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Assessment of the acrylamide intake of the Belgian population and the effect of mitigation strategies

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The acrylamide (AA) intake of the Belgian consumer was calculated based on AA monitoring data of the Belgian Federal Agency for the Safety of the Food Chain (FASFC) and consumption data of the Belgian food consumption survey coordinated by the Scientific Institute for Public Health (3214 participants of 15 years or older). The average AA exposure, calculated probabilistically, was $0.4\,\mu g\,kg^{-1}$ body weight (bw) day^{-1} ($P97.5 = 1.6\,\mu g\,kg^{-1}$ bw day^{-1}), the main contributors to the average intake being chips (23%), coffee (19%), biscuits (13%), and bread (12%). Additionally, the impact of a number of AA mitigation scenarios was evaluated (German minimization concept, scenarios for mitigation from the literature, signal values), which is an important issue for public health as well as for policy-makers. Specific actions in cooperation with the food industry to reduce the AA content of foods seems to be a more efficient strategy than mere implementation of signal values. Considering that an important share of the AA intake is due to prepared meals, the catering industry as well as consumers need to be better informed on the various possibilities for keeping the AA content of meals as low as possible.

Keywords: risk assessment; exposure assessment; probabilistic modelling; liquid chromatography/mass spectrometry (LC/MS); process contaminants; acrylamide; processed foods

Introduction

Acrylamide (AA, $CH_2{=}CHCONH_2$, CAS No. 79-0601, EC No. 201-173-7) is neurotoxic, and probably genotoxic and carcinogenic to humans as well. Recently, the European Chemicals Agency (ECHA) announced that it would include AA on the European Union's candidate list of Substances of Very High Concern (ECHA 2009). Under the ECHA proposal, AA has been listed as a category 2 carcinogen and a category 2 mutagen. The chemical has a large number of industrial applications including the production of polyacrylamides, which are among others used in cosmetics, pesticides, paints, as a flocculant in water treatment, and in the paper industry. AA is also present in cigarette smoke (Joint FAO/WHO Expert Committee on Food Additives (JECFA) 2005; International Agency for Research on Cancer (IARC) 1994).

In 2002, it was demonstrated that relatively high levels of AA are formed during heating of certain foods (baking, roasting, frying). Since then, intensive research has been conducted regarding the various formation mechanisms and the toxicology of AA (e.g. bioavailability), the development of accurate analytical methods (e.g. cheap and fast screening methods), factors that influence the AA content of foods (e.g. storage), etc. (Stadler and Scholz 2004; Taeymans et al. 2004; Claeys et al. 2005; Friedman and Levin 2008; European Food Safety Authority (EFSA) 2008a; Tardiff et al. 2010).

The observed AA levels in food are a result of competitive, complex processes of formation and elimination or degradation (Mottram et al. 2002). The largest amount of AA is accumulated during the last stages of baking, roasting or frying when the moisture content of the food drops and the surface temperature rises, except for coffee where the AA level drops significantly during the later stages of the roasting process. AA appears to be stable in the large majority of foodstuffs. Grounded coffee, where the

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AA content decreases during storage, is once more an exception (Hoenicke and Gatermann 2005; Lanz et al. 2006).

Until present, there are no legal regulations regarding the AA content of food, neither at national nor at European levels. Germany is the only country with a systematic mitigation strategy (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit (BVL) 2005) and the only legal action undertaken so far was the withdrawal of child biscuits containing greater than $1000\,\mu g\,AA\,kg^{-1}$ from the Swiss market in 2005 (Grob 2007). In California, a court agreement was reached with a number of important chips and crisp producers and some fast-food chains to reduce the AA content of their products significantly and to place warning labels regarding the presence of AA on the packaging (Hills 2008).

The Belgian Federal Agency for the Safety of the Food Chain (FASFC) has been monitoring for a number of years the AA content of different foodstuffs. When AA is detected at a level above $1000\,\mu g\,kg^{-1}$, the producer is urged to take possible mitigation actions. The vast amount of data acquired through the monitoring programme as well as the availability of a nationwide Belgian food-consumption survey allow the assessment of the dietary exposure of the Belgian population to AA. The present study is the first large-scale study conducted with respect to the AA intake of the Belgian consumer.

Materials and methods

Food consumption data

Food consumption data were obtained from the Belgian Food Consumption Survey (BFCS) of 2004 which was performed by the Scientific Institute of Public Health (Devriese et al. 2005). The survey involved 3214 participants of 15 years or older, who were interviewed twice about their consumption during the last 24 h (repeated non-consecutive 24-h recall) in combination with a self-administered food-frequency questionnaire. The fieldwork was spread over one year to anticipate seasonal effects, and was carried out by trained dieticians. The selection of interviewees and the times of interviews were chosen in order to obtain a representative consumption profile of the Belgian population over one year anticipating seasonal effects.

In this study, the total data set, including zero intakes ('zero consumption days'), were used as part of an 'average' diet. Note that the duration of the consumption survey affects the distribution of consumption data, particularly the upper percentiles or the group of high or frequent consumers. As such, a brief survey often underestimates the consumption of less frequently consumed foods, but at the same time overestimates the quantities of frequently consumed foods. High percentiles based on a 1–2-day consumption survey are often an overestimation compared with high percentiles obtained on the basis of a 7-day survey. The reliability of the high percentiles depends not only on the duration of the survey, but also on the number of people or data on which their calculation is based. Percentiles that are calculated based on a limited amount of data have a higher uncertainty and give only a rough indication of the higher consumption levels. According to Kroes et al. (2002), a high percentile, P ($>$P75), can only be evaluated with sufficient accuracy when the sample size, n, satisfies with $n(1-P) \geq 8$. The minimum amount of data thus required for P95, P97.5 and P99 can be estimated as 160, 320 and 800, respectively. The same restrictions apply to the lower percentiles (EFSA 2008b).

Acrylamide concentration data

AA levels were measured in various foodstuffs on the Belgian market within the framework of the monitoring programme of the FASFC. The AA content of the samples was determined by a liquid chromatography-mass spectrometry (LC-MS)-accredited method in the Federal Laboratory for the Safety of the Food Chain (FLVVG), with a limit of quantification (LOQ) of $50\,\mu g\,kg^{-1}$ and a limit of detection (LOD) of $25\,\mu g\,kg^{-1}$. After AA extraction, defatting and further clean-up of the sample over an Oasis HLB SPE column, $10\,\mu l$ were injected on an Sequant ZIC-HILIC column (2.1×150 mm $5\,\mu m$, equipped with a pre-column) with acetonitrile as a mobile phase, coupled to a triple quadrupole mass spectrometer operating in atmospheric pressure chemical ionization (APCI) mode (TSQ Quantum Ultra, Thermo Fisher Scientific, Tournai, Belgium). The content was measured in MS^2 on the ions m/z 72 and 52 (AA) and 75 and 58 (labelled AA, used as internal standard). Depending on the matrix, the recovery is situated between 81% and 100%. The extended measurement uncertainty is situated between 26% (clean matrix) and 52% (dirty matrix).

Statistical comparison of the AA levels measured between 2002 and 2007 showed no decrease or increase of the AA level as a function of time. Consequently, data from 2002 until 2007 could be pooled when calculating the intake, which resulted in a data set of 759 data points. The statistical analysis of the data was performed with SPSS® 11.0 for Windows (SPSS, Inc., USA). The Kolmogorov–Smirnov test was used to test normality. Means were compared using analysis of variance (one-way ANOVA) and post-hoc multiple comparison tests (Tukey when variances were equal or Games–Howell when variances were unequal). Homogeneity of variances was tested using the Levene test.

Table 1. Contribution of the different food groups to the dietary exposure of the Belgian population to acrylamide (μg kg^{-1} bw day^{-1}).

Food group	P25	P50	P75	P90	P95	P97.5	P99
Chips	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.15 (0.10–0.22)	0.44 (0.32–0.59)	0.77 (0.54–1.06)	1.33 (0.89–2.21)
Crisps	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.10 (0.06–0.17)	0.32 (0.21–0.47)	0.67 (0.43–1.03)
Bread	0.01 (0.01–0.02)	0.03 (0.03–0.04)	0.06 (0.05–0.06)	0.09 (0.08–0.10)	0.11 (0.10–0.13)	0.14 (0.12–0.16)	0.18 (0.15–0.22)
Bread rolls	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.02 (0.01–0.02)	0.05 (0.05–0.06)	0.08 (0.07–0.09)	0.10 (0.09–0.12)	0.13 (0.11–0.17)
Biscuits	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.07 (0.05–0.10)	0.18 (0.13–0.26)	0.34 (0.24–0.51)	0.64 (0.39–1.08)
Gingerbread	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.15 (0.08–0.24)	0.36 (0.21–0.68)
Sweet spiced biscuits	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.05 (0.03–0.08)	0.13 (0.09–0.20)	0.26 (0.17–0.44)
Chocolate	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.05 (0.03–0.07)	0.11 (0.07–0.17)	0.18 (0.11–0.32)	0.32 (0.17–0.55)
Coffee	0.00 (0.00–0.00)	0.03 (0.03–0.04)	0.09 (0.08–0.10)	0.16 (0.14–0.19)	0.23 (0.20–0.28)	0.31 (0.26–0.40)	0.45 (0.34–0.63)
Coffee surrogate	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.34 (0.20–0.75)
Breakfast cereals	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.01 (0.00–0.03)	0.09 (0.05–0.15)	0.21 (0.13–0.31)	0.37 (0.22–0.52)
Toast	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.01)	0.03 (0.01–0.05)	0.07 (0.03–0.13)
Popcorn	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Cereal bars	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Intake (total)	0.10 (0.09–0.11)	0.19 (0.18–0.21)	0.40 (0.35–0.44)	0.76 (0.67–0.88)	1.12 (0.94–1.35)	1.54 (1.24–1.97)	2.26 (1.68–3.25)

Note: Values are given as the best estimation (95% confidence interval).

For exposure assessment, foods were grouped in fourteen categories: chips, crisps, coffee (liquid), coffee surrogate (liquid), bread, bread rolls (including pastry), toast, biscuits, gingerbread, almond or sweet spiced biscuits, chocolate, popcorn, breakfast cereals and cereal bars. The classification is based on the AA levels in different foodstuffs and is in line with the grouping applied in other studies (Boon et al. 2005; Matthys et al. 2005; Mestdagh et al. 2007).

The AA data were further expanded with German data from the AA European Monitoring Database, which is compiled by the Institute for Reference Materials and Measurements (IRMM) (2006). Based on a statistical analysis showing no significant differences, the Belgian AA database could be supplemented with German data for chips, crisps, chocolate, coffee, biscuits and sweet spiced biscuits. In total, the AA data set used for the exposure assessment thus contained more than 3000 results.

Estimation of the acrylamide intake

The AA intake was determined per food group and overall by a probabilistic approach considering all data or the full distribution of the different variables (i.e. AA content and consumption). Hereto, a (one-dimensional) Monte Carlo simulation was performed with 100,000 iterations. To evaluate the uncertainty of the sampling, 'bootstrap sampling' (two-dimensional Monte Carlo model) was applied. In this method, n observations (AA concentration and consumption of the relevant food) were theoretically re-sampled from the original data set resulting in a 'bootstrap' data set with n observations. By repeating this process 500 times, 500 'bootstrap' data sets are obtained, on which the same statistical calculations (e.g. 97.5th, 99.9th percentile, etc.) can be applied as in the original data set. As such a 'bootstrap' distribution of five hundred 97.5th, 99.9th percentiles, etc. is created that characterizes the uncertainty of the original data set (Vose 2006). The model input distributions were randomly sampled by the Latin Hypercube method. Calculations were performed by the software @Risk® (Version 4.5.5; Palisade Corporation, NY, USA).

AA concentrations below the LOQ were replaced by LOQ/2 ('middle bound scenario'). For the conversion of the AA level of roasted or grounded coffee beans (coffee surrogate) to liquid coffee (coffee surrogate), a conversion factor of 0.046 was applied (Van Dooren et al. 1995). Regarding the AA level of chocolate biscuits, chocolate and biscuit were considered separately. Based on chocolate levels mentioned on the package, it was assumed that 40% of the biscuit consists of chocolate. Variability in preparation conditions (e.g. deep-frying of chips, toasting of bread, etc.) was not taken into account.

Results and discussion

Dietary exposure of the Belgian consumer to acrylamide

Table 1 shows the AA intake per food group and the overall AA intake of the Belgian population. The contribution of the most relevant food groups to the AA intake (contribution greater than 1%) is also shown in Figure 1.

The average AA intake was calculated as $0.35\,\mu g\,kg^{-1}$ bw day^{-1} ($P50 = 0.2\,\mu g\,kg^{-1}$ bw day^{-1}). For high consumers the intake may be several times higher, amounting to $1.58\,\mu g\,kg^{-1}$ bw day^{-1} for the 97.5th percentile or P97.5. Overall, about 6% of the population has an intake higher or equal to the average intake of $1\,\mu g\,kg^{-1}$ bw estimated by JECFA (2005).

On average, chips contributed the most to the AA intake (23%), followed by coffee (19%), biscuits

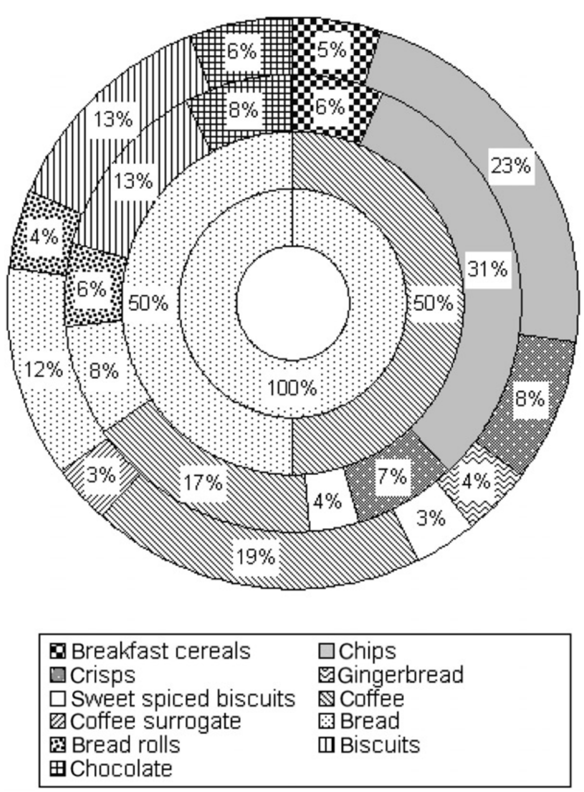

Figure 1. Contribution of the most important food groups to the estimated dietary exposure to acrylamide in terms of percentages: inner circle = P25 < P50 < P95 < outer circle = mean.

(13%), and bread (12%) (Figure 1). For the lower intake percentiles, coffee and bread appeared to be most important sources of AA, whereas for the higher percentiles ($\geq$P85) chips, crisps, and biscuits became more important sources. This reflects the difference in dietary pattern according to the AA intake (Dybing et al. 2005; Matthys et al. 2005).

The AA level, and as such the contribution to the AA intake, of different food groups and of foods within the same food group can vary greatly depending on the formulation of the food, manufacturing conditions, etc. The contribution of a food or food group to the intake is defined, however, not only by its AA level, but also by the amount consumed. For example, gingerbread and coffee surrogate contributed relatively little to the exposure despite their relatively high mean AA level (for Belgium, the mean AA level is $692 \pm 566\,\mu g\,kg^{-1}$ for gingerbread and $2531 \pm 825\,\mu g\,kg^{-1}$ for coffee surrogate powder). With respect to bread the opposite is observed (mean AA level for bread $= 30 \pm 9\,\mu g\,kg^{-1}$) due to its high consumption compared with, for example, gingerbread and coffee surrogate powder.

The AA intake given in Table 1 corresponds well to the range of values calculated previously for Belgium (restricted to a target population of adolescents and visitors to a university canteen) (Matthys et al. 2005; Mestdagh et al. 2007) and reported for other European countries (Svensson et al. 2003; Boon et al. 2005; Dybing et al. 2005). In general, values between 0.3 to $2.0\,\mu g$ AA kg^{-1} bw day^{-1} are reported for the average AA intake of adults. The high intake percentiles (P90–P97.5) range from 0.6 to $3.5\,\mu g\,kg^{-1}$ bw day^{-1} with $5.1\,\mu g\,kg^{-1}$ bw day^{-1} reported for P99. Food that contribute most to the AA intake are in general chips (16–30%), crisps (6–46%), coffee (13–39%), fine bakery and sweet biscuits (10–20%), and bread and rolls/toast (10–30%). Other relevant foodstuffs contribute less than 10% to the intake (JECFA 2005; World Health Organisation (WHO) 2006). The absolute figure of the exposure and the relative contribution of each food group to the exposure may differ from study to study, depending on the number and nature of the food groups considered, the methodology applied for the calculation, the type of consumption survey, etc. (Dybing et al. 2005; JECFA 2005).

Any exposure assessment is confronted with a number of uncertainties (Kroes et al. 2002). In this study, the long-term intake was predicted based on a 2-day consumption survey and consumption data were considered to be independent. The linkage between the analysed and consumed food items, the categorization into food groups, the conversion factors applied (i.e. for chocolate in chocolate biscuits and for liquid coffee), and the fact that variability in preparation conditions was not accounted for and that values below the LOQ were unknown and replaced by

LOQ/2, are additional sources of uncertainty in the estimated AA intake.

Risk characterization

Given that AA is probably genotoxic and carcinogenic to humans (IARC group 2A) (IARC 1994; JECFA 2005), it is recommended to keep the AA exposure 'as low as reasonably achievable' (ALARA). Nevertheless, to prioritize risks associated with unavoidable contaminants that are both genotoxic and carcinogenic, the 'margin of exposure' (MOE) concept has been put forward (EFSA 2005). The MOE is the ratio between a particular point on the dose–response curve leading to tumours in experimental animals and the exposure. The size of the MOE gives an indication about the possible extent of the risk. The higher the MOE, the lower the risk of exposure to the component concerned. The Scientific Committee of the European Food Safety Authority (EFSA) considers the figure of 10,000 or higher as (in general) being of low concern from a public health point of view and might reasonably be considered as a low priority for risk-management actions. For AA, MOE values between 50 and 2000 have been reported depending on the exposure data and toxicological values used (Table 2). JECFA calculated a MOE of 300 based on an average exposure of $1\,\mu g\,AA\,kg^{-1}\,bw\,day^{-1}$ and a $BMDL_{10}$ (the lower confidence limit on the benchmark dose associated with 10% response) of $300\,\mu g\,AA\,kg^{-1}\,bw\,day^{-1}$ for the induction of breast tumours in rats. For high consumers with an intake of $4\,\mu g\,AA\,kg^{-1}\,bw\,day^{-1}$, the MOE was 75 (JECFA 2005). The average ($0.4\,\mu g\,kg^{-1}\,bw\,day^{-1}$) and the P97.5 ($1.6\,\mu g\,kg^{-1}\,bw\,day^{-1}$) intake calculated in this study would thus correspond to MOE values of 750 and 188, respectively. Such low MOE values imply that additional efforts have to be taken for reducing the AA content in foods and that AA is a process contaminant of high priority. (For comparison: MOE values between 17,900 and 9500 are given for the polycyclic aromatic hydrocarbons (EFSA 2008c).)

Possible strategies to reduce the acrylamide exposure

Various methods are reported in the literature to reduce the AA content of food, such as the selection of potato, wheat and other plant cultivars with low levels of the AA precursors asparagine and glucose, the removal of the AA precursors (e.g. soaking of potatoes, hydrolysis of asparagine to aspartic acid using asparaginase), adaptation of process and storage conditions (temperature, time, water activity (a_w) and pH), adding ingredients that inhibit the formation of AA (acids, amino acids, antioxidants, non-reducing sugars, chitosan, garlic components, protein hydrolysates, proteins, multivalent ions), the removal or 'capture' of AA through chromatography, evaporation or polymerization (Stadler and Scholz 2004; Taeymans et al. 2004; Claeys et al. 2005; Friedman and Levin 2008).

Table 3 shows the effect of some of the specific AA mitigation possibilities reported in the literature on dietary exposure. It should be noted, however, that the reduction percentages mentioned are indicative values and that the yield of the proposed mitigation possibilities might be different in practice (for one because there are different types of biscuits, breads, etc. with their own recipe, process conditions, etc.). Furthermore, the reductions mentioned are often based on laboratory (model) experiments, of which the industrial applicability has in most cases not been evaluated yet.

For 50% of the population, the AA intake is primarily due to the consumption of bread and coffee. The AA content of bread is more than 99% located

Table 2. Comparison of margins of exposure (MOEs) determined in the present study with MOE values given in the literature for acrylamide.

T25 ($\mu g\,kg^{-1}$ bw day^{-1})	$BMDL_{10}$ ($\mu g\,kg^{-1}$ bw day^{-1})	Exposure ($\mu g\,kg^{-1}$ bw day^{-1})	MOE T25	MOE BMDL	Remark	Reference[a]
650	310	0.41	1600	760	Mean exposure ♂ (Norway)	(1)
		0.42	1600	740	Mean exposure ♀ (Norway)	(1)
		0.43	1500	720	Mean exposure (USA)	(1)
		0.92	710	340	P90 exposure (USA)	(1)
		2.31	280	130	P90 exposure 2–5 years old (USA)	(1)
	200[b]	1/4		200/50	Mean/high exposure	(2)
	2000[b]			2000/500		
	300	1/4		300/75	Mean/high exposure	(2)
	300	0.4/1.6		750/188	Mean/P97.5 exposure	Present study

Notes: [a](1) O'Brien et al. (2006); and (2) Joint FAO/WHO Expert Committee on Food Additives (JECFA) (2005).
[b]NOAEL, no observed adverse effect level instead of $BMDL_{10}$.

Table 3. Effect of some specific mitigation scenarios on the acrylamide intake of the Belgian population (expressed as percentage reduction of the intake assuming the percentage decrease in AA content as stated in the scenario).

Scenario		Average	P50	P75	P90	P95	P97.5	P99
1	Bread and bread rolls – 60%	9.7	29.6	27.6	15.4	8.0	5.1	3.3
2	Coffee – 30%	5.6	15.2	16.2	8.7	4.7	3.3	2.4
3	Biscuit – 70%	9.1	0.0	0.0	7.4	9.9	10.6	11.2
4	Chips – 35%	7.7	0.0	0.0	9.4	11.0	9.4	8.2
	Crisps – 35%	2.7	0.0	0.0	0.0	2.5	3.6	4.3
	Chips and crisps – 35%	10.4	0.0	0.0	9.4	13.6	13.0	12.4
5	Gingerbread – 60%	2.2	0.0	0.0	0.0	0.0	3.1	4.2
4 + 5	Chips and crisps – 35% plus gingerbread – 60%	12.6	0.0	0.0	9.4	13.6	16.1	16.6

in the crust (Surdyk et al. 2004). Some of the AA mitigation options for bread mentioned in the literature are amongst others the addition of Ca^{2+} or Mg^{2+} to the dough (resulting in a potential reduction of 20% of the AA content), a prolonged yeast fermentation of the dough (50% to 77–78% reduction), and addition of a high dose of glycine (80% reduction) (Fredriksson et al. 2004; Claus et al. 2008). Assuming that a reduction of 60% of the AA content in bread is possible (scenario 1), the P50 and P75 of the AA intake could be significantly reduced by almost 30% (Table 3).

With respect to coffee, only a few options for reducing the AA level are put forward such as the selection of coffee bean species, darker roasting of the beans, a prolonged shelf life, and the use of asparaginase (Hoenicke and Gatermann 2005; Lanz et al. 2006). If the AA level of coffee could be reduced by 30% (scenario 2), the P50 and P75 of the AA intake would be decreased by approximately 15–16%.

Other major sources of AA in the diet are chips, crisps and biscuits. The AA content in biscuits could be reduced by 70% by adjusting the baking process and by replacing glucose and fructose with sucrose (Graf et al. 2006; Gökmen et al. 2007) (scenario 3). The application of these measures would reduce the average intake by 9%. For potato products, a significant reduction of the AA level is reported when potatoes are soaked or blanched in an acetic acid solution (40–80%) or at 70°C for 10–15 min (65–96%) before frying (Kita et al. 2004; Mestdagh, De Wilde, Delporte et al. 2008; Mestdagh, De Wilde, Fraselle et al. 2008). Reducing the baking temperature from 185°C to 175°C can reduce the AA level of potato products by 35% (scenario 4). Such an adjustment of the baking process results in an approximate 10% reduction of average AA intake, which is of the same order of magnitude as the average reduction of 13% determined by Boon et al. (2005) for Dutch consumers. For a high consumer of fried potato products, the intake can even be reduced by 20%.

In addition, Boon et al. (2005) calculated that the AA intake decreases on average by about 4% when the AA level in gingerbread is reduced by 60%, which can be obtained when sodium bicarbonate is used instead of ammonium carbonate as a baking agent (scenario 5). In the present study, a similar reduction of the intake was obtained for the higher percentiles. Boon et al. also determined the reduction that would be achieved when the two latter mitigation options are combined (scenarios 4 and 5) and they obtained an average reduction of 17%. A comparable reduction of 9–25% for the higher intake percentiles was calculated in this study.

Seal et al. (2008) addressed the effect of some mitigation options on the AA intake as well, discussing not only the benefits (reduction of the AA intake), but also the risks (health, quality or nutritional implications). The mitigation scenarios studied by Seal et al. decreased exposure by 1–14%, which is in the same range as observed in the present study. The application of all mitigation measures simultaneously resulted in a reduction of 31–39% depending on the percentile of exposure considered.

A possible policy measure for reducing AA intake is by establishing signal values (action values). In this respect, Germany introduced in 2002 the 'minimization concept', which pursues a gradual reduction of AA levels in foodstuffs while retaining products' properties (BVL 2005). In this concept, the lowest AA level of 10% of the food with the highest AA concentration (P90) is taken as a signal value, with a ceiling of 1000 μg AA kg^{-1} food product. The German P90 signal value is revised each year and reduced when necessary. A signal value can be maintained, but never increased. When a signal value is exceeded, it is discussed with the companies involved which actions might be taken to lower the AA level.

Table 4 shows the effect of the German 2008 signal values on the total AA intake of the Belgian consumer (see the bottom line of Table 4). Here, AA levels above the German signal values were replaced by the P90 signal value. It should be noted that there are no German signal values given for chocolate, bread, bread rolls, popcorn and cereal bars. For biscuits the signal value for diet biscuits was applied. For toast the signal

Table 4. Application of signal values ($\mu g\,kg^{-1}$) on the acrylamide intake of the Belgian population (expressed as a percentage intake reduction): (1) effect of applying Belgian P90 signal values on each food group separately and on all food groups together; and (2) effect of applying German 2008 signal values on all food groups together (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit (BVL) 2005).

	P90 signal ($\mu g\,kg^{-1}$)								
Food group	German 2008	Belgian	Average	P75	P90	P95	P97.5	P99	P99.9
Breakfast cereals	80	430	0.2	0.0	0.0	0.0	0.0	0.6	0.4
Chips	1000 (1063)[a]	1000 (1053)	0.8	0.0	0.0	0.2	0.2	0.9	2.3
Coffee	937[b]	506[b]	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Chips	530 (589)	622	3.5	0.0	0.3	0.3	2.2	4.4	13.3
Biscuits	545 (738)	650	2.7	0.0	0.1	0.6	1.5	2.7	8.1
Chocolate	–	414	0.9	0.0	0.0	0.3	0.4	1.4	2.4
Gingerbread	1000 (1262)	1000 (1698)	0.8	0.0	0.0	0.0	0.1	1.4	2.7
Sweet spiced biscuits	416 (563)	719	0.3	0.0	0.0	0.1	0.2	0.4	0.5
Toast	496 (661)	230	0.1	0.0	0.0	0.0	0.0	0.1	0.3
Coffee surrogate	801 (1370)[b]	1000 (3440)[b]	1.9	0.0	0.0	0.0	0.0	3.9	5.5
Bread	–	50	11.9	35.3	15.7	7.9	4.9	3.1	1.6
Bread rolls	–	50	0.4	0.3	0.6	0.7	0.4	0.4	0.3
Popcorn	–	494	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cereal bars	–	135	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total for Belgian signal values[c]			11.6	0.3	1.0	1.8	4.7	16.1	35.3
Total for German signal values[c]			16.3	0.0	0.0	37.4	59.3	72.9	84.2

Notes: [a]Values in parentheses are the measured but not the applied values.
[b]Powder.
[c]Effect of P90 signal values applied on all food groups considered.

value of knäckebröd was considered, but this value turned out to be higher than the levels measured for toast. The effect of applying the P90 signal value concept on the Belgian data (P90 of Belgian AA concentration data as a signal value) is also presented in Table 4, (1) for each food group separately and (2) for all food groups together.

The application of the German signal values to the Belgian data results in a significant reduction of the intake for the higher ($\geq$P95), but not for the lower intake percentiles. This can partly be explained by the fact that the signal values are P90 values limiting the higher AA concentration data. In addition, the intake at these percentiles is mainly determined by bread and coffee; no German signal value is presented for bread and in the case of coffee less than 2% of the samples exceeds the German signal value. Regarding the hypothetical Belgian signal values, a similar observation is made.

As expected, the introduction of P90 signal values affects the intake mainly through the food groups that contribute most to the exposure, namely chips, bread and biscuits.

Conclusion

Acrylamide (AA) is formed mainly during heating of carbohydrate-rich food. AA has always been present in food and is as such not a new contaminant. The derived margin of exposure (MOE) values, however, indicate that additional efforts to reduce AA exposure are a prerequisite.

This study examined the effect of some mitigation strategies on AA exposure. The most efficient approach for reducing AA exposure seems to be the reduction of the AA content in foodstuffs that are potentially important contributors to AA intake rather than the introduction of signal values (action limits). When starting from food with a high AA level, an already significant reduction of the dietary exposure can be achieved with some relatively minor measures. Signal values or action limits can be a useful tool for policy-makers to encourage the food industry to take action by means of a specific AA value. It is nevertheless the task of the food industry to ensure that the AA content of their products is as low as possible. In the literature several possibilities are proposed for reducing the AA level in food. For example, the Confederation of the Food and Drink Industries of the EU (CIAA) developed the 'AA Toolbox', which contains a brief description of possible intervention steps evaluated in cooperation with industry for reducing the AA content of food products and it has published AA pamphlets for five different sectors (CIAA 2009a, 2009b). However, the consumer also has to take responsibility for reducing his AA intake. It is estimated that about half the AA intake results from home-made meals or meals prepared in restaurants (Grob 2007). Even by means of some simple measures such as avoiding excessive browning when frying, baking or roasting potato and cereal products, the AA intake can be significantly reduced. In addition, the recommendations of having a diversified diet including sufficient vegetables and fruit, without exaggerating the consumption of fried food, are still valid and help reduce the AA intake (Mestdagh et al. 2007).

Finally, it must be stressed that an awareness of the food industry and consumers as well as a clear information campaign are indispensable for dealing with the AA issue.

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