SCIENTIFIC REPORT OF EFSA

RESULTS ON ACRYLAMIDE LEVELS IN FOOD FROM MONITORING YEAR 2008[1]

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ABSTRACT

Commission Recommendation 2007/331/EC of 3 May 2007 on the monitoring of acrylamide levels in food requires the Member States to perform annually in 2007, 2008 and 2009 the monitoring of acrylamide levels in certain foodstuffs. The current report describes the results of the monitoring exercise for 2008. A total of 22 Member States and Norway submitted to EFSA 3461 results. The mean acrylamide level (upper bound values) ranged from 23 µg/kg for 'bread non-specified' to 1124 µg/kg for 'substitute coffee'. Both the highest 95th percentile value and maximum value were reported for 'substitute coffee' at 3300 and 7095 µg/kg, respectively. The 2008 results were compared with the 3281 results collected in 2007. The product categories 'potato crisps', 'instant coffee' and 'substitute coffee' showed statistically significantly higher levels of acrylamide in 2008 data compared to 2007 data. On the other hand, 'French fries' and 'fried potato products for home cooking', 'soft bread', 'bread not specified', 'infant biscuit', 'biscuit not specified', 'muesli and porridge' and 'other products not specified' showed statistically significantly lower levels of acrylamide in 2008 data compared to 2007 data. There were no statistically significant differences in acrylamide level for the other food groups. This report suggests lower acrylamide values in 2008 compared to 2007. Whether this represents a trend towards lower acrylamide levels over time will become clearer from the results obtained in the coming years. An exposure assessment will be carried out next year to determine the biological relevance of any change in acrylamide levels over the three years analysed.

KEY WORDS

Acrylamide, food, monitoring, trend, French fries, potato crisps, coffee, mitigation measures.

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Summary

Commission Recommendation 2007/331/EC of 3 May 2007 on the monitoring of acrylamide levels in food requires the Member States to perform annually in 2007, 2008 and 2009 the monitoring of acrylamide levels in certain foodstuffs. The current report describes the results from the monitoring exercise of 2008.

Member States were invited to analyse altogether approximately 2000 food samples in the following main 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’.

A total of 22 Member States and Norway submitted results for acrylamide level in foodstuffs. There were 3461 results reported for foods sampled in 2008, with a minimum of 96 reported for ‘processed cereal-based baby foods’ and a maximum of 782 reported for ‘other products’.

Two scenarios were assumed for handling data below the limit of detection (LOD) or quantification (LOQ). First, according to a lower bound scenario, values below LOD and values between the LOD and the 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.

The upper bound mean acrylamide level ranged from 23 µg/kg for ‘bread non-specified’ to 1124 µg/kg for ‘substitute coffee’. Both, the highest 95th percentile value and maximum value were reported for ‘substitute coffee’ at 3300 and 7095 µg/kg, respectively.

The 2008 results were compared with the 3281 results collected in 2007. In 2007, the upper bound mean acrylamide level ranged from 44 µg/kg for ‘jarred baby foods’ to 800 µg/kg for ‘substitute coffee’. Both, the highest 95th percentile value and maximum value were reported for ‘substitute coffee’ at 3025 and 4700 µg/kg, respectively.

The product categories ‘potato crisps’, ‘instant coffee’ and ‘substitute coffee’ showed statistically significantly higher levels of acrylamide in 2008 data compared to 2007 data. On the other hand, ‘French fries’ and ‘fried potato products for home cooking’, ‘soft bread’, ‘bread not specified’, ‘infant biscuit’, ‘biscuit not specified’, ‘muesli and porridge’ and ‘other products not specified’ showed significantly lower levels of acrylamide in 2008 data compared to 2007 data. There were no statistically significant differences in acrylamide level for the other food groups.

The food industry has developed voluntary measures, such as the so-called ‘toolbox’ approach, which provides guidance to help producers and processors in identifying ways to lower acrylamide in their respective products. High upper bound mean and 95th percentile acrylamide levels were found in all coffee groups and in particular in ‘substitute coffee’ and ‘instant coffee’ where no mitigation measures have been suggested. In the first acrylamide report in which 2003-2006 data were compared to 2007 data no clear trend towards lower acrylamide values over time was found. When comparing 2008 to 2007 data there seems to be a more apparent trend towards lower acrylamide values over time. However, it may be appropriate to assume that the application of the acrylamide toolbox was effective only in a limited number of food groups.

Whether this represents a trend towards lower acrylamide levels over time will become clearer from the results obtained in the coming years. An exposure assessment will be carried out next year to determine the biological relevance of any change in acrylamide levels over the three years analysed.

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BACKGROUND AS PROVIDED BY THE EUROPEAN COMMISSION

In order to give the Commission an overview of the data collected during the year 2007 and 2008, EFSA is asked to compile the 2008 data in an updated occurrence report and compare them with the existing database for the year 2007 compiled by EFSA in 2009. This would allow the Commission to identify whether or not the voluntary measures taken by the food industry have shown desirable effects.

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REPORT

1. Introduction

In 2005, the European Food Safety Authority (EFSA) adopted a statement to endorse 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 this assessment JECFA concluded that the margins of acrylamide 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 to identify ways to lower acrylamide in their respective products (CIAA, 2006). This toolbox was updated in 2009 (CIAA, 2009).

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 have 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 undertake annual monitoring of acrylamide levels in foodstuffs for the years 2007, 2008 and 2009 in accordance with 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 the first report the results of the monitoring on acrylamide levels in 2007 were presented and compared to the results collected in 2003-2006 (EFSA, 2009).

In the current report the results of the monitoring of acrylamide levels in 2008 are presented and compared to the updated results covering year 2007.

2. Materials and Methods

2.1. Sampling procedure

2.2.1. Sampling points and analytical procedures

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

Furthermore it was requested to use 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 is 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’ and ‘pre-cooked French fries or potato products for home cooking’ it was also recommended to sample twice a year. 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 crisp bread. 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.

3. Data handling

For the first report covering 2007 sampling, Member States transmitted data for 2007 as well as some data for 2008 (not included in the report). For this updated report covering the 2008 sampling Member States transmitted data for 2008 as well as some new data for 2007. Consequently in this report presenting the new data for 2008, the descriptive statistics for 2007 data have been slightly amended from the previous report to reflect the new submissions.

After a meeting of the Commission Expert Group on Industrial and Environmental Contaminants held in October 2009, the Commission requested five food groups (‘potato products for home cooking’, ‘bread’, ‘biscuits including infant biscuits’, ‘roasted coffee’ and ‘other products’) to be subdivided into more refined subgroups (as presented in Table 6) in order to compare more specific groups in a trend analysis.

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

Two scenarios were assumed for handling data below the limit of detection (LOD) or quantification (LOQ). First, according to a lower bound scenario, values below LOD and values between the LOD and the 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.

Results that did not meet the specifications for LOD and LOQ given in the Commission Recommendation 2007/331/EC were kept in the dataset as the difference between lower and upper bound values (as presented in Table 6 and 7) were minor and thus the data with high LOD and LOQ did not significantly influence the outcome of the data evaluation.

Acrylamide results from 2008 were compared with results from 2007 using regression analysis, separately for each food group. Statistical significance was consistently assessed at the 5% level ($p<0.05$). Similarly, regression models were used to compare the acrylamide content of potato products sampled in 2008 between January and June with samples collected between July and December. Consistently in all models, estimates were adjusted by country by means of random effects to remove some geographical correlation in the data when evaluating time or seasonal trends.

In the first report on acrylamide occurrence levels (EFSA, 2009) exposure assessment estimates were presented based on published food consumption data from the Netherlands and Sweden aggregated per broad food group. In this report no exposure assessment is presented. More accurate exposure assessments based on more detailed food consumption data will be presented in the 2011 annual report comparing 2007 and 2008 data to 2009 data. This detailed data is available from the EFSA Comprehensive database, a new database containing detailed food consumption data from 21 different Member States which will be accessible for exposure assessment from December 2010.

3. Results

3.1. Data reported in 2007 and 2008

Table 2 and 3 summarise the number of samples for which acrylamide values were reported by the individual Member States and Norway in 2007and 2008 sorted into the 10 main food categories

Table 2: Number of samples per food group submitted by individual Member States and Norway in 2007

		Sampling year 2007										
	ISO-code	**Total number of samples**	**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	0	4	10	4	4	6	4	2	5	10
Belgium	BE	178	19	5	0	31	27	20	10	0	4	62
Bulgaria	BG	45	4	4	4	4	4	4	5	4	5	7
Cyprus	CY	33	2	2	2	4	4	4	7	3	4	1
Czech Republic	CZ	130	42	10	5	5	5	15	5	5	4	34
Germany	DE	1757	427	121	25	143	14	302	134	0	1	590
Estonia	EE	50	2	13	2	4	4	4	4	4	4	9
Spain	ES	25	0	0	0	0	0	0	6	0	11	8
Finland	FI	70	0	14	8	10	2	24	6	0	0	6
United Kingdom	GB	172	66	5	6	30	10	15	10	10	10	10
Greece	GR	20	1	4	1	2	2	2	2	2	3	1
Ireland	IE	93	20	6	2	18	6	21	5	7	3	5
Italy	IT	45	0	8	2	8	2	9	0	0	0	16
Lithuania	LT	40	4	4	4	4	4	5	4	4	4	3
Latvia	LV	38	1	4	5	4	4	5	4	4	4	3
Malta	MT	20	2	2	2	4	2	2	2	2	2	0
Netherlands	NL	73	6	6	12	8	6	15	6	6	4	4
Norway	NO	86	16	28	24	0	0	0	0	0	0	18
Poland	PL	119	7	7	7	14	14	14	14	14	14	14
Sweden	SE	67	8	8	8	8	4	4	4	15	4	4
Slovenia	SI	119	20	10	11	20	10	13	5	5	6	19
Slovakia	SK	52	0	8	4	5	4	8	6	0	0	17
Total number		**3281**	**647**	**273**	**144**	**330**	**132**	**492**	**243**	**87**	**92**	**841**

Table 3: Number of samples per food group submitted by individual Member States and Norway in 2008.

		Sampling year 2008										
	ISO-code	**Total number of samples**	**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	56	4	3	6	6	4	6	10	4	2	11
Belgium	BE	171	21	10	0	21	15	34	13	0	0	57
Cyprus	CY	41	4	4	6	4	4	6	4	4	5	0
Czech Republic	CZ	195	85	5	0	10	6	20	5	6	1	57
Germany	DE	1553	236	175	27	107	3	313	165	22	12	493
Denmark	DK	105	17	9	10	4	5	8	16	4	2	30
Estonia	EE	57	6	3	6	10	3	9	3	4	2	11
Spain	ES	100	3	6	20	18	0	10	18	18	4	3
Finland	FI	70	0	16	3	10	1	23	3	3	0	11
United Kingdom	GB	303	66	53	74	35	10	14	10	10	10	21
Greece	GR	70	5	13	4	6	8	9	6	6	4	9
Hungary	HU	104	24	8	2	9	12	13	7	10	9	10
Ireland	IE	60	11	9	4	4	4	7	6	4	5	6
Italy	IT	96	3	43	10	5	6	6	6	1	0	16
Lithuania	LT	40	4	4	4	4	4	4	4	4	4	4
Latvia	LV	42	0	6	6	6	3	3	4	4	4	6
Malta	MT	20	2	2	2	2	2	2	2	1	3	2
Netherlands	NL	77	6	6	12	9	6	9	7	4	13	5
Norway	NO	61	8	16	7	4	4	4	6	4	4	4
Romania	RO	81	4	16	10	7	14	8	8	7	4	3
Sweden	SE	56	8	8	8	8	4	4	4	4	4	4
Slovenia	SI	41	4	4	4	4	0	8	4	4	4	5
Slovakia	SK	62	0	16	8	5	2	7	10	0	0	14
Total number		**3461**	**521**	**435**	**233**	**298**	**120**	**527**	**321**	**128**	**96**	**782**

Table 2 shows that 21 Member States and Norway submitted 3281 results for the 2007 acrylamide monitoring exercise whereas Table 3 shows that 22 Member States and Norway submitted 3461 results for the 2008 acrylamide monitoring exercise to EFSA.

Approximately 54% and 49% of the results originated from Germany for 2007 and 2008 monitoring exercise, respectively. The number of samples per food group in 2007 varied between 87 for ‘processed cereal-based baby foods’ to 841 for ‘other products’. The number of results sampled in 2008 ranged between 96 for ‘processed cereal-based baby foods’ to 782 for ‘other products’.

It can be observed from Tables 2 and 3 that the number of samples across the main food groups is quite evenly distributed across the two monitoring years.

3.2. Reported LOD and LOQ

In Table 4 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 food category.

Table 4: Number of samples below the limits of detection (≤LOD) and quantification (≤LOQ) are reported and range of the reported LOD and LOQ in µg/kg per food category in 2008.

		N	Minimum µg/kg	Maximum µg/kg
Biscuits	≤LOD	31	6	75
	≤LOQ	63	21	250
	Detects	433		
Bread	≤LOD	33	6	75
	≤LOQ	88	5	60
	Detects	177		
Breakfast cereals	≤LOD	21	6	75
	≤LOQ	20	5	100
	Detects	79		
Cereal-based baby food	≤LOD	18	5	75
	≤LOQ	45	3	85
	Detects	33		
Coffee	≤LOD	10	6	75
	≤LOQ	19	10	50
	Detects	292		
French fries	≤LOD	10	10	75
	≤LOQ	42	12	100
	Detects	469		
Jarred baby foods	≤LOD	33	5	75
	≤LOQ	54	5	85
	Detects	41		
Other products	≤LOD	52	5	250
	≤LOQ	139	2	500
	Detects	591		
Potato crisps	≤LOD	23	7	75
	≤LOQ	4	12	50
	Detects	408		
Potato products for home cooking	≤LOD	19	6	75
	≤LOQ	37	5	50
	Detects	177		

The minimum and maximum values for LOD and LOQ ranged from 5 to 250 µg/kg for the samples below LOD and from 3 to 500 µg/kg for the samples below LOQ. The minimum and maximum values for LOD and LOQ ranged from 0.5 to 75 µg/kg for the samples above LOQ.

Twelve countries reported using liquid chromatography-tandem mass spectrometry (LC-MS/MS) for the analysis of acrylamide. Three countries reported the use of gas chromatography-mass spectrometry (GC-MS) or tandem mass spectrometry (GC-MS/MS). One country reported the use of ultra performance liquid chromatography-tandem mass spectrometry (UPLC-MS/MS) and one country reported the use of electron capture detector-gas chromatography. Three countries reported the use of both liquid chromatography-tandem mass spectrometry (LC-MS/MS) and gas chromatography-tandem mass spectrometry GC-MS/MS. Three countries reported the use of three methods (LC-MS/MS, GC-MS, LC-MS and HPLC-MS/MS, LC-MS/MS, LC-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 (now FERA), York (UK) with satisfactory results.

To better illustrate the percentage of numerical values above the LOQ and censored values below LOD or between the LOD and the LOQ, the respective frequencies shown in Table 4 have been plotted in Figure 1.

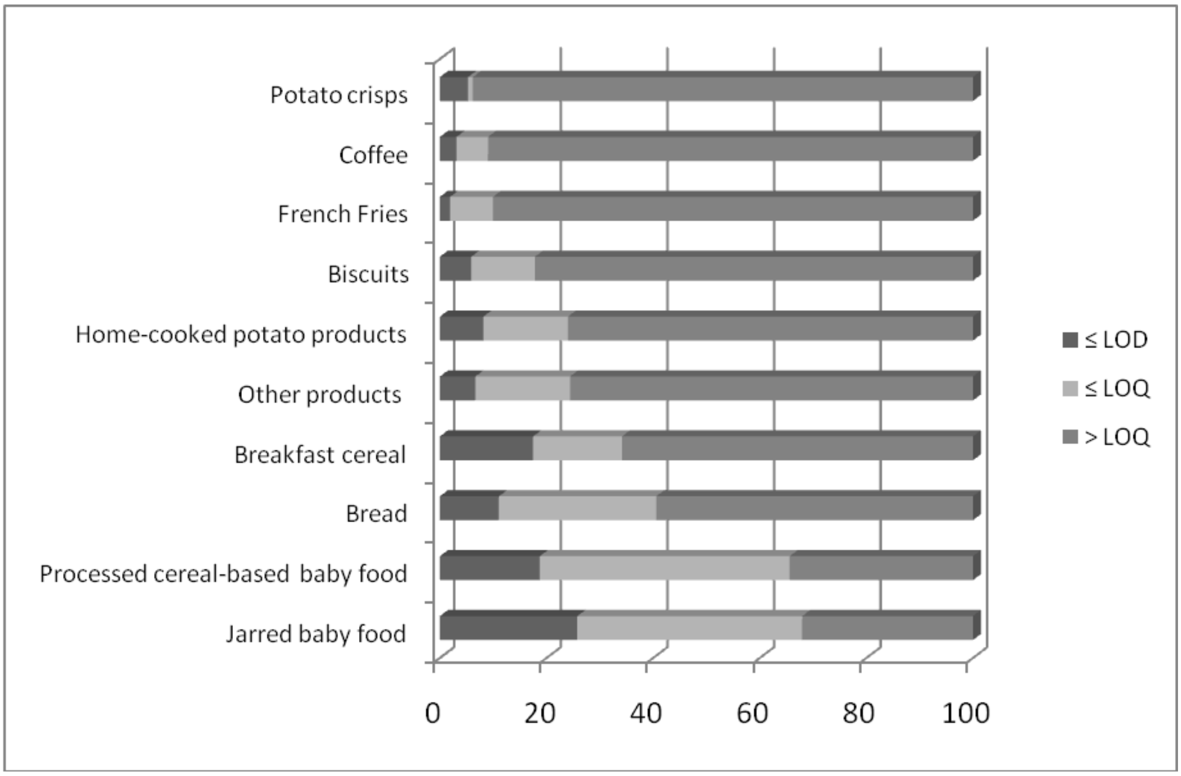

Figure 1: Percentage of values below LOD, between LOD and LOQ, and above the LOQ per food category for the pooled data from all Member States in 2008.

Eight out of ten food categories show more than 60% of numerical values. Only the food categories 'jarred baby foods' and 'cereal-based baby food' show percentages of numerical values lower than 40%.

3.3. Reported Measurement Uncertainty

All countries reported a value for measurement uncertainty (MU). In Table 5 the minimum and maximum MU is reported per food category for the LC-MS/MS method.

Table 5: Reported Measurement Uncertainty (%) for the LC-MS/MS method per food category.

	LC-MS/MS	
	Minimum MU %	**Maximum MU %**
Biscuits	5	53
Bread	4.6	40
Breakfast cereals	4.9	26
Cereal-based baby food	5	25
Coffee	4.1	95
French fries	5	40
Jarred baby foods	5	40
Other products	5	53
Potato crisps	5	40
Home-cook potato products	5	40

The reported MU for LC-MS/MS varied between 4.6 and 95%. The highest MU of 95% for LC-MS/MS was reported for the food category 'coffee'. The variation in reported values for Measurement Uncertainty is high. However, it is not always clear how the individual Member States calculated the value.

3.4. Statistical descriptors of the reported acrylamide content

In Tables 6 and 7 the descriptive statistics for the data collected in 2007 and in 2008, respectively, are given at food and at sub food group level.

With the exception of the maximum value, a range is provided when there was a difference between the estimated lower and upper bound acrylamide content calculated from the data reported by the Member States.

Table 6: Sample size (N), 5th percentile (P05), median, arithmetic mean, standard deviation (SD), 90th percentile (P90), 95th percentile (P95), 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								
Crackers	66	25-30	181	283-284	316-315	755	1024	1526
Infant	97	0-6	100	197-204	355-352	440	714	2300
Not specified	291	0-22	173	299-303	436-433	673	960	4200
Wafers	38	0-20	118	206-210	259-256	478	694	1378
Bread								
Bread crisp	153	0-18	124	224-228	330-328	480	740	2430
Bread soft	123	0-10	12-37	55-70	121-116	114	230	910
Non specified	54	0-30	53-58	172-190	431-424	310	794	2565
Breakfast cereals	132	0-30	70-100	131-152	195-184	310	420	1600
Cereal-based baby food	92	0-1	0-38	48-69	80-72	176	220	353
Coffee								
Instant	51	21-22	188	357	328-327	826	898	1047
Not specified	41	12-22	183	259-261	270-268	486	916	1158
Roasted	151	0-38	200	248-253	208-203	480	772	958
French fries	647	0-30	246	354-357	384-382	740	1072	2668
Jarred baby foods	87	0-5	0-30	22-44	37-35	86-94	94-100	162
Other products								
Gingerbread	357	9-21	226	423-425	495-494	1140	1460	3615
Muesli and porridge	47	0-31	173	210-215	189-183	509	586	805
Not specified	378	0-18	150-157	258-271	361-355	608	953	2529
Substitute coffee	59	0-25	338	796-800	1064-1062	2700	3025	4700
Potato crisps	273	0-21	400	563-565	591-589	1200	1602	4180
Home-cook potato product								
Deep fried	54	0-38	182	344-354	421-413	838	1450	1661
Not specified	82	0-25	150	266-277	399-392	639	886	2175
Oven fried	8	0-40	260	380-385	348-342	941	941	941

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

The mean values ranged between 22 and 44 µg/kg for 'jarred baby foods' and 796 and 800 µg/kg for 'substitute coffee' for foods sampled in 2007. The highest P95 and maximum values were reported for 'substitute coffee' of 3025 and 4700 µg/kg, respectively.

Table 7: Sample size (N), 5th percentile (P05), median, arithmetic mean, standard deviation (SD), 90th percentile (P90), 95th percentile (P95), and maximum for results covering foods sampled in 2008.

	N	P05# µg/kg	Median # µg/kg	Mean# µg/kg	SD# µg/kg	P90# µg/kg	P95# µg/kg	Maximum µg/kg
Biscuits								
Crackers	131	0-21	181	202-204	180-178	361	597	1042
Infant	88	0-11	64	98-110	154-147	250	280	1200
Not specified	260	0-24	120-121	198-209	254-247	525	689	1940
Wafers	48	0-41	109	250-252	417-416	645	1230	2353
Bread								
Bread crisp	90	0-10	109	233-235	274-273	603	770	1538
Bread soft	191	0-10	0-30	32-49	62-56	86	129	528
Non specified	17	0-5	0-19	11-23	23-19	34	86	86
Breakfast cereals	120	0-10	61-94	151-170	256-247	349	590	2072
Cereal-based baby food	96	0-5	0-25	27-45	84-81	83-85	130	660
Coffee								
Instant	58	0-30	482	499-502	290-285	851	929	1373
Not specified	10	0-30	195	232-241	225-215	550	720	720
Roasted	253	0-50	167	204-208	186-182	350	525	1524
French fries	521	0-30	211	276-280	283-279	591	770	2466
Jarred baby food	128	0-5	0-25	16-35	39	55-85	85	297
Other products								
Gingerbread	246	0-50	227	432-437	548-545	974	1572	3307
Muesli and porridge	18	0-7	0-40	21-43	34-27	75	112	112
Not specified	445	0-10	66-73	183-198	314-309	518	700	2592
Substitute coffee	73	97	856	1124	1138	2392	3300	7095
Potato crisps	435	0-68	416	613-616	637-634	1431	1913	4382
Home-cooked potato products								
Deep fried	39	0-10	152	220-228	259-253	588	710	1220
Not specified	100	0-10	54-75	177-192	408-402	415	741	3025
Oven fried	94	19-22	149	235	269-268	503	967	1439

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

The mean values ranged between 11 and 23 µg/kg for 'bread not specified' and 1124 µg/kg for 'substitute coffee' for foods sampled in 2008. The highest P95 and maximum values were reported for 'substitute coffee' of 3300 and 7095 µg/kg, respectively.

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.

Sample distribution per value ranges across the food and sub food groups are shown for the monitoring years 2007 and 2008 in Figures 2 to 20.

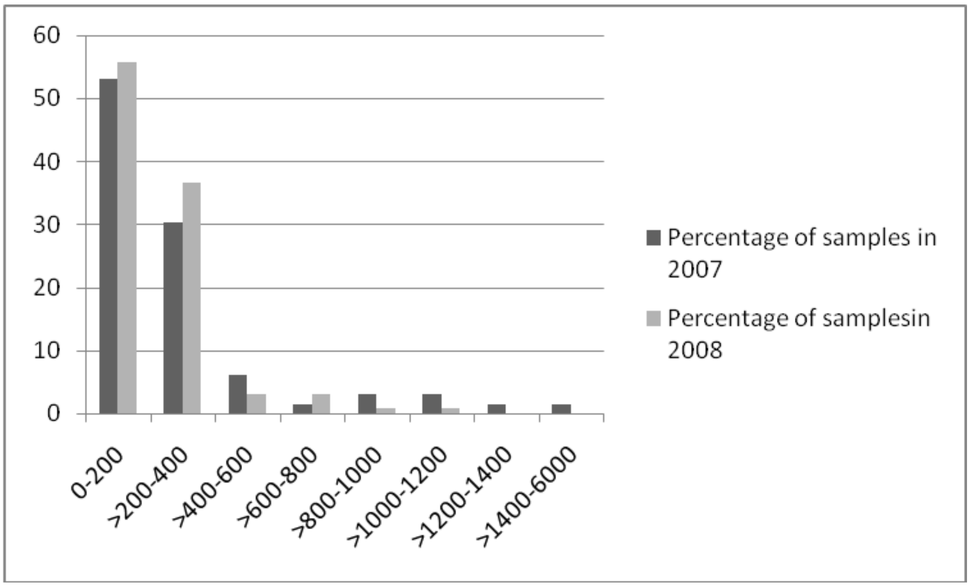

Figure 2: Sample distribution across value ranges (µg/kg) for 'biscuit crackers' in 2007 and 2008.

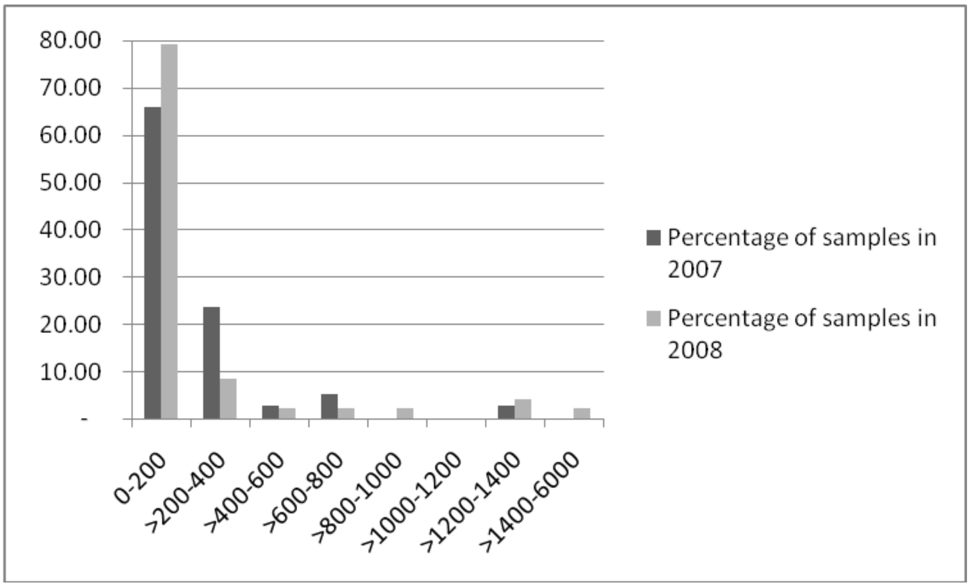

Figure 3: Sample distribution across value ranges (µg/kg) for 'biscuit wafers' in 2007 and 2008.

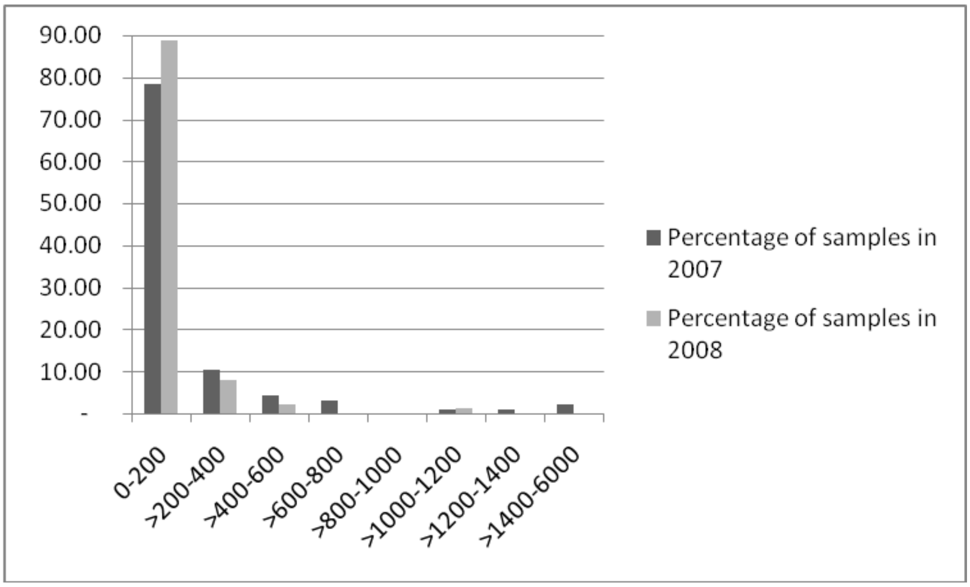

Figure 4: Sample distribution across value ranges (µg/kg) for 'infant biscuit' in 2007 and 2008.

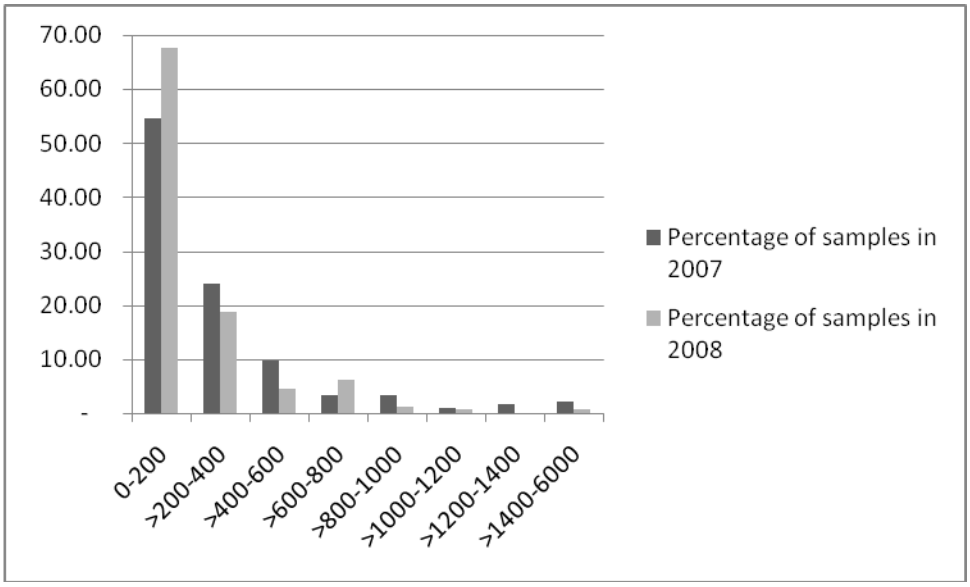

Figure 5: Sample distribution across value ranges (µg/kg) for 'biscuit non specified' in 2007 and 2008.

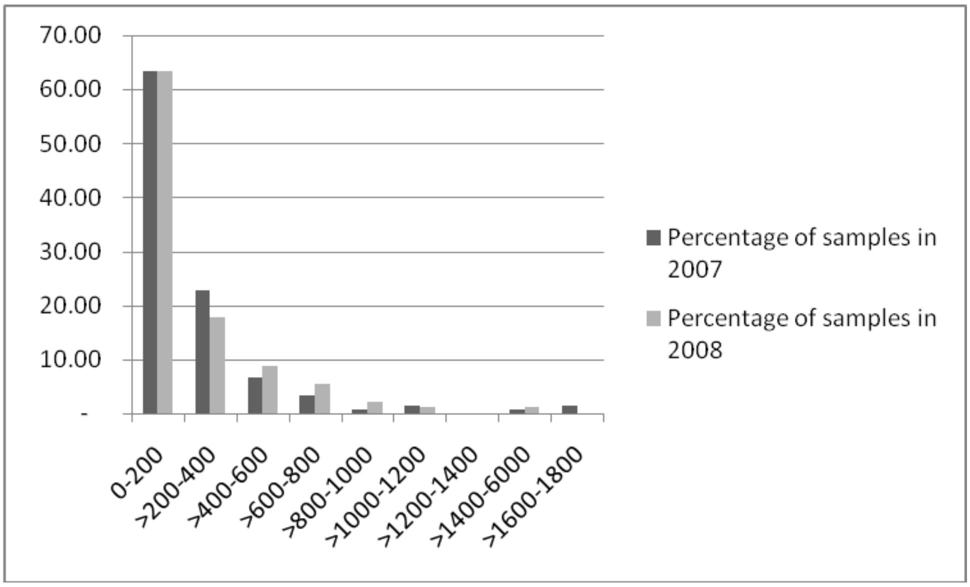

Figure 6: Sample distribution across value ranges (µg/kg) for 'crisp bread' in 2007 and 2008.

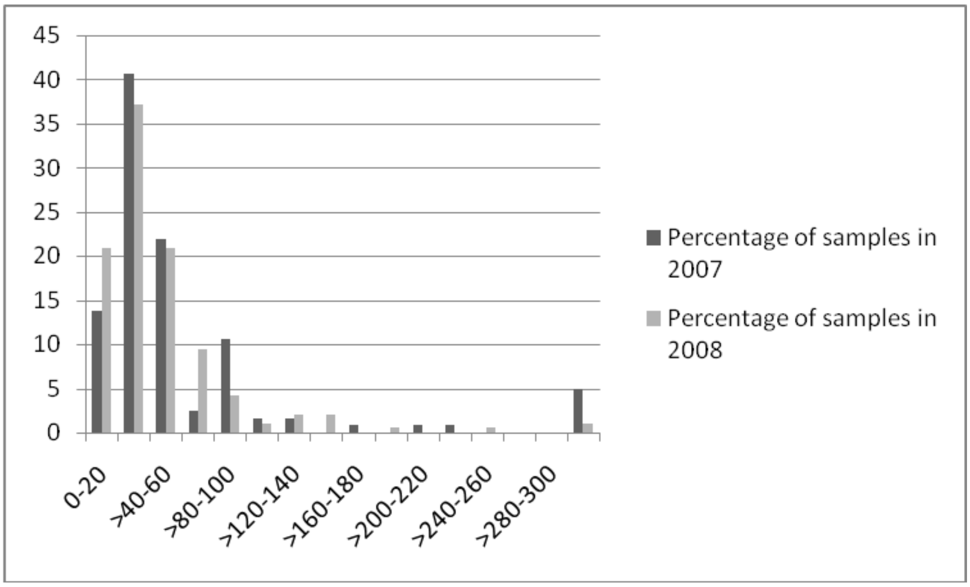

Figure 7: Sample distribution across value ranges (µg/kg) for 'soft bread' in 2007 and 2008

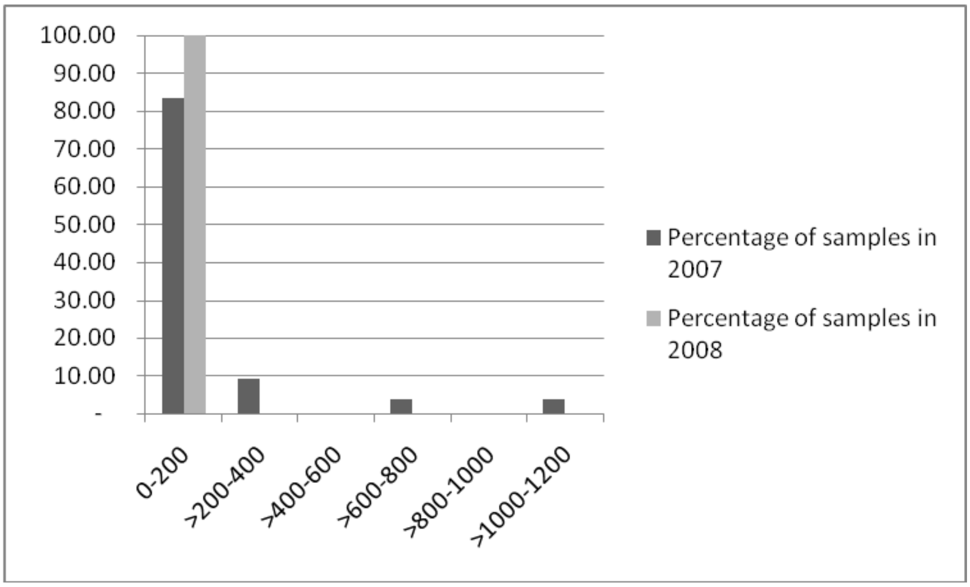

Figure 8: Sample distribution across value ranges (µg/kg) for 'non specified bread' in 2007 and 2008

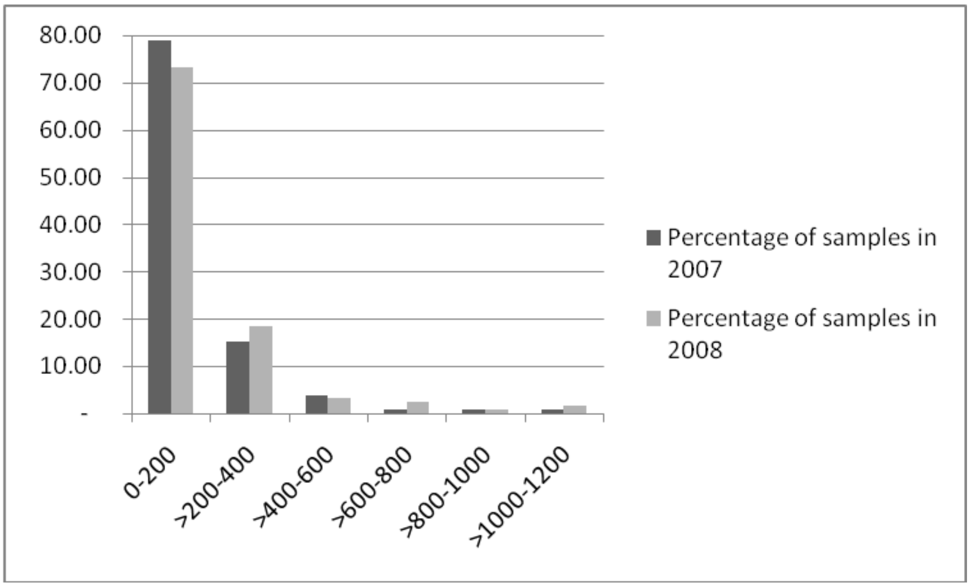

Figure 9: Sample distribution across value ranges (µg/kg) for 'breakfast cereal in 2007 and 2008

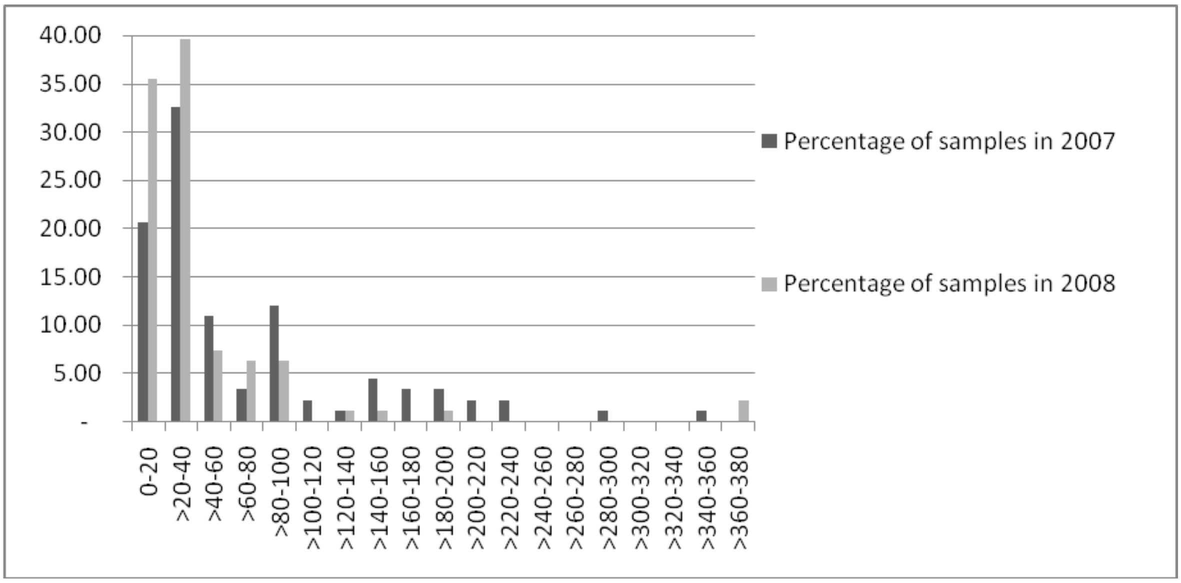

Figure 10: Sample distribution across value ranges (µg/kg) for 'cereal-based baby food' in 2007 and 2008

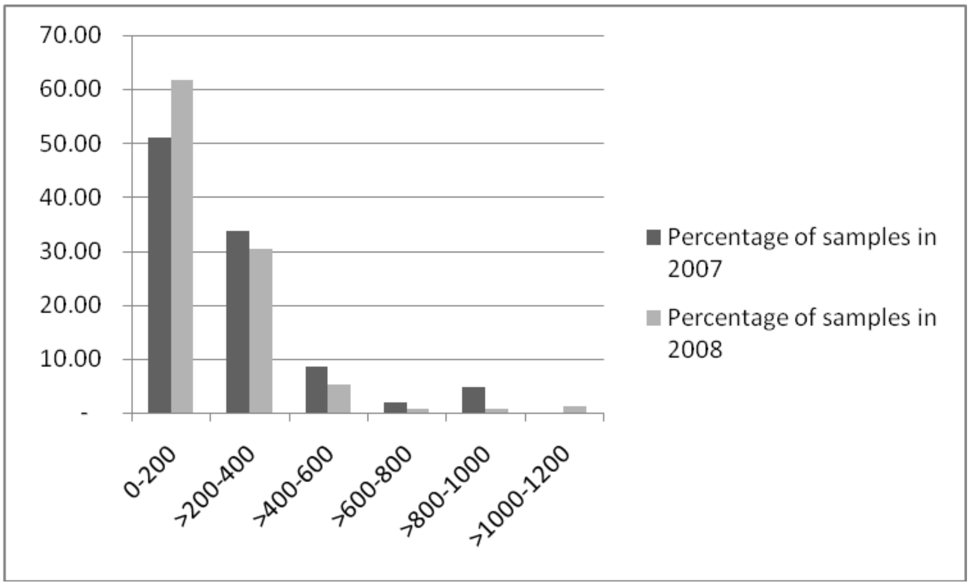

Figure 11: Sample distribution across value ranges (µg/kg) for 'roasted coffee' in 2007 and 2008

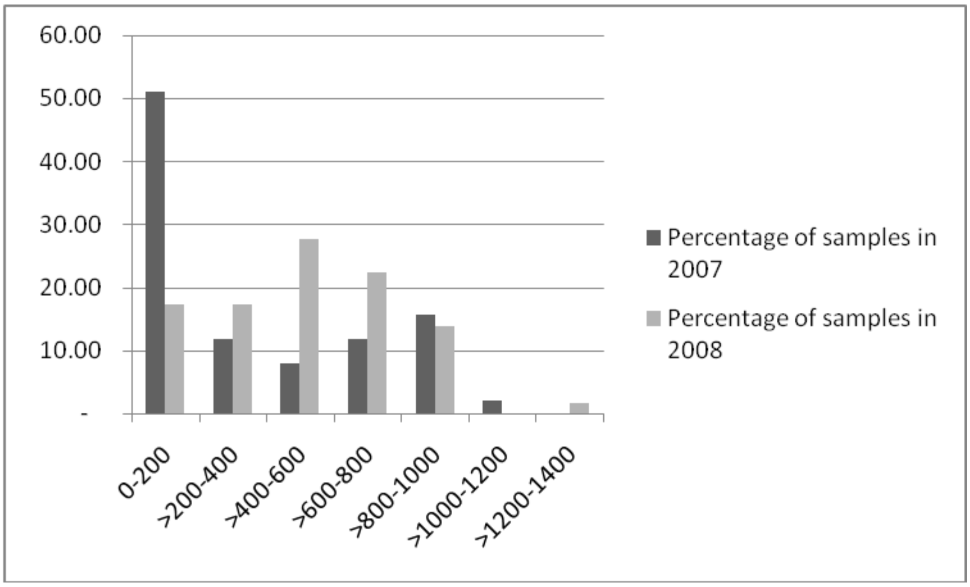

Figure 12: Sample distribution across value ranges (µg/kg) for 'instant coffee' in 2007 and 2008

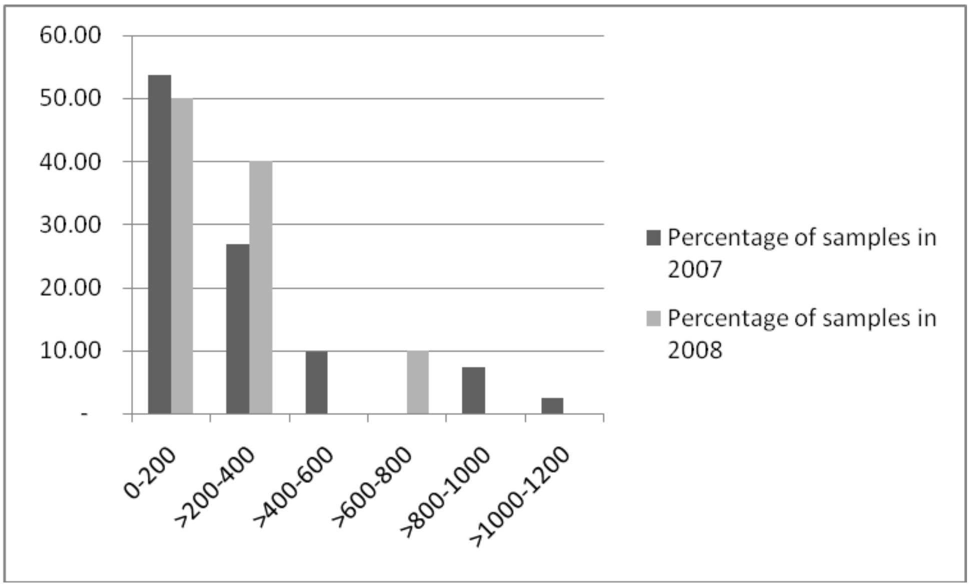

Figure 13: Sample distribution across value ranges (µg/kg) for 'not specified coffee' in 2007 and 2008

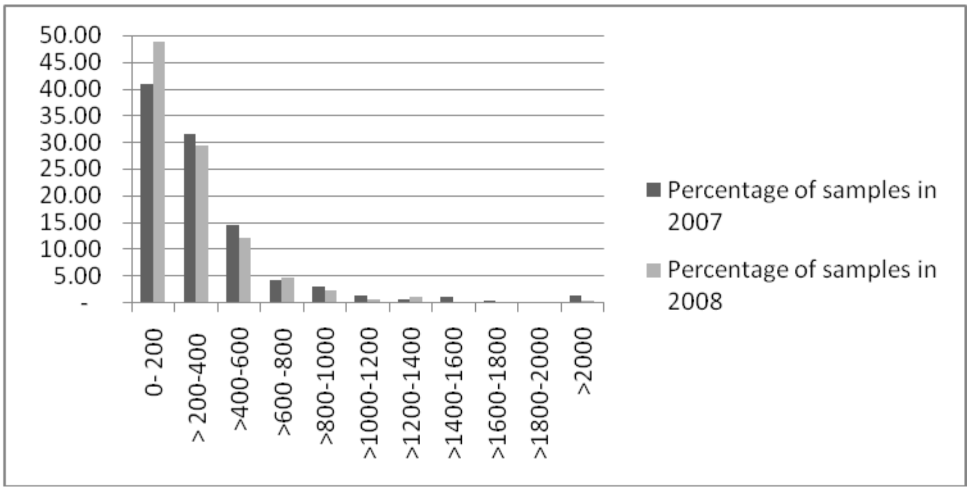

Figure 14: Sample distribution across value ranges (µg/kg) for 'French fries' in 2007 and 2008

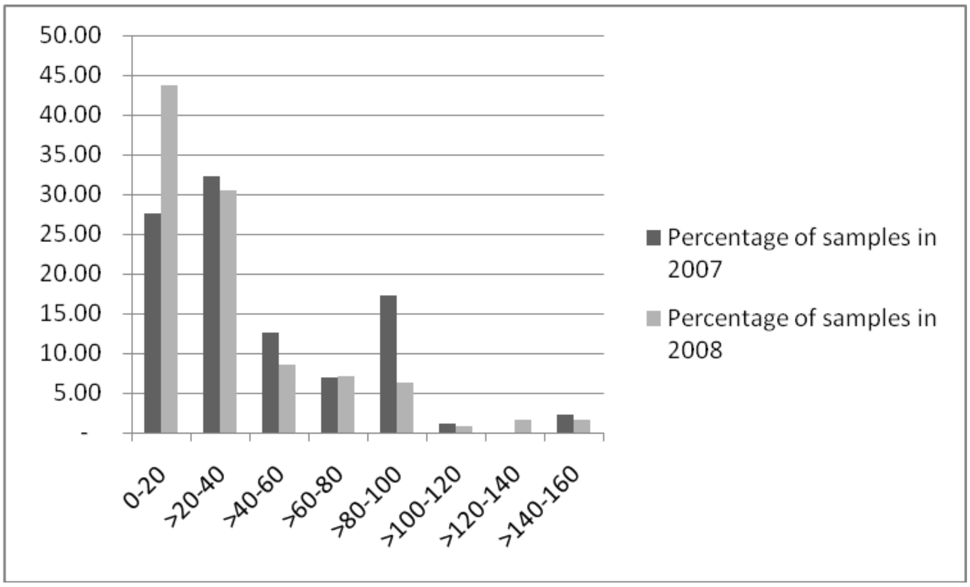

Figure 15: Sample distribution across value ranges (µg/kg) for 'jarred baby food' in 2007 and 2008

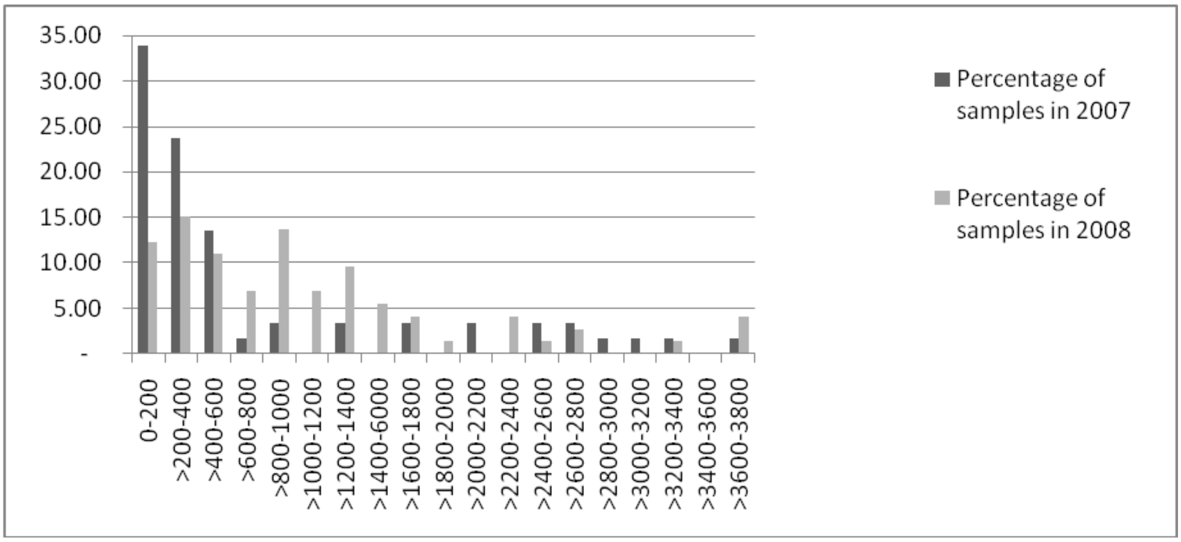

Figure 16: Sample distribution across value ranges (µg/kg) for 'other products: substitute coffee' in 2007 and 2008

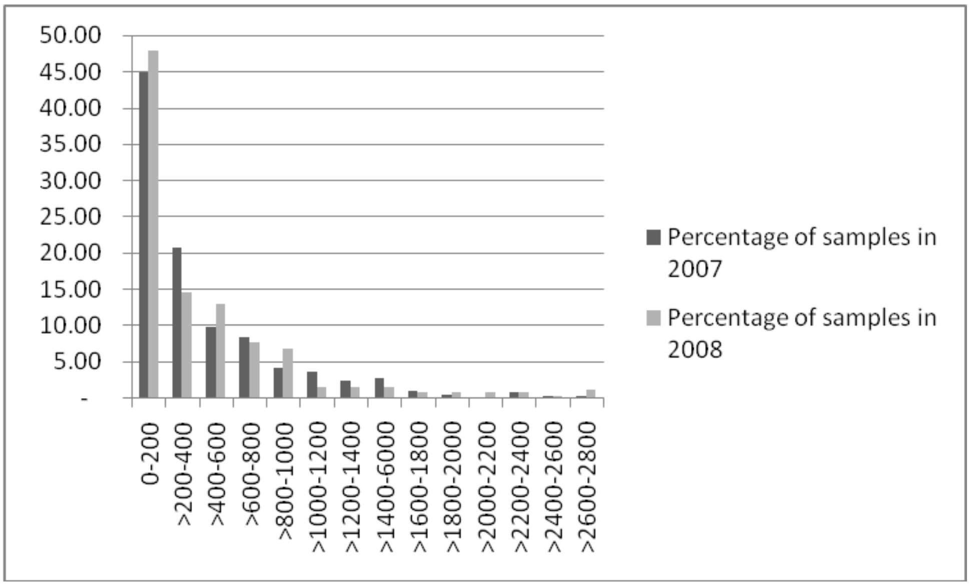

Figure 17: Sample distribution across value ranges (µg/kg) for 'other products: gingerbread' in 2007 and 2008

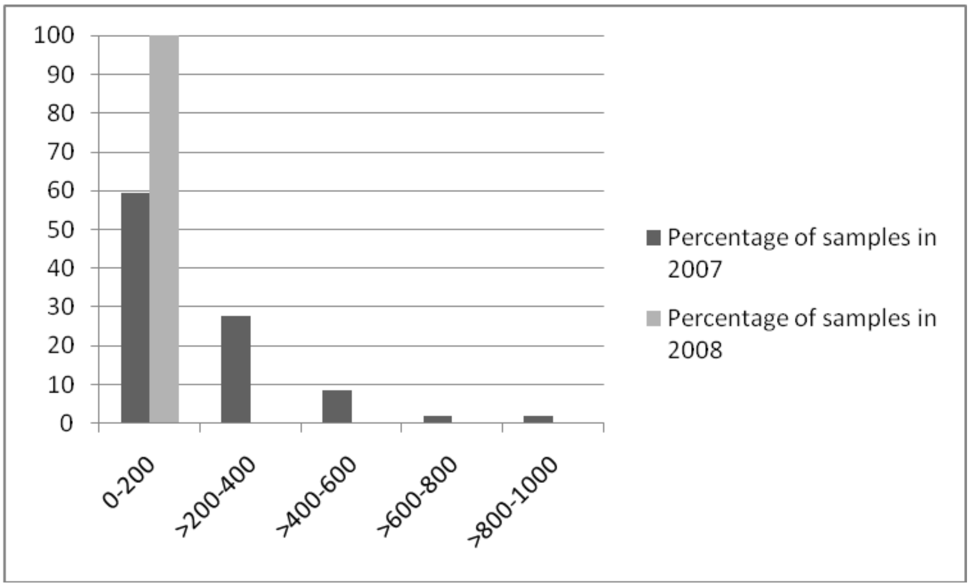

Figure 18: Sample distribution across value ranges (µg/kg) for 'other products: muesli and porridge' in 2007 and 2008

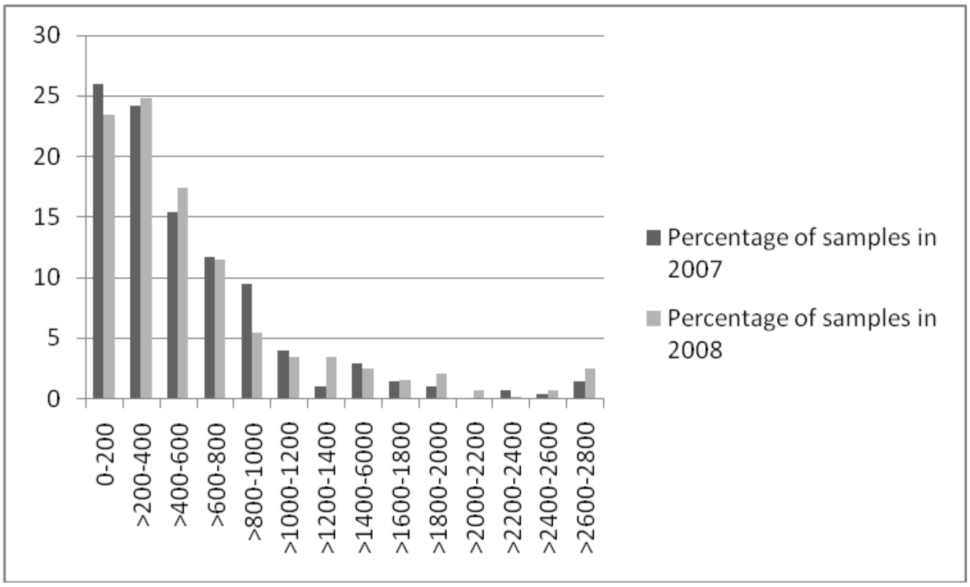

Figure 19: Sample distribution across value ranges (µg/kg) for 'potato crisps' in 2007 and 2008

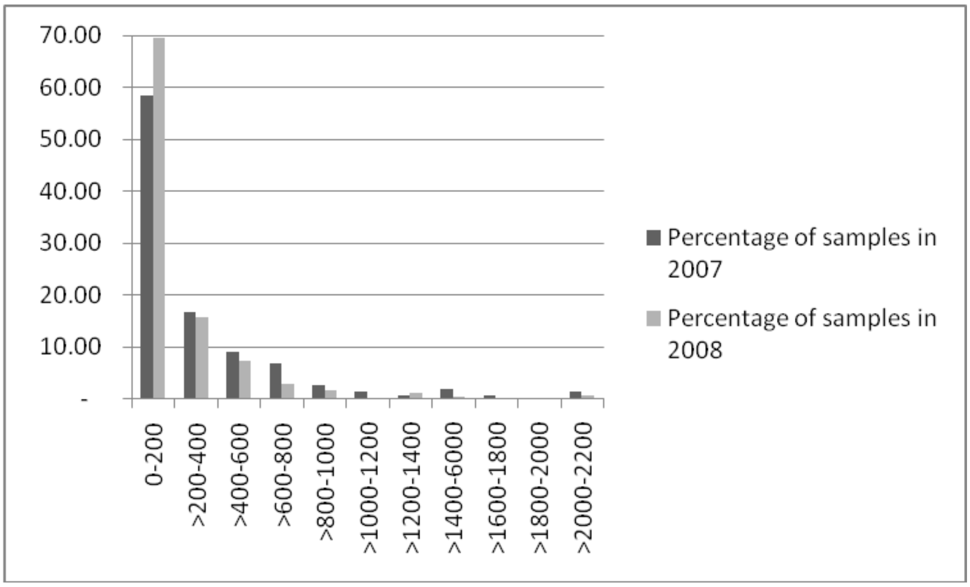

Figure 20: Sample distribution across value ranges (µg/kg) for 'home cooked potato products' in 2007 and 2008

Figures 2 to 20 illustrate that the vast majority of food groups and sub-groups show a right skewed distribution for the acrylamide content.

3.5. Comparison between acrylamide levels of foods sampled in 2007 and 2008

The acrylamide upper bound mean content of each food group and sub-group sampled in 2007 and 2008 is compared by an analysis of variance (ANOVA) in Table 8. A regression model was used to assess statistical significance of upper bound mean value differences across all food groups and food sub-groups. Results were consistently adjusted by country effect to remove any geographical bias when evaluating time trends.

Analyses of variance of the influence of sampling year for the respective food and food sub-groups resulting in a p-value lower than 0.05 suggests that there is a statistically significant difference.

Table 8: Sample size (N), upper bound mean and significance for the analysis of variance (p) across food sub-groups when comparing results from 2007 and 2008.

	2007		2008		
	N	**Mean µg/kg**	**N**	**Mean µg/kg**	p
Biscuits					
Crackers	66	284	131	204	0.696
Infant	97	204	88	110	<0.001
Not specified	291	303	260	209	0.003
Wafers	38	210	48	252	0.531
Bread					
Bread crisp	153	228	90	235	0.711
Bread soft	123	70	191	49	0.025
Non specified	54	190	17	23	<0.001
Breakfast cereals	132	152	120	170	0.333
Cereal-based baby food	92	69	96	45	0.593
Coffee					
Instant	51	357	58	502	<0.001
Not specified	41	261	10	241	0.964
Roasted	151	253	253	208	0.417
French fries	647	357	521	280	<0.001
Jarred baby foods	87	44	128	35	0.224
Other products					
Gingerbread	357	425	246	437	0.777
Muesli and porridge	47	215	18	43	<0.001
Not specified	378	271	445	198	<0.001
Substitute coffee	59	800	73	1124	<0.001
Potato crisps	273	565	435	616	<0.001
Home-cook potato product					
Deep fried	54	354	39	228	0.007
Not specified	82	277	100	192	0.061
Oven fried	8	385	94	235	0.551

Table 8 shows a statistically significant decrease in the mean acrylamide content between sample year 2007 and 2008 for the groups ‘French fries’, ‘deep fried home cooked potato products’, ‘bread soft’, ‘bread not specified’, ‘infant biscuit’, ‘biscuit not specified’, muesli and porridge’ and ‘other products not specified’ whereas a statistically significant increase is shown for ‘potato crisp’, ‘instant coffee’ and ‘substitute coffee’. No statistical difference was shown for the remaining (50%) of the food sub-groups in the mean acrylamide content between the sampling years 2007 and 2008.

3.6. Influence of sampling season on acrylamide formation in potato products in 2008

Twenty countries reported in total 1056 results on acrylamide content of 'French fries', 'potato crisps' and 'potato products for home cooking' sampled in different seasons. Data were split into two groups. The first group contains data for food sampled between January and June. The second group contains data for food sampled between July and December. In Table 9 results of a comparison between acrylamide contents in potato products per sampling period are shown together with the statistical significance level (p) determined in a regression model. Results were consistently adjusted by country to remove any geographical bias when evaluating seasonal trends.

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

	January-June		**July-December**		p
	N	**Mean µg/kg**	**N**	**Mean µg/kg**	
French fries	177	285	244	283	0.156
Potato crisps	228	615	176	591	0.002
Home-cook potato products	101	217	130	218	0.830
Total Potato products	**506**	**420**	**550**	**366**	**0.135**

From Table 9 it is clear that the acrylamide content of French fries and home cooked potato products shows no statistically significant difference between results from products sampled between January and June and products sampled between July and December.

There was a statistical significant influence of season for 'potato crisps' showing a higher upper bound mean value in results from products sampled between January to June compared to products sampled between July and December.

4. Discussion

In March 2006, a joint workshop was organised by the European Commission and the CIAA for governments, industries and academia to discuss up to date knowledge of acrylamide formation, results of recent studies and projects, opportunities, gaps and constraints in attempt 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 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 minimise acrylamide formation. The brochures or pamphlets were designed for several categories: biscuits, crackers, crisp breads, bread products, breakfast cereals and fried potato products, such as potato crisps and French fries.

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 relatively high content of acrylamide. Different tools have been identified to lower the acrylamide formation in heated potato food, including selection of potato variety, potato storage regime, process control through thermal input and pre processing, final preparation and colour control.

Potato crisps were identified as a food product with potential for high levels of acrylamide formation (Tareke et al. 2002). Given their popularity as a snack food, particularly among younger age groups, it is important to reduce its acrylamide content. A strong correlation was found between acrylamide formation and the concentration of reducing sugars varying from 0.97 to 0.98 (Matthäus et al., 2004; Williams, 2005). Controlling the sugar content is currently the primary measure employed by the industry to reduce acrylamide levels in crisps. This is achieved by selecting potato varieties with low levels of reducing sugars (CIAA, 2009).

For samples of potato crisps in 2008, as reported by Member States to EFSA, the mean acrylamide level was 616 µg/kg, which was a statistically significant increase compared to the acrylamide level of 565 µg/kg reported in 2007. These values are still in the range of the reported values in literature for acrylamide in potato crisps where mitigation measures were applied. Monitoring data from the Lebensmittelchemisches Institut in Germany 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). From a Spanish analysis dated March 2008, Arribas- Lorenzo and Morales (2009) reported an average level of 740 µg/kg for samples of potato crisps. When comparing German samples from May-June 2002 with the same period in 2003, Foot et al. (2007) reported a significant decline in acrylamide levels of potato crisps from around 1000 µg/kg to around 600 µg/kg,. However, they suggested that a level of 500 µg/kg measured leading up to July 2006 seemed to be the minimum level possible with the then available mitigation tools and that new practical tools and long-term developments for lowering sugar/asparagine levels were needed. A promising mitigation involves asparaginase, an enzyme that converts asparagine to aspartic acid. Trials at pilot plant scale confirmed the laboratory findings that asparaginase significantly reduces the acrylamide level in potato dough-based products like formed potato crisps (CIAA 2006). The same effect was not found for sliced or chipped potato products. For the enzyme to be effective it must be able to reach the asparagine, which is difficult if the cell remains intact.

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. Indeed, a statistical significant decrease was shown in this study when comparing results of French fries in 2007 to results sampled in 2008, with mean acrylamide content of 357 and 280 µg/kg, respectively. A similar trend towards lower acrylamide content was shown when comparing mean results of deep fried home cooked potato products from 2007 to 2008. This looks promising although French fries are still 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). The problem is that the acrylamide level is also influenced by the end user: a low content in reducing sugars is an important first step, but the final product can still be heated too high and for too long. Similar advice with respect to browning, frying and baking temperatures is given to consumers by various consumer organisations. However, domestic or restaurant preparation of French fries cannot be controlled or standardised as strictly as it is the case for processing conditions applied in the food industry, e.g. in the production of potato crisps (Dybing et al., 2005).

To minimise losses from spoilage and shrinkage, potatoes are stored at low temperatures. However, low temperatures tend to increase sugar levels, in a process known as cold sweetening, particularly if stored below 6°C. 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). Cultivars used in the crisps trade tend to be stored for longer periods of time than those used for French fries (Cummins et al., 2009).

In the present study, a significant seasonal difference in mean acrylamide content could not be identified for the general potato group, however, for 'potato crisps' the mean acrylamide content was statistically significantly higher for products sampled between January and June (615 µg/kg), compared to products sampled between July and December (591 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 organised by the European Commission and the CIAA 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).

Four food groups belonging to the broad group of cereal products were sampled in the present study: 'biscuits', 'breakfast cereals', 'cereal based baby food' and 'bread'. In order to create more comparable datasets the 'bread' and 'biscuit' group were subdivided into more detailed food groups.

From the comparison of acrylamide data between 2007 and 2008 it is observed that the overall trend in cereal products tends towards lower acrylamide content showing a statistically significant decrease in 'soft bread', 'infant biscuit' and 'muesli and porridge'. However no statistical difference in acrylamide content between 2007 and 2008 is found for the other cereal products. 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). Unfortunately, such a decrease could not be confirmed in our comparison study of 'gingerbread' between 2007 and 2008.

Claus et al. (2008) demonstrated that superficial application of cysteine to the dough of wheat bread and bread rolls prior to baking showed acrylamide lowering potential. Furthermore, addition of cysteine to the dough led to remarkably lower acrylamide levels in the bread. According to a review study by Claus et al. (2008) on cereal products, the most promising field for acrylamide reduction is the addition of low molecular additives such as polyphenols, which so far have not been applied in cereal products. Such additives ideally combine acrylamide reduction with little or no changes in product technology or, most importantly, sensory quality.

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). Lantz et al. (2006) arrived to a similar conclusion when investigating the factors affecting the acrylamide level in the chain from green coffee to coffee beverages. Worst, process conditions resulting in low acrylamide levels, like darker roasting and longer roast time, tend to lead to high levels of furan, another process contaminant. 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 no mitigation measure is proposed in the toolbox, it is not surprising that in all three coffee categories, 'roasted', 'instant' and 'substitute', the present study shows no difference for the first group and a statistical increase for the two latter groups between mean values of 2007 and 2008. Moreover, in both monitoring years 'substitute coffee', a cereal-based product, shows highest mean acrylamide content across all food groups with 800 µg/kg and 1124 µg/kg for 2007 and 2008, respectively. Studies at pilot scale show that asparagine content of dried chicory is correlated to the formation of acrylamide (CIAA, 2009).

5. Conclusions

In the first acrylamide report issued in 2009 in which 2003-2006 data were compared to 2007 data no clear trend towards lower acrylamide values over time was found. In this report a trend towards lower acrylamide values in 2008 compared to 2007 seems to be more apparent. A statistically significant decrease appears in a third of the food groups, whereas no statistically significant change is shown in half of the food groups.

It may be appropriate to assume that the application of the acrylamide toolbox was effective only in a limited number of food groups like' French fries', 'deep fried home cooked potato products', 'soft bread', 'infant biscuit', and 'muesli and porridge'. Whereas, in the food groups 'biscuits', 'crackers', 'crisp bread', 'cereal breakfast', 'gingerbread', 'wafers' and 'baby foods' despite the numerous proposed mitigation measures in the toolbox at recipe and processing level no statistically significant change could be observed when comparing 2007 to 2008 results. Despite an initial decrease in acrylamide content between 2002 and 2006 in the food group 'potato crisps', the mitigation measures appear to have reached their limitations since the level appears not to reduce further, but to slightly increase between year 2007 and 2008. High levels of acrylamide are found consistently between the years in all coffee groups and in particular in 'substitute coffee' and 'instant coffee'.

In order to confirm whether the acrylamide levels tend indeed towards a decrease over time more food samples need to be collected and analysed in the coming years. An exposure assessment will be carried out next year to determine the biological relevance of any change in acrylamide levels over the three years analysed.

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