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ORIGINAL ARTICLE

Occurrence of relevant mycotoxins in food commodities consumed in Chile

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Abstract
The aims of this study were to analyse the occurrence of aflatoxins, aflatoxin M1 (AFM_1), fumonisins, ochratoxin A (OTA), patulin (PAT), zearalenone (ZEN) and deoxynivalenol (DON) in foodstuffs consumed in Chile between 2008 and 2017 and to estimate the contribution of main contaminated foodstuff in human exposure by the probable daily intake (PDI) estimation. In 9 years of surveillance, 2020 food samples were analysed with an occurrence of 18.2% and with 2.7% of the samples being over the Chilean regulation. The occurrence of mycotoxins in food were 16% for aflatoxins, 6% for AFM_1, 30% for OTA, 12% for DON, 7% for PAT, 21% for fumonisins and 2% for ZEN. The estimated median PDI of DON because of bread consumption was 129.2 ng/kg bw/day for children and 96.0 ng/kg bw/day in adults. Median PDI because of capsicum consumption was 0.006 ng/kg bw/day for OTA and 0.005 ng/kg bw/day for aflatoxins. Median PDI of aflatoxins was estimated at 0.02 ng/kg bw/day for spices and 0.04 ng/kg bw/day for nuts consumption. In children, the median PDI of AFM_1 for dairy consumption was 0.07 ng/kg bw/day. The derived margin of exposure (MoE) values ranged from 1133 to 8500 suggested that aflatoxins would be of public health concern. The PDI of the other mycotoxins did not show a health risk. This is the first survey of mycotoxins in food made in Chile; further research is needed to improve surveillance and guidelines based on national risk assessments and considering sensitive population groups.

Keywords Mycotoxins · Occurrence · Dietary exposure · Risk assessment · Chile

Introduction

Mycotoxins are a group of chemicals produced by fungi which exert a toxic effect on animals and humans (Bennett and Klich 2003). For that reason, different efforts have been put forward to reduce human exposure, particularly through food intake. Among those efforts, maximum limits in food commodities have been set in different countries (van Egmond and Jonker 2004). The regulation on mycotoxins in food in Chile is specified in the Food Sanitary Regulation (2017) and is carried out by the Mycotoxins Surveillance Program from the Ministry of Health. It started in 2009,

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monitoring aflatoxins (B1, B2, G1 and G2) with a regulatory limit of 5 μg/kg; aflatoxin M1 (AFM_1) with a regulatory limit of 0.05 μg/kg and zearalenone (ZEN) with a regulatory limit of 200 μg/kg, with no specification of the foodstuff to analyse. In 2013, aflatoxins and AFM_1 regulatory limits were actualized, and regulations for ochratoxin A (OTA), patulin (PAT), fumonisins (B1, B2 and B3) and deoxynivalenol (DON) were added (Table 1). Compared to the regulation of the European Union (EU), the Chilean regulation is less specific, since sensitive groups are not considered in the determination of the regulatory limits. For example, in the EU, processed cereal-based foods and baby foods for infants and young children have a special regulation of 200 μg/kg for DON and fumonisins and 20 μg/kg for ZEN (European Commission 2007). Additionally, the EU regulation includes a more detailed list of foodstuffs with different mycotoxin regulatory limits according to the processing and consumption of food (European Commission 2006).

In Chile, there is a lack of information about the source of exposure in humans to different mycotoxins, although some studies have shown the occurrence of aflatoxin-adducts and OTA in plasma, urine and breast milk (Nogueira et al. 2015; Muñoz et al. 2006, 2010, 2014). In this context, information is needed regarding mycotoxin occurrence in different food commodities and also respecting food preferences. In a case-control study, measurements of aflatoxin B1-lysine adduct in plasma indicated that patients with gallbladder cancer had a significantly higher frequency (and levels) of this biomarker than gallstones controls (odds ratio (OR), 9.4; 95% CI, 2.8–37.2) and community controls (OR, 13.2; 95% CI, 4.3–47.9) with a 35% of the participants presenting quantifiable levels (Nogueira et al. 2015). On the other hand, analyses of OTA in plasma indicated high prevalence (between 84 and 96%) in a Chilean rural population (Muñoz et al. 2006). High OTA prevalence has also been observed in nursing mothers and their children, measured in the plasma and milk from mothers, and urine from the infants (Muñoz et al. 2010, 2014); in the latter, OTA in urine ranged 30–433 ng/L (Muñoz et al. 2014), higher than what was found in Germany 30–220 ng/L (Muñoz et al. 2017), but lower than some African countries such as Sierra Leone, where OTA in urine of infants ranged between 70 and 148,000 ng/L (Jonsyn-Ellis 2001).

In addition to measuring biomarkers, exposure to mycotoxins can be assessed indirectly based on data from contaminated foods and population food consumption. For this estimation, the degree of exposure is measured in terms of the probable daily intake (PDI) per unit of body weight, and it is generally expressed in ng/kg of body weight (bw) per day (WHO 2002; Jager et al. 2013). For risk assessment, the PDI is compared with the tolerable daily intake (TDI) or provisional maximum tolerable daily intake (PMTDI), generally determined by toxicological studies in sensitive laboratory species (Renwick and Walker 1993). In the case of genotoxic carcinogens like aflatoxins, where any level can potentially cause an adverse effect, the margin of exposure (MoE) method is used. MoE is defined as a reference point on the dose-response curve, e.g. a benchmark dose lower confidence limit (BMDL), divided by the estimated human intake (Benford 2016); a MoE below 10,000 may indicate a public health concern (EFSA 2013).

For effective prevention and control of these broadly distributed exposures, it is necessary to focus efforts on food commodities that pose the highest risks for the local populations. Similarly, regulatory limits should be established based on national realities. Thus, the first step to control the problem is to assess mycotoxins exposure level and distribution at the regional or country level. The aims of this study were to analyse the occurrence of mycotoxins in foodstuffs consumed in Chile between 2008 and 2017 and to estimate the main contribution of contaminated foodstuff in human exposure, as the first step to address gaps in research and surveillance to improve mycotoxin risk management in Chile.

Table 1 Chilean mycotoxin regulation in food according to the Food Sanitary Regulation (2017)

Mycotoxin	Food	Limit (μg/kg)
Aflatoxins	Cereals and derivatives, spices (capsicum, pepper, nutmeg, ginger, curcumin), nuts (peanuts, almonds, walnuts, hazelnuts, pistachios, dried figs and Brazil nuts)	10
AFM_1	Raw milk, thermally treated natural milk and milk for the manufacture of dairy products	0.5
ZEN	Cereals and their derivatives	200
PAT	Juices, concentrates, nectars, compote and mashed fruit from apples, pears, Asian pears, loquats and quinces	50
OTA	Cereals and their derivatives; cocoa; raisins, juices or juices, nectars and grape concentrate and coffee beans	5
	Soluble coffee (instant coffee)	10
DON	Cereals and derivatives	750
Fumonisins	Unprocessed corn	4000
	Corn and its derivatives for direct consumption	1000

Materials and methods

Data collection on mycotoxins in food

Data on mycotoxins in food were requested to the Chilean Mycotoxin Surveillance Program of the Health Ministry by the National Transparency Law, which allows the request of any public information through the page https://www.portaltransparencia.cl/PortalPdT/.

The Mycotoxin Surveillance Program conducts systematic sampling of food commodities sold in retail stores, local markets or by importers in Chile, for later mycotoxin analysis by reference laboratories. In general, the sampling plan involved three sub-lots for each incremental sample, based on an annual sampling plan involving the majority of the Regions of Chile. Mycotoxins included in the Program are those regulated in the Food Sanitary Regulation (Table 1), and other food-mycotoxins matrices of interest e.g. OTA in capsicum. Further information on the number and origin of the samples, types of commodities and mycotoxins evaluated by this Program between 2008 and 2017 are specified in official reports (Delgado and Villarroel n.d.; Delgado 2011; Delgado n.d.; Instituto de Salud Pública de Chile n.d.) and Supplementary file S1**.**

Analytical method

The analysis of mycotoxins in food was performed until 2015 by the Public Health Institute i.e. the reference laboratory of Chile, in charge of the standardization of the analytical techniques, procedures and methodologies with high-quality standards and international validations. The Health Regional Ministerial Secretariat Laboratory of the Metropolitan region, accredited by the Public Health Institute of Chile, performed the mycotoxins analyses on 2016 and 2017.

From the aggregate sample, the following weights were measured according to the specific analysis: 50 g for aflatoxins, DON and ZEN, 25 g for OTA, 20 ml for AFM_1 (if the sample was powdered, 10 g were taken and reconstituted with 100 ml of water) and 10 g for PAT.

Aflatoxins, OTA and ZEN analyses were based in immunoaffinity columns for sample extraction (VICAM, MA, USA) and high-performance liquid chromatography (HPLC) with a fluorescence detector (FLD) for separation and quantification (Agilent 1200), as described by Kumagai et al. (2008) in the case of aflatoxins and OTA and Campbell and Armstrong (2007) for ZEN. A solid phase sample extraction for sample clean-up and HPLC with an ultraviolet and diode array detector (HPLC/UV/DAD) was used for DON and PAT (Agilent 1100), based on the methodology described by Sugita-Konsihi et al. (2006) and Barreira et al. (2010) respectively. The limit of detection (LOD), the limit of quantification (LOQ) and recovery of the methods are shown in Table 2. A Ridascreen® ELISA kit (R-Biopharm, Germany) was used for fumonisins with a LOD of 25 μg/kg. Liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS) was used for the confirmation of samples when mycotoxin concentrations were over the regulated limits (Agilent 6430 Triple Quad). The results were expressed in μg/kg. Specifications of the analytical methods are detailed in Supplementary file S2.

Human food consumption

Bread and breakfast cereal consumption data was obtained from the first Chilean National Survey of Food Consumption (ENCA) applied between 2010 and 2011.ENCA consisted of a random cluster national sample of 4920 participants, stratified by macrozone (North, Center or South of Chile), residence area (urban or rural) and age of the survey participants (2–5; 6–13; 14–18; 19–29; 30–49; 50–64 and > 65 years old). Information on consumption was collected through two methods: (1) Quantified Food Consumption Trend Survey and (2) 24-h recall (ENCA 2014).

Capsicum (i.e. powder pepper and chilli) and coffee consumption data were obtained from the Maule cohort (MAUCO) health survey which included 4487 participants from Molina, a rural county representative of 40% of rural towns of Chile (Berdegué et al. 2010). This population-based cohort includes residents from Molina aged 38 to 74 years old and is the first cohort study that collects information about exposures to natural or anthropogenic chemicals in Chile (Ferreccio et al. 2016).

For nuts, spices, apple juice and milk consumption, was used the information compiled by World Health Organization (WHO) Global Environment Monitoring System (GEMS)/Food Cluster diets, group C05 (WHO 2012).

Exposure assessment

The estimation of the mycotoxin dietary intakes was made by the PDI using the following formula (F1):

$$(\text{F1})\ \text{PDI} = \frac{\text{Mycotoxin level in food (ng/g)r food consumption (g/person/day)}}{\text{Average weight}}$$

Following the European Food Safety Authority (EFSA) recommendations, the highest concentration values of mycotoxins in food were combined in a deterministic approach with high levels of food consumption (point estimate deterministic approach). If the resulting exposure was below the threshold for safety concern, further analysis was not necessary (EFSA 2010).

The mean body weight was set at 70 kg for adults according to the National Health Survey of Chile (2017), and 15 kg for children aged 2–5 years old, according to the WHO Child Growth Standards (WHO 2006).

Table 2 Parameters of mycotoxins in food commodities

Mycotoxin	Commodity	Recovery (%)	LOD (μg/kg)	LOQ (μg/kg)
OTA	Cacao	69.4	0.2	1.0
OTA	Flour	98.5		
OTA	Capsicum	94.8		
OTA	Coffee	82.5		
Aflatoxin G1	Capsicum	98.8	0.2*	1.0*
Aflatoxin B1		75.3		
Aflatoxin G2		111.6		
Aflatoxin B2		68.1		
Aflatoxin G1	Pepper	80.0	0.2*	1.0*
Aflatoxin B1		81.5		
Aflatoxin G2		85.7		
Aflatoxin B2		87.1		
Aflatoxin G1	Almonds	68.3	0.2*	1.0*
Aflatoxin B1		86.9		
Aflatoxin G2		90.7		
Aflatoxin B2		66.7		
Aflatoxin G1	Walnut	79.8	0.2*	1.0*
Aflatoxin B1		78.6		
Aflatoxin G2		82.5		
Aflatoxin B2		77.7		
Aflatoxin G1	Pistachio	67.0	0.2*	1.0*
Aflatoxin B1		69.9		
Aflatoxin G2		82.2		
Aflatoxin B2		74.4		
Aflatoxin G1	Peanut	101.4	0.2*	1.0*
Aflatoxin B1		98.1		
Aflatoxin G2		74.8		
Aflatoxin B2		60.0		
AFM_1	Milk	94.8	0.005	0.010
DON	Flour	97.6	75	150
ZEN	Flour	98.3	5	20
PAT	Puree	70.1	4	10
PAT	Juice	75.1		

*For aflatoxins (G1, B1, G2 and B2)

Risk characterisation

The health risk characterisation of each mycotoxin was obtained by dividing the calculated point estimate PDI by the TDI or PMTDI recommended by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (WHO 2017). If the resulting exposure was above the threshold for safety concern (PDI/TDI > 1), a probabilistic or semi-probabilistic approach was assessed depending on the information available (EFSA 2010). In the case of aflatoxins, the MoE was calculated as the ratio between the BMDL at the 10% effect level (BMDL10) derived from animal data, according to EFSA (2007) of 170 ng/kg bw/day, and the estimated PDI; a MoE < 10,000 was considered of high health concern (EFSA 2013).

Statistical analysis and modelling

A descriptive analysis of the available data was performed using the IBM SPSS Statistics Base 22.0 software (PASW Statistics). The probabilistic exposure assessment used the database information of mycotoxin levels (Supplementary file S1), assuming in < LOD a LOD/2.

Probabilistic models of each variable were sampled by the hypercubic Latin sampling method, and variables were associated with a Montecarlo simulation, using the @Risk 7.5 software (Palisade, Australia) with 100,000 iterations. Since mycotoxin levels and food consumption data were not normally distributed, they were adjusted by best fitting model or the model with the lowest Akaike information criterion (AIC), included in the @ Risk 7.5 software.

Results

Occurrence of mycotoxins in food

In 9 years of surveillance (2008–2017), the Mycotoxin Surveillance Program conducted 2020 analyses, with a total of 18.2% of the samples with quantifiable results and 2.7% over the regulated limits. The percentage and mean concentrations of quantifiable levels of mycotoxins in food were respectively: 16% and 4.9 μg/kg for aflatoxins, 6% and 0.015 μg/kg for aflatoxin M1, 30% and 10.5 μg/kg for OTA, 12% and 251 μg/kg for DON, 7% and 27 μg/kg for PAT and 21% and 2% for fumonisins and ZEN respectively, with no quantitative information. The maximum levels found were 176.4 μg/kg for aflatoxins in capsicum, 416.3 μg/kg for OTA in capsicum and 175 μg/kg for PAT in apple juice (Table 3). Only aflatoxins and OTA were quantified in 3 or more different years. In general, the trend of samples above the Chilean regulation over time has increased for OTA and has decreased for aflatoxins (Supplementary file S3).

The number of samples, food commodities studied and number and levels of mycotoxins over the regulated limits from each year are summarized in Table 4. Full information is specified in official reports between 2008 and 2012 (Delgado and Villarroel n.d.; Delgado 2011; Delgado n.d.; Instituto de Salud Pública de Chile n.d.) and database of occurrence of mycotoxins between 2014 and 2017, available in Supplementary file S1.

Dietary exposure to mycotoxins

According to the consumption information available, the deterministic approach to dietary mycotoxin exposure was assessed for aflatoxins due to the consumption of spices, capsicum and nuts; AFM_1 from dairy consumption; OTA from capsicum, coffee, bread and cereal consumption; and DON from bread consumption. Results are summarised in Table 5. In the case of aflatoxins, all PDI estimated a MoE < 10,000; DON may pose a health risk to children because of bread consumption, along with OTA because of capsicum consumption in adults. In these food-mycotoxin matrices, a probabilistic estimation of dietary exposure was calculated. Results are shown in Table 6. The estimated mean PDI of DON because of bread consumption was 154.7 ng/kg bw/day for children and 114.4 ng/kg bw/day in adults. The P95 PDI/TDI was below 1 in both children and adults. Regarding capsicum consumption, mean and median PDI of OTA was 0.47 ng/kg bw/day and 0.006 ng/kg bw/day respectively. The P95 PDI was 0.3 ng/kg bw/day (PDI/TDI = 0.02). The mean and 95 percentile (P95) PDI of aflatoxins were 0.01 and 0.06 ng/kg bw/day respectively. In adults, the mean PDI of aflatoxins was estimated at 0.08 ng/kg bw/day for spices and 0.04 ng/kg bw/day for nuts consumption. In children, the mean and P95 PDI of AFM_1 due to dairy consumption were 0.07 ng/kg bw/day and 0.09 ng/kg bw/day respectively. Nuts and spices consumption in adults and dairy consumption in children proved to be of high public health concern (MoE < 10,000), along with high consumers of capsicum (Table 6).

Discussion

This is the first data compilation of the occurrence of mycotoxins in food made in Chile. Also, it is the first dietary exposure estimation of mycotoxins using Chilean data. Levels of mycotoxins exceeding the regulatory limits were found for OTA, aflatoxins and PAT. In contrast with reports from the EU, where Brazil nuts and pistachios presented the highest occurrences and levels of aflatoxins (Marin et al. 2013), only five samples of nuts were positive for aflatoxins, one over the regulatory limits. The probabilistic approach gave a mean PDI of 0.04 ng/kg bw/day due to nut consumption, lower than the estimations of Jager et al. (2013) in Brazil (1.56 ng/kg bw/day); even with this lower PDI, nut consumption represents public health concern in Chile (MoE: 6250). In children, a median PDI of AFM_1 because daily consumption (0.07 ng/kg bw/day), also estimates a MoE < 10,000. This estimation is

Table 3 Summary of mycotoxins detected in food sold in Chile according to the Chilean Mycotoxin Surveillance Program 2008–2017

	Aflatoxins	AFM_1	OTA	DON	PAT	ZEN	Fumonisins	Total
Total samples	671	52	632	225	166	193	81	2020
Number above LOQ	113	3	190	28	12	4	17	367
Above LOQ (%)	17	6	30	12	7	2	21	18.2
LOQ of the method (μg/kg)	1.0	0.010	1.0	150	10	20	25	–
Mean (S.D) concentration (μg/kg)	4.9 (3.9)	0.015 (0.003)	10.5 (8.1)	251 (166)	27 (21)	n.i	n.i.	–
Above regulatory limits (%)	2.6	0	6.8	0	1.2	0	0	2.7
Highest concentration (μg/kg)	176.4	0.018	416.0	250.6	175	n.i	583	–
Regulatory limit (μg/kg)[a]	10	0.5	5	750	50	200	1000	–

n.i. no information; [a] Food Sanitary Regulation of Chile

Table 4 Mycotoxins, food commodities and levels over the limits according to the Chilean Surveillance Program 2008–2017

Year	Total samples	Mycotoxins evaluated	Commodities evaluated	Commodity over Chilean regulation (*n*), levels (μg/kg)
2008–2009	234	Aflatoxins	Almonds, nuts, pistachios, peanuts, Japanese peanuts	Japanese peanuts (1), 33.3
		DON, ZEN	Flour, cereals	–
		OTA	Rice, wheat flour and bran, cereals	Wheat bran (1), 8.1
		PAT	Juice	Apple juice (1), 175
2010	71	Aflatoxins	Almonds, peanuts, spices	Nutmeg (5), 4.5 to 35.8; Capsicum (4) 9.9 to 10.9
		DON	Wheat flour	
2011	50	Aflatoxins	Almonds, peanuts, spices	Nutmeg (1), 173.3; Curry (1), 23
		OTA	Rice	–
2012	108	Aflatoxins	Nuts, spices, cereal	
		DON, ZEN, OTA	Wheat flour, cereal	–
		PAT	Fruit juice and pulp	–
2013	306	Aflatoxins	Spices, wheat flour, nuts	–
		DON, ZEN	Wheat flour, cereal	–
		OTA	Capsicum,cereal, cocoa, coffee	Capsicum (3), 16 to 416.3
		Fumonisins	Wheat flour	–
		PAT	Fruit juice	Apple juice (1), 50.7
		AFM_1	Milk	–
2014–2015	419	Aflatoxins	Capsicum, spices, almonds, peanuts, pistachios	–
		DON, ZEN, fumonisins	Wheat flour, cereal	–
		OTA	Capsicum, coffee, wheat flour, cereal, cocoa	Capsicum (2), 71.9 and 222.1
		PAT	Fruit juice and pulp	–
2016	393	Aflatoxins	Capsicum, spices, cereal, nuts	–
		OTA	Capsicum, cocoa, wheat flour, cereal	Capsicum (6), 19.7 to 71.8
2017	439	Aflatoxins	Capsicum and other spices	Nutmeg (3), 13.8 to 36.3; Capsicum (2), 31.7 and 176.4
		DON, ZEN	Wheat flour, cereal	–
		OTA	Capsicum and coffee	Coffee (2), 10.4 and 16.4; Capsicum (19), 16.3 to 387.9
		PAT	Fruit puree	–
		AFM_1	Milk	–

similar to the PDI of 0.1 (± 0.08) ng/kg bw/day reported in the Brazilian study (Jager et al. 2013) but higher than estimations by biomarkers (0.001 ± 0.002 ng/kg bw/day) also in Brazil (Franco et al. 2019).

The food that was most contaminated with aflatoxins were spices; of these, 70% (40/57) were capsicum products. Other authors have also found aflatoxins in this matrix in Chile (Asai et al. 2012; Tsuchiya et al. 2011). According to the estimated PDI of aflatoxins, high consumers of capsicum could be at health risk (MoE 8333). The relevance of these findings is that two studies conducted in Chile, have associated chilli consumption to gallbladder cancer, one of the most prevalent cancers in Chilean women (Serra et al. 2002; Nogueira et al. 2015). The proposed hypothesis for this association is that xenobiotics like aflatoxins (which are in capsicum) are attached to cholesterol, that is rapidly excreted from the liver to gallbladder in most of the Chilean population because of genetic predisposition (Foerster et al. 2016).

High levels in capsicum were also seen for OTA, with a maximum level of almost 26 times higher than the regulated limit (Table 4). Ikoma et al. (2015) found a mean of 355 μg/kg, (range < 5–1059 μg/kg) of OTA in chilli, which corroborates the high contamination of this matrix in Chile. This could bear out the results of Muñoz et al. (2006, 2010, 2014) that the Chilean population is continuously exposed to low concentrations of OTA. Even today, there is no regulation for OTA in any type of spices in Chile, so its incorporation into the Food Sanitary Regulation must be a priority to improve the control of this mycotoxin.

Capsicum and its derivative-products are highly susceptible to mycotoxin contamination (Costa et al. 2019; El Darra et al. 2019). High OTA and aflatoxins occurrences in spices

Table 5 Dietary exposure to mycotoxins from specific foods according to the PDI with a point estimate deterministic approach, along with risk characterisation based on PDI/TDI ratio or MoE

Mycotoxin	Commodity	Highest level (μg/kg)	Consumption (g)		PDI (ng/kg bw/day)		TDI[e] or BMDL10[f] (ng/kg bw/day)	PDI/TDI or MoE*	
			Adults	Children	Adults	Children		Adults	Children
DON	Bread (wheat)	250	276.0[a]	81.0[a]	985.7	1350.0	1000	0.99	1.35
OTA	Breakfast cereal	2.9	209.0[a]	20.0[a]	8.8	3.9	16	0.55	0.25
OTA	Coffee	16.4	28.0[b]	–	6.5	–	16	0.41	–
OTA	Capsicum	416.0	4.0[b]	–	23.8	–	16	1.49	–
PAT	Apple juice	175	6.4[c]	6.4[c]	1.9	74.3	400	–	0.19
Aflatoxins	Nuts	33.3	15.9[c]	–	7.6	–	170	22.37	–
Aflatoxins	Capsicum	176.4	4.0[b]	–	11.1	–	170	15.31	–
Aflatoxins	Other spices	173.0	4.4[c]	–	10.9	–	170	15.59	–
AFM_1	Milk	0.02	174.9[c]	400.0[d]	0.04	0.48	170	4250	354.17

*MoE for aflatoxins; PDI/TDI for all other mycotoxins. [a] ENCA (2014) P75, [b] MAUCO Health Survey (2016–2017) P75, [c] GEMS WHO (2012), [d] Universidad de Chile (2018), [e] WHO (2017), [f] EFSA (2007)

have been reported especially in capsicum products, associated to inadequate hygiene (Jalili and Jinap 2012; Zafar Iqbal et al. 2013; Prelle et al. 2014; Yogendrarajah et al. 2014; Ali et al. 2015). Most of capsicum is imported to Chile from Peru and India; therefore, increasing import control must be a priority for mycotoxin prevention. Co-occurrence of OTA and aflatoxins in capsicum was high (20.6%) and presented with high levels. Co-occurrence of these two mycotoxins was higher than that found by Prelle et al. (2014) in spices in Italy, (4.6%), but lower than that detected in Turkey (62.5% in red chilli flake and 40.9% in red chilli powder) (Ozbey and Kabak 2012). The combination of OTA and aflatoxins has been associated with increasing cytotoxicity (Golli-Bennour et al. 2010; Corcuera et al. 2011), antagonistic effects in reducing genotoxicity (Corcuera et al. 2011) as well as no effect (Corcuera et al. 2012). Gambacorta et al. (2018) found multiple co-occurrences of mycotoxins in sweet pepper, which strengthens the importance of analysing this matrix for other mycotoxins, which are often non-regulated, such as fumonisins, ZEN and DON. The study of the interactions between multiple mycotoxins in different matrices should be a priority, along with the incorporation of co-contamination in future regulations (Klarić et al. 2013).

The current Chilean food safety regulation was based on international risk assessments (Food Sanitary Regulation 2017). Although harmonised regulatory limits would be beneficial from a commercial point of view, this does not necessarily promote equal protection of human health in a homogeneous way around the world. The risks associated with mycotoxins depend on both the hazard and the exposure. The danger posed by mycotoxins to humans is probably similar worldwide, but not the exposure, because of differences in contamination levels and diet habits; therefore, reliable exposure assessments for mycotoxins in each region are necessary (FAO 2004). This can be exemplified by the high consumption of bread in Chile i.e. 90 kg/year, with an average of 250 g of bread/day (ENCA 2014), which positions the country within the first places for bread consumption in the world. For this,

Table 6 Dietary exposure to mycotoxins from specific foods according to the PDI with a probabilistic approach, along with the risk characterisation based on PDI/TDI ratio or MoE

Mycotoxin	Commodity	Best fit of mycotoxin levels	Population group	Best fit of consumption	PDI: mean (SD) ng/kg bw/day	PDI: median (P25-P75) ng/kg bw/day	PDI: P95 ng/kg bw/day	PDI/TDI or MoE (median)	PDI/TDI or MoE (P95)
Aflatoxins	Nuts	Pareto	Adults	15.9	0.04 (0.008)	0.04 (0.03–0.04)	0.06	4250	2833
Aflatoxins	Capsicum	Pareto	Adults	Exponential	0.01 (0.05)	0.005 (0.002–0.01)	0.03	34000	5666
Aflatoxins	Spices	Pareto	Adults	4.4	0.08 (2.8)	0.02 (0.01–0.03)	0.15	8500	1133
AFM_1	Dairy	Pareto	Children	400	0.07 (0.008)	0.07 (0.06–0.08)	0.09	2429	1889
OTA	Capsicum	RiskInvgauss	Adults	Exponential	0.49 (13.4)	0.006 (0.002–0.02)	0.26	0.0004	0.02
DON	Bread (wheat)	Pareto	Children	Triangular	154.70 (121.1)	129.21 (100.0–170.5)	311.8	0.13	0.31
			Adults	Triangular	114.41 (85.9)	96 (75–126.5)	229.2	0.10	0.23

*MoE for aflatoxins; PDI/TDI for all other mycotoxins it is necessary to have a systematic sampling of OTA, aflatoxins, ZEN, DON, fumonisins and other not regulated mycotoxins (e.g. T-2 toxin) for accurately estimate dietary exposure of this highly consumed commodity. Since baking could reduce some mycotoxin levels in wheat (Karlovsky et al. 2016), it is necessary to analyse the final product instead of flour.

The contribution of coffee to OTA exposure is relatively low in mean consumption and worst-case scenarios. This is in accordance with results reported by Galarce-Bustos et al. (2014), who found 100% occurrence of OTA in instant coffee in Chile, but with low levels ranging from 0.30 to 0.84 μg/kg. On the other hand, Chile is one of the largest consumers of tea worldwide; sampling and analysis of this matrix are also needed, since aflatoxins, OTA and fumonisins have been found in it (Sedova et al. 2018).

Regarding PAT, detectable levels were reported in apple juice in 2 of the 5 years in which it was measured, both times with levels above Chilean regulation. For proper exposure assessment, it is urgent that vulnerable populations in which mycotoxins can induce worse effects, such as children (Sherif et al. 2009; Raiola et al. 2015), are included in Chilean mycotoxin regulations. This is an important gap, as the Food Sanitary Regulation (2017) only specifies nutritional and microbiological safety aspects for children food. Moreover, often PAT-contaminated products (i.e. apple juice and compotes) are destined exclusively for consumption by infants and children, while even the LOD for PAT (25 μg/kg) in the Chilean official analyses is above the EC limits for this toxin for children (10 μg/kg) (European Commission 2006). Therefore, a short-term objective in Chile should be to conduct human risk assessments focusing on foods for children and children exposure (Sherif et al. 2009), for which data on children intake, food preferences and weights must be generated. Nursing mothers and their infants should also be considered in the PDI and TDI estimations, as suggested by Degen et al. (2017), who estimated that lactating exposure to mycotoxins exceeded the age-adjusted TDI values.

Among the most important limitations of this study was the food consumption information: that the two consumption surveys assessed differed in participants' age, representability and survey objectives; ENCA is a whole population nutrition-based survey conducted in 2010 while MAUCO's health survey was applied in 2016–2017 and focuses on rural population to assess health and risk factors. Also, some estimates were made with Latin-American consumption information. Therefore, the estimates are not appropriately comparable. Additionally, the inherent uncertainties of food surveys must be taken into account (Kettler et al. 2015). Also to be considered is the low representativeness of the Surveillance Program's food sampling; depending on the budget, some years only included a very low number of food samples from a few regions of Chile. It would be desirable to improve sampling protocols according to international standards e.g. the sampling guidance of the International Agency for Research on Cancer (IARC 2012) and EU Regulation (European Commission 2006). Representative sampling would allow identifying all food items that are susceptible to mycotoxin contamination to calculate total dietary exposure for mycotoxins and not just the contribution of certain foodstuffs.

Despite these limitations, this is the first description of mycotoxins occurrence in food commodities sold in Chile. In light of these results, it is urgent to develop regulatory guidelines based on national information, with a focus on sensitive groups.

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Compliance with ethical standards

Conflict of interest None

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