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Is the dietary acrylamide exposure in Chile a public health problem?

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ABSTRACT
This study estimates for the first time dietary acrylamide intake in Chile and conducts exposure risk assessments using the margin of exposure (MOE) method. A consumption frequency survey of starchy foods was carried out in the metropolitan region of Santiago, Chile on people from different socioeconomic levels aged between 12 and 65 years old. The acrylamide contents of the most frequently consumed foods were determined by an in-house validated GC-MS technique. The potatoes and bread group contributed ~77% to the dietary acrylamide exposure in Chile, with estimated daily mean exposure of 0.55 µg kg_{bw}^{-1} day^{-1} and 0.22 µg kg_{bw}^{-1} day^{-1}, respectively. Chilean population aged between 12 and 17 years old presented the highest acrylamide intake (mean, 1.27 µg kg_{bw}^{-1} day^{-1}; 95th percentile, 3.90 µg kg_{bw}^{-1} day^{-1}). Finally, since the estimated MOEs were lower than 10,000, the dietary acrylamide exposure in the metropolitan region of Santiago, Chile is of public health concern according to the EFSA criteria.

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Acrylamide; GC/MS; starchy foods thermally treated; dietary exposure; MOE; food processing

Introduction

Acrylamide (C_3H_5NO) is an α,β-unsaturated carbonyl compound with high reactivity and water solubility, widely used in the chemical industry. It is considered probably carcinogenic to humans (2A) by the International Agency for Research on Cancer (IARC 1994). In 2002, Swedish researchers reported its presence in starch-rich food products that are subjected to high processing temperatures, such as frying, baking and roasting under low-humidity conditions (Tareke et al. 2002). The main chemical mechanism by which it is generated in foods processed at high temperatures (baked and fried) is through the Maillard reaction, from sugars and amino acids (mainly asparagine) that are naturally present in many foods (Friedman 2003). Paradoxically, this same non-enzymatic browning reaction is responsible for the main organoleptic attributes of smell, colour and flavour of fried, baked, roasted or grilled foods (Arnoldi 2003).

Instrumental analysis based on the principles of chromatography (gas or liquid) and mass spectrometry is the main methods for detecting acrylamide content in food, obtaining high precision and sensitivity, as well as good reproducibility (Pan et al. 2020). In this sense, thermally processed starchy foods are often complex matrices for the determination of acrylamide (Oracz et al. 2011). Because of this, it is advisable to perform a specific methodology validation for each food group with similar physicochemical characteristics, in order to have more reliable results (Pan et al. 2020).

Acrylamide concentrations in foods reported by FDA range from 10 µg kg^{-1} to 8,440 µg kg^{-1}, and according to the EFSA from 24 µg kg^{-1} to 2,942 µg kg^{-1}: coffee substitutes (1,499 µg kg^{-1}), instant coffee (716 µg kg^{-1}) and potato chips (580 µg kg^{-1}) were the foods that most contributed to acrylamide exposure (EFSA 2015; FDA 2015).

Due to the toxicological characteristics of acrylamide, risk assessment of its dietary exposure has been a controversial issue for both health authorities and the scientific community. Different indicators and approaches have been proposed to quantify the risk associated with its intake, being the margins of exposure (MOE) the best agreed criterion. The MOE is

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a tool that used in risk assessment to explore safety issues arising from the presence of a potentially toxic substance in food (EFSA 2012). This can be defined as the ratio of no-observed-adverse-effect level (NOAEL) obtained from animal toxicology studies to the predicted or estimated human exposure level or dose. In general, an MOE exposure margin of 10,000 or more, based on a lower confidence limit on the benchmark dose associated with a 10% response ($BMDL_{10}$) from an animal study, would be of little concern from a public health point of view (EFSA 2015). In this sense, MOEs reported for acrylamide intake in countries, such as Poland, Italy and Denmark (52–2,073), have suggested that the exposure to acrylamide through food consumption may be considered a public health risk (Jakobsen et al. 2016; Branciari et al. 2020; Cieślik et al. 2020).

In 2015, EFSA published the first comprehensive risk assessment of acrylamide in foods, concluding that acrylamide in food products potentially increases the risk of developing cancer for consumers in all age groups. Due to this, different entities have taken some measures, such as regulation 2017/2158 of the European Commission (EC) which establishes reference levels for the presence of acrylamide in several food products, such as bread 50 μg kg^{-1} and crackers 750 μg kg^{-1} (European Commission 2017).

The above would indicate that it is relevant to establish whether the Chilean population is exposed to dietary acrylamide, especially considering that Chilean consumer preferences include foods such as bread and potato-based products that could contain considerable amounts of acrylamide. According to the National Food Survey, most Chileans have a diet rich in carbohydrates, with a contribution between 58% and 61% of the total food consumption (ENCA 2010). Thus, the aim of this research was to assess for the first time the risk of dietary acrylamide intake in the Chilean population of the metropolitan region of Santiago, Chile based on the acrylamide content of Chilean starchy foods highly consumed and their frequency of intake.

Materials and methods

Chemicals and reagents

Acrylamide (2-propenamide) (>99.5%, Sigma–Aldrich, St. Louis, MO, USA); labelled d_3-acrylamide (>98%, Polymer Source Inc., Dorval, Quebec, Canada), methanol (HPLC grade, Rathburn, Walkerburn, Scotland) and acetonitrile (HPLC grade, Rathburn, Walkerburn, Scotland) were used for acrylamide quantification.

Food consumption data

Using the information reported in the literature (Wilson et al. 2009; Lin et al. 2011; Normandin et al. 2013), a semi-closed survey of dietary consumption frequency in the metropolitan region of Santiago, Chile was developed. Highly consumed Chilean starchy foods were considered (Liberona et al. 2011; Valenzuela et al. 2015; ENS 2016), and those that are characteristic of Chilean traditional cuisine.

The survey involved 1510 people from different socioeconomic levels, men and women, young and adults from the metropolitan region of Santiago, Chile (Adimark 2004). Four age categories were established: (i) 12–17 years, (ii) 18–44 years, (iii) 45-64 years and (iv) >65 years. The study was approved by the ethics committee of the Pontificia Universidad Católica de Chile. In the case of children (aged <18 years), an informed consent was signed by the parents and an assent by the respondents.

Sample collection

For analysing acrylamide in foods, the 43 most consumed thermally treated starchy foods reported by the National Survey of Food Consumption (ENCA 2010) were selected and distributed in six groups: (i) bread (n = 5; hallulla bread, marraqueta bread, whole-meal bread, white bread, pita bread), (ii) potato chips (n = 3; baked potatoes, homemade chips, potato chips), (iii) breakfast cereals (n = 7; chocolates, sugar flakes, puffed cereals, oats, oat-based cereals), (iv) coke shop (n = 9; cake, kuchen, lemon pie, "brazo de reina" cake, donuts), (v) cookies (n = 13; filled, sweet, salty) and vi) others (n = 6; fried wheat dough called "sopaipillas", fried/baked cheese/meat pie). The foods were obtained from randomly selected commercial establishments in seven different sectors (centre, north-west, north-east, south, south-east and south-west) of Santiago, Chile, in order to reflect the diversity of the community. Two samples of each brand were collected from each geographic sector and immediately stored at 4°C for 4 h prior to the acrylamide analysis. Prior to the acrylamide analysis, starchy food samples were reduced to ~2 mm diameter using a 99 cutting mill Oster blender (Sunbeam Products, Inc., Boca Raton, FL, USA).

Acrylamide quantification in starchy foods

Sample extraction and clean up

The procedure was performed based on the study by Mariotti-Celis et al. (2017). Two grams of milled samples was transferred to a 50-ml centrifuge tube. Furthermore, 40 µl of 20 µg ml^{-1} d_3-acrylamide was added as an internal standard to the centrifuge tube before 10 mL of methanol was added. Samples were placed in a vortex (model REAX top, Heidolph, Germany) by 30 s and left for 20 min in an ultrasonic bath (model 970,493–966, VWR, NJ, USA) at 60°C to extract the acrylamide. After that, the samples were centrifuged (model MIKRO 220 R, Hettich, Germany) for 10 min at −4°C and 6000 rpm. Then, an aliquot of 5 ml of the supernatant was cleaned through a C-18 reverse-phase cartridge and a second extraction was made with 5 ml of methanol. Both extracts were combined and collected in a 100-ml balloon flask. Subsequently, the solvent was evaporated (model Hei-VAP advantage, Heidolph, Göteborg, Sweden) until dryness to 40°C and reconstituted with 1 ml of methanol. The eluate was transferred to Miniprep PTFE filter HPLC vials with a pore diameter of 0.20 µm (Whatman, Inc., Piscataway, NJ, USA) and put in 2-ml vials for GC-MS analysis.

GC/MS analysis

Acrylamide was determined by GC-MS in ECI mode using an Agilent 7890 GC (California, USA) equipped with MS Detector 597C XL (Agilent Technologies, Santa Clara, California, USA) under the following conditions: split/splitless inlet 250°C, 2-µl pulsed splitless, single-tapered liner with glass wool, oven 60°C (1.0 min), 10°C min^{-1} to 240°C (0 min), column 30 m × 0.25 mm × 0.25 µm (Agilent DB-FFAP 122-3232), helium as a carrier gas, 43.8-ml min^{-1} constant flow, single ion monitoring mode, interface/source/quadrupole 245/150/270°C, tune NCI CH4.U, reagent gas methane 2 ml min^{-1}, EM offset 400 above tune, resolution low, dwell time 150 ms. Signals at m/z 70 for acrylamide and m/z 73 for deuterium-labelled acrylamide were used for quantitation. All analyses were run in triplicate.

Acrylamide quantification

Acrylamide was determined using a linear calibration curve established with standard solutions of acrylamide dissolved in methanol. Concentrations of acrylamide used were 25, 150, 300, 450, 600, 750, 875 and 1000 pg μl^{-1}. Additionally, each solution contained 200 µl of 20-µg ml^{-1} d_3-acrylamide. The results were expressed as µg of acrylamide per gram of dried solid (µg gds^{-1}) or gram of defatted solid (µg $gdds^{-1}$) for baked or fried food products, respectively.

Determination of analytical quality parameters

The analytical method of acrylamide quantification in starchy foods by GC-MS was submitted to an in-house validation in which the limits of determination (LOD) and quantification (LOQ), linearity, % of recovery, % of repeatability and % of replicability were evaluated for low (baked) and high (fried) oil content foods. Both LOD and LOQ were determined by preparing the matrices as described above and defined at the signal-to-noise (S/N) ratio of 3 and 10, respectively.

The data of the calibration curve were subjected to linear regression analysis and the goodness-of-fit test was performed. The percent of recovery of acrylamide in both baked and fried samples was determined using the following equation:

$$\%\ \text{Recovery} = ((\mu g\ \text{acrylamide found})/(\mu g\ \text{acrylamide added})) * 100 \quad (1)$$

where µg acrylamide found corresponds to the amount of acrylamide calculated with the calibration curve (the background level was subtracted); µg acrylamide adde corresponds to the level of fortification. Finally, the repeatability was obtained out to establish the variability of the measurements caused by the analyst and replicability to establish the variability of the measurements caused between the analysts, both parameters were calculated with n = 7 and expressed as coefficients of variation.

Exposure assessment of acrylamide

An exposure assessment of acrylamide in analysed starchy foods was carried out based on the acrylamide concentration of each sample and the dietary data obtained from the starchy food consumption survey. The following equation was used:

$$\text{Estimated daily intake (EDI)} = \sum_{i=1}^{n} (C_i \, x \, C_{ri}) / (\text{BW x 1000}) \quad (2)$$

where C_i is the mean concentration level of acrylamide in food (μ kg^{-1}); C_{ri} is the daily intake of i food (g day^{-1}); BW is the average body weight (kg); and n is the number of tested foods. BWs reported in the National Health Survey (ENS 2016) were used for the calculations (Table 1).

Additionally, for the risk characterisation, the MOE method was used. The MOE is the most scientifically credible approach to the formulation of advice because it takes account of the intake/exposure and the available data on the dose–response relationship, without considering the extrapolation or the generation of possibly uncertain risk estimates (Barlow et al. 2006).

The MOE was determined considering the total acrylamide intakes estimated (for each gender, age group and the socioeconomic level) and the $BMDL_{10}$ for neoplastic effects (0.17 mg kg_{bw}^{-1} day^{-1}) and neurological effects (0.43 mg kg_{bw}^{-1} day^{-1}) (EFSA 2015).

The calculation of MOE was made using the following equation:

$$MOE = BMDL_{10}/EDI \quad (3)$$

Finally, the information obtained of EDI and MOE was expressed as a function of the mean and the 95th percentile (this is a value higher than 95% of the observations, but lower than the remaining 5%, allows us to know the higher intake patterns).

Results and discussion

Starchy food consumption

A food consumption survey was conducted among a group of 1,510 people in the metropolitan region of Santiago, Chile. The sample was characterised with respect to its distribution according to gender, socioeconomic level and age group (Table 2). The 51.7% of sample corresponded to women and 48.3% to men. For both socioeconomic level and the age group, a close relation of 1:1 between men and women was observed, except for people older than 65 years old, where a relation of 1:3 was presented. This behaviour is representative of the elderly Chilean population as was reported in the last census of Chile (INE 2017).

Regarding food consumption, the bread group was the highest consumed (216.9 g day^{-1}), while cereals and cookies were the lowest ones with 16.6 g day^{-1} and 34.8 g day^{-1}, respectively (Table 3). These results are consistent with those previously reported in a furan exposure study carried out in the Chilean population, where a preference for bread consumption was evident (Mariotti-Celis et al. 2013).

Table 1. Average weights of Chilean population from the metropolitan region of Santiago.

Age group [years]	General population [kg]	Males [kg]	Females [kg]
12–17	66.7	71.7	61.8
18–44	74.2	79.7	68.8
45–64	75.0	79.7	70.6
>65	69.7	74.4	66.3

Average body weight (bw) = 72.3; males = 77.3; females: 67.5 kg.
Source: Adapted from ENS (2016).

Analytical performance

Once the most widely consumed starchy foods in Chile were identified, their acrylamide content was determined. The quantification of acrylamide was done by GC-MS performing an in-house validation for baked and fried foods. The implemented technique was sensitive and robust, presenting excellent analytical performance parameters (Table 4). The goodness-of–fit test ($p > .05$) showed that the linear model is reasonable (r^2: 0.999) over a concentration range of 25 to 10,000 μg kg^{-1}, with an LOD of 2.69 μg kg^{-1} and LOQ 8.99 μg kg^{-1} for the baked and fried food matrices, respectively. Recovery percentages were greater than 100%, repeatability and replicability varied between 0.53–9.11% and 0.09–1.98%, respectively, which are within the tolerances established by European Decision 2002/657/EC, based on the Horwitz equation (European Union 2002).

Acrylamide content of Chilean starchy foods

With the validated methodology, acrylamide was quantified in the different starchy foods randomly sampled from Santiago, Chile (Figure 1). The acrylamide content of starchy foods presented a high variability (Figure 1). This variability is consistent with

Table 2. Distribution according to the gender, socioeconomic level and age group of the population of the metropolitan region of Santiago, Chile (n = 1510).

	Socioeconomic level [% (n)]						Age groups (years) [% (n)]			
Gender	Very low	Low	Medium Low	Medium high	High	Very high	0–17	18–44	45–64	>65
Males	2.5 (38)	18.2 (275)	13.6 (205)	8.5 (128)	3.8 (57)	1.7 (26)	8.8 (133)	27.4 (413)	10.9 (165)	1.2 (18)
Females	5.1 (77)	18.5 (279)	11.6 (175)	10.4 (157)	4.4 (67)	1.7 (26)	9.9 (150)	27.5 (415)	11.3 (170)	3.0 (46)

Table 3. Estimated daily intake of acrylamide in the metropolitan region of Santiago, Chile.

Group food*	Mean acrylamide content [μg kg^{-1}]	Mean edible portion [g day^{-1}]	Mean acrylamide intake [μg kg$_{bw}$$^{-1}$ day^{-1}]
Bread (n = 5)	73.34	216.87	0.22
Cereals (n = 7)	87.32	16.56	0.02
Potatoes (n = 3)	354.13	112.29	0.55
Cookies (n = 13)	207.94	34.77	0.10
Cake shop (n = 9)	72.21	40.05	0.04
Others (n = 6)	85.40	42.33	0.05
Total (n = 43)			0.98

Average body weight = 72.3 kg.
*n indicates the number of products in the same category. Each product was tested in triplicate.

Table 4. Analytical performance parameters of a GC-MS method for acrylamide quantification in foods (n = 7).

Parameter	Fried foods	Baked foods
r^2	0.999	0.999
Lack of fit	0.910	0.960
LOD [μg kg^{-1}]	2.698	2.698
LOQ [μg kg^{-1}]	8.9959	8.9959
Recovery [%]	109.050	101.760
Repeatability [CV]	0.530	9.110
Replicability [CV]	0.090	1.980

CV: coefficient of variation.

results previously reported in other studies carried out in thermally treated starchy foods (Arisseto et al. 2007; Normandin et al. 2013). Variations between and within food categories can be explained by processing conditions, differences in the food composition and/or the ingredients used (Lasekan and Abbas 2011; Przygodzka et al. 2015).

The highest concentrations of acrylamide occurred in the potato group, evidencing contents above 1000 μg kg^{-1} in homemade and commercial potato chips (Figure 1). These values were similar to those detected in the same food group in other countries: Syria: 396–1844 μg kg^{-1}, Iran: 244–1688 μg kg^{-1}, Italy: 13–2267 μg kg^{-1} and Poland: 113-3647 μg kg^{-1} (Boroushaki et al. 2010; Mojska et al. 2010; Alyousef et al. 2016; Branciari et al. 2020) and are in the maximum ranges reported by the FDA (FDA 2015). However, the acrylamide content of Chilean starchy foods was considerably higher than the limits established by the European Union in regulation 2017/2158 (Figure 2). Chilean potato chips presented the highest content of acrylamide (1909 μg kg^{-1}) being approximately three times higher than the limit established by the European Union (Figure 2). Similarly, homemade potato chips, homemade popcorn, and packaged popcorn presented acrylamide contents (Figure 1) which exceeded twice the European Union limits.

On the other hand, regarding starchy foods with lower acrylamide contents such as bread (Figure 1), it important to mention that due to their large intakes (Table 3), these food matrixes should also be considered of interest for acrylamide mitigation. In this sense, Chilean bread contained similar acrylamide amounts compared to those previously reported for hallulla bread (Pedreschi et al. 2018) and Italian products (100 μg kg^{-1}) (Branciari et al. 2020), but lower than those reported for Belgian breads (154 μg kg^{-1}) (Claeys et al. 2016). Probably not only the fermentation process of bread, but also the fibre content of wheat flour was responsible for the observed results (Katsaiti and Granby 2016). Both Chilean and Italian breads are made using long fermentation periods, in which the level of acrylamide precursors is decreased, disadvantaging acrylamide formation (Katsaiti and Granby 2016). Regarding Belgium bread, the flour used for this preparation contains a higher percentage of fibre, which would increase the acrylamide formation (Katsaiti and Granby 2016).

Due to its toxicological characteristics, since 2011, acrylamide is defined as an ALARA compound, that is, it is recommended that its presence in food should be as low as reasonably or technically possible. Although in Chile, there is no regulation regarding the maximum acrylamide content limits to be met by different foods, our results would indicate the critical need to develop

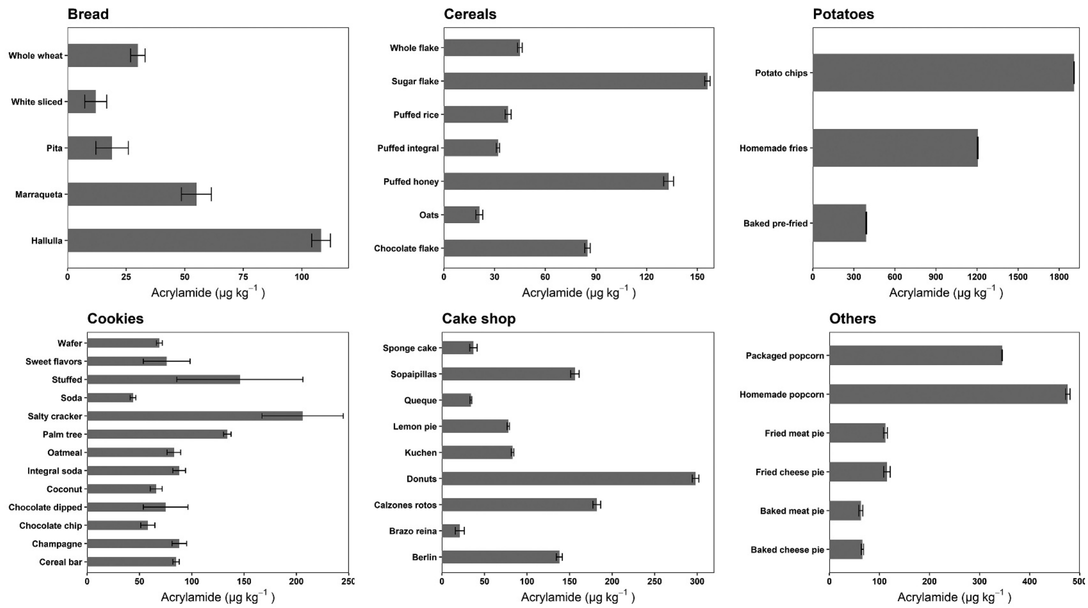

Figure 1. Acrylamide content of starchy foods highly consumed in the metropolitan region of Santiago, Chile.

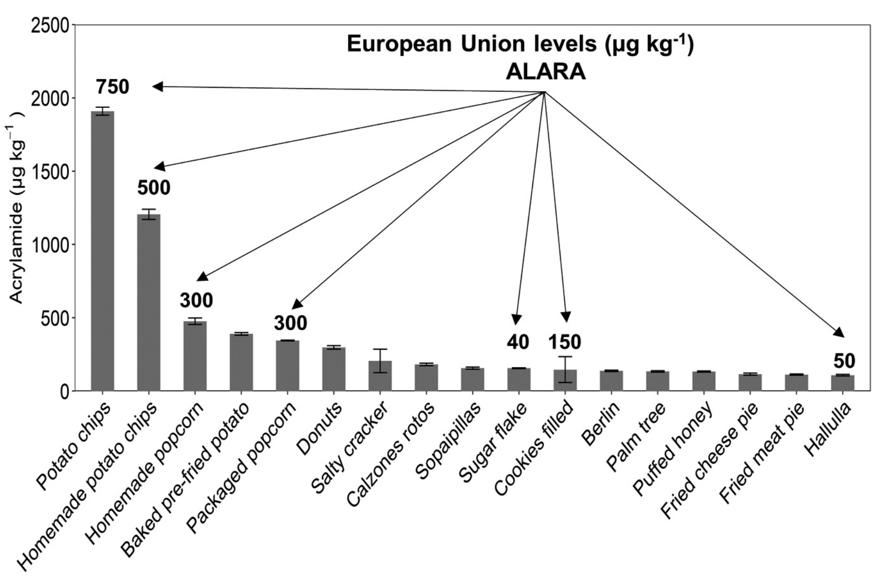

Figure 2. Chilean starchy foods with critical levels of acrylamide.

scalable acrylamide mitigation strategies. In addition, it is important to communicate to the Chilean population the appropriate information that allows them to make a correct selection of the foods in their daily diet.

Exposure assessment of dietary acrylamide in Chile

In Chile, neither the average dietary acrylamide intake nor the food categories that most contribute to it have been reported yet. Thus, this is the first research that characterises the dietary acrylamide exposure in Chile.

The EDI of acrylamide in the metropolitan region of Santiago, Chile, was 0.98 µg kg_{bw}^{-1} day^{-1} and 2.89 kg_{bw}^{-1} day^{-1} for the mean and the 95th percentile of population, respectively. Although the Chilean acrylamide mean intake is within the ranges (0.2–1.0 µg kg_{bw}^{-1} day^{-1}) reported by JECFA (2011) for the general population, it is relatively higher compared to other countries such as Poland (0.21–0.45 µg kg_{bw}^{-1} day^{-1})

(Cieślik et al. 2020). Moreover, the dietary exposure for the 95th percentile of Chilean population significantly exceeded the JECFA values (0.6–1.8 μg kg_{bw}^{-1} day^{-1}). Compared to EFSA (2015), the mean exposure in the present investigation was greater than the reported range of 0.4–0.9 μg kg_{bw}^{-1} day^{-}, as well as for the 95th percentile (0.6–2.0 μg kg_{bw}^{-1} day^{-1}), for adolescents, adults, elderly and very elderly. This indicates that dietary acrylamide in Chile should be considered a safety issue of concern

The main contributors to dietary acrylamide exposure in Chile were the potato and bread groups, representing approximately 77% of the total acrylamide intake. The EDI of acrylamide was calculated as the product between the daily food consumption and its acrylamide content. Therefore, although potato group was not the most consumed (Table 3), its acrylamide content was the highest (Figure 1). Conversely, the bread group despite its lower acrylamide concentration (Figure 1) presented the highest consumption (Table 3), becoming the second food group in terms of contribution to the total intake of the contaminant.

Potato chips and bread have also been identified as major dietary sources of acrylamide in studies conducted in other countries such as Canada (Normandin et al. 2013), United Kingdom (Burley et al. 2010) and Italy (Branciari et al. 2020), which supports further development of mitigation technologies for these food matrices.

On the other hand, the acrylamide EDI of Chilean men was 33% and 13% higher than the EDI of women for the mean and 95th percentile of population, respectively (Table 5). Although the observed ratio between the acrylamide mean intake of Chilean men and women was very close to that reported for the Danish population (Jakobsen et al. 2016), the Chilean acrylamide EDIs of men and women were considerably higher than the Danish ones (men: 0.36 μg kg_{bw}^{-1} day^{-1} and women: 0.27 μg kg_{bw}^{-1} day^{-1}). Similarly, different European countries have reported a lower acrylamide intake for women, for example, the Netherlands (Hogervorst et al. 2019), Japan (Kotemori et al. 2018), United Kingdom (Burley et al. 2010) and Switzerland (Wilson et al. 2010) with EDIs of 0.32 μg kg_{bw}^{-1} day^{-1}, 0.14 μg kg_{bw}^{-1} day^{-1}, 0.23 μg kg_{bw}^{-1} day^{-1} and 0.42 μg kg_{bw}^{-1} day^{-1}, respectively. These heterogeneous results can be attributed to differences in the questionnaires applied, different food consumption patterns and differences in the acrylamide content of foods (Mariotti et al. 2013).

Regarding the distribution of acrylamide intake by age group (Table 5), the segment aged between 12 and 17 years old presented the highest EDI, with a mean and a 95th percentile of 1.27 and 3.90 μg kg_{bw}^{-1} day^{-1}, respectively. This age group consumed 45% and 70% more acrylamide than Chileans aged between 45-65 and >65 years old, respectively. Elderly people aged >65 years old presented the lowest acrylamide EDI (mean 0.39 μg kg_{bw}^{-1} day^{-1} and 95th percentile 1.05 μg kg_{bw}^{-1} day^{-1}) in the metropolitan region of Santiago, Chile.

These results could be attributed to different causes. First, Chileans aged between 12 and 17 years old presented the highest consumption of potato chips, the food with the highest acrylamide concentration. Second, as the population gets older, their food intake per kg body weight decreases, reducing their acrylamide EDI (Branciari et al. 2020). Interestingly, when the furan exposure of Chilean population was estimated, it presented a similar behaviour when the effect of age on the contaminant exposure was evaluated (Mariotti et al. 2013).

On the other hand, the acrylamide mean intake was considerably lower in the higher socioeconomic levels (Table 5), compared to low (30%) and very low (50%) socioeconomic levels. In this sense, the low and very low socioeconomic levels presented the highest acrylamide mean exposure (1.19 and 1.16 μg kg_{bw}^{-1} day^{-1}, respectively), with 95th percentile exposure of 3.11 and 3.40 μg kg_{bw}^{-1} day^{-1}, respectively. This is related to their higher consumption of starchy foods (ENCA 2010).

Additionally, an associative analysis of gender in the different age groups and socioeconomic levels was carried out. In all age groups there is a difference between genders, but the difference is larger in the older population. The mean acrylamide intake in men aged between 45–64 and >65 years old was higher than in the women of the same age groups in approximately 35% and 44%, respectively (Table 5). Regarding the effect of socioeconomic circumstances, only differences in the medium-high and high socioeconomic levels were observed in the

Table 5. Exposure assessment of dietary acrylamide in the metropolitan region of Santiago, Chile.

		Mean exposure (μg kg_{bw}^{-1} day^{-1})	High exposure 95th percentile (μg kg_{bw}^{-1} day^{-1})	MOE peripheral neuropathy		MOE neoplastic effects	
				Mean	95th percentile	Mean	95th percentile
General average		0.98	2.89	436.96	148.79	172.75	58.82
Gender	Males	1.11	2.95	387.39	145.76	151.50	57.63
	Females	0.74	2.54	581.08	169.29	229.73	66.93
Age group	12–17 years	1.27	3.90	337.48	110.26	133.42	43.59
	18–44 years	1.04	2.86	414.74	150.35	163.97	59.44
	45–64 years	0.71	2.05	602.18	209.76	238.07	82.92
	>65 years	0.39	1.05	1099.77	409.52	434.79	161.90
Socioeconomic level	Very low	1.19	3.11	361.84	138.26	143.05	54.66
	Low	1.16	3.40	370.32	126.47	146.41	50.00
	Medium low	0.96	2.47	448.89	174.09	177.47	68.82
	Medium high	0.72	2.07	596.19	207.73	235.70	82.13
	High	0.79	2.02	544.13	212.87	215.12	84.16
	Very high	0.58	1.40	738.03	307.14	291.78	121.43
Age group by gender							
Males	12–17 years	1.39	4.38	309.12	98.17	122.21	38.81
	18–44 years	1.14	3.08	377.08	139.61	149.08	55.19
	45–64 years	0.85	2.45	506.60	175.51	200.29	69.39
	>65 years	0.57	1.82	756.71	236.26	299.16	93.41
Females	12–17 years	1.16	3.39	369.56	126.84	146.11	50.15
	18–44 years	0.92	2.29	469.26	187.77	185.52	74.24
	45–64 years	0.56	1.66	761.31	259.03	300.98	102.41
	>65 years	0.32	0.72	1333.92	597.22	527.36	236.11
Socioeconomic level by gender							
Males	Very low	1.22	2.80	353.82	153.57	139.88	60.71
	Low	1.32	3.45	326.41	124.64	129.04	49.28
	Medium low	1.06	2.64	404.85	162.88	160.06	64.39
	Medium high	0.88	2.26	489.32	190.26	193.45	75.22
	High	0.98	2.38	439.7	180.67	173.83	71.43
	Very high	0.65	1.73	656.95	248.55	259.73	98.27
Females	Very low	1.22	3.31	351.1	129.91	138.81	51.36
	Low	1.00	3.00	431.62	143.33	170.64	56.67
	Medium low	0.82	2.05	527.3	209.76	208.47	82.93
	Medium high	0.59	1.62	729.23	265.43	288.3	104.94
	High	0.62	1.69	690.82	254.43	273.11	100.59
	Very high	0.51	1.07	850.70	401.87	336.32	158.88

The weights specified in Table 1 were used for the calculations.
$BMDL_{10}$ = 0.43 mg kg_{bw}^{-1} day^{-1} for peripheral neuropathy (EFSA 2015).
$BMDL_{10}$ = 0.17 mg kg_{bw}^{-1} day^{-1} neoplastic effects (EFSA 2015).

mean exposure. Men consumed 32% and 36% more acrylamide than women, respectively. It should be noted that men from the very low socioeconomic level and women from the low socioeconomic level presented the highest intake mean of acrylamide in the metropolitan region of Santiago, Chile, reaching acrylamide EDIs of 1.32 μg kg_{bw}^{-1} $day^{-1}$and 1.22 μg kg_{bw}^{-1} day^{-1}, respectively. Additionally, men presented higher 95th percentile values than women, between 1.73 and 3.45 μg $kg_{bw}^{-1}day^{-1}$, indicating a higher exposure in men due to the consumption of carbohydrate-rich foods.

Complementary to acrylamide EDI, the MOEs of each age group and socioeconomic levels to different pathologies were calculated, to determine if the presence of acrylamide in starchy Chilean foods is a public health problem. The MOE to peripheral neuropathy and neoplastic effects calculated for the Chilean population in the metropolitan region of Santiago was between 133.4 and 1099.8 for mean exposure and 50.2 to 597.2 for the 95th percentile (Table 5). The group >65 years old and the very high socioeconomic level presented the highest MOEs values (mean exposure: 1099.8 and 738.0, respectively; 95th percentile 409.5 and 307.1, respectively). When gender segmentation was applied, women who belonged to the age group over 65 years old and very high socioeconomic level presented the highest MOEs (1333.9 and 850.7 for mean intake; 597.2 and 401.9 for 95th percentile intake).

The MOEs for dietary acrylamide determined in this study were in or around the range 45-310, reported by JECFA (2011) as of concern. Moreover, considering the criteria of EFSA, the exposure to dietary acrylamide in Chile should be consider a public health problem. Therefore, the development of scalable acrylamide mitigation strategies for Chilean starchy foods should be considered mandatory safety task not only for the scientific community but also for the Chilean food industry and Chilean health authorities.

Finally, considering that Santiago represents more than 50% of the Chilean population, the results reported in the present study can be applied to all of Chile. It is also important to highlight that dietary patterns are quite similar throughout the country, with carbohydrate-rich foods being the most consumed in all regions, in all age groups and genders.

Conclusions

The results presented in this work provide original data on the presence of acrylamide in foods purchased and consumed in Chile. Estimates of dietary acrylamide exposure in different age groups revealed that Chile's young population is exposed to the highest level of acrylamide.

For all age groups studied, starchy foods with low moisture content, such as potato chips and bread, were the main source of acrylamide in the diet. In addition, considering the MOE values obtained for all age ranges and for different socioeconomic levels, dietary exposures to acrylamide in Chile can be considered a potential public health problem. This situation makes clear the need to transfer the available information on acrylamide mitigation technologies to the Chilean food industry.

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Declaration of competing interest

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.

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