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SCIENTIFIC REPORT OF EFSA

Results on the monitoring of acrylamide levels in food[1]

A Report of the Data Collection and Exposure Unit in Response to a request from the European Commission

(Question N° EFSA-Q-2008-343)

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Summary

Commission Recommendation 2007/331/EC on the monitoring of acrylamide levels in food of 3 May 2007 requires the Member States to perform annually in 2007, 2008 and 2009 the monitoring of acrylamide levels in certain foodstuffs. These data have to be transmitted directly to EFSA by 1 June each year.

Member States were invited to sample altogether approximately 2000 foods in the following food categories: 'French fries', 'potato crisps', 'potato products for home cooking', 'bread', 'breakfast cereals', 'biscuits', 'roasted coffee', 'jarred baby foods', 'processed cereal-based baby foods' and 'other products'. Results reported for foods sampled in 2007 have been collected and evaluated.

A total of 21 Member States and Norway submitted results for acrylamide content in foodstuffs. There were 2715 results reported for foods sampled in 2007, with a minimum of 76 reported for 'processed cereal-based baby foods' and a maximum of 854 reported for 'other products'. The arithmetic mean acrylamide content ranged from 44 μg/kg for 'jarred baby foods' to 628 μg/kg for 'potato crisps' with the equivalent geometric mean of 31 μg/kg and 366 μg/kg. The highest 95th percentile value was reported for 'potato crisps' at 1690 μg/kg and the highest maximum for 'other products' at 4700 μg/kg.

The 2007 results were compared with results collected by the European Commission Joint Research Centre's Institute for Reference Materials and Measurements in the years 2003 to 2006. There were 9311 results reported for foods sampled in 2003-2006. There were only eight results reported for the food category 'jarred baby foods' and they were not included in the comparison. The arithmetic mean acrylamide content ranged from 55 μg/kg for 'cereal-based baby foods' to 678 μg/kg for 'potato crisps' with the equivalent geometric mean of 35 μg/kg and 514 μg/kg. The highest 95th percentile value was reported for 'potato crisps' at 1718 μg/kg and the highest maximum for 'other products' at 7834 μg/kg.

There were some statistically significant differences between the two sampling occasions. Thus the product categories 'biscuits', 'breakfast cereals', 'French fries' and 'potato products for home cooking' showed higher contents of acrylamide in 2007 compared to 2003-2006, while on the other hand 'coffee', 'bread', 'potato crisps' and 'other products' showed lower contents. There was no statistically significant difference in acrylamide content for 'cereal-based baby foods'. Lower acrylamide content in the product categories 'bread' and 'coffee' contributed most to an approximately 30% decrease in acrylamide exposure based on detailed consumption data from two countries.

The food industry has developed voluntary measures, such as the so-called 'toolbox' approach, which provides guidance to help producers and processors identify ways to lower acrylamide in their respective products. After evaluating the data, there seems to be a trend towards lower exposure. This trend is not uniform across food groups and therefore it is not yet clear if the acrylamide toolbox had its desired effects. However, the acrylamide levels in particular for potato crisps and bread seemed to have decreased over time from an arithmetic mean of 678 to 628 μg/kg (514 to 366 μg/kg for the geometric mean) and from 274 to 136 μg/kg (122 μg/kg to 66 μg/kg for the geometric mean), respectively. The latter decrease may in part be due to changes in crispbread processing implemented by industry. A decrease from 427 to 253 μg/kg (327 to 177 μg/kg for the geometric mean) in the acrylamide content in coffee might have been caused by an initial overestimation, because there are no suitable mitigation measures for coffee so far.

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Background as provided by the European Commission

Commission Recommendation 2007/331/EC on the monitoring of acrylamide levels in food of 3 May 2007 requires the Member States to perform annually in 2007, 2008 and 2009 the monitoring of acrylamide levels in certain foodstuffs. These data have to be transmitted directly to EFSA by 1 June each year.

The data for the first year (2007) when made available are needed by the Commission in order to get an overview of the current occurrence situation in the foodstuffs tested. These data, together with other information, will be used by the Commission as a basis for deciding on any possible risk management measures.

A database on acrylamide occurrence is held by the European Commission Joint Research Centre's Institute for Reference Materials and Measurements (JRC-IRMM) in Geel who compiled data collected between 2003 and 2006. In the acrylamide monitoring recommendation this task was transferred to EFSA as foreseen under Article 33 of Regulation (EC) No. 178/2002.

Terms of Reference as provided by the European Commission

In order to give the Commission an overview of the data collected during the year 2007, EFSA is asked to compile these data in an occurrence report and compare them with the existing database for the years 2003-2006 compiled by the JRC-IRMM as far as this is possible. This would allow the Commission to identify whether or not the voluntary measures taken by the food industry have shown desirable effects.

Report

1. Introduction

In 2005, the European Food Safety Authority (EFSA) adopted a statement in which it endorsed the risk assessment on acrylamide in food carried out by the joint FAO/WHO Expert Committee on Food Additives (JECFA) in February 2005 (EFSA, 2005; FAO/WHO, 2005). In the assessment JECFA concluded that the margins of exposure for average and high consumers were low for a compound that is genotoxic and carcinogenic and that this may indicate a human health concern. Therefore, efforts to reduce acrylamide content in foodstuffs should be continued.

The food industry has investigated pathways of acrylamide formation. As a result voluntary measures were developed, such as the so-called 'toolbox' approach, which provides guidance to help producers and processors identify ways to lower acrylamide in their respective products (CIAA, 2006).

The collection of reliable data on acrylamide levels in food over at least a three-year time span across the European Community has been advocated in order to describe a clear picture of the levels of acrylamide in those foodstuffs that are known to contain high acrylamide levels and/or contribute significantly to the dietary intake of the whole population (EC, 2007). Special attention should be given to products for specific vulnerable groups, such as infants and young children.

In 2007, the European Commission issued a recommendation that Member States perform annually in 2007, 2008 and 2009 monitoring of acrylamide levels in foodstuffs according to an agreed sampling procedure (EC, 2007). Member States should provide by 1 June each year the monitoring data of the previous year to EFSA, who will compile these data into a database.

The European Commission Joint Research Centre's Institute for Reference Materials and Measurements (JRC-IRMM) established a database on acrylamide levels in food between 2003 and 2006 (Wenzl and Anklam, 2007).

In this report the results of the monitoring on acrylamide levels in 2007 are presented and compared to the results collected in 2003-2006.

2. Materials and Methods

2.1. Sampling procedure

2.1.1. Sampling points and analytical procedures

The requested sampling procedure required the sampling of products to be done at the market level (e.g. at supermarkets, smaller shops, bakeries, French fries outlets and restaurants), or at production sites. The analysis should be carried out before the expiry date of the sample.

Furthermore it was requested to choose analytical methods that can achieve a limit of quantification (LOQ) of 30 μg/kg for bread and baby foods, and 50 μg/kg for potato products, other cereal products, coffee and other products to ensure comparability in the analytical accuracy of results.

2.1.2. Products, sample numbers and frequencies

All 27 European Union Member States were invited to take samples according to a distribution based on population size with a minimum number of four per product category and Member State. In Table 1 the requested number of samples by food product are reported.

Table 1: Total number of samples to be taken in ten specified product categories.

Product categories	Requested number of samples
French fries sold as ready to eat	202
Potato crisps	202
Pre-cooked French fries/potato products for home cooking	202
Bread	202
Breakfast cereals	202
Biscuits including infant biscuits	202
Roasted coffee	202
Jarred baby foods	202
Processed cereal-based baby foods	202
Other products	224

For 'French fries' it was recommended to sample twice during the year (in March and November), and to sample at small outlets, fast food chains and restaurants. For 'potato crisps' it was also recommended to sample twice a year. Pre-cooked French fries or potato products should also be sampled twice. Analysis of each sample should be carried out on the product after preparation (e.g. frying, baking). The choice of the bread samples should reflect the eating habits of each country and include also crispbread. In the category 'breakfast cereals', muesli and porridge were excluded. Biscuits also included infant biscuits. Jarred baby foods should contain potato, root vegetables or cereals. The category 'other products' includes potato products, cereal products, coffee products, cocoa products and infant food other than those products specified in one of the other categories. This category would contain products like gingerbread, coffee substitutes, and snacks.

2.1.3. JRC-IRMM database

In a similar initiative to collect data on acrylamide in foods, the JRC-IRMM, in close collaboration with representatives of the Confederation of the European Food and Drink Industry (CIAA), established a database on acrylamide levels in food assessed in the years 2003 to 2006. The database was opened for submissions in April 2003 (Wenzl and Anklam, 2007). Official and private food control laboratories were requested to submit data on acrylamide levels in all kinds of food. Data were received mainly from Germany (77.6%), but also from Austria, Belgium, Finland, Greece, Ireland, Italy, the Netherlands, Spain, the United Kingdom (together 10.3%), and the food industry (12.1%). By the end of 2006 a total number of 9228 individual results had been entered into the database. A number of results were excluded according to several criteria with respect to the quality of the data. The final database included 7147 results. Another 2164 results from Germany for the year 2006 were added to the database at a later stage, resulting in 9311 results in the database at the end of the period. This complete database has not been published yet on the JRC-IRMM website, but was included in the analysis for this report.

2.2. Data handling

This report focuses on acrylamide results from foods sampled in 2007. Those results are compared with the results collected in 2003-2006. No outliers or extreme values were removed.

In this report, two scenarios were assumed for handling non-quantified results. First, according to a lower-bound scenario, values below the limit of detection (LOD) and values between the LOD and the limit of quantification (LOQ) were set to zero. Secondly, according to an upper-bound scenario values below LOD and values between LOD and LOQ were set to the LOD or the LOQ value, respectively. Both lower-bound and upper-bound scenarios were used to report descriptive statistics for the characteristics of the data distribution. For other descriptive statistics throughout this report, upper-bound scenarios were consistently used.

Acrylamide results from 2007 were compared with results from 2003-2006 by analysis of variance (ANOVA). Statistical significance was consistently evaluated at the 5% probability level ($p<0.05$). For this purpose, acrylamide values were log-transformed before the analysis to approximate a normal distribution. An indicator variable (1 = 'Germany'/0 = 'other countries') was included in the ANOVA model. In this way the different proportion of samples from Germany in the two datasets was taken into account. The same approach was taken for the 2007 results to compare the acrylamide content of potato products sampled between January and June with product sampled between July and December, respectively.

To determine the proportion of variance attributable to the between country variation, as compared to the total variability in the amount of acrylamide in food, the intraclass correlation (ICC) coefficient was calculated for each food group sampled in 2007 (Dunn, 1989).

In order to estimate the acrylamide dietary exposure in 2003-2006 and 2007, respectively, consumption data from Sweden and the Netherlands were used. The food consumption data from Sweden originated from 'Riksmaten 1997-1998' and were previously used to estimate acrylamide exposure by Svensson *et al.* (2003). The Dutch Food Consumption Survey 1997-1998 produced food consumption data for the Netherlands previously used to estimate acrylamide exposure by Konings *et al.* (2003).

Not all countries reported information on preparation, detailed information on products like kind of biscuits, type of bread, sampling information of potato products, type of cereals, or degree of roasting.

3. Results

3.1. Data reported in 2007

Table 2 summarises the number of samples and the different food groups for which acrylamide values were reported by the individual Member States and Norway in 2007.

Table 2: Number of samples for which acrylamide values were reported by the individual Member States and Norway.

	ISO-code	Total number of submitted samples	Sampling year 2007											
			Number of samples covering 2007	French fries as sold	Potato crisps	Precooked French fries/ potato products	Bread	Breakfast cereals	Biscuits including infant biscuits	Roasted coffee	Jarred baby foods	Processed cereal-based baby foods	Other products
Austria	AT	49	49	0	4	10	4	4	6	4	2	5	10
Belgium	BE	178	178	19	5	0	23	27	18	10	0	0	76
Bulgaria	BG	45	45	4	4	4	4	4	4	5	4	5	7
Czech Republic	CZ	130	130	42	10	5	5	5	15	5	5	4	34
Germany	DE	2048	1225	311	67	4	99	14	46	106	0	0	578
Estonia	EE	50	50	2	13	2	4	4	4	4	4	4	9
Spain	ES	25	25	0	0	0	0	0	0	6	0	5	14
Finland	FI	70	70	0	14	8	10	2	24	6	0	0	6
United Kingdom	GB	172	172	66	5	6	30	10	15	10	10	10	10
Greece	GR	41	20	1	4	1	2	2	0	2	2	3	3
Hungary	HU	50	0	0	0	0	0	0	0	0	0	0	0
Ireland	IE	93	93	20	6	2	18	6	21	5	7	3	5
Italy	IT	44	44	0	7	2	8	2	9	0	0	0	16
Lithuania	LT	40	40	4	4	4	4	4	4	4	4	4	4
Latvia	LV	38	38	1	4	5	4	4	5	4	4	4	3
Malta	MT	20	20	2	2	2	2	2	2	2	2	2	2
Netherlands	NL	73	73	6	6	12	8	6	15	6	6	4	4
Norway	NO	233	86	16	28	24	0	0	0	0	0	0	18
Poland	PL	119	119	7	7	7	14	14	14	14	14	14	14
Sweden	SE	67	67	8	8	8	8	4	4	4	15	4	4
Slovenia	SI	119	119	20	10	11	20	10	13	5	5	5	20
Slovakia	SK	52	52	0	8	4	5	4	8	6	0	0	17
Total number		**3756**	**2715**	**529**	**216**	**121**	**272**	**128**	**227**	**208**	**84**	**76**	**854**

Some Member States reported values of foods sampled in 2006 or 2008. For the current submissions only acrylamide values for foods sampled in 2007 are considered. Table 2 shows that 21 Member States and Norway submitted results of acrylamide content in foodstuffs to EFSA. Approximately 55% of the 3756 results originated from Germany, whereas approximately 30% of the submitted results covered foods not sampled in 2007. The number of results of foods sampled in 2007 ranged between 76 for 'processed cereal-based baby foods' to 854 for 'other products'.

3.2. Reported LOD and LOQ

In Table 3 the number of samples below the limits of detection (≤LOD) and quantification (≤LOQ) are reported, as well as the minimum and maximum reported values for LOD and LOQ for each product group. Two out of the 22 countries reported only the LOQ and one country reported only the LOD.

Table 3: Number of samples below the limits of detection (≤LOD) and quantification (≤LOQ) are reported, as well as the minimum and maximum reported values for LOD and LOQ for each product group.

		N	Minimum µg/kg	Maximum µg/kg
Biscuits	≤LOD	2	10	100
	≤LOQ	23	21	50
	Detects	202		
Bread	≤LOD	8	10	100
	≤LOQ	66	5	60
	Detects	198		
Breakfast cereals	≤LOD	4	30	100
	≤LOQ	34	21	100
	Detects	90		
Cereal-based baby food	≤LOD	14	1	100
	≤LOQ	23	10	85
	Detects	39		
Coffee	≤LOD	4	100	100
	≤LOQ	10	10	100
	Detects	194		
French fries	≤LOD	5	10	20
	≤LOQ	21	30	100
	Detects	503		
Jarred baby foods	≤LOD	11	10	100
	≤LOQ	34	5	85
	Detects	39		
Other products	≤LOD	16	10	250
	≤LOQ	92	3	500
	Detects	746		
Potato crisps	≤LOD	5	18	20
	≤LOQ	11	20	60
	Detects	200		
Potato products for home cooking	≤LOD	6	30	100
	≤LOQ	19	25	50
	Detects	96		

The minimum and maximum values for LOD and LOQ ranged from 1 to 250 and from 3 to 500 µg/kg, respectively. The lowest LOD value was reported for 'cereal-based baby food', whereas the lowest LOQ value was reported for 'other products'.

Fifteen countries reported using a liquid chromatography-tandem mass spectrometric (LC-MS/MS) method for the analysis of acrylamide. Six countries reported the use of a gas chromatography-mass spectrometric (GC-MS) or tandem mass spectrometric (GC-MS/MS) method. One country reported the use of both an ultra performance liquid chromatography-tandem mass spectrometric (UPLC-MS/MS) method and GC-MS/MS.

Seventeen countries reported the participation in one or more proficiency tests organised by the Food Analysis Performance Assessment Scheme (FAPAS) of the Central Science Laboratory York (UK) with satisfactory results.

In Figure 1 the arithmetic mean of the acrylamide content for each food category is shown. Each column has been sub-divided in order to include also the proportion of non-detected, non-quantified and quantified results reported.

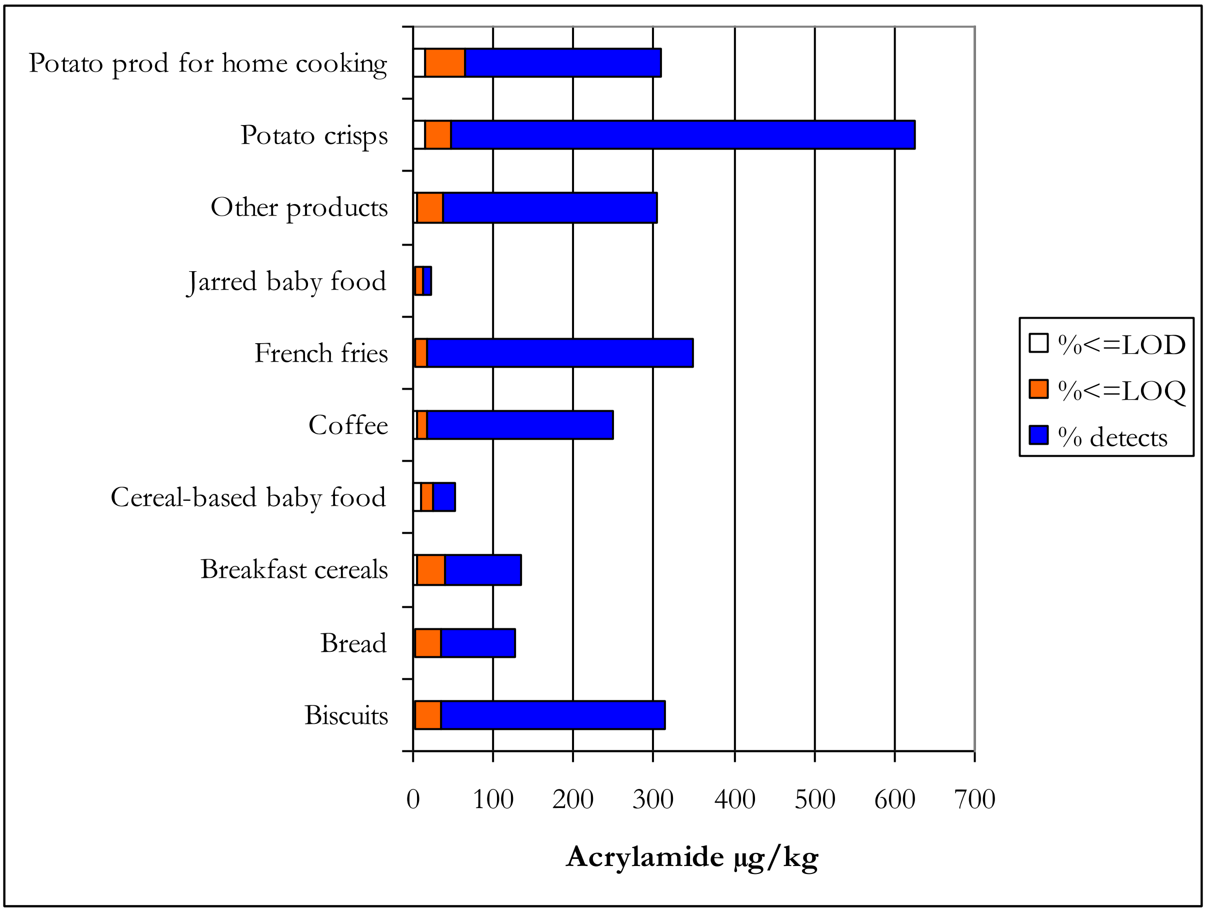

Figure 1: Acrylamide levels (µg/kg) in food groups, and percentage of non-detected (white), non-quantified (orange), and detected samples (blue) as a proportion of the total number of samples.

A relatively large part of the reported acrylamide values in the food categories 'jarred baby foods' (54%) and 'cereal-based baby food' (49%) consists of values below LOD or between LOD and LOQ.

3.3. Reported Measurement Uncertainty

All countries with the exception of Germany and Lithuania reported a value for Measurement Uncertainty (MU). In Table 4 the minimum and maximum MU is reported per method of analysis and product category. Thirteen countries reported that the LC-MS/MS method was accredited while three countries reported the use of a non-accredited LC-MS/MS method. Among countries that used a GC-MS or GC-MS/MS method, five reported the use of an accredited method while two reported the use of a non-accredited method.

Table 4: Reported Measurement Uncertainty (%) for the respective analytical method used and product category.

	LC-MS/MS		GC-MS(/MS)	
	Minimum MU %	Maximum MU %	Minimum MU %	Maximum MU %
Biscuits	6	53	3	53
Bread	8	26	11	64
Breakfast cereals	10	53	6	46
Cereal-based baby food	20	40	11	55
Coffee	7	53	10	39
French fries	6	26	5	28
Jarred baby foods	20	30	11	31
Other products	6	53	0	38
Potato crisps	6	44	3	36
Home-cook potato products	6	50	5	27

The reported MU for LC-MS/MS ranged between 6 and 53%, and for GC-MS/MS between 0 and 64%. The highest MU of 53% for LC-MS/MS was reported for the food categories 'biscuits', 'breakfast cereals' and 'other products'. The highest MU of 64% for GC-MS/MS was reported for the food category 'bread'. The variation in reported values for Measurement Uncertainty is high. However, it is not clear how the individual Member States calculated the value. After inquiring about an unacceptable high value reported by one Member State, it appeared that the recovery value was reported instead of the Measurement Uncertainty. It might be possible that countries reported the higher expanded measurement uncertainty rather than the standard measurement uncertainty.

3.4. Descriptive statistics of the results

In Tables 5 and 6 the descriptive statistics for the data collected in 2007 and in 2003-2006, respectively, are given. When there is a difference between values based on a lower bound scenario for LOD/LOQ and an upper-bound scenario, a range is given.

Table 5: Sample size (N), 5th percentile (P05), median, arithmetic mean, standard deviation (SD), 90th percentile, 95th percentile, and maximum for results covering foods sampled in 2007.

	N	P05# µg/kg	Median# µg/kg	Mean# µg/kg	SD# µg/kg	P90# µg/kg	P95# µg/kg	Maximum µg/kg
Biscuits	227	0-25	169	313-317	474-472	768	1127	4200
Bread	272	0-12	46-50	126-136	243-238	332	504	2430
Breakfast cereals	128	0-30	79-100	135-156	197-186	323	420	1600
Cereal-based baby food	76	0-5	5-42	52-74	83-75	181	237	353
Coffee	208	0-30	188	249-253	228-223	524	871	1158
French fries	529	3-30	253	348-350	369-367	720	996	2668
Jarred baby foods	84	0-5	0-31	23-44	37-36	86-94	94-100	162
Other products	854	0-20	160-169	305-313	476-472	689	1265	4700
Potato crisps	216	0-21	490	626-628	637-635	1430	1690	4180
Home-cook potato products	121	0-25	150	310-319	424-417	796	1144	2175

Range based on lower bound scenario for LOD/LOQ compared to an upper-bound scenario.

Table 6: Sample size (N), 5th percentile (P05), median, arithmetic mean, standard deviation (SD), 90th percentile, 95th percentile, and maximum for results covering foods sampled in 2003-2006.

	N	P05# µg/kg	Median# µg/kg	Mean# µg/kg	SD# µg/kg	P90# µg/kg	P95# µg/kg	Maximum µg/kg
Biscuits	1169	0-20	138	235-243	317-311	565	800	3324
Bread	767	0-10	116	267-274	376-371	641	997	2838
Breakfast cereals	223	0-10	74	109-116	123-118	260	320	846
Cereal-based baby food	77	0-10	31-34	50-55	73-71	118	229	386
Coffee	410	107	294	427	381-380	905	982	4948
French fries	1655	0-27	191	281-284	313-311	592	846	3428
Jarred baby foods	8	60	155	180	139	470	470	470
Other products	3877	0-15	206	436-441	633-630	1141	1647	7834
Potato crisps	947	149	510	678	533	1381	1718	4215
Home-cook potato product	178	0-10	119	260-267	506-502	570	1017	4653

Range based on lower bound scenario for LOD/LOQ compared to an upper-bound scenario.

The mean values ranged between 23 and 44 µg/kg for 'jarred baby foods' and 626-628 µg/kg for 'potato crisps' for foods sampled in 2007. The highest P95 value of 1690 µg/kg was reported for 'potato crisps'. Generally, the difference between descriptive statistics based on lower-bound and upper-bound scenarios was small, because a low number of samples had acrylamide values below the LOD or between the LOD and LOQ. However, approximately 50% of the data of the food categories 'jarred baby foods' and 'cereal-based baby foods' consist of values below the LOD or between the LOD and LOQ, which is reflected in the larger range seen for these categories.

The mean values ranged between 50 and 55 µg/kg for 'cereal-based baby foods' and 678 µg/kg for 'potato crisps' for foods sampled in 2003-2006. The highest P95 value of 1718 µg/kg was reported for 'potato crisps'.

P95 values in 2007 for the food categories 'biscuits', 'breakfast cereals', 'cereal-based baby foods', 'French fries', and 'potato products for home cooking' were higher than for samples in 2003-2006.

Arithmetic mean acrylamide content for results submitted by country in 2007 are shown per food category in Figures 2 to 11. It should be noticed that some Member States reported less than five measurements per food type (see Table 2).

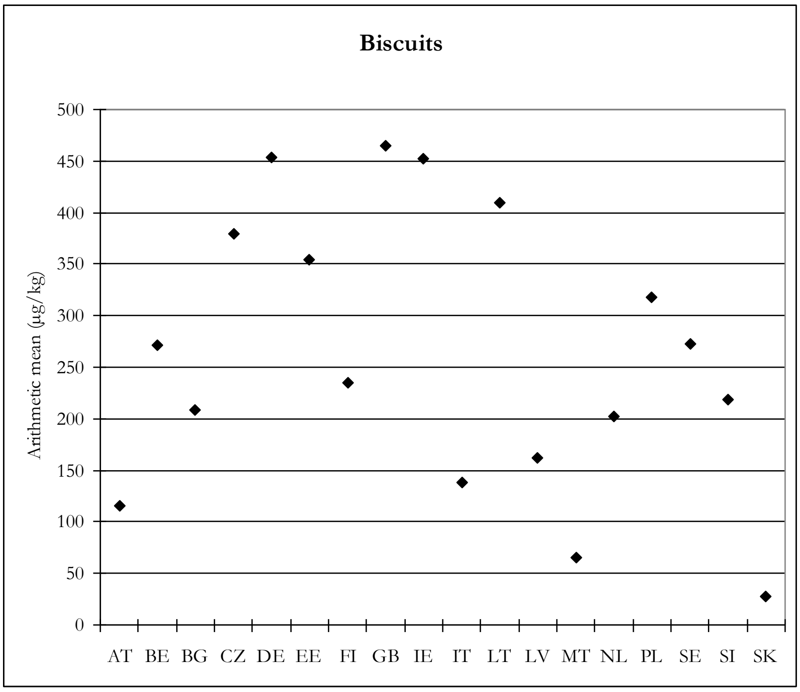

Figure 2: Arithmetic mean acrylamide content (marker) for 'biscuits' as reported by country indicated by ISO-country codes.

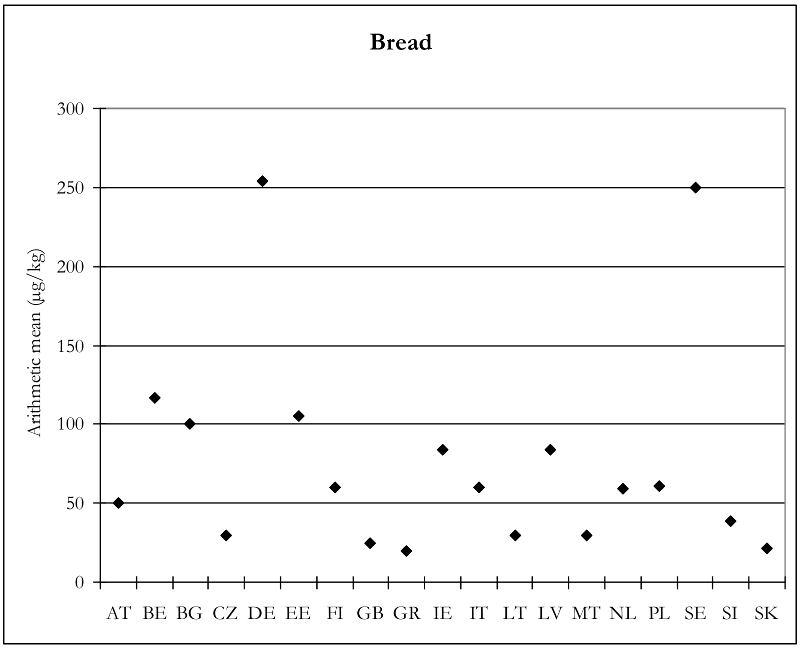

Figure 3: Arithmetic mean acrylamide content (marker) for 'bread' as reported by country indicated by ISO-country codes

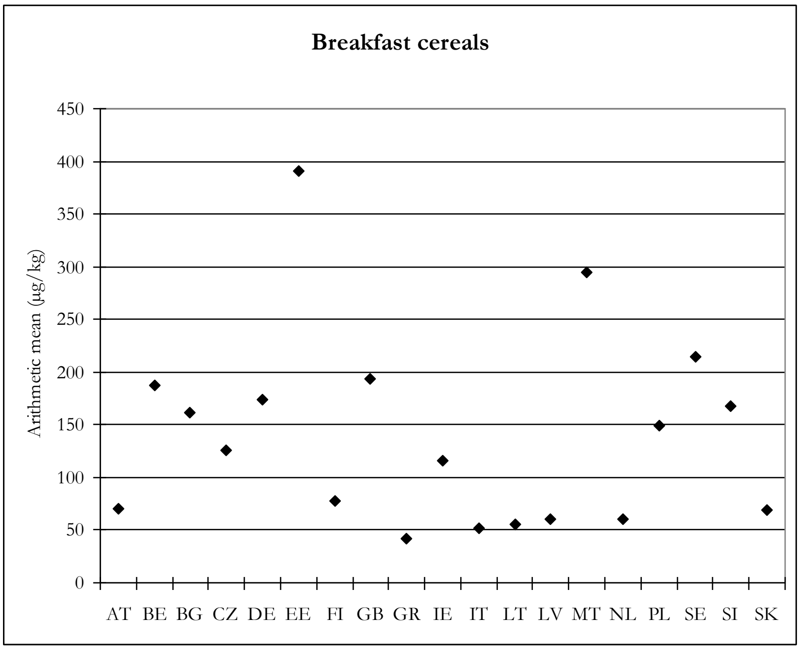

Figure 4: Arithmetic mean acrylamide content (marker) for 'breakfast cereals' as reported by country indicated by ISO-country codes.

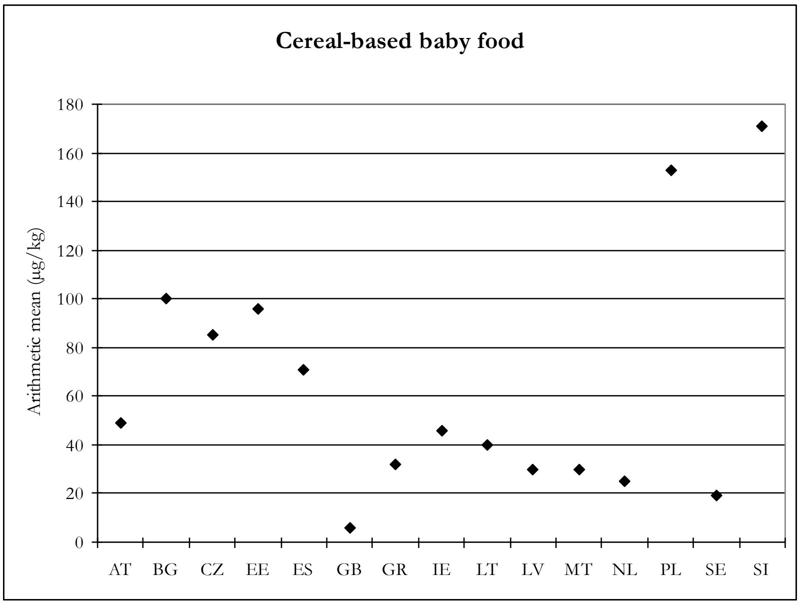

Figure 5: Arithmetic mean acrylamide content (marker) for 'cereal-based baby food' as reported by country indicated by ISO-country codes.

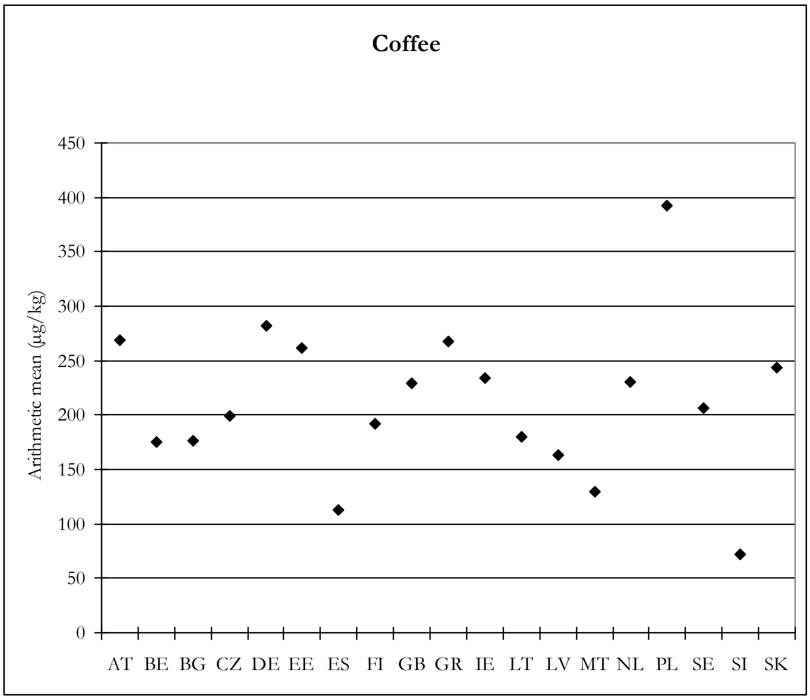

Figure 6: Arithmetic mean acrylamide content (marker) for 'coffee' as reported by country indicated by ISO-country codes.

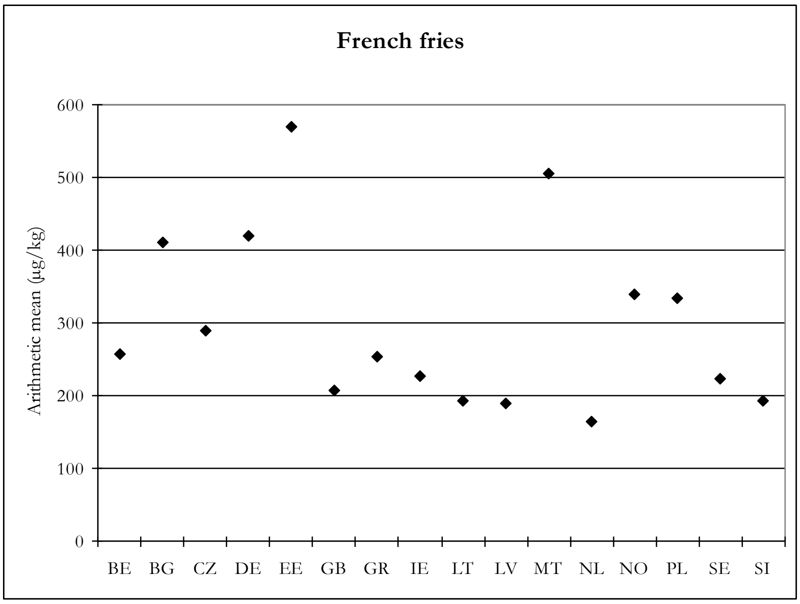

Figure 7: Arithmetic mean acrylamide content (marker) for 'French fries' as reported by country indicated by ISO-country codes.

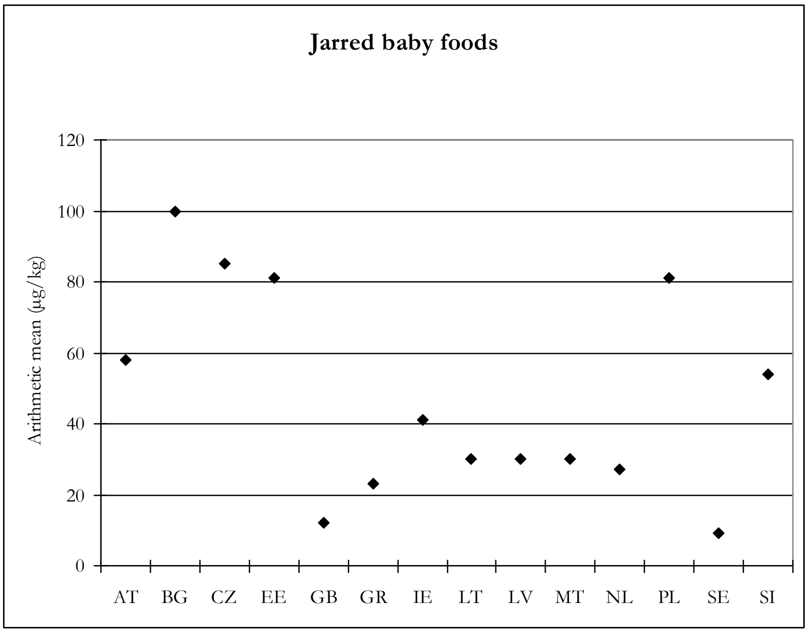

Figure 8: Arithmetic mean acrylamide content (marker) for 'jarred baby foods' as reported by country indicated by ISO-country codes.

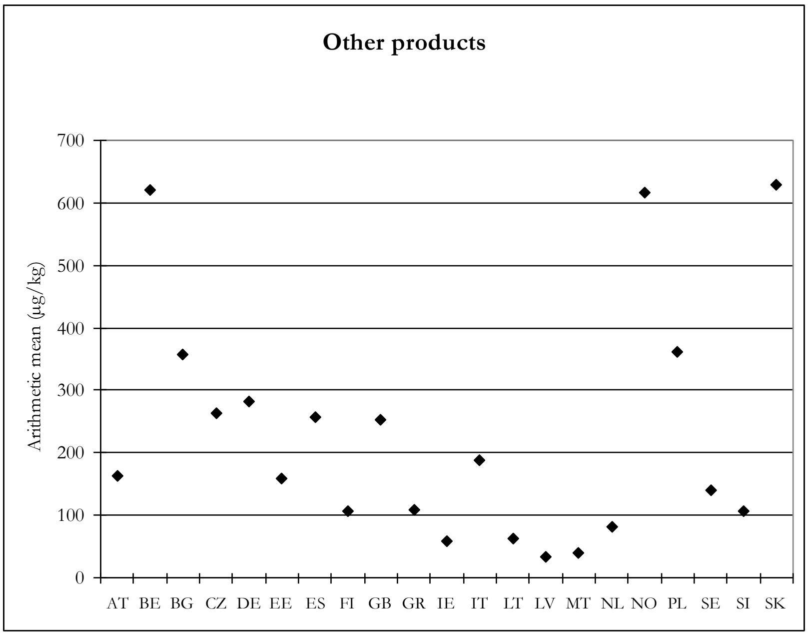

Figure 9: Arithmetic mean acrylamide content (marker) for 'other products' as reported by country indicated by ISO-country codes.

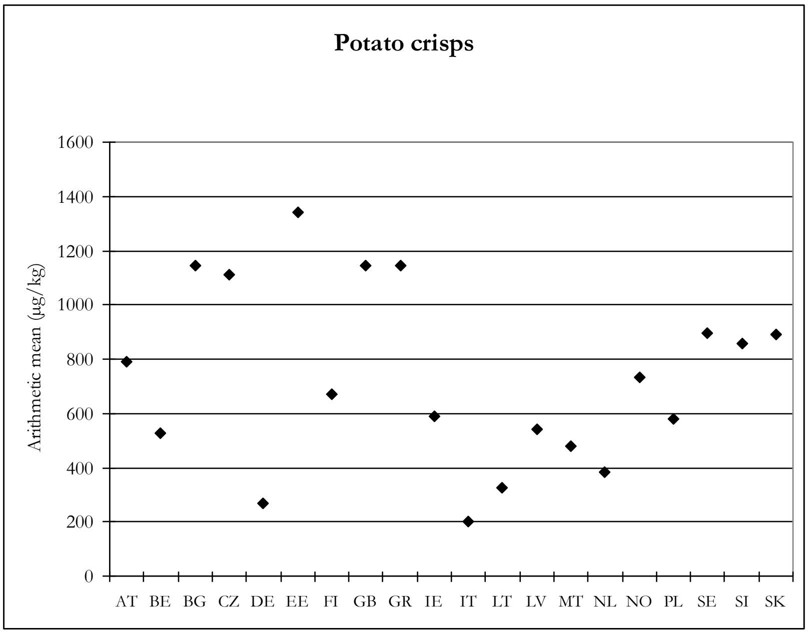

Figure 10: Arithmetic mean acrylamide content (marker) for 'potato crisps' as reported by country indicated by ISO-country codes.

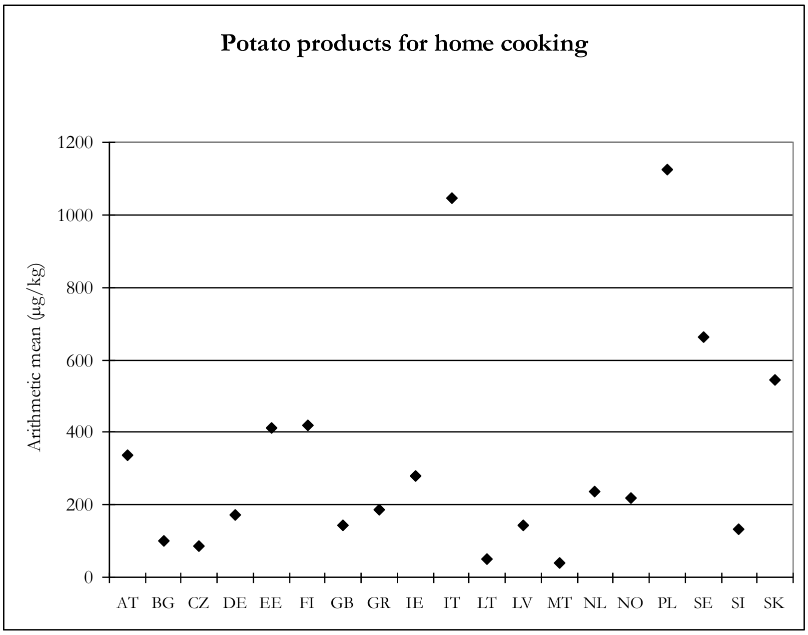

Figure 11: Arithmetic mean acrylamide content (marker) for 'potato products for home cooking' as reported by country indicated by ISO-country codes.

3.5. Comparison between acrylamide levels of foods sampled in 2007 and in 2003-2006

The acrylamide content for each food category as reported for foods sampled in 2007 and in 2003-2006 were compared by an analysis of variance (ANOVA). Descriptive statistics of this comparison are given in Table 7. The geometric mean was used because the two sample collections both basically exhibited lognormal distributions. The geometric mean is less influenced by extreme values compared to the arithmetic mean.

Table 7: Sample size (N), arithmetic mean (AM), geometric mean (GM), and significance for the analysis of variance (p) when comparing results reported in 2007 and in 2003-2006.

	2007			2003-2006			
	N	AM µg/kg	GM µg/kg	N	AM µg/kg	GM µg/kg	p
Biscuits	227	317	172	1169	243	135	0.007
Bread	272	136	66	767	274	122	<0.001
Breakfast cereals	128	156	108	223	116	77	0.015
Cereal-based baby food	76	74	43	77	55	35	0.725
Coffee	208	253	177	410	427	327	<0.001
French fries	529	350	227	1655	284	178	<0.001
Jarred baby foods[#]	84	44	31	8	180	142	-
Other products	854	313	154	3877	441	192	<0.001
Potato crisps	216	628	366	947	678	514	<0.001
Home-cook potato products	121	319	158	178	267	102	0.002

[#] Data of this product group is not compared.

Analyses of variance of the influence of sampling year for the respective product category resulting in a p-value lower than 0.05 suggests that there is a statistically significant difference. Results of the product category 'jarred baby foods' were not compared as the 2003-2006 material contained only eight samples. Geometric mean values for 'biscuits', 'breakfast cereals', 'French fries' and 'potato products for home cooking' for foods sampled in 2007 were higher, while the geometric mean values for 'bread', 'coffee', 'other products', and 'potato crisps' were lower than for foods sampled in 2003-2006.

The values for GM, P5 and P95 for foodstuffs sampled in 2007 and in 2003-2006 are visualised for each food category in Figure 12.

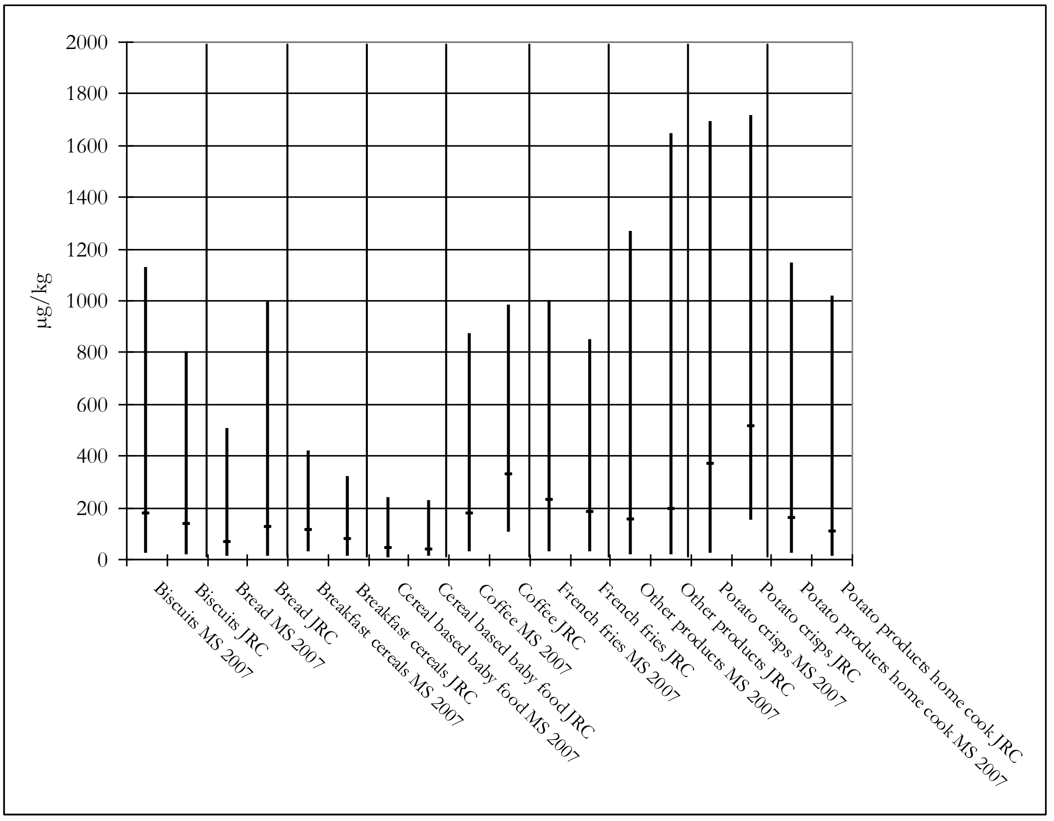

Figure 12: Comparison of geometric mean (cross bar), P5 and P95 (vertical line end points) for acrylamide values and food category for samples in 2007 and in 2003-2006.

In Table 8 the intraclass correlation (ICC) coefficients as influenced by Member State are reported for each food category sampled in 2007.

Table 8: ICC calculated for Member State influence in each product category.

Food Category	N	ICC
Biscuits	227	0.155
Bread	272	0.211
Breakfast cereals	128	0.190
Cereal-based baby food	76	0.642
Coffee	208	0.098
French fries	529	0.073
Jarred baby food	84	0.768
Other products	854	0.220
Potato crisps	216	0.265
Home-cook potato products	121	0.327

From Table 8 it is clear that the proportion of variance attributable to between country variability compared to total variability ranges from 7.3% for 'French fries' to 76.8% for 'jarred baby food'.

3.6. Influence of sampling season on acrylamide formation in potato products

Six countries reported in total 812 results on acrylamide content of 'French fries', 'potato crisps', and 'potato products for home cooking' sampled in different seasons. From these 812 results, 588 originated from Germany, for which foods were sampled throughout the whole year. Data were split into two groups. The first group contains data for which foods were sampled between January and June. The second group contains data for which foods were sampled between July and December. In Table 9 results of a comparison between acrylamide contents in potato products per sampling period are given as well as the significance (p) of the influence of season as measured by an analysis of variance (ANOVA).

Table 9: Sample size (N), geometric mean acrylamide content (GM), and significance for the analysis of variance (p) for acrylamide contents in potato products in two different seasons.

	January-June		**July-December**		p
	N	**GM µg/kg**	**N**	**GM µg/kg**	
French fries	213	246	345	201	0.017
Potato crisps	55	275	143	244	0.846
Home-cook potato products	19	155	36	212	0.319
Total Potato products	**287**	**244**	**524**	**213**	**0.117**

The acrylamide content of French fries sampled between January and June is significantly higher than the acrylamide content of French fries sampled between July and December. There was no significant influence of season for the other potato product groups 'potato crisps' and 'potato products for home cooking' as well as the overall group of potato products.

3.7. Acrylamide dietary exposure

Estimates of acrylamide dietary exposure were calculated based on food consumption data from Sweden and the Netherlands as described in Section 2.2 (Table 10). In this context the arithmetic mean food consumption is used. On the occurrence side, the geometric mean of acrylamide content estimated in foods sampled in 2007 and 2003-2006 is used.

Table 10: Estimates of acrylamide exposure based on food consumption data from Sweden and the Netherlands (NL) and geometric mean acrylamide content.

	Mean consumption		Acrylamide		Exposure Sweden		Exposure NL	
	g/day	g/day	2003-06 µg/g	2007 µg/g	2003-06 µg/day	2007 µg/day	2003-06 µg/day	2007 µg/day
Bread	102	133	0.122	0.066	12.4	6.7	16.2	8.8
Breakfast cereals	7.4	1	0.077	0.108	0.6	0.8	0.1	0.1
Biscuits	6.2	11	0.135	0.172	0.8	1.1	1.5	1.9
Coffee	25.7#	25.6#	0.327	0.177	8.4	4.6	8.4	4.5
French fries	12	20	0.178	0.227	2.1	2.7	3.6	4.5
Home-cook potato products	11	5	0.102	0.158	1.1	1.7	0.5	0.8
Potato crisps	2.9	5	0.514	0.366	1.5	1.1	2.6	1.8
Total					**27.0**	**18.7**	**32.8**	**22.5**

Consumption of coffee is based on 7 gram roasted coffee per 125 ml coffee.

Acrylamide exposure estimates decreased from 27.0 µg/day in 2003-2006 to 18.7 µg/day in 2007 when using Swedish food consumption data and from 32.8 to 22.5 µg/day when using Dutch food consumption data, a 31% decrease in both cases. The food categories contributing the most to the decrease in acrylamide exposure were bread and coffee with a reduction of 21% and 14%, respectively in Sweden, and 23% and 12% in the Netherlands.

Acrylamide exposure estimates based on arithmetic mean values, decreased from 50.0 µg/day in 2003-2006 to 33.0 µg/day in 2007 when using Swedish food consumption data and from 60.6 to 39.9 µg/day when using Dutch food consumption data.

4. Discussion

In March 2006, a joint workshop was organised by the European Commission and the CIAA for government, industry and academia to discuss current knowledge of acrylamide formation, results of recent studies and projects, opportunities, gaps and constraints in attempts to reduce the formation of acrylamide. One of the aims of the workshop was to update the toolbox approach to improve industrial processes in relation to acrylamide formation (CIAA, 2005). The toolbox document was published in October 2006 (CIAA, 2006). Following the workshop, a number of actions were agreed in the Expert Committee on Environmental and Industrial Contaminants of the European Commission so as to ensure that voluntary measures, such as the toolbox approach, were effectively applied by food operators and the results monitored. These actions included the development of the European monitoring program as issued on 3 May 2007, and the development and distribution of sector-specific brochures giving guidance to small- and medium-sized food operators on how to take steps to minimise acrylamide formation. The brochures or pamphlets were designed for several product categories: 'biscuits', 'crackers' and 'crispbreads', 'bread product's, 'breakfast cereals', and 'fried potato products'.

The formation of acrylamide generally takes place via the reaction of asparagine and reducing sugars at temperatures higher than 120 °C. The following measures have been recommended to reduce the amounts of acrylamide in food: control levels of reducing sugars, control temperature and time of cooking, aim for a lighter golden colour when cooking, and control of the final moisture content, replacement of ammonium bicarbonate with other raising agents, use of fructose should be avoided, avoidance of over baked products.

4.1. Potato products

The area of potato products has drawn much attention because of their important contribution to the acrylamide exposure based both on a high consumption of the products and on a high content of acrylamide. Controlling the sugar content is currently the primary measure employed by the industry to reduce acrylamide levels in crisps by selecting potato varieties with low levels of reducing sugars (CIAA, 2009). This has proven to be at least partly successful. For samples of potato crisps in 2007, as reported by Member States to EFSA, the geometric mean acrylamide level was 366 µg/kg, which was a statistically significant decrease compared to the acrylamide level of 514 µg/kg reported in 2003-2006.

Also Foot *et al.* (2007) reported a significant decline in acrylamide levels of potato crisps, from around 1000 µg/kg to around 600 µg/kg, when comparing German samples from May-June 2002 with the same period in 2003. However, they suggested that a level of 500 µg/kg measured leading up to July 2006 was the minimum level possible with the then available mitigation tools, and that new tools for lowering sugar/asparagine levels were needed.

Monitoring data from the Lebensmittelchemisches Institut in Germany also showed a decrease in acrylamide content of potato crisps from about 1000 µg/kg in 2002 to 300-500 µg/kg in 2008 (Matissek, 2008).

As indicated by the Union of the European Potato Processing Industry (UEITP), Foot *et al.* (2007) reported a decrease between 2002 and 2006 in average acrylamide content in French fries cooked according to the on-pack instructions. However, this could not be confirmed in the current study. On the contrary, the geometric mean acrylamide content in French fries reported in 2007 was 227 µg/kg, which was significantly higher than 178 µg/kg reported in 2003-2006. This was also the case for the food category 'potato products for home cooking' where the geometric mean acrylamide content of 158 µg/kg in 2007 was significantly higher than the value of 102 µg/kg in 2003-2006.

The acrylamide content in French fries are still several times above what seems to be achievable with potatoes low in reducing sugars and the use of low final oil temperatures. The median acrylamide content in 147 samples from restaurants in the area of Zurich was 76 µg/kg after following some simple instructions (Foot *et al.*, 2007).

To minimise losses from spoilage and shrinkage, potatoes are stored at low temperatures. However, low temperatures tend to increase sugar levels. This means that potatoes stored over the winter season and processed in spring may have higher acrylamide content than potato products processed immediately after harvesting. Storage of tubers at higher temperatures reduces sugar levels (Foot *et al.*, 2007). In the present study, a significant difference in mean acrylamide content could not be identified for the general potato group, however, for 'French fries' the geometric mean acrylamide content was significantly higher for products sampled between January and June (246 µg/kg), compared to products sampled between July and December (201 µg/kg). Controlling storage conditions of tubers is one of the measures added to the toolbox approach (CIAA, 2009).

4.2. Cereals and cereal products

A second large group of products contributing to acrylamide exposure is the cereals and cereal products area. During the joint workshop mentioned above it was concluded that there had been only limited success in reducing acrylamide formation in cereals and cereal products in relation to recipe formulation and processing conditions (Konings *et al.* 2007). However, there were some promising leads for the future, for example, the use of the enzyme asparaginase, which is now listed as a separate tool in the acrylamide toolbox (CIAA, 2009).

Three food groups belonging to the broad group of cereal products were sampled in the present study: 'biscuits', 'breakfast cereals' and 'bread'. From the comparison of acrylamide data between 2007 and 2003-2006, the trend is ambiguous. The average acrylamide content in the food categories 'biscuits' and 'breakfast cereals' were significantly higher in 2007 than in 2003-2006, but for 'bread' it was the opposite.

The decrease in acrylamide content from a geometric mean of 122 µg/kg in 2003-2006 to 66 µg/kg in 2007 in the 'bread' category may in part be due to changes in crispbread processing. A survey by the European Association of Chocolate, Biscuit and Confectionary Industries (CAOBISCO) assessed the extent to which bread manufacturers had been successful in reducing the acrylamide content. In the case of non-fermented crispbreads, changes to the oven profile had led to a 25-75% reduction in acrylamide levels (Konings *et al*., 2007).

The spread in the reported results, as measured by the standard deviation and illustrated as a range in Figure 12, increased in the latest sampling period for 'biscuits' and 'breakfast' cereals, but decreased for 'bread'. The low intraclass correlation coefficients for all three food categories indicate that the spread is due more to within than between country differences with possible large variations in product mix and processing conditions within countries.

4.3. Coffee

For coffee, also an important contributor to acrylamide exposure, results of laboratory scale experiments have led to the conclusion that only limited process options are available to reduce acrylamide levels without affecting the quality in respect to the consumer acceptance of a product (CIAA, 2009, Guenther *et al*., 2007). On the other hand, preliminary results from lab/pilot plant studies show a possible significant reduction in green coffee asparagine levels after asparaginase treatment.

Since little progress in reducing acrylamide formation in coffee has been achieved in practice, it was surprising that the current study found a significant decrease in the acrylamide content in coffee from a geometric mean of 327 µg/kg in 2003-2006 to 177 µg/kg in 2007. Most of the samples from 2003-2006 originated from Germany and were classified as 'coffee extract' or 'coffee roasted'. Many food analysis laboratories initially experienced major problems with the determination of acrylamide in 'difficult' matrices, such as coffee, leading to potential overestimation (Guenther *et al*., 2007). This might have influenced the acrylamide results for samples collected in 2003-2006. Caution is thus advocated when interpreting the perceived acrylamide reduction for coffee.

4.4. Other products

The category 'other products' is a disparate collection of potato products, cereal products, coffee products, cocoa products and infant food other than those products specified in one of the specific categories (e.g. gingerbread, coffee substitutes). Of the data from 2007, 67% of the 'other products' can be classified as cereal product, whereas another 8% can be classified as potato product.

The geometric mean acrylamide content in the category 'other products' decreased significantly from 192 µg/kg as reported in 2003-2006 to 154 µg/kg as reported in 2007. Of the samples classified as 'other products' in the 2003-2006 data collection, many were products like 'wafer gingerbread' and 'brown gingerbread'. Results from monitoring activities in the Netherlands have shown a decrease in the acrylamide levels of gingerbread type products, particularly for Dutch spiced cakes analysed in 2006, probably because of a change in raising agent (Konings *et al*., 2007). Such a change, if applied also in other Member States, might be at least partially an explanation to the lower acrylamide levels seen in 2007 for the category 'other products'.

4.5. Acrylamide exposure

Dybing *et al.* (2005) reviewed data on the contribution of different food sources to acrylamide exposure across different population groups in Europe. Although there are large differences between countries, the authors identified some common dietary patterns. Foods contributing consistently to about 80-100% of the total acrylamide exposure included potatoes (French fries, chips, fried potatoes), coffee, bread, and biscuits/cakes with minor contributions from breakfast cereals, crackers, and rusks.

To measure trends in overall acrylamide exposure over time, consumption data for the specific food groups 'bread', 'breakfast cereals', 'biscuits', 'coffee', 'French fries', 'potato products for home cooking' and 'potato crisps' available from two previous studies were used (Svensson *et al.* 2003; Konings *et al.* 2003). Results indicated a 30% decrease from about 30 μg/day to about 20 μg/day in acrylamide exposure between 2003-2006 and 2007 when using the geometric mean for the calculation. However, it should be noted that only consumption data from two European countries were included and that bread and coffee contributed to most of the reduction. As has been highlighted previously, results for coffee may have been influenced by methodological difficulties in the 2003-2006 material.

Conclusions

There seems to be an overall trend towards lower acrylamide values over time. However, this trend is not consistent across food groups. The food categories 'biscuits', 'breakfast cereals', 'French fries', and 'potato products for home cooking' showed an increase in acrylamide content over time, while 'coffee', 'bread', 'potato crisps', and 'other products' showed a decrease. There was no difference in acrylamide content of 'cereal-based baby foods'. The lower acrylamide content in the product categories 'bread' and 'coffee' contributed most to a decrease in total acrylamide exposure. Some caution should be taken when comparing acrylamide values over time because of the small sample size in some food groups.

It is not yet clear if the acrylamide toolbox has achieved its desired effects. However, the acrylamide levels for potato crisps and crispbreads seemed to have decreased over time, which is encouraging because early mitigation efforts have focussed on those two food groups. A decrease in the acrylamide content in coffee is considered less realistic, since there are no suitable mitigation measures for coffee available so far. The perceived reduction might have been caused by methodological difficulties in early testing.

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