Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food and Chemical Toxicology 43 (2005) 271–278
www.elsevier.com/locate/foodchemtox

Risk assessment of dietary acrylamide intake in Flemish adolescents

C. Matthys [a,*], M. Bilau [a], Y. Govaert [b], E. Moons [c], S. De Henauw [a,d], J.L. Willems [a]

[a] Department of Public Health, Ghent University, UZ-2 Blok A, De Pintelaan 185, B-9000 Ghent, Belgium
[b] Department of Pharmaco-Bromatology, Scientific Institute of Public Health, Brussels, Belgium
[c] Federal Agency for the Safety of the Food Chain, Brussels, Belgium
[d] Department of Health Sciences, Vesalius, Hogeschool Gent, Belgium

Received 18 May 2004; accepted 9 October 2004

Abstract

Acrylamide has recently been found in a range of heat treated food items. As it is a neurotoxic agent and a probable, human carcinogen (IARC 2A), human exposure to this chemical might constitute an important public health issue. The purpose of the study was to estimate the acrylamide intake in Flemish adolescents (based on 7-day food record) and to evaluate the possible health risks due to the exposure. The Belgian Federal Agency for the Safety of the Food Chain collected 150 food items from different supermarkets and restaurants to analyse the acrylamide level. The limit of quantitation was 30 μg acrylamide/kg foodstuffs. Exposure modelling was based on Monte Carlo simulations. The estimated dietary intake of acrylamide per person given as the 5th, 50th and 95th percentile were 0.19, 0.51 and 1.09 μg/kg bw/d. Bread, despite its low acrylamide content, is relevant as a source of acrylamide exposure at the lower percentiles. At higher percentiles the contribution of French fries and crisps is more important. It must be emphasised that the exposure assessment has several limitations. Risk of neurotoxicity seems negligible. The relevance of current intake levels in terms of cancer risk remains a subject of debate.

Keywords: Acrylamide; Dietary intake; Risk assessment; Exposure

1. Introduction

In April 2002, scientists in Sweden—quite unexpectedly—discovered large amounts of the chemical acrylamide ($CH_2 = CHCONH_2$) in foods rich in starch that have been heated at high temperatures (SNFA, 2002b). These included crisps, French fries, bread and crisp breads. Acrylamide may be formed through the Maillard reaction from amino acids and reducing sugars (Mottram et al., 2002; Stadler et al., 2002). Acrylamide has been shown to be neurotoxic in humans and laboratory animals (FAO/WHO, 2002; IARC, 1994). It has been classified as a Group 2A carcinogen by the International Agency for Research on Cancer (IARC, 1994). This might represent a potential threat to public health (European Commission, 2002a; FAO/WHO, 2002). In view of this, the FAO/WHO Expert Consultation urges more research on acrylamide in food. It includes formal research, surveillance/monitoring and industry investigations (FAO/WHO, 2002). Against that background a post-hoc

Abbreviations: IARC, International Agency for Research on Cancer; SNFA, Swedish National Food Administration; FAO/WHO, Food and Agriculture Organisation/World Health Organisation; LC–MS–MS, Liquid chromatography–mass spectrometry–mass spectrometry; US FDA, United States Food and Drug Administration; DI*i*, Daily Intake of subject *i*; NOAEL, no observed adverse effect level; AF, assessment factor; US-EPA, United States Environmental Protection Agency; NOEL, no observed effect level; RfD, reference dose; CSF, cancer slope factor; LMS, linearised multistage model; bw, body weight; USDA, United States Department of Agriculture; JIFSAN/NCFST, Joint Institute for Food Safety and Applied Nutrition/National Center for Food Safety and Technology

* Corresponding author. Tel.: +32 9240 3718; fax: +32 9240 4994.
E-mail address: christophe.matthys@ugent.be (C. Matthys).

0278-6915/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.fct.2004.10.003

analysis was made using an existing food consumption database.

The purpose of the current study was to estimate the acrylamide intake in a Belgian subpopulation, namely Flemish adolescents and to evaluate the possible health risks due to this exposure. In the present communication, a risk assessment of acrylamide intake is described and discussed.

2. Material and methods

2.1. Sampling and chemical analysis

In 2003, the Belgian Federal Agency for the Safety of the Food Chain collected 150 food items from different supermarkets and restaurants. The samples comprised baby's biscuits, bread, small bread type, crisps, chocolate, choco-spread, French fries, coffee, breakfast cereals, gingerbread, sweet spiced biscuit, biscuits and popcorn. The choice of food items was based on what was known end of 2002–early 2003 on the occurrence of acrylamide in foodstuffs (FAO/WHO, 2002; FOD VVVL, 2002; Norwegian Food Agency, 2002; SNFA, 2002a; van Donkersgoed et al., 2002), priority was given to food groups that, in those studies, had been shown to contain relevant amounts of acrylamide.

The acrylamide analysis was carried out by a Beltest accredited laboratory of the Department of Pharmaco-Bromatology of the Scientific Institute of Public Health in Brussels, by using a validated method according to the ISO 17025 standards. In the experimental procedure acrylamide is extracted from food with water before a clean-up of the extract on Solid Phase Extraction combining Oasis HLB and BondElut Accucat cartridges as described in the US FDA methodology (www.cfsan.fda.gov). A further concentration step by evaporation was introduced before analysis using the LC–MS–MS technique. The limits of the method are respectively 15 and 30 μg acrylamide/kg foodstuff for detection and quantitation. The acrylamide content of coffee was partially determined on the basis of coffee powder and was recalculated to coffee drink using a conversion factor of 0.046 proposed by Dooren et al. (1995). Also liquid coffee was analysed. For the intake estimation, levels of acrylamide below the limit of quantitation were set at one third of that limit (4 samples < limit of quantitation). No data were available on the acrylamide content of rusk, therefore the authors used Dutch contamination data with a reporting limit of 60 μg/kg (Konings et al., 2003). Other food groups, which were not analysed because they are not known to contain acrylamide, were supposed to contain no acrylamide at all.

Due to the restricted number of analyses a major assumption was made: acrylamide contents of analysed food items were also applied to a number of related food items for which no analytical data were available. Food items were considered related when a similar type of food technology was used to produce them, e.g., salty crisps and sweet and sour crisps. The type and amount of amino acid and reducing sugar of the related products were not considered. Although the acrylamide levels vary among product categories and within categories (Petersen, 2002; Svensson et al., 2003), we assumed that differences between food items of a certain food group would be small.

2.2. Exposure estimation

We started from a food intake survey carried out in Spring 1997, the most recent, detailed dietary survey available for Belgium (Matthys et al., 2003). That survey was based on a representative sample of 341 adolescents (129 boys and 212 girls), aged 13–18 years, from the region of Ghent (±250,000 inhabitants) in the Dutch-speaking part of Belgium. Different educational options—'classical' education (mainly theoretical courses) and vocational training (based on practical skills)—were proportionally represented in the sample. A 7-day estimated food record method (semi-structured diary) was used to quantify food and nutrient intake. Instructions for the completion of the diary and regular checks for quality and completeness of the diaries were carried out by experienced dieticians. The storage of data on intake of individual food items was very detailed and contained altogether 745 different food items. Although the adolescent survey was conducted in 1997, it was assumed that the current intake of relevant acrylamide containing foods has not substantially changed since 1997.

Weight of the respondents was measured according to the standardised method proposed by the WHO (World Health Organization, 1995). Data on measured weights were completed in the same period (within one week) as the food diary.

Dietary exposure distributions for acrylamide were generated in a probabilistic way for the total adolescent population and for boys and girls separately, using a so-called one-dimensional Monte Carlo simulation programme (see Fig. 1) (Cullen and Frey, 1999; Petersen, 2000).

In this approach, a distribution of food consumption from the target population and available distributions of acrylamide levels in the foods under consideration are being sampled repeatedly in a random way. During each sampling round across these databases, intake data from the subjects are being linked to contamination data, thereby generating series of theoretically occurring acrylamide intakes on individual level.

Mathematically, a subject's usual daily acrylamide intake is computed according to the equation:

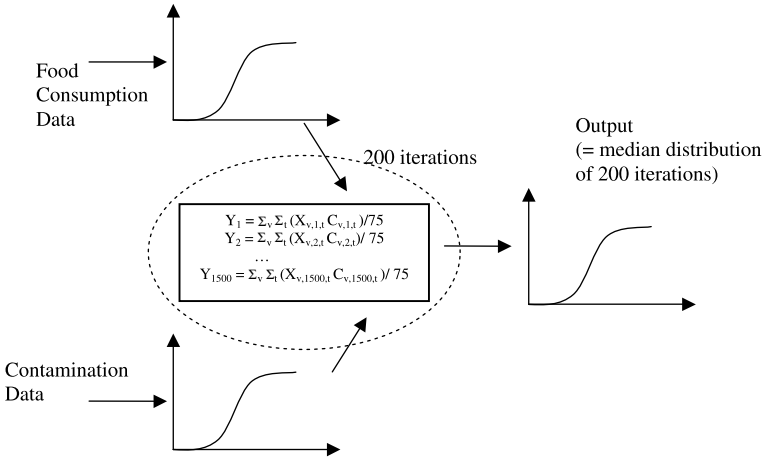

Fig. 1. Graphical presentation of the one-dimensional Monte Carlo simulation model used in the current paper.

$$Y_i = \sum_v \sum_t (X_{v,i,t} C_{v,i,t})/T$$

where $X_{v,i,t}$ is the amount (g) of relevant acrylamide containing food item v (see above), consumed by subject i, at day t ($t = 1, \ldots, T$) and $C_{v,i,t}$ is the concentration of acrylamide in a food item, expressed by μg/kg food stuff, randomly chosen.

For each subject i, the average body weight adjusted daily intake via food of acrylamide (DIi) is computed according to the equation: DIi = Yi/bw$i$, where Yi is the subject's average total daily intake of acrylamide and bw$i$ is body weight (kg).

Sampling rounds across databases are being repeated in the same way until saturation is reached, i.e., until further sampling does not add measurably to the available information.

For the purpose of optimising integration of respectively the intra-individual and inter-individual variability in food consumption in the overall exposure assessment model, the 7-day diary was extended to a fictive 75 day diary for all subjects (by simply copying the diary repeatedly until 75 days are reached) and the number of subjects was artificially extended to 1500 (by randomly copying subjects until the target number was reached).

The former procedure thereby increases the likelihood of combining all existing food combinations and portions in the diaries with all available contamination values for these foods. The latter procedure accounts predominantly for the uncertainty arising from a relatively small sample size.

Finally, the above described procedure has been repeated in 200 consecutive loops, yielding 200 theoretical distributions of acrylamide intake. The median distribution from these 200 obtained distributions is the one finally reported in this paper. All simulations presented were run using the Hexalog software (Aardex Ltd.).

2.3. Reference doses and cancer slope factors

A Joint FAO/WHO Consultation recognized neurotoxicity as the key non-cancer, non-genotoxic effect of acrylamide in humans (FAO/WHO, 2002). A No Observed Adverse Effect Level (NOAEL) for acrylamide-induced neuropathy was identified as 0.5 mg/kg body weight/day in a chronic rat experiment (Spencer and Schaumburg, 1974). Based on that life long experiment, an oral reference dose (RfD) of 5 μg/kg bw/d can be calculated—by dividing the NOAEL by an assessment factor (AF) of 10×10 for inter-species and intra-species extrapolation—following the conventional EU procedure to determine an acceptable daily intake for pesticides in food and in analogy with the US-EPA procedure given below. It can be assumed that an intake below this reference dose of 5 μg/kg bw/d will be without appreciable risk for neurotoxic health effects in man.

The US-EPA (1993), however, based its risk assessment on neurotoxic effects observed in subchronically exposed rats (Burek et al., 1980), where a No Observed Effect Level (NOEL) of 0.2 mg/kg bw/d was identified. Applying an AF of $10 \times 10 \times 10$ (for inter-species, intra-species, and subchronic to chronic extrapolation), they calculated an oral RfD of 0.2 μg/kg bw/d for this non-carcinogenic effect (US-EPA, 1993). This approach, therefore, identifies a significantly lower intake below which it is assumed that no appreciable neurotoxic effects will occur in man.

Acrylamide has been shown to be clastogenic and carcinogenic in the animal (Friedman, 2003). It is classified as a probable human carcinogen (IARC, 1994; US-EPA, 1993) or as a substance, which should be regarded as if carcinogenic to man (http://ecb.jrc.it/classification-labelling/) (European Commission, 2002b). Within the EU regulatory framework, no quantitative risk estimation is performed for that kind of substances and intake should remain as low as possible. Starting from life long

animal experimental data, however, the dose that would produce cancer in 25% of the animals exposed can be calculated and a linear extrapolation towards zero can be performed. This leads to an oral cancer slope factor (CSF) applicable to man of 1.6 $(mg/kg\,bw/d)^{-1}$ (Dybing and Sanner, 2003). This predicts that the number of extra cancers caused over a lifetime is equal to the daily acrylamide dose multiplied by 1.6 $(mg/kg\,bw/d)^{-1}$, e.g., a daily intake of 1 μg/kg body weight/day could produce 1.6 extra-cancers per 1000 men exposed. Applying a linearised multistage (LMS) model to the animal experimental data, the US-EPA (1993) derived an oral cancer slope factor (CSF) for man of 4.5 $(mg/kg\,bw/d)^{-1}$ (US-EPA, 1993). Similar estimations regarding intake via water, led to drinking water unit risks of 1.3 $(\mu g/l)^{-1}$ (US-EPA, 1993) or 5 $(\mu g/l)^{-1}$ (WHO, 1996).

3. Results

3.1. Intake estimation

In Table 1 the acrylamide levels (μg/kg) in various food groups are shown. The levels of acrylamide varied considerably between single food items within food groups. In Table 1 the food consumption of the food groups used in the intake calculations are shown.

Fig. 2 shows the cumulative distribution function of the total acrylamide. The exposure to acrylamide via food in the total Flemish adolescent group ranges from 0.19 μg/kg bw/d at the 5th percentile, over 0.51 μg/kg bw/d at the 50th percentile, to 1.09 μg/kg bw/d at the 95th percentile. For boys the range varies from 0.23 (P5) over 0.64 (P50) to 1.26 (P95) μg/kg bw/d, and for girls from 0.17 (P5) over 0.46 (P50) to 0.94 (P95) μg/kg bw/d. Fig. 2 also shows the distribution of the intake via different food groups. The percentile distribution for each food group is estimated independently. Therefore, the total intake at a certain percentile is different from the sum of the different food items at that percentile.

The separate analysis for each food group or food item separately, indicates that bread is the most important contributor of background acrylamide-intake for the lower percentiles (up to the 21st percentile). From the 21st percentile French fries are the main source of acrylamide exposure. From the 55th percentile on, biscuits are the second important source of acrylamide intake. For the subgroups with higher intakes, above the 93rd percentile, French fries, crisps, biscuits, breakfast cereals and coffee (in order of importance) become the more important sources of acrylamide. Other food items, such as popcorn, chocolate, choco-spread, gingerbread and sweet spiced biscuit, contribute little to the total exposure via food (Table 2).

3.2. Intake and health based exposure limits

The intakes shown in Fig. 2, including the highest 99th percentile of intake, i.e., for boys, 1.41 μg/kg bw/d, are lower than the dose of 5 μg/kg bw/d below which neurotoxic effects in man would be negligible (see Section 2). They are, however, all above the US-EPA RfD for neurotoxicity of 0.2 μg/kg bw/d.

On the basis of the CSF of 1.6 $(mg/kg\,bw/d)^{-1}$ (Dybing and Sanner, 2003), a lifetime cancer cumulative incidence in our population would vary from 2.9×10^{-4} for an acrylamide intake at 0.18 μg/kg bw/d (3rd percentile), over 8.2×10^{-4} at 0.51 μg/kg bw/d (50th percentile), up to 17.4×10^{-4} at 1.09 μg/kg bw/d (95th percentile).

4. Discussion

The median dietary acrylamide intake in Flemish adolescents can be estimated to be 0.51 μg/kg bw/d. The 95th percentile of intake is 1.09 μg/kg bw/d. Both

Table 1
Acrylamide amounts (μg/kg) of food groups and consumption (g/day) of those food groups in adolescents

	Contamination data (μg/kg food stuff)		Consumption data (g/day)		
	Number of samples	Median (Min–Max)	All (n = 341)	Boys (n = 129)	Girls (n = 212)
			Mean (P50–P95)	Mean (P50–P95)	Mean (P50–P95)
Baby's biscuits	5	324 (225–1217)	1.97 (0–15)	1.20 (0–0)	2.44 (0–25)
Bread	6	30 (27–36)	119.30 (100–315)	146.45 (135–360)	102.77 (90–265.63)
Small bread type	4	38 (29–51)	44.31 (0–200)	47.65 (0–207.60)	42.28 (0–192.50)
Crisps	29	676 (38–1612)	5.93 (0–45)	7.91 (0–60)	4.72 (0–30)
Chocolate	3	108 (104–109)	9.73 (0–50)	12.34 (0–60)	8.14 (0–50)
Choco-spread	2	88.5 (65–112)	7.64 (0–40)	10.30 (0–60)	6.02 (0–30)
French fries	33	254 (56–729)	39.88 (0–250)	45.84 (0–300)	36.26 (0–200)
Biscuits	6	143 (20–1514)	17.51 (0–83)	19.11 (0–90)	16.53 (0–79.75)
Coffee	11	114 (11–1291)	44.90 (0–300)	46.25 (0–300)	44.07 (0–293.75)
Gingerbread	5	1403 (108–1697)	0.88 (0–0)	1.75 (0–0)	0.35 (0–0)
Breakfast cereals	20	135 (37–623)	9.17 (0–60)	13.79 (0–75)	6.36 (0–40)
Popcorn	5	160 (129–216)	0.14 (0–0)	0.06 (0–0)	0.19 (0–0)
Sweet spiced biscuit	5	204 (160–677)	1.49 (0–14)	2.17 (0–21)	1.08 (0–0)

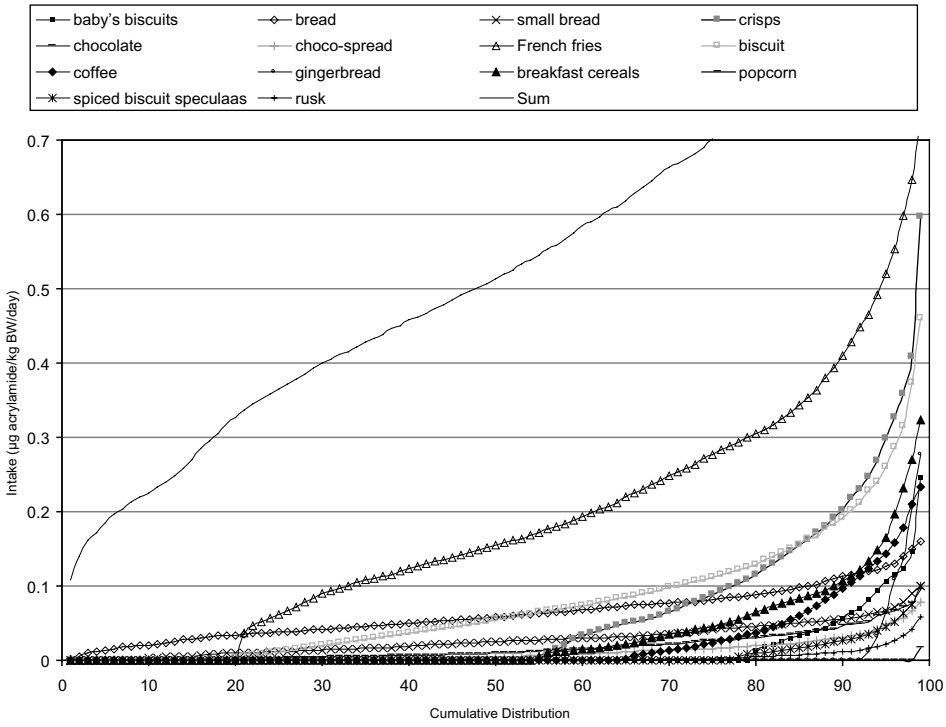

Fig. 2. Cumulative distribution functions in the background intake of acrylamide (µg/kg bw/day). The cumulative distribution functions for total intake and for the intakes via different food items are estimated separately. Therefore, the total intake at each percentile is not equal to the sum of the intake via the individual food items.

Table 2
Variation in simulated daily acrylamide exposure in the adolescent population, via French fries, crisps, bread and in total

Percentile	Via French fries (µg AA/kg bw/day)[a]	Via crisps (µg AA/kg bw/day)[a]	Via bread (µg AA/kg bw/day)[a]	Via biscuit (µg AA/kg bw/day)[a]	Total exposure (µg AA/kg bw/day)[a]
1	0	0	0.002	0	0.108
5	0	0	0.013	0	0.185
20	0	0	0.034	0.004	0.327
50	0.155	0	0.057	0.055	0.513
55	0.171	0	0.063	0.064	0.545
75	0.276	0.087	0.081	0.111	0.702
95	0.521	0.298	0.127	0.260	1.089
99	0.725	0.596	0.159	0.459	1.411

[a] AA: acrylamide and bw: body weight.

median and 95th percentile are higher in boys than in girls. This is explained by the fact that boys have a higher intake of food than girls. Our study addresses the adolescent population since in Belgium, up to date, detailed consumption data for people older than 18 years of age are lacking. At a Joint FAO/WHO Consultation it was stated that the average intakes for the general population were estimated to be in the range of 0.3–0.8 µg acrylamide/kg bw/d. In Sweden, a median dietary intake of acrylamide of approximately 0.38 µg/kg bw/d and a 95th percentile intake of 0.89 µg/kg bw/d (assuming a body weight of 70 kg) was calculated for 1211 individuals between 18 and 74 years old (Svensson et al., 2003). In Norway the median acrylamide exposure varied from 0.41 to 0.42 µg/kg bw/d, respectively males and females between 16 and 79 years old. In Norwegian 13 years old youngsters the median exposure varied from 0.30 to 0.28 µg/kg bw/d, respectively for boys and girls (Dybing and Sanner, 2003). In the Netherlands the median exposure of acrylamide for 7–18 years children was estimated to be 0.2 µg/kg bw/d and the 95th percentile was 0.9 µg/kg bw/d (Konings et al., 2003). Based on a duplicate diet study, the mean acrylamide exposure in a Swiss population (16–67 years) was 0.28 µg/kg bw/d (Swiss Federal Office of Public Health, 2002). Based on the USDA Continuing Survey of Food Intake for Individuals an average acrylamide exposure of 0.8 µg/kg bw/d was estimated (Petersen, 2002). It appears that the acrylamide intake by Flemish adolescents is of the same order as that in other developed countries.

Differences in absolute figures are probably due to the fact that different subpopulations were included and that different methodologies were applied, e.g., different food consumption questionnaires, different models, and probably the inclusion of more food items because of the extrapolation of analytical data among related food items. As in other studies (Sweden, Norway, the Netherlands) the most important solid food sources are French fries and related potato products, the consumption of which may be higher in our country than in others (Dybing and Sanner, 2003; Konings et al., 2003; Svensson et al., 2003). Bread contains a low amount of acrylamide but is the most important contributor in the lower percentiles. This could be explained by the relatively large daily consumption of this food group in Belgium. Coffee contributes considerably in the higher percentiles of the acrylamide intake. Compared to an adult population, however, the coffee consumption in our adolescents remains rather low; in an adult setting coffee would become more important. Swedish and Norwegian studies indeed revealed the high contribution of coffee in the intake of acrylamide by adult populations (Dybing and Sanner, 2003; Svensson et al., 2003).

It must be emphasized that, for several reasons, the exposure assessment presented here has several limitations. The exposure assessment is still based on a limited number of analytical measurements in a limited number of food items and samples. This is only partially remediated by the extrapolation of analytical results to strongly related food items that were not analysed for acrylamide. Based on the findings of Konings and co-workers, the impact of this extrapolation would be rather small (Konings et al., 2003). The choice to introduce into the model a value of one third of the limit of quantitation, for concentrations below the limit of quantitation, might lead to an under or over estimation of the acrylamide intake. French fries, which are important contributors to the total intake, are mainly processed at home at variable conditions and it is known that the acrylamide content is highly affected by frying temperature and frying time (Tareke et al., 2002). No analyses, however, were carried out on home prepared food and no uncertainties were introduced in the model to take this into account. Finally, the issue of under-reporting can not be neglected. Several studies have shown that under-reporters have a specific pattern of under-recording (Heitmann and Lissner, 1995; Lafay et al., 2000). Snack-type foods are preferentially forgotten in food questionnaires and food items rich in fat and/or carbohydrates (such as butter, French fries, sugars and confectionery, cakes and pastries) are reported less frequently and/or in smaller quantities than actually consumed. Due to the lack of complementary data (e.g., the effect of home processing) and the unavailability of a valid indicator to detect adolescent under reporters, it remains difficult to predict the total impact of all these factors on the intake assessment; it is almost certain that the real intake in most studies, as in ours, is higher than calculated.

For risk assessment purposes, the length of time over which dietary samples are to be collected is several consecutive days at multiple intervals of months, seasons and years (Kroes et al., 2002). In the present study, the only existing, available food consumption data-set, which was collected for other purposes, is used. The population was followed during 7 days and included all foods and beverages consumed at meals and in between, in quantified amounts. In general, it is accepted that a 7-day dietary record represents a habitual intake. However, in exposure assessment no consensus is achieved to the time frame to be used in the assessment of intake of food chemicals (Kroes et al., 2002). On the other hand, it was found that the diet history method is probably the best choice, followed by dietary records, to estimate exposure to food additives (Lowik, 1996). Nevertheless, various strategies for exposure calculation can be achieved depending on the nature of the available data; this is extensively described by Kroes et al. (2002). In the current study, a one-dimensional Monte Carlo has been executed. Individual food consumption distributions and food contamination distributions were used in the model. In the current method, the information on the input variability is passed on through the model to the output.

A quantitative estimation of the risk for adverse health effects in our population, on the basis of the estimated intake of acrylamide and health based exposure limits (oral reference doses), remains fraught with uncertainty. Indeed reference doses calculated for non-carcinogenic endpoints predict that intakes below these will not be accompanied by appreciable toxicity in man. Intakes slightly above these reference limits may be accompanied by adverse health effects, but quantitative figures are nearly impossible to estimate. An estimation of the risk for neurotoxic effects in our population heavily depends on the choice of the reference dose, 5 μg/kg bw/d or 0.2 μg/kg bw/d, depending on the reference experiment and assessment factors chosen (see methodology). Accordingly, no or small, undefined neurotoxic effects would be predicted at the estimated intake levels. It seems rather unlikely that even a detailed, controlled epidemiological study performed in the high intake group might be able to detect neuronal effects that can be undeniably attributed to acrylamide intake via food. Neurotoxicity has been observed in occupational studies (Hagmar et al., 2001; He et al., 1989; Marsh et al., 1999) but exposure was almost certainly substantially higher.

A similar caution should be applied when deducing extra-cancer numbers in our population as a result of the estimated acrylamide intakes and its CSF. As shown above, CSFs may be quite different depending on the data used and procedure followed. Furthermore, in the

LMS approach the CSF 95th confidence limit is calculated according to a worst case approach. The actual cancer risk in man may be much lower or even zero (Crump, 1996; Lovell and Thomas, 1996). The LMS model (US-EPA) was indeed developed for regulatory purposes and not to predict cancer numbers in a particular situation (Crump, 1996).

Until now, epidemiological studies found no association between consumption of foods containing acrylamide and cancer risk (Erdreich and Friedman, 2004; Mucci et al., 2003, 2004; Pelucchi et al., 2003). However, epidemiological studies have limited power to detect small increases in tumour incidence. Negative epidemiological studies may therefore provide an upper-bound to possible carcinogenic effects, rather than proof that no such effects exist (FAO/WHO, 2002). However, Granath and Tornqvist (2003) concluded that acrylamide can contribute approximately 1% of the lifetime cancer risk, considering that a large fraction of all cancers has been attributed to dietary factors (American Cancer Society, 1999; Granath and Tornqvist, 2003).

Biomarkers of acrylamide exposure have been reported and estimated a background level (non-smoker) of 1.43 μg/kg bw/d (assuming a body weight of 70 kg) (Svensson et al., 2003). Based on our findings and observations in the literature, the estimated dietary intake cannot explain the overall acrylamide exposure. Non-food acrylamide exposures may be substantial for some populations (FAO/WHO, 2002). Other sources of acrylamide are cosmetics, drinking water, packaging materials and a possible endogenous formation in the body and also cigarette smoke (active and passive) and occupational exposure (European Commission, 2002b). Nevertheless, a reduction of acrylamide content in food could still contribute to a decrease of total acrylamide exposure, certainly at the higher percentiles of intake, supposing that all other intermediate factors are kept constantly.

Strategies to reduce the acrylamide content of food have been proposed by the European Commission after a workshop with the member states and stakeholder organisations in October 2003 (European Commission, 2003), by Friedman (2003) and at the Acrylamide in Food Workshop (JIFSAN/ NCFST).

Meanwhile, because of undefined, although quite low, risks for neurotoxic effects and carcinogenic potency of acrylamide, its intake should be as low as possibly achievable. People should be advised to avoid excessive frying of baking, especially with regard to potato products.

Acknowledgments

The authors thank the Federal Agency for the safety of the Food Chain: the Belgian Food Agency (FAVV-AFSCA, Belgium) for access to the analytical data. We would like to thank Dr. C. Vinkx (Federal Public Service Health, Food Chain Safety and Environment, Brussels) for fruitful discussions. We thank the dieticians Mrs. M. Bellemans and Mrs. M. De Maeyer (Department of Public Health, Ghent University) for their important contribution to the fieldwork and the data input of the food consumption data. The food consumption data collection was financially supported by the National Fund for Scientific Research (fund no. 31557898), the Kellogg's Benelux Company, Unilever Belgium, the Belgian Nutrition Information Center and the 'Vlaams Wetenschappelijk Fonds'. Food safety research at the Department of Public Health is funded by the Centre for Health and Environment of the Flemish Ministry of Public Health. The intake and risk assessment performed are solely the responsibility of the authors and do not engage the FAVV-AFSCA.

References

American Cancer Society, 1999. Cancer facts and figures—1997. American Cancer Society, Atlanta, GA.

Burek, J.D., Albee, R.R., Beyer, J.E., Bell, T.J., Carreon, R.M., Morden, D.C., Wade, C.E., Hermann, E.A., Gorzinski, S.J., 1980. Subchronic toxicity of acrylamide administered to rats in the drinking water followed by up to 144 days of recovery. Journal of Environmental Pathology & Toxicology 4, 157–182.

Crump, K.S., 1996. The linearized multistage model and the future of quantitative risk assessment. Human and Experimental Toxicology 15, 787–798.

Cullen, A., Frey, H., 1999. Probabilistic Techniques in Exposure Assessment. Plenum, New York.

Dooren, M.M.H., Boeijen, I., van Klaveren, J.D., van Donkersgoed, G., 1995. Conversion of Foods to Primary Agriculturally Products. Rikilt, Wageningen, The Netherlands, Report 95.17.

Dybing, E., Sanner, T., 2003. Risk assessment of acrylamide in foods. Toxicological Sciences 75, 7–15.

Erdreich, L.S., Friedman, M.A., 2004. Epidemiologic evidence for assessing the carcinogenicity of acrylamide. Regulatory Toxicology and Pharmacology 39, 150–157.

European Commission, 2002a. Opinion of the scientific committee on food on new findings regarding the presence of acrylamide in food. http://europa.eu.int/comm/food/fs/sc/scf/out131_en.pdf.

European Commission, 2002b. Risk assessment of acrylamide (CAS no. 79-06-1, EINECS no. 201-173-7) Summary risk assessment report. European Commission, Joint Research Center, European Chemicals. Bureau Ispra, Italy.

European Commission, 2003. Information on ways to lower the levels of acrylamide formed in food. Acrylamide Workshop. European Commission, http://europa.eu.int/comm/food/food/chemicalsafety/contaminants/acryl_guidance.pdf.

FAO/WHO 2002. Health implications of acrylamide in food. Report of a Joint FAO/WHO Consultation. 25–27 June 2002. World Health Organisation, Geneva, Switzerland.

FOD VVVL 2002. Acrylamide in voedingsmiddelen op de Belgische markt: een eerste reeks metingen. FOD VVVL, Brussels, http://www.belgium.be/eportal/ShowDoc/health/imported_content/pdf/Acrylamide_rapport_NL.pdf?contentHome=entapp.BEA_personalization.eGovWebCacheDocumentManager.nl.

Friedman, M., 2003. Chemistry, biochemistry, and safety of acrylamide. A review. Journal of Agricultural and Food Chemistry 51, 4504–4526.

Granath, F., Tornqvist, M., 2003. Who knows whether acrylamide in food is hazardous to humans? Journal of the National Cancer Institute 95, 842–843.

Hagmar, L., Tornqvist, M., Nordander, C., Rosen, I., Bruze, M., Kautiainen, A., Magnusson, A.L., Malmberg, B., Aprea, P., Granath, F., Axmon, A., 2001. Health effects of occupational exposure to acrylamide using hemoglobin adducts as biomarkers of internal dose. Scandinavian Journal of Work, Environment and Health 27, 219–226.

He, F.S., Zhang, S.L., Wang, H.L., Li, G., Zhang, Z.M., Li, F.L., Dong, X.M., Hu, F.R., 1989. Neurological and electroneuromyographic assessment of the adverse effects of acrylamide on occupationally exposed workers. Scandinavian Journal of Work, Environment and Health 15, 125–129.

Heitmann, B.L., Lissner, L., 1995. Dietary underreporting by obese individuals—is it specific or non-specific? British Medical Journal 311, 986–989.

IARC, 1994. Acrylamide. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, vol. 60, International Agency for Research on Cancer, Lyon.

Konings, E.J., Baars, A.J., van Klaveren, J.D., Spanjer, M.C., Rensen, P.M., Hiemstra, M., van Kooij, J.A., Peters, P.W., 2003. Acrylamide exposure from foods of the Dutch population and an assessment of the consequent risks. Food and Chemical Toxicology 41, 1569–1579.

Kroes, R., Muller, D., Lambe, J., Lowik, M.R., van Klaveren, J., Kleiner, J., Massey, R., Mayer, S., Urieta, I., Verger, P., Visconti, A., 2002. Assessment of intake from the diet. Food and Chemical Toxicology 40, 327–385.

Lafay, L., Mennen, L., Basdevant, A., Charles, M.A., Borys, J.M., Eschwege, E., Romon, M., 2000. Does energy intake underreporting involve all kinds of food or only specific food items. Results from the Fleurbaix Laventie Ville Sante (FLVS) study. International Journal of Obesity and Related Metabolic Disorders 24, 1500–1506.

Lovell, D.P., Thomas, G., 1996. Quantitative risk assessment and the limitations of the linearized multistage model. Human and Experimental Toxicology 15, 87–104.

Lowik, M.R., 1996. Possible use of food consumption surveys to estimate exposure to additives. Food Additives and Contaminants 13, 427–441.

Marsh, G.M., Lucas, L.J., Youk, A.O., Schall, L.C., 1999. Mortality patterns among workers exposed to acrylamide: 1994 follow up. Journal of Occupational and Environmental Medicine 56, 181–190.

Matthys, C., De Henauw, S., Devos, C., De Backer, G., 2003. Estimated energy intake, macronutrient intake and meal pattern of Flemish adolescents. European Journal of Clinical Nutrition 57, 366–375.

Mottram, D.S., Wedzicha, B.L., Dodson, A.T., 2002. Acrylamide is formed in the Maillard reaction. Nature 419, 448–449.

Mucci, L.A., Dickman, P.W., Steineck, G., Adami, H.O., Augustsson, K., 2003. Dietary acrylamide and cancer of the large bowel, kidney, and bladder: absence of an association in a population-based study in Sweden. British Journal of Cancer 88, 84–89.

Mucci, L.A., Lindblad, P., Steineck, G., Adami, H.O., 2004. Dietary acrylamide and risk of renal cell cancer. International Journal of Cancer 109, 774–776.

Norwegian Food Agency 2002. Risk assessment of cancer risk due to acrylamide intake from coffee consumption. Oslo, http://www.snt.no.

Pelucchi, C., Franceschi, S., Levi, F., Trichopoulos, D., Bosetti, C., Negri, E., La Vecchia, C., 2003. Fried potatoes and human cancer. International Journal of Cancer 105, 558–560.

Petersen, B. 2002. Exposure and Biomarkers. JIFSAN/NCFST Acrylamide in Food Workshop. Scientific Issues, Uncertainties, and Research Strategies. Joint Institute for Food Safety and Applied Nutrition, Maryland.

Petersen, B.J., 2000. Probabilistic modelling: theory and practice. Food Additives and Contaminants 17, 591–599.

SNFA 2002a. Acrylamide in Foodstuffs, Consumption and Intake. Swedish National Food Administration, Uppsala, www.slv.se.

SNFA 2002b. Acrylamide is formed during the preparation of food and occurs in many foodstuffs. Swedish National Food Administration, Uppsala, www.slv.se.

Spencer, P.S., Schaumburg, H.H., 1974. A review of acrylamide neurotoxicity. Part I. Properties, uses and human exposure. Canadian Journal of Neurological Sciences 1, 143–150.

Stadler, R.H., Blank, I., Varga, N., Robert, F., Hau, J., Guy, P.A., Robert, M.C., Riediker, S., 2002. Acrylamide from Maillard reaction products. Nature 419, 449–450.

Svensson, K., Abramsson, L., Becker, W., Glynn, A., Hellenas, K.-E., Lind, Y., Rosen, J., 2003. Dietary intake of acrylamide in Sweden. Food and Chemical Toxicology 41, 1581–1586.

Swiss Federal Office of Public Health 2002. Assessment of acrylamide intake by duplicate diet study. Swiss Federal Office of Public Health, Bern.

Tareke, E., Rydberg, P., Karlsson, P., Eriksson, S., Tornqvist, M., 2002. Analysis of acrylamide, a carcinogen formed in heated foodstuffs. Journal of Agricultural and Food Chemistry 50, 4998–5006.

US-EPA 1993. Acrylamide. Environmental Protection Agency, USA; Integrated Risk Information System (IRIS).

van Donkersgoed, G., Koopman, N., van Klaveren, J.D., 2002. Acrylamide in food. RIVM, RIKILT, Wageningen.

WHO, 1996. Acrylamide. Guidelines for drinking-water, vol. 2, Health Criteria and other Supporting Information, World Health Organisation, Geneva, pp. 541–547.

World Health Organization, 1995. Physical status: the use and interpretation of anthropometry, Technical Report Series 854. WHO, Geneva.