):77. https://doi.org/10.3390/toxins10020077
Makun HA, Dutton MF, Njobeh PB, Mwanza M, Kabiru AY (2011) Natural multi-occurrence of mycotoxins in rice from Niger state, Nigeria. Mycotoxin Res 27(2):97–104
Manizan AL, Oplatowska-Stachowiak M, Piro-Metayer I, Campbell K, Koffi-Nevry R, Elliott C, Akaki D, Montet D, Brabet C (2018) Multi-mycotoxin determination in rice, maize and peanut products most consumed in Côte d'Ivoire by UHPLC-MS/MS. Food Control 87:22–30. https://doi.org/10.1016/j.foodcont.2017.11.032
Meca G, Mañes J, Font G, Ruiz MJ (2012) Study of the potential toxicity of enniatins A, A 1, B, B 1 by evaluation of duodenal and colonic bioavailability applying an invitro method by Caco-2 cells. Toxicon 59:1–11. https://doi.org/10.1016/j.toxicon.2011.10.004
Meerpoel C, Vidal A, Andjelkovic M, Boevre D, Marthe T, Emmanuel K, Huybrechts B, Devreese M, Croubels S, Saeger D, Sarah. (2021) Dietary exposure assessment and risk characterization of citrinin and ochratoxin A in Belgium. Food Chem Toxicol 147:111914. https://doi.org/10.1016/j.fct.2020.111914
Nguyen MT, Tozlovanu M, Tran TL, Pfohl-Leszkowicz A (2007) Occurrence of aflatoxin B1, citrinin and ochratoxin A in rice in five provinces of the central region of Vietnam. Food Chem 105(1):42–47. https://doi.org/10.1016/j.foodchem.2007.03.040
Panrapee I, Phakpoom K, Thanapoom M, Nampeung A, Warapa M (2016) Exposure to aflatoxin B 1 in Thailand by consumption of brown and color rice. Mycotoxin Res 32(1):19–25. https://doi.org/10.1007/s12550-015-0236-4
Park JW, Kim Y-B (2006) Effect of pressure cooking on aflatoxin B1 in rice. J Agric Food Chem 54(6):2431–2435. https://doi.org/10.1021/jf053007e
Park JW, Lee C, Kim Y-B (2005) Fate of aflatoxin B1 during the cooking of Korean polished rice. J Food Prot 68(7):1431–1434. https://doi.org/10.4315/0362-028X-68.7.1431
Phan LT, Kim T, Minh T, Audenaert K, Jacxsens L, Eeckhout M (2021b) Contamination of fusarium proliferatum and aspergillus flavus in the rice chain linked to crop seasons, cultivation regions, and traditional agricultural practices in Mekong Delta, Vietnam. Foods 10(9):2064. https://doi.org/10.3390/foods10092064
Phan LTK, Tran TM, De Boevre M, Jacxsens L, Eeckhout M, De Saeger S (2021a) Impact of season, region, and traditional agricultural practices on aflatoxins and fumonisins contamination in the rice chain in the Mekong Delta, Vietnam. Toxins 13(9):667. https://doi.org/10.3390/toxins13090667
Raad F, Nasreddine L, Hilan C, Bartosik M, Parent-Massin D (2014) Dietary exposure to aflatoxins, ochratoxin A and deoxynivalenol from a total diet study in an adult urban Lebanese population. Food Chem Toxicol 73:35–43. https://doi.org/10.1016/j.fct.2014.07.034
Reddy KRN, Reddy CS, Abbas HK, Abel CA, Muralidharan K (2008) Mycotoxigenic fungi, mycotoxins, and management of rice grains. Toxin Rev 27(3–4):287–317. https://doi.org/10.1080/15569540802432308
Reddy KRN, Farhana NI, Salleh B (2011) Occurrence of aspergillus spp. and aflatoxin B1 in Malaysian foods used for human consumption. J Food Sci 76(4):T99–T104. https://doi.org/10.1111/j.1750-3841.2011.02133
Sakuma H, Watanabe Y, Furusawa H, Yoshinari T, Akashi H, Kawakami H, Saito S, Sugita-Konishi Y (2013) Estimated dietary exposure to mycotoxins after taking into account the cooking of staple foods in Japan. Toxins 5(5):1032–1042. https://doi.org/10.3390/toxins5051032
Sales AC, Yoshizawa T (2005) Mold counts and aspergillus section Flavi populations in rice and its by-products from the Philippines. J Food Prot 68(1):120–125. https://doi.org/10.4315/0362-028X-68.1.120
Sani AM, Azizi EG, Salehi EA, Rahimi K (2014) Reduction of aflatoxin in rice by different cooking methods. Toxicol Ind Health 30(6):546–550. https://doi.org/10.1177/0748233712462466
Serrano AB, Font G, Ruiz MJ, Ferrer E (2012) Co-occurrence and risk assessment of mycotoxins in food and diet from Mediterranean area. Food Chem 135(2):423–429. https://doi.org/10.1016/j.foodchem.2012.03.064
Shephard GS, Leggott NL, Somdyala NIM, Stockenstrom S, Marasas WFO (2002) Preparation of south African maize porridge: effect on fumonisin mycotoxin levels. S Afr J Sci 98(7):393–396 https://hdl.handle.net/10520/EJC97505
Shephard GS (2008) Risk assessment of aflatoxins in food in Africa. Food Addit Contam 25(10):1246–1256. https://doi.org/10.1080/02652030802036222
Sirot V, Fremy J-M, Leblanc J-C (2013) Dietary exposure to mycotoxins and health risk assessment in the second French total diet study. Food Chem Toxicol 52:1–11. https://doi.org/10.1016/j.fct.2012.10.036
Thieu NQ, Ogle B, Pettersson H (2008) Screening of aflatoxins and Zearalenone in feedstuffs and complete feeds for pigs in southern Vietnam. Tropl Anim Health Prod 40(1):77–83
Tran MT, Ameye M, Phan LT-K, Devlieghere F, De Saeger S, Eeckhout M, Audenaert K (2021a) Impact of ethnic pre-harvest practices on the occurrence of fusarium verticillioides and fumonisin B1 in maize fields from Vietnam. Food Control 120:107567. https://doi.org/10.1016/j.foodcont.2020.107567
Tran TM, Ameye M, Phan LT-K, Devlieghere F, De Saeger S, Eeckhout M, Audenaert K (2021b) Post-harvest contamination of maize by fusarium verticillioides and fumonisins linked to traditional harvest and post-harvest practices: a case study of small-holder farms in Vietnam. Int J Food Microbiol 339:109022. https://doi.org/10.1016/j.ijfoodmicro.2020.109022
Tran VN, Viktorova J, Augustynkova K, Jelenova N, Dobiasova S, Rehorova K, Fenclova M, Stranska-Zachariasova M, Vitek L, Hajslova J (2020) In silico and in vitro studies of mycotoxins and their cocktails; their toxicity and its mitigation by silibinin pre-treatment. Toxins 12:148. https://doi.org/10.3390/toxins12030148
Trung TS, Bailly JD, Querin A, Le Bars P, Guerre P (2001) Fungal contamination of rice from South Vietnam, mycotoxinogenesis of selected strains and residues in rice. Rev Med Vet 152(7):555–560. https://doi.org/10.1016/j.foodchem.2007.03.040
Udovicki B, Tomic N, Trifunovic BS, Despotovic S, Jovanovic J, Jacxsens L, Rajkovic A (2021) Risk assessment of dietary exposure to aflatoxin B1 in Serbia. Food Chem Toxicol 151:112116. https://doi.org/10.1016/j.fct.2021.112116
Van NT, Viktorová J, Ruml T (2020) Mycotoxins: biotransformation and bioavailability assessment using caco-2 cell monolayer. Toxins 12:628. https://doi.org/10.3390/toxins12100628
Vietnamese Ministry of Health (2011). Circular 02/2011/TT-BYT National Technical Regulations for the the limit of mycotoxin contamination in food. Retrived Accessed: 09/10/2022, from (https://thuvienphapluat.vn/van-bag-tu-02-2011-TT-BYT-Quychuan-ky-thuat-quoc-gia-gioi-han-o-nhiem-hoa-hoc-118442.aspx)
Vietnamese Ministry of Health (2007). Circular 19/02/2007/TT-BYT National Technical Regulations for the the limit of mycotoxin contamination in food. Retrived Accessed: 09/10/2022, from (https://thuvienphapluat.vn/van-ban/The-thao-Y-te/Quyet-dinh-46-2007-QD-BYT-Quy-dinh-gioi-han-toi-da-o-nhiem-sinh-hoc-hoa-hoc-thuc-pham-65493.aspx)
Vinci RM, Jacxsens L, Van Loco J, Matsiko E, Lachat C, de Schaetzen T, Canfyn M, Van Overmeire I, Kolsteren P, De Meulenaer B (2012) Assessment of human exposure to benzene through foods from the Belgian market. Chemosphere 88(8):1001–1007. https://doi.org/10.1016/j.chemosphere.2012.03.044

Yazdanpanah H, Zarghi A, Shafaati AR, Foroutan SM, Aboul-Fathi F, Khoddam A, Nazari F (2012) Exposure assessment of the Tehran population (Iran) to zearalenone mycotoxin. Iran J Pharmaceut Res 11(1):251

Yogendrarajah P, Jacxsens L, Lachat C, Walpita CN, Kolsteren P, De Saeger S, De Meulenaer B (2014) Public health risk associated with the co-occurrence of mycotoxins in spices consumed in Sri Lanka. Food Chem Toxicol 74:240–248. https://doi.org/10.1016/j.fct.2014.10.007

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