Acrylamide in commercial potato crisps from Spanish market: Trends from 2004 to 2014 and assessment of the dietary exposure

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ABSTRACT

This research updates the acrylamide content of commercial potato crisps marketed in Spain with the aim to evaluate its trend since 2004. Two different batches of 40 potato crisps brands from 18 producers were analysed. Acrylamide content ranged from 108 to 2180 µg/kg, with an average value of 630 µg/kg and a median of 556 µg/kg. Data revealed a continuous decreased trend from 2004 to 2014. In 2014, potato crisps showed an average acrylamide content 14.6% lower than the previous report in 2009 and 57.6% lower than the first report in 2004. These data confirm the overall effectiveness in the mitigation strategies implemented by the Spanish industrial sector, although variations up to 80% were observed between a number of brands. However, 17.5% of the samples registered values higher than the indicative value recommended by European Commission for potato crisps. The dietary exposure of the Spanish population to this contaminant through potato crisps intake was estimated to be 0.035 µg/kg body weight/day. Although exposure has decreased over the last ten years, it is necessary to continue efforts to reduce acrylamide content in potato crisps since there is still margin for it.

KEYWORDS: Potato crisps, acrylamide, dietary intake, exposure, trend.

INTRODUCTION

Acrylamide is a process contaminant generated in several foods during cooking as a consequence of the Maillard reaction, derived from the reaction between the free amino acid asparagine with reducing sugars or other carbonyl compounds (Mottram and Wedzicha, 2002). This chemical reaction mainly occurs when foods are subjected to high temperatures as during frying, roasting or baking (Tareke et al., 2002), and in low moisture conditions (Stadler et al., 2004). According to the European Food Safety Agency (EFSA), processed potatoes together with coffee and cereal based food (cookies, crackers, breakfast cereals and toasted bread) are the main sources of exposure to acrylamide in the diet (EFSA, 2014). Due to the natural presence of large concentration of acrylamide precursors in the potato, when this product is subjected to high temperatures, as during frying, acrylamide is generated (Williams, 2005). Levels of this contaminant by up to 3000 or even more than 4000 µg/kg have been detected in potato chips and crisps (Becalski et al., 2010; Friedman, 2003; Hilbig et al., 2004; Shamlal and Nisha, 2014).

It is known that dietary habits have changed over the last few years, increasing the consumption of processed foods and decreasing this of natural foods (Delgado-Andrade, 2014). Such dietary changes are particularly evident in younger generations whose habits are associated with high levels of snacking and fast food consumption which contributes to high levels of acrylamide intake (Delgado-Andrade et al., 2012; Gilbert and Khokhar, 2008). Among snacks foods, potato chips are one of the most popular foodstuffs and large quantities are consumed worldwide, especially by young people (Ouhtit et al., 2014; Wyka et al., 2015). According to Katz et al. (2012) French fries and potato chips may contribute 56% of the total acrylamide intake in the Western diet of the adolescents. Due to this fact, recent researches have been focused on different aspects affecting acrylamide formation in fried potato products and possible mitigation strategies, which could be summarized in two approaches: (1) to control acrylamide precursors in the fresh product

and, (2) to control the thermal treatment conditions applied during processing (Medeiros Vinci et al., 2012). Authorities and producers have invested great efforts in mitigating acrylamide formation and reducing acrylamide concentration in processed potatoes (Biedermann et al., 2010). In this respect, reductions in the acrylamide content in potato chips/crisps as compared with previous results have been reported by several authors (Arribas-Lorenzo and Morales, 2009; Biedermann et al., 2010; Cressey et al., 2012).

The aim of the present investigation was to determine the acrylamide content of commercial potato crisps marketed in Spain as a major source of acrylamide in the diet. Results were compared with data previously reported by our research group since 2004, in order to evaluate the trend in the acrylamide content in Spanish potato crisps over the last years and the effectiveness of the mitigation strategies. Finally, an assessment of the dietary exposure of the Spanish population to this contaminant through potato crisps intake was conducted.

MATERIALS AND METHODS

Chemicals and materials

Acrylamide standard (99%), potassium ferrocyanide (Carrez I), and zinc acetate (Carrez-II) and methanol (HPLC grade) were purchased from Sigma-Aldrich (St. Louis, MO, USA). [$^{13}\text{C}_3$]-acrylamide (isotopic purity 99%) was from Cambridge Isotope Labs (Andover, MA, USA). Acetic acid was from Merck (Darmstadt, Germany) and hexane from Panreac (Madrid, Spain). Milli-Q water used was produced using an Elix3 Millipore water purification system coupled to a Milli-Q module (model Advantage10) (Millipore, Molsheim, France). All other chemicals, solvents and reagents were of analytical grade. Reversed-phase Oasis-HLB cartridges (30 mg, 1 mL) were from Waters (Milford, MA, USA). Syringe filter units (0.45 μm , cellulose) were purchased from Análisis Vínicos (Tomelloso, Ciudad Real, Spain).

Samples

Two different batches from 40 brands of commercial potato crisps from 18 producers were purchased in different Spanish supermarkets in September 2014. Samples containing different flavourings and/or added spices were excluded for the sampling. Initially, ten slices of potato crisps samples were randomly selected from each container and weighed in order to calculate the mean weight of one slice of potato crisp. After that, samples (200–500 g, according to the size of the bag) were mixed and grounded to assure a homogeneous distribution of potential hotspots. A portion (100–200 g) was distributed in two containers and stored under vacuum and light protected at 4 °C until analysis. Eighty different samples were therefore individually analysed by duplicate.

Colour determination

Colour parameters were expressed according to CIE $L^*a^*b^*$ scale (CIE Colorimetry Committee, 1974; McLaren and Riggs, 1976). The measurements were made using a HunterLab Spectrophotometer CM-3500D colorimeter (Hunter Associates laboratory, Stamford, Connecticut, USA). Three independent measurements of a^* (redness), b^* (yellowness) and L^* (lightness) parameters were carried out on different areas of the grounded potato crisps. E index, C index and Y index were calculated according to the following equations: $E = (L^2 + a^2 + b^2)^{1/2}$; $C = (a^2 + b^2)^{1/2}$; $Y = 142.86^{b/L}$, which allows evaluating the colour changes in the potato samples (Giangiacomo and Messina, 1988).

LC-ESI-MS-MS determination of acrylamide

Sample extraction and clean up were based on the method described by Morales et al. (2007) with some modifications. Grounded sample (0.500 g) was weighed and mixed with 9.4 mL of water in polypropylene centrifugal tubes. Two mL of hexane were added in the tubes in order to remove the fat content of the potato crisps. Mixture was spiked with 100 μ L of a 5 μ g/mL [$^{13}\text{C}_3$]-acrylamide methanolic solution as internal standard and later homogenized (Ultra Turrax, IKA, Mod-T10 basic, Germany) for 10 min. Afterwards, sample was treated with 250 μ L of each Carrez I (15 g potassium ferrocyanide/100 mL water) and Carrez II (30 g zinc acetate/100 mL water) solutions and centrifuged (9000 g for 10 min) at 4 °C. Hexane was removed and samples were cleaned up by using of Oasis-HLB cartridges. Cartridges were preconditioned with 1 mL methanol and 1 mL water. An aliquot of the clear supernatant (1 mL) was loaded onto the cartridge at a flow rate of 2 mL/min and first drops were discharged and the rest collected. Solution was filtered through a 0.45 μ m filter into an amberlite LC-MS vial.

Sample extracts and calibration standards were analysed on an Agilent 1200 liquid chromatograph coupled to an Agilent Triple Quadrupole MS detector (Agilent Technologies, Palo Alto, CA, USA). Analytical separation was achieved with an Inertsil ODS-3 column (250 $\times$ 4.6 mm, 5 μ m; GL Sciences Inc., Tokyo, Japan) at 30 °C. Isocratic elution was achieved with a mobile phase of formic acid in water (0.2 mL/100 mL) at a flow rate of 0.4 mL/min. The injection volume was 10 μ L. Electrospray ionization in the positive ionization mode was used. Under these chromatographic conditions, acrylamide eluted at 6.1 min. The needle was set at 1.0 kV. Nitrogen was used as nebulizer gas (12.0 L/min) and the source temperature was set at 350 °C. Signals at m/z 72.1 – m/z 55.1 and m/z 75.1 – m/z 58.1 were isolated for acrylamide and [$^{13}\text{C}_3$]-acrylamide, respectively. For the transitions m/z 72.1 > m/z 55.1 and m/z 75.1 > m/z 58.1 the fragmentation was set at 76 V and the collision energy at 8 V. Masses were recorded using multiple reactions monitoring (MRM). For quantitation the signals at m/z 75.1 and 78.1 were used, while signals at m/z 58.1 and 55.1 served for qualification.

Acrylamide was quantified with standard solutions (5–100 μ g/L) spiked with 50 μ g/L [$^{13}\text{C}_3$]-acrylamide. The peak identity is confirmed by comparison of the peak area ratios for the transitions m/z 72 > 55 and 75 > 58 from sample extracts and standard solutions, respectively. The limit of the quantitation was set at 20 μ g/kg. The accuracy of the results was recently demonstrated for potato crisps in an interlaboratory comparison study launched by the Food Analysis Performance Assessment Scheme (FAPAS) program (2013), yielding a z-score of 0.3. Precision (reproducibility) was lower than 10% and recovery between 84 and 109%. Analysis was performed in duplicate and results were expressed as μ g/kg of product.

Statistical analysis

Statistical analyses were performed using Statgraphics Centurion XV (Herndon, VA, USA). Data were expressed as mean $\pm$ standard deviation (SD). Analysis of variance (ANOVA) and Student's t test were applied to determine significant differences between means. Differences were considered to be significant at $p < 0.05$. Relationships between the different parameters analysed were evaluated by computing Pearson linear correlation coefficients at the $p < 0.05$ confidence level.

RESULTS AND DISCUSSION

Acrylamide content in potato crisps

In the present study, two different batches from 40 classical potato crisps brands, without flavour or species added, from 18 different Spanish producers were analysed for the determination of acrylamide content ($n = 80$). Acrylamide content ranged from 108 to 2180 μ g/kg, with an average value of 630 μ g/kg and a median of 556 μ g/kg

(Table 1). These results are in concordance with those reported by other authors, who found data ranging from 591 to 1999 $\mu\text{g/kg}$ (Arisseto et al., 2009), 430–1100 $\mu\text{g/kg}$ (Wong et al., 2014) or 244–1688 $\mu\text{g/kg}$ (Boroushaki et al., 2010), being lower than other values described in potato chips from Indian (82.0–4245.5 $\mu\text{g/kg}$, Shamla and Nisha, 2014) or Canadian market (106–4630 $\mu\text{g/kg}$, Becalski et al., 2010). Similarly, both mean and median are close to the values published by EFSA in 2010 for the category of potato crisps from fresh potatoes (mean: 758 $\mu\text{g/kg}$; median: 543 $\mu\text{g/kg}$), and the highest content observed in our dataset was lower than that reported by EFSA (4533 $\mu\text{g/kg}$) (EFSA, 2011).

The acrylamide distribution in the forty brands from potato crisps marketed in Spain is shown in Fig. 1, where each value represents the mean $\pm$ standard deviation from the two different batches analysed for the same brand. All the crisps contained acrylamide levels higher than the limit of quantification (LOQ = 20 $\mu\text{g/kg}$). The identification of two outliers in the distribution is noticeable. Data distribution showed high variability in the acrylamide content among samples, which is likely the result of the unsatisfactory raw material used and/or processing conditions applied. It is not the aim of this investigation to describe the mitigation strategies applied for potato products and exhaustively reviewed somewhere (Medeiros Vinci et al., 2012).

The application of signal values (P90, percentile 90) is useful for companies to monitor the success during application of the mitigation strategies, if any. This concept can be applied to the whole dataset. Three levels can be defined: acceptable (samples below the P50), under evaluation (samples between P50 and P90) and unacceptable (samples above P90). P90 is identified as the signal value of the dataset and points out the reference value from which actions might be taken to lower the acrylamide levels in these products. In our investigation, 10% of the samples overcome the signal value (1169 $\mu\text{g/kg}$), as depicted in Fig. 1.

Another reference used for quality control is considering the indicative values recommended by the European Commission (EC). EC has recently adopted new indicative acrylamide values based on the EFSA monitoring data from 2007 to 2012 for the main sources of acrylamide exposure. These recommendations involve reference values for acrylamide content in the major contributors to the intake of this compound. In cases where the level of acrylamide in a foodstuff exceeds the acrylamide indicative value set for the respective food category according to the recommendation, investigations into the production and processing methods used by food producers must be carried out. Thereby, risk associated with the acrylamide intake can be regulated and, consequently, controlled. Indicative acrylamide value for potato chips according to the latest EC Recommendation of 8 November 2013 (2013/647/EU) is reported to be 1000 $\mu\text{g/kg}$ (EC, 2013). In the present study seven of the brands analysed exceed this indicative value, which means that additional efforts should be implemented by these companies in order to decrease acrylamide levels in their samples.

Additional information about the samples was taken into account to establish the possible relationship with the acrylamide content. In this respect, samples were classified according to (1) the presence or absence of oil drops on the container layer after visual inspection (oily, medium oily, not oily), (2) type of frying oil based on the information provided by the manufacturer (sunflower oil, olive oil and other or undefined oil), (3) light protection of the container (light-, partly light- or not light-protected) and (4) packaging under protective atmosphere (with or without protective atmosphere), as described in Table 1. In addition, price (EUR/100 g) of the potato samples was also considered as variable.

Statistically significant differences ($p < 0.05$) were observed with respect to the presence of oil drops on the container, where higher oil drops observed by consumer, higher acrylamide level. Type of frying oil used and protective packaging, however, were not directly related with the acrylamide content in the potato crisps. The price of the container ranged from 0.33 to 1.40 EUR/100 g (mean: 0.75 ± 0.27 EUR/100 g). Only one of the batches from one of the 40 brands analysed showed a discordant result if price and acrylamide are correlated. Surprisingly, a significant negative correlation between both parameters was observed ($p = 0.0198$, $r^2 = -0.2617$), which involved more expensive samples associated with lower levels of the process contaminant. This observation probably could be associated with the fact that the largest companies, whose products may be more expensive, applied more effectively the mitigation strategies than did the smaller companies. In that sense, the cost for the implementation of the mitigation strategies is reflected in the price for consumers.

Regarding colour parameters, means of *E* index, *C* index and *Y* index were calculated to be 68.14 ± 2.11 , 26.72 ± 1.84 and 0.75 ± 0.27 , respectively. Colour of the samples was also related with the acrylamide content. Thereby, acrylamide concentrations were positively correlated with *Y* index ($p = 0.0036$, $r^2 = 0.3260$) and negatively correlated with *E* index ($p = 0.0016$, $r^2 = -0.3468$), which would be expected due to more severe frying treatment, and the formation of brown pigments in the advance of the Maillard reaction would involve loss of lightness and progress of the colour in the red zone (Pedreschi et al., 2006). However, it is important to highlight that colour parameters are not expressed as increment since the original potato tuber was not available.

A relevant aspect to be considered is the difference observed between the batches for the same brand of potato crisps. Two different batches from each commercial brand were analysed. In case the differences between batches were higher than 20%, analyses were repeated to confirm the results. Figure 2 shows the distribution in number of cases of percentage of the variation found between acrylamide content of the two different batches for the same commercial brand. The variability among batches, expressed as coefficient of variation (CV), ranged from 1.5% to 83.8%. Most of the samples reported differences among batches lower than 20%. However it must be emphasized that 40% of the samples presented variations higher than 20%, highlighting eight samples displaying variations among batches in the range of 50–80% and another one with batches presenting differences even higher than 80%. Similar observations have been reported by Cressey et al. (2012) in potato chips from New Zealand, where some brands were extremely consistent across batches while concentrations for acrylamide detected in other brands varied considerably (range 371–1460 $\mu\text{g/kg}$). The results indicate that the products vary considerably in the amount of acrylamide due to differences in the potato tuber and processing/manufacturing conditions during the industrial process.

Figure 3 shows the mean and standard deviation of the acrylamide concentration for the 18 producers in the potato crisps analysed in the current study. Even though different number of brands were analysed per producer, it is interesting to mark that the acrylamide content of some potato crisp producers were notably more variable than others. Acrylamide concentrations varied not only from brands to brands, but also within some producers. For instance, producers 1 and 6, both providing 2 batches $\times$ 7 different brands, exhibited totally different results; while results for acrylamide content in potato crisps from producer 6 ranged from 145 to 1332 $\mu\text{g/kg}$, values for samples from producer 1 were very close (range: 145–432 $\mu\text{g/kg}$), involving low variability in the levels of acrylamide among both batches and brands. In agreement with Cressey et al. (2012), the small deviations observed for some brands support the statement that it is possible for a crisp manufacturer to produce a consistent product with respect to acrylamide content.

Trends in acrylamide levels

Successful mitigation achievements of acrylamide levels in potato crisps and chips have been reported by several authors in some countries during the last few years. Biedermann et al. (2010) explored the acrylamide content in potato chips from Switzerland and observed that levels of the contaminant, evaluated from April 2007 to December 2009, were diminished from 6900 µg/kg to 420 µg/kg over the years. In studies carried out in New Zealand the range of acrylamide concentration in potato crisps decreased from 370–2320 µg/kg in 2006 (Love and Grounds, 2006) to 112–1460 µg/kg in 2012 (Cressey et al., 2012), possibly due to the application of mitigation measures by potato chips industries. In a similar way, average acrylamide levels in German potato crisps produced from stored potatoes decreased from the range of 800–1000 µg/kg in 2002–2003 to 400–600 µg/kg in 2004–2009 (WHO, 2011). Recently Powers et al. (2013) evaluated the acrylamide concentrations in potato crisps in Europe from 2002 to 2011, observing a decrease in the levels of the contaminant from 763 µg/kg in 2002 to 358 µg/kg in 2011. Overall the study demonstrated the effectiveness of the approaches taken by potato crisp manufactures to reduce acrylamide levels in their products. On the contrary, this downward trend in acrylamide levels in potato crisps was not shown in data compiled by the EFSA (EFSA, 2012). In this report, mean acrylamide level of 570 µg/kg in 2007 was slightly increased to 758 µg/kg in 2010, suggesting, therefore, the limited evidence of active mitigation efforts.

In the present study levels of acrylamide in potato crisp marketed in Spain in 2014 were compared with data previously reported by our group research in 2004 (Rufián-Henares and Morales, 2006) and 2009 (Arribas-Lorenzo and Morales, 2009). In the 2004 sampling, potato crisps showed a mean and median of 1484 µg/kg and 1180 µg/kg, respectively (range: 211–5492 µg/kg). Nearly a 50% reduction was reached in the 2009 study, reporting a mean content of 740 µg/kg (range: 81–2622 µg/kg, median: 592 µg/kg). In the current study, levels of acrylamide were reduced again as compared with the previous sampling data. In 2014, mean acrylamide content was 14.6% lower than that from 2009 and 57.6% lower than that from 2004. Values for the first and third quartiles were, however, very close to those reported in 2009, all of them being diminished when compared with 2004 results. Even though minimum values detected were close in the three studies, maximum level was substantially reduced over the years, which minimizes the heterogeneity of the distribution (Fig. 4). Among the samples marketed in the present study, ten potato crisps brands were also analysed in the previous 2009 sampling. Seven of these ten samples showed lower acrylamide content in the current study compared with the previous results; the reduction was between 22% and 66%. The remaining three samples showed practically the same results than those reported in 2009. All these findings illustrate the effectiveness in the mitigation strategies carried out to diminish acrylamide levels in potato products.

Acrylamide exposure from potato crisps

Exposure assessment was estimated from the latest national consumption database available, containing data obtained from households, hotels, restaurants, and institutions (MAGRAMA, 2010). During 2010, the total consumption of processed potatoes was 65.78 million kg/year, which represents an overall estimation of annual consumption of 1.43 kg processed potato products per capita. Assuming an average body weight of 70 kg for adults, the average contribution of potato crisps to dietary acrylamide exposure in Spain was calculated to be 0.035 µg/kg BW/day. If minimum and maximum levels of acrylamide quantified in the potato crisps of this experiment are considered, the range of acrylamide exposure from these products would be 0.006–0.12 µg/kg BW/day. The mean value was similar to those reported in other studies on adults from Latvia (Pugajeva et al., 2014) or the UK (Mills et al., 2008), being higher than those from France (Sirost et al., 2012), Poland (Mojska et al., 2010) or Hong Kong (Wong et al., 2014). With regard to the previous study,

the annual consumption of processed potato products per capita in 2009 and 2014 are similar but due to the mean of acrylamide levels in potato crisps found to have been decreased, the dietary acrylamide exposure of Spanish consumers has been reduced (Arribas-Lorenzo and Morales, 2009). Table 2 describes the estimation of total dietary exposure to acrylamide and the contribution calculated for potato chips and crisps as reported in different studies. As can be observed the contribution of potato chips and crisps to the dietary acrylamide exposure ranges from 1 to 46%.

For dietetics purposes, we consider useful to provide adequate information to professionals in the nutrition area since these professionals use the concept of food portions. Then, the mean weight of one slice of potato crisp was calculated by weighing ten slices of potato crisps samples randomly selected from each container. This mean weight was estimated to be 1.5 g/slice, which would involve an average of acrylamide intake of 0.94 µg/slice (range: 0.16–3.27 µg/slice).

The risk assessment for acrylamide in potato crisp was conducted according to the harmonized approach of the EFSA (EFSA, 2005), which recommends the use of the margin of exposure (MOE) based on the benchmark dose (BMD) as standardised reference point of departures (Benford et al., 2010). Likewise MOE is calculated for the most sensitive carcinogenic effect of acrylamide by using the ratio of the reference point (BMDL10 when using data from experimental animals) and a conservative estimate of human exposure (JECFA, 2010). EFSA Scientific Committee on Contaminants in the Food Chain (CONTAM Panel) adopted that an MOE above 10,000 for a compound that is both genotoxic and carcinogenic is considered of low health concern (EFSA, 2005) and would not be a priority for risk management action (Barlow et al., 2006). The MOE calculated for acrylamide in food is low and this may indicate a human health concern (EFSA, 2005).

In this respect, an MOE value of 8857 was obtained when comparing mean acrylamide exposure with the established BMDL10 (310 µg/kg BW/day) for mammary tumours in female rats. Similarly, an MOE value of 5143 was obtained when comparing with the established BMDL10 (180 µg/kg BW/day) for Harderian gland tumours in male mice. Former MOE values are just restricted to the contribution of the consumption of potato crisp and are lower than the value of 10,000 categorized by EFSA as low concern from a public health point of view. It is worth commenting that the uncertainty should be always considered before any risk extrapolation since the confidence of the MOE estimation is very much dependent on the quality of the dose–response and exposure information. The dose–response data are derived from rodent bioassays where differences in species toxicokinetics may have an impact on extrapolation to human exposure (Bolger et al., 2010). These results are in line with data recently revised by EFSA (EFSA, 2014). Therefore it is necessary to continue efforts to reduce acrylamide content in potato crisps and, consequently, the dietary exposure to acrylamide.

CONCLUSIONS

The present research reports acrylamide content in commercial potato crisps marketed in Spain. Results were compared with data previously reported by our research group, in order to evaluate the trend in acrylamide content in Spanish potato crisps over the last ten years and, subsequently to assess the effectiveness of the mitigation strategies over time. Results revealed a decreased trend in acrylamide content from 2004 to 2014, which illustrates the effectiveness in the mitigation strategies carried out to diminish acrylamide levels in potato products. However, the high variability among batches for several brands is noticeable. The dietary exposure of the Spanish population to this contaminant through potato crisps intake was also estimated, and we conclude that although exposure has decreased over the last few years, it is

necessary to continue efforts to reduce acrylamide content in potato crisps since it is technically realistic. These data are useful for risk assessment purposes in the Spanish population.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

TRANSPARENCY DOCUMENT

The Transparency document associated with this article can be found in the online version.

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FIGURES AND TABLES

Table 1. Statistical analysis of the acrylamide content ($\mu\text{g/kg}$) of different potato crisps categories.

Category	Mean $\pm$ SD	Median	Minimum	Maximum	n
Total	630 $\pm$ 412	556	108	2180	80
Oily	705 $\pm$ 466 ^b	576	108	2180	42
Medium oily	677 $\pm$ 349 ^{a,b}	633	145	1204	20
Non-oily	402 $\pm$ 244 ^a	314	148	1000	18
Sunflower oil	670 $\pm$ 415	608	145	2180	46
Olive oil	543 $\pm$ 335	453	108	1332	22
Other or undefined oil	632 $\pm$ 528	497	148	1716	12
Light-protected	582 $\pm$ 444	424	145	2180	44
Semi-light-protected	718 $\pm$ 431	662	108	1716	24
Non-light-protected	627 $\pm$ 189	625	226	930	12
High protective atmosphere	713 $\pm$ 441	576	145	2180	32
Low protective atmosphere	574 $\pm$ 386	505	108	1716	48

Different letters in the same column mean significant differences in the same category ($p < 0.05$).

40 brands $\times$ 2 batches, n = 80.

Table 2. Contribution of potato chips/crisps to dietary acrylamide exposure in different studies.

Country	Total intake ($\mu\text{g/kg}$ BW/day)	Potato chips/crisps (%)	Partial contribution ($\mu\text{g/kg}$ BW/day)	Age (years)	Reference
Belgium	0.35	23 ¹ 8 ²	0.080 0.028	15s	Claeys et al. (2010)
Canada	0.58	10.34 ¹	0.06	10–17	Normandin et al. (2013)
Egypt	1.75	46 ¹	0.805	4–50	Saleh and El-Okazy (2007)
France	0.692	4 ^{1,2}	0.028	3–17	Sirof et al. (2012)
France	0.43	2.4 ^{1,2}	0.010	18–79	Sirof et al. (2012)
Hong Kong	0.213	3.35 ¹	0.007	20–84	Wong et al. (2014)
Latvia	0.26	16 ¹	0.042	19–64	Pugajeva et al. (2014)
Poland	0.75	17 ²	0.127	1–6	Mojska et al. (2010)
Poland	0.62	16 ²	0.099	7–18	Mojska et al. (2010)
Poland	0.33	1 ²	0.003	19–96	Mojska et al. (2010)
Poland	0.43	6 ²	0.026	1–96	Mojska et al. (2010)
UK	0.56	7.17 ¹	0.040	19–64	Mills et al. (2008)
USA	0.44	18 ¹	0.079	13–19	Katz et al. (2012)

¹ Potato chips.

² Potato crisps.

BW, Body weight.

Figure 1. Box-and-whisker plot and distribution graph for the acrylamide content in Spanish potato crisps.

Figure represents the distribution of acrylamide content in 40 different brands. Two different batches were analysed from each brand. Values are mean $\pm$ SD from the two different batches for the same brand. An empty bar represents samples declared as having a low fat content (<40%) by industrials. Dotted lines represent median and the observed signal value.

Figure 2. Percentage of the variation found between acrylamide content of two different batches for the same commercial brand of potato crisps. Data are distributed by number of cases (total n = 40).

Figure 3. Acrylamide concentrations in potato crisps samples from Spanish market grouped according to their producers.

Squares represent the mean acrylamide concentration for different batches and brands of potato crisps for the same producer, while the vertical lines represent variations of acrylamide concentration. Producers 12, 15, 17 and 18 included two batches for a single brand and a small standard deviation was observed.

Figure 4. Time trends of acrylamide content (µg/kg) in Spanish potato crisps sampled from 2004 to 2014.