Acrylamide: Update on Selected Research Activities Conducted by the European Food and Drink Industry

DOMINIQUE TAEYMANS
Confédération des Industries Agro-Alimentaires de l’UE (CIAA), Ave des Arts 43, B-1040, Brussels, Belgium

ANDERS ANDERSSON
Kraft Foods Sverige AB, SE-19486 Upplands Väsby, Sweden

PETER ASHBY
Cereal Partners Worldwide, Welwyn Garden City, United Kingdom

IMRE BLANK
Nestlé Research Center, Vers-chez-les-Blanc, 1000 Lausanne 26, Switzerland

PIERRE GONDÉ and PAUL VAN EIJCK
McCain Continental Europe R&D Center, 62440 Harnes, France

VIRGINIE FAIVRE
Danone Vitapole, RD 128, 91767 Palaiseau Cedex, France

SAM P.D. LALLJIE
Safety and Environmental Assurance Centre, Unilever Colworth, Sharnbrook, Bedford MK44 1LQ, United Kingdom

HANS LINGERT
The Swedish Institute for Food and Biotechnology (SIK), SE-402 29 Göteborg, Sweden

MARIANNE LINDBLOM
Kraft Foods Sverige AB, SE-19486 Upplands Väsby, Sweden

REINHARD MATISSEK
Lebensmittelchemisches Institut (LCI) des Bundesverbandes der Deutschen Süß-warenindustrie e.V., D-51063, Köln, Germany

DETFLEF MULLER
Procter and Gamble Product Safety and Regulatory Affairs, 65823 Schwalbach am Taunus, Germany

RICHARD H. STADLER and ALFRED STUDER
Nestlé Research Center, Vers-chez-les-Blanc, 1000 Lausanne 26, Switzerland

DAVID SCLVANT
The Ryvita Co. Ltd, Old Wareham Rd, Poole, Dorset BH12 4QW, United Kingdom

DAN TALLMADGE
Procter and Gamble Co., 6071 Center Hill Ave, Cincinnati, OH 45224

GEOFF THOMPSON
Danone Vitapole, RD 128, 91767 Palaiseau Cedex, France

TRICIA WHITMORE
The Ryvita Co. Ltd, Old Wareham RD, Poole, Dorset BH12 4QW, United Kingdom

JOHN WOOD
CIAA, Ave des Arts 43, B-1040, Brussels, Belgium

DAVID ZYZAK
Procter and Gamble Co., 6071 Center Hill Ave, Cincinnati, OH 45224

This paper reviews the progress made by the European food and drink industry (CIAA) on acrylamide with regard to analytical methods, mechanisms of formation, and mitigation research in the major food categories. It is an update on the first CIAA review paper, “A Review of Acrylamide: An Industry Perspective on Research, Analysis, Formation and Control.” Initial difficulties with the establishment of reliable analytical methods, in most cases, have now been overcome, but challenges remain in terms of the need to develop simple and rapid test methods and certified reference materials. Many trials have been conducted under laboratory and experimental conditions in a variety of foods, and a number of possible measures have been identified to relatively lower the amounts of acrylamide in food. Promising applications were studied in...
reconstituted potato models by addition of amino acids or use of asparaginase. In bakery wares, predictive models have been established to determine the role of ammonium carbonate and invert sugar in acrylamide formation. Studies in several commercial foods showed that acrylamide is not stable over time in roasted and ground coffee. Some progress in relatively lowering acrylamide in certain food categories has been achieved, but at this stage can only be considered marginal. Any options that are chosen to reduce acrylamide in commercial products must be technologically feasible and must not adversely affect the quality and safety of the final product.

Since the announcement by the Swedish National Food Authority in April 2002 of the finding of low levels of acrylamide, predominantly in carbohydrate-rich foods (1), considerable progress in the science has been made. Several of the priorities initially identified by the World Health Organization (WHO) and Scientific Committee on Food (SCF) in the science have been addressed, viz., methods of analysis, occurrence, formation, chemistry, toxicology, and potential health risk in the human diet.

Several research groups have developed methods to quantify acrylamide reliably at relatively low levels in a wide variety of different foodstuffs. Most of the methods published to date are based on either gas chromatography-mass spectrometry (GC/MS) or liquid chromatography-mass spectrometry (LC/MS) techniques, with comparable distribution and performance of the 2 approaches. Based on the conclusions of a recent interlaboratory trial (2), a workshop organized by the European Commission’s Directorate General Joint Research Center held in April 2003 (3), and subsequent task force group meetings thereof, many of the methods did not perform well in difficult matrices. Consequently, laboratories have adapted their methods to achieve the required precision and sensitivity for those foods in which gaps in the analytical data were initially identified. A fully validated method, with adequate performance and that can be applied to difficult matrices such as coffee and cocoa, is briefly described in this report, as well as a method with minimal sample preparation that can be used for starch-rich foods.

Thermal processes in the production of foodstuffs are generally complex, and the initial results on acrylamide content did not seem to indicate a common pattern, except that carbohydrate-rich foods seemed to generate relatively more acrylamide. Several researchers have established that the main pathway of formation of acrylamide in foods is linked to the Maillard reaction and in particular the amino acid asparagine (4-7). Decarboxylation of the resulting Schiff base is a key step, and the reaction product may either furnish acrylamide directly or via 3-aminopropionamide (8). An alternative proposal is that the corresponding decarboxylated Amadori compound may release acrylamide by a beta-elimination reaction (9). In this report, we provide evidence that supports a beta-elimination pathway by synthesis of model decarboxylated Amadori products.

This fundamental knowledge opens the way to concrete studies on kinetic modeling (formation over temperature/time, role of water, elimination, competitive reaction kinetics with amino acids and sugars), and identifying the rate limiting steps under actual food processing conditions. Measures can then be devised to attempt to reduce acrylamide in commercial and domestic food products. In this context, very little information is available on the role of water (10). This report addresses the importance of molecular mobility and provides an explanation for the difference in reactivity of the various reducing sugars.

Shortly after the Swedish announcement, the CIAA established an Acrylamide Technical Expert Group as a forum for constant exchange of the industry’s research results on acrylamide. The output of this group has been actively shared with all other stakeholders at scientific meetings on acrylamide (10-12) and has culminated in a first peer-reviewed article (13).

This second report summarizes the current state of knowledge and the collective efforts of the European food and drink industries in acrylamide research. It focuses on the progress achieved in analytical, mechanistic, and mitigation aspects. Furthermore, the complexity of the research is highlighted in a number of different food products, so indicating the challenges and constraints faced by industry in finding appropriate and practical solutions for commercial application.

Methods of Analysis

One of the first priorities is the development of reliable and robust analytical methods to determine acrylamide in cooked foods with the adequate accuracy and precision (14). The adherence to stringent method performance criteria is of pivotal importance to ascertain that the data generated are reliable and can be used for intake assessments: many data gaps have been identified (3, 14).

Two methods, based on isotope dilution LC coupled to electrospray ionization tandem mass spectrometry (LC/MS/MS), will be briefly described here. The first method (method 1) was applied to high-starch containing foods and illustrates very good intermediate reproducibility over extended periods of time. The second method (method 2) entails a number of sample pretreatment steps to ensure adequately clean extracts for the testing of difficult matrices such as coffee and cocoa powder.

**Method 1.—**This method can be applied to essentially all starch-based foods and, as illustrated in Figure 1, comprises an acetone/nitrile extraction to remove co-extractives, followed by a Carrez I and II precipitation step, centrifugation, and subsequent filtration. No solid-phase or liquid-liquid extraction is required, which considerably speeds up sample pretreatment.

The performance of the method is monitored over time using in-house quality standards that are stored at 4°C in
Figure 1. Flow diagram highlighting essential sample pretreatment steps to determine acrylamide in high-starch food.

Method 2.—Recently a method has been reported (15) that can achieve good sensitivity and selectivity for acrylamide in practically all of the relevant food matrixes. The same authors have also optimized the method for a difficult matrix such as coffee (16).

Most laboratories experience problems with the analysis of acrylamide in difficult matrixes such as cocoa powder and coffee, mainly owing to considerable loss of the analyte during the sample preparation steps. Improvements were thus made to an existing method (17), and sample pretreatment essentially encompassed (1) protein precipitation with Carrez I and II solutions, (2) extraction of the analyte into ethyl acetate, and (3) solid-phase extraction on a Multimode cartridge. This approach provided good performance in terms of linearity, accuracy, and precision. Full validation was conducted in soluble chocolate powder, with adequate precision. The method achieved a limit of quantitation at 12.5 µg/kg in cocoa powder, and recovery (expressed as extractability of the analyte during sample pretreatment) of 43–51% over 3 concentration ranges: 13, 305, and 2504 µg/kg. The method was extended to the analysis of acrylamide in various foods such as mashed potatoes, crispbread, and butter biscuits and cookies. Furthermore, the accuracy of the method is demonstrated by the results obtained in 3 interlaboratory trials (17).

Acrylamide is not stable in certain foods and can react with inherent food constituents (16). We therefore investigated the stability of acrylamide in selected dry food products by retesting the foods a certain period after their initial analysis. All samples were kept in the dark at room temperature and in tightly closed containers. As shown in Table 2, acrylamide is stable in some foods (e.g., breakfast cereals) over prolonged storage periods of up to 12 months. On the other hand, loss of acrylamide was appreciable in coffee (roasted and soluble) and chicory (dried and roasted) after 5–12 months of storage. Similar observations for coffee were also recently shown by Andrzejewski et al. (16), and possibly acrylamide is interacting over time with inherent nucleophiles.

To ensure the quality of data on acrylamide levels in foods and food companies requiring acrylamide analysis should use laboratories that are accredited or can demonstrate competence in the analysis. These are also requirements for official food control laboratories that have to be accredited according to ISO 17025. Laboratories must prove their competence by regular and successful participation in appropriate proficiency testing schemes. These measures will allow better comparison of available data and thus a better estimate of acrylamide intake from the diet.

### Table 1. Intermediate reproducibility of method 1 in quality control standards comprising potato crisps and crispbread

<table>
<thead>
<tr>
<th>Parameter</th>
<th>QC sample potato crisps(\text{a})</th>
<th>QC sample crispbread(\text{b})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean, µg/kg</td>
<td>1091</td>
<td>41</td>
</tr>
<tr>
<td>Median, µg/kg</td>
<td>1099</td>
<td>41</td>
</tr>
<tr>
<td>Minimum, µg/kg</td>
<td>900</td>
<td>30</td>
</tr>
<tr>
<td>Maximum, µg/kg</td>
<td>1320</td>
<td>52</td>
</tr>
<tr>
<td>SD, µg/kg</td>
<td>88</td>
<td>5.4</td>
</tr>
<tr>
<td>RSD, %</td>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>

\(\text{a}\) \(n = 244\) Samples over a time period November 2002–July 2003.

\(\text{b}\) \(n = 207\) Samples over a time period July 2003–March 2004.
Table 2. Time-dependent stability of acrylamide in various foodstuffs (adapted from ref. 17)

<table>
<thead>
<tr>
<th>Food product</th>
<th>Interval, month</th>
<th>Initial</th>
<th>Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast cereal</td>
<td>12</td>
<td>238</td>
<td>238</td>
</tr>
<tr>
<td>Soluble coffee powder</td>
<td>12</td>
<td>771</td>
<td>256</td>
</tr>
<tr>
<td>Roasted barley</td>
<td>9</td>
<td>265</td>
<td>225</td>
</tr>
<tr>
<td>Roasted coffee</td>
<td>7</td>
<td>203</td>
<td>147</td>
</tr>
<tr>
<td>Dried chicory</td>
<td>5</td>
<td>214</td>
<td>174</td>
</tr>
<tr>
<td>Roasted chicory</td>
<td>5</td>
<td>4015</td>
<td>3395</td>
</tr>
<tr>
<td>Cocoa</td>
<td>3</td>
<td>180</td>
<td>177</td>
</tr>
<tr>
<td>Chocolate with almond</td>
<td>2</td>
<td>94</td>
<td>73</td>
</tr>
<tr>
<td>Soluble chocolate powder</td>
<td>1</td>
<td>54</td>
<td>41</td>
</tr>
</tbody>
</table>

Strecker degradation product (i.e., styrene in place of benzaldehyde). Evidence of the reactivity of a key intermediate (Figure 2) is therefore provided for the first time and illustrates that a common mechanism is operative that may lead to the corresponding vinylogous structures of the reacting amino acids (18).

Far less studied in the Maillard-driven reaction to acrylamide are the physical aspects of the reaction. Water content and the physical state of the food matrix could affect the mechanistic pathway for acrylamide formation. Water impacts the chemical route (e.g., hydrolysis of the imine) as well as the mobility of the chemical constituents. Model studies have shown that fructose leads to the formation of relatively higher levels of acrylamide (5, 6), whereas glucose, although considered to be more reactive in Maillard chemistry, leads to the formation of relatively lower levels. Differential scanning calorimetry (DSC) experiments have revealed that the higher reactivity is related to the melting point of fructose (ca 126°C), and that molecular mobility is a key factor in model test tube experiments that indirectly contributes to the formation of acrylamide.

To understand the exact meaning of these physical changes, DSC was performed by recording changes in the physical state of each component and sugar/asparagine monohydrate binary mixtures as a function of temperature in open reaction systems. As shown in Figure 3, water crystallization release from the asparagine monohydrate occurred at the same temperature (93°C) in all 3 reaction systems, and evaporated below 105°C without interacting significantly with sugar crystals.

In the resulting fructose/asparagine system, a first endothermic signal was observed at about 124°C corresponding to fructose melting. A second endothermic phenomenon occurred at 142°–143°C, which could be either asparagine fusion or asparagine solubilization in the liquid water/fructose phase. In the glucose and galactose systems, first fusion phenomena were observed at about 148° and 167°C, respectively. These temperatures were about 5°–10°C lower than the melting point of pure sugars. In all systems, no exothermic signal was visible, although some browning was observed at the end of the reaction.

Interestingly, heating sugar/asparagine binary mixtures in dimethyl sulfoxide (DMSO) as reaction medium revealed glucose as the most reactive sugar generating high amounts of acrylamide followed by galactose and fructose (Figure 4). These results indicate that the chemical reactivity of the sugar is the major driver of acrylamide formation in reaction systems where molecular mobility does not play a limiting role.

In low moisture systems, however, molecular mobility is the major driver of acrylamide formation. Therefore, physical parameters such as fusion, mobility, and water activity are key and do influence the amounts of acrylamide generated. As identified in a recent workshop on acrylamide hosted by the European Food Safety Authority (10), water management may be a key factor in controlling acrylamide levels in food and warrants study in both industrial processing and domestic cooking.

Progress in Different Food Categories

Potato Products

Fried potatoes is the food category on which the most work has been done so far to understand the critical factors that may control or reduce acrylamide (19). Numerous possible avenues of reduction of acrylamide in potato products have
been identified and highlighted in several recent reports (20-25). These entail a combination of measures, e.g., controlling the storage temperature of the raw potato, variety selection, and modifying processing conditions (time and temperature). It should be noted that changes in raw materials may impact the organoleptic properties (taste and color) of the cooked food. However, all these measures must be placed in the perspective of consumer acceptance, as well as those related to the supply chain management and logistics of harvesting, storage, and transport of the raw potatoes.

Figure 5 gives an example of what industry can achieve by adopting such technological measures. The deep-frying temperature was reduced by 10°-15°C, while product moisture was simultaneously increased by 0.5%. The result of a series of 8 tests on different production lines was a significant reduction in the acrylamide concentrations by an average of 15%.

A weekly moving average illustrates this effect but is of course subject to seasonal fluctuation (time of harvest), storage, and processing conditions (Figure 6). The impact of long-term effects, i.e., year-to-year, have not yet been adequately assessed and considered.

Several possibilities have already been elaborated and discussed to reduce acrylamide in potato-based products. In salted snacks and crisps, control can be exercised at several points, including raw material selection, storage, and processing, either individually or collectively. Of these possibilities, the most common relate to process control, i.e., temperature/time control (inlet/outlet temperature), water content, blanching, and optimization of optical sorters to remove dark chips.

Under controlled conditions, within a specific batch of potato crisps, there are good statistical correlations between the acrylamide content and process parameters such as frying outlet temperature, blanching temperature, moisture content, and color (Agtron/Hunter). However, when samples are taken randomly from several different plants, or even from an individual plant, the statistical correlation between the acrylamide content and the above-mentioned process parameters (taken from production records) is inconsistent. It therefore seems that raw material variations impact the acrylamide levels more than do changes in processing conditions.

Several studies indicate that the limiting factor for acrylamide formation in chipping potato tissue is the reducing sugar content (20, 22). In the Nordic area, there are significant differences in acrylamide levels between different geographical growing areas that cannot be entirely explained by differences in reducing sugar content. There are indications that levels and type of nitrogen-fertilizer and storage conditions affect the amino acid content and composition of the raw potato, which indirectly have an effect on acrylamide formation.

In theory, the reducing sugar content also seems to be the limiting factor for chipping varieties in the Nordic area (reducing sugar: 0.02-0.15% versus asparagine: 0.25-0.50%), but in practice, amino acids that promote competing reactions might have an impact. Hence, the proportion of asparagine and the total amount of free amino acid seem to be of more importance than the absolute asparagine content. Asparagine seems to constitute roughly 50% of the total free amino acid pool in Nordic chipping varieties. In trials where the asparagine level was adjusted to roughly 30% by addition of amino acids that promote competing reactions, the acrylamide levels were reduced significantly. The reduction effects and off-flavor levels were, of course, specific for different amino acids. Studies are under way to investigate the effects of nitrogen-fertilizing programs on the total asparagine content and the proportion of asparagine in the total free amino acid pool.
The addition of competing amino acids, e.g., to the blanching water prior to frying, showed that glycine (0.1%, v/v) was particularly effective in achieving a reduction of acrylamide of about 50% in preformed potato cakes prepared from water and potato flakes. Glycine together with reducing sugars will enhance browning but is considered taste neutral, and should therefore not have a measurable impact on the organoleptic quality of the cooked products.

A number of potentially promising measures to reduce acrylamide in reconstituted crisps include dilution; replacement of part of the potato content by maize, wheat, or rice; increase in residual moisture (control at maximum limits); optimized thermal point (flash-frying), which takes advantage of the decomposition of acrylamide at higher temperatures (>200°C); rapid cooling, providing a shorter passage through the acrylamide formation phase; raw materials optimization (specifications).

Shortly after the Swedish announcement, studies were performed with asparaginase to confirm the key role of free asparagine in acrylamide formation (8). Asparaginase is available from a number of commercial chemical suppliers, as a laboratory fine biochemical. This technology has already been assessed on an experimental scale with success in reconstituted potato products.

Cereal-Based Products

A study of 3 variables on the formation of acrylamide in biscuit baking (ammonium carbonate, sodium bicarbonate, and invert sugar; Figure 7) showed that invert sugar and ammonium bicarbonate were both significant variables in terms of acrylamide formation.

A separate study looked at the influence of processing variables on acrylamide formation and confirmed that the concentration of acrylamide in the finished product correlated directly with baking temperature and moisture content. There was also a clear relationship between the color of the baked product and acrylamide content, with darker, more highly baked samples containing higher levels of acrylamide (Figure 8). Using a model system, based closely on an actual product, it was possible to develop a predictive model for acrylamide formation based on process variables alone, but not one that permitted reduction of acrylamide without significant changes to the finished product.

When recipe variables were superimposed on this model, a number of interesting observations were made, albeit not all of which can be clearly explained (Figure 9). As the proportion of sugar present as fructose was increased, so did the production of acrylamide. However, once fructose accounted for 50% of the total sugar content, any further increase actually reduced acrylamide formation. Ammonium bicarbonate led to increased acrylamide formation, an effect not simply attributable to changes in pH. However, contrary to previous observations, a diminution in acrylamide formation was observed with increasing pH. A major complication to the interpretation of the results was the effect of changes in dough mixing time, whereby, according to whether the mixing time was short or long, the effect of increasing fructose or pH on acrylamide formation could be either positive or negative (Figure 10).

Finally the effect of a range of minor ingredients, including spices, was examined, and again significant, but difficult to explain results were obtained. Certain spices, such as ginger and cardamom, led to increased levels of acrylamide, whereas others, such as nutmeg, caused a reduction in levels compared to when no spices were used. This effect was very significant and not simply caused by changes in pH.

Thus, based on these experiments on model systems, it has not been possible to develop a predictive model for the influence of recipe variables on acrylamide formation in biscuits, or to identify process variables that can be manipulated so as to reduce acrylamide formation without impacting on finished product quality.

Figure 6. Minimization of acrylamide in potato crisps: weekly average extracted from data of companies in Germany (trend line based on production date).

Figure 7. Acrylamide content (µg/kg) in biscuits as related to levels of ammonium carbonate and sodium bicarbonate in dough.
The use of asparaginase in yeast during bread production is said to successfully reduce levels of acrylamide in bread, although the fermentation time is significantly increased (10).

Coffee

Roasted coffee can be considered a unique product in terms of production technology and food chemical constituents. The relatively high temperatures of green coffee roasting (>220°C) results in a plethora of new reaction products, some with clear chemo-protective properties (26).

Initial studies on coffee have shown that acrylamide is formed at the early stages of roasting and then sharply declines until the end point of roasting (13). Experiments with isotope-labeled acrylamide show that >95% of the total acrylamide generated by roasting is further degraded during the process and is no longer found in the final product, and only a small percentage of the free asparagine is converted to acrylamide.

This behavior of coffee is unique and, as shown (16, 17), acrylamide is not stable in the finished product (Table 2). Follow-up experiments to this observation were performed on roasted beans, stored for 34 h at 60°C. One portion of the beans was placed in a closed jar and another equal portion in a jar open to the atmosphere. The acrylamide content of the coffee in the closed jar was reduced up to 30% compared with that in the open jar, which showed the same acrylamide content as the untreated control. These results suggest that nonthermal interactions (matrix, aroma) may be important in loss of acrylamide in coffee, and possibly open avenues for mitigation.

A further variable in the dietary contribution of acrylamide in coffee is the current uncertainty in the analytical methods. Even though we have reported that methods have recently been improved for coffee, they have not been assessed to determine acrylamide “in the cup,” i.e., as consumed. Therefore, the actual extractable amount of acrylamide in coffee preparation may be different (lower) than that measured by the analytical methods. This important point must still be clarified.

In summary, all studies conducted so far on coffee show no possibility for achieving a significant reduction of acrylamide without drastically affecting the sensory characteristics, and thus acceptability, of the product.

Cocoa

There is a clear paucity of information on the levels of acrylamide in cocoa and cocoa intermediate products. A survey conducted at the different stages of the cocoa process (raw beans, roasted beans, nibs, cocoa liquor, cocoa powder, and cocoa butter) show that acrylamide levels are in most cases <400 µg/kg.

As depicted in Figure 11, acrylamide remains in the cocoa powder and is not extracted into the butter fraction. Dutching (alkalization) of cocoa powder has a variable effect on acrylamide levels; in some experiments a significant reduction was achieved while in others the effect was limited. Moreover, cocoa powder is used as an ingredient of other foods and beverages and not consumed as such. In contrast to most other foods, the roasting cycle (temperature and time of roast) has basically no effect on acrylamide levels in cocoa products.
translating these laboratory and experimental findings to being undertaken. The ultimate challenge will be in momentum in the fundamental and applied research currently detected.

fractions during cocoa bean processing; n.d. = not unknown, adverse, medium- to long-term effects.

resolve the acrylamide issue: (7) to maintain a transparent and between regulatory authorities, industry, and consumers, to actual processing conditions on an industrial scale.

constantly increasing, and it will be important to maintain the acrylamide in foods under essentially dry conditions is evident.

achieve even marginal reductions in acrylamide levels are yet evident.

Nevertheless, the knowledge base on the formation of acrylamide in foods under essentially dry conditions is constantly increasing, and it will be important to maintain the momentum in the fundamental and applied research currently being undertaken. The ultimate challenge will be in translating these laboratory and experimental findings to actual processing conditions on an industrial scale.

It remains essential, in the overall collaborative endeavor between regulatory authorities, industry, and consumers, to resolve the acrylamide issue: (1) to maintain a transparent and open dialogue, involving all stakeholders; (2) to ensure that decisions intended to secure reductions in acrylamide intake are soundly based on scientific evidence; (3) to acknowledge and consider, when implementing potential mitigation strategies, the practical constraints and possible risks of unknown, adverse, medium- to long-term effects.

Conclusions

From the studies to date on a range of foods, it is evident that any measures to achieve significant reductions in the relative levels of acrylamide in specific foods will entail a combination of different measures. This report shows that in the research environment substantial progress has been made in several important areas, but for some foods, no solutions to achieve even marginal reductions in acrylamide levels are yet evident.

References

(1) Swedish National Food Administration Information about Acrylamide in Food (24 April 2002) www.slv.se


(10) European Food Safety Authority Workshop on Acrylamide Formation in Food (November 17, 2003) Brussels, Belgium

(11) CIFA/UK FSA/Dutch WKA Joint Workshop on Acrylamide (March 28, 2003) Brussels, Belgium


Figure 11. Distribution of acrylamide in different fractions during cocoa bean processing; n.d. = not detected.