Workshop on Acrylamide Formation in Food
17 November 2003, Brussels

Report of the Workshop[*]

1. SUMMARY

The meeting demonstrated that since April 2002 international research on acrylamide in food has progressed rapidly, however there are still many questions that need to be answered. The interest in the acrylamide issue is apparent from the response to this meeting: 60 participants from the food processing and catering industry, governmental bodies and academia from Europe, Canada and the USA attended the workshop. A full list of attendees is given in Annex II.

During the course of discussions several areas were identified to further investigate the formation of acrylamide in food. The results of this work may then be used to inform methods of reducing acrylamide levels. It was highlighted that there is a need to develop a better understanding of the fundamental chemistry of acrylamide, how it is formed, what the rate-limiting steps of formation are and how formation can be reduced. The main challenge for researchers is to understand how acrylamide is formed and how to influence the mechanism of formation, in order to reduce acrylamide levels whilst retaining the food's nutritional and organoleptic properties, and not adversely affecting other food safety parameters.

Areas identified as needing further research included:

- The role of water and the physical state of the food matrix.
- Time and temperature processing parameters.
- The influence of ammonia/ammonium bicarbonate and other CO_2-releasing agents on acrylamide levels.
- Chemical or enzymatic reduction of acrylamide e.g. using asparaginase to reduce asparagine levels.
- Developing profiles of acrylamide precursors in raw materials and examining the effects of natural variation (e.g. crop variety, weather, season and agronomic practices) on these. This information could be used to advise farmers, concerning husbandry and crop storage to potentially minimise the acrylamide precursors, or could be transferred into a plant-breeding programme.
- Optimising storage conditions of potatoes to obtain a balance between acrylamide production potential and organoleptic properties.

[*] This report reviews the current knowledge and ideas for future work, as described by researchers who attended the workshop. The comments provided are the opinions of the workshop attendees and do not necessarily reflect the views of the European Food Safety Authority (EFSA).

2. BACKGROUND

In 2002 Stockholm University and the Swedish National Food Authority announced the results of research which showed that unexpectedly high levels of acrylamide were generated in a wide range of starch-rich foods cooked at high temperatures[1]. Further research has since confirmed these findings.

In 1991 the EC's SCF (see Annex I for a glossary of terms and abbreviations) evaluated acrylamide as a monomer in food contact materials and concluded that acrylamide is a genotoxic carcinogen. In light of the Swedish findings the SCF considered the implications of acrylamide formation in food in July 2002 and recommended that levels of acrylamide in food should be as low as reasonably achievable (ALARA)[2]. At this stage the SCF could only offer general advice due to the lack of detailed knowledge on scientific issues relevant to the risk management. On an international level, the WHO/FAO held a joint consultation to assess the full extent of the public health risk from acrylamide in food[3]. Both this consultation and the SCF recommended that further research be conducted on acrylamide in food, to cover topics such as formation, toxicity and possible means of reduction.

In response to the recommendations made by the SCF and the WHO/FAO consultation, the VWA and the FSA, in association with the CIAA, held the 28 March 2003 Workshop "Research on Acrylamide in Food"[4]. The outcomes and recommendations of the meeting were detailed in a "White Paper on Acrylamide" and presented to the EFSA Advisory Forum[4]. Following EFSA's consideration of the White Paper, a "Consultation Paper" was presented to the EFSA Advisory Forum, requesting that EFSA take the lead role in two of the six recommendations made at the meeting: to formulate a research plan to fill the gaps in current knowledge and co-ordinate the implementation of individual projects, and secondly to create a mechanism for information exchange and discussion, envisaged as a forum/task force for technical level discussion[5].

As a result of these activities and willingness from stakeholders the 17 November 2003 EFSA Workshop on Acrylamide Formation in Food was organised on EFSA's behalf by the FSA and VWA, with assistance from CIAA and the EC.

3. WORKSHOP OVERVIEW

The workshop provided an opportunity for those conducting research on acrylamide formation in food to engage in technical level discussions on current research activity, both within and beyond the EU. The aim of the workshop was to stimulate an exchange of ideas and findings so as to enhance the current understanding of the mechanisms of formation and facilitate an effective and sustainable means of reducing levels of acrylamide in foods and to thereby protect consumer health. This workshop was specifically a technical level discussion looking at research being conducted on formation of acrylamide in foods. The analytical methodology, toxicology, and methods of reducing acrylamide were not within the scope of this workshop.

The Chair, Dr Herman Koëter, opened the workshop with an overview of the aims and expected outcomes, and an introduction to EFSA's role in co-ordinating acrylamide activities. As an introduction to the workshop and to stimulate ideas for the discussion group sessions, presentations were given by representatives of the EFSA, EC, CIAA and US JIFSAN. The workshop agenda can be found in Annex III.

Following this introductory plenary session, participants were assigned to two discussion groups made up of individuals from a mix of research backgrounds and expertise. Each group participated in informal discussions, covering a range of issues from the intricacies of the chemistry of formation to the effects of processing techniques on acrylamide formation.

4. REPORT OF DISCUSSION GROUPS

The outcomes of the discussion groups are summarised below. It must be taken into consideration that in certain circumstances further work may be required to confirm results described and this is highlighted in the text. As well as looking at how understanding the formation can be used to reduce acrylamide levels, the effects of changing food production methods should also be considered, for example the effects on food safety parameters, nutrient content and organoleptic qualities.

Much of the research carried out to date has been completed in model systems. The use of model systems is effective in testing the importance of physical factors; however, when using model systems it is important to remember that they are simplifications of complex food systems and therefore caution should be taken when relating findings to real foods.

4.1. Chemistry of Formation

To fully understand the acrylamide concentrations observed in certain foods, it is important to consider both the formation and elimination reactions of acrylamide. Evidence so far shows that acrylamide is eliminated by reaction with numerous food constituents, such as inherent nucleophiles (e.g. amines and sulfhydryls) and that thermal degradation products of sugars and starch may also play a role. Rapid elimination reactions may provide an explanation for the low levels of acrylamide found in particular food types, for example meat[6]. Also, above certain temperatures, acrylamide levels have been shown to decrease, i.e. where the rate of elimination exceeds the rate of formation.

Although several mechanisms for the formation of acrylamide have been proposed, the precise mechanism(s) or pathway(s) for acrylamide formation in food have not yet been fully elucidated. Further knowledge on the precise mechanistic pathway is required and the rate-limiting steps need to be identified with the help of kinetic studies.

4.1.1 Formation of Acrylamide via Asparagine and the Maillard Reaction

Several research groups[6,7,8,9,10,11] have independently proposed that the main pathway to acrylamide formation in foodstuffs is by the reaction between asparagine and a carbonyl source (e.g. reducing sugars). In the Maillard reaction, acrylamide may be formed by at least two competing pathways starting from a common precursor, the Schiff base. This could lead via classical Strecker degradation to the Strecker aldehyde of asparagine[7], or the Schiff base could undergo rapid decarboxylation and subsequent beta-elimination to form acrylamide[12].

Glucose and fructose are the important reactants so far identified. In the case of potatoes, fructose is approximately twice as efficient at promoting acrylamide formation than glucose, and 15 times more than lactose[6,13]. The amino acid asparagine is the source of the nitrogen in acrylamide, this observation has been corroborated by nitrogen-15 labelling studies[14]. Other amino acids present in food will react with the available reducing sugars, competing with asparagine, which consequently may lead to a reduction in the levels of acrylamide. The quantity of acrylamide formed is largely dependent on the availability of the reducing sugar and asparagine. The rate of formation can be approximated by a bimolecular reaction between fructose/glucose and asparagine[13,15]. However, other subsequent steps are also likely to contribute to determining the rate. In cereal products the rate-limiting factor appears to be the availability of asparagine, whereas in potato products the availability of reducing sugar is the determining factor. In model reactions between amino acids and glucose it has been demonstrated that the yield of acrylamide is approximately 0.1%[9,13].

There were discussions about the role of sucrose as an alternative carbonyl source. The general opinion appeared to be that sucrose does not contribute to the formation of acrylamide, however, it may be important in supporting elimination of acrylamide in some foods, such as, gingerbread. Other carbonyls in food (some being intermediates in the Maillard pathway) may also react with asparagine to form acrylamide.

The formation of acrylamide appears to be strongly linked to the Maillard reaction and hence the favourable qualities of colour, texture and flavour that are associated with roast and fried foods. Acrylamide formation is therefore linked to some of the desirable organoleptic qualities in such foods.

4.1.2 Additional Acrylamide Formation Pathways

It was the general view of the participants that oxidation of lipids and starch did not significantly contribute to the formation of acrylamide in food. Acrylamide is generally formed in starch-rich foods, however, the influence of starch on acrylamide formation is thought to be limited to physical rather than chemical properties e.g. its effect on the dry matter content.

In model experiments, other pathways have been identified that may lead to the formation of acrylamide from reaction precursors, such as, acrolein, acrylic acid and other carbonyls[16,17] (Table 1). In starch-rich foods it was agreed that asparagine is the main source of nitrogen in the acrylamide molecule. However, other potential sources have been identified, for example, when heating lipids in the absence of carbohydrate, ammonia is an alternative source of nitrogen in the acrylamide molecule, provided via the deamination of amino acids[17]. This work suggests that ammonia and acrolein could play an important role in acrylamide formation in lipid-rich foods. However, these alternative formation mechanisms have yet to be demonstrated in real food systems.

Table 1: Summary of known acrylamide formation mechanisms in model experiments

Acrylamide Formation Mechanism	Reference
• Intramolecular cyclisation of Schiff base to oxazolidin-5-one and – CO_2, beta-elimination of the decarboxylated Amadori product to afford acrylamide	Yaylayan et al. 2003[12]
• Also non-classical Maillard compounds + Asparagine lead to Acrylamide formation. Thus, two mechanisms may be operating. • Methionine (or other amino acids) may be active after $–CO_2$, $-NH_2$ to methional, behaves as an aldehyde + Asparagine ↔ Acrylamide • Acrolein + NH_3 ↔ Acrylamide or, acrolein + Asparagine ↔ Acrylamide by the Maillard pathway • Acrylic acid (from Asparagine or other degradation products) + NH_3 ↔ Acrylamide	Friedman, M. J. 2003[18]
• Acrylic acid + NH_3 ↔ Acrylamide (ammonia from thermal degradation of amino acids) • Only approx. 5% of the yield compared to Asparagine	Stadler et al. 2003[16]
• Acrolein (from triolein) + Asparagine ↔ Acrylamide (88.6 µg/g) • Acrolein + NH_3 ↔ Acrylamide (753 µg/g) • Acrylic acid + NH_3 ↔ Acrylamide (190 000 µg/g)	Yasuhara et al. 2003[17]
• Non-oxidative mechanism proposed: acrylic acid from 2-propenal	Vattem & Shetty, 2003[19]
• Formation from a common precursor (decarboxylated Schiff base) by two routes: beta elimination to Acrylamide or 3-aminopropionamide and deamination ↔ Acrylamide	Zyzak et al., 2003[14]
• Heating polyacrylamide at 175°C (15, 30 min) in presence of transition metals	Ahn et al., 2003[20]

Many studies have investigated the formation and reduction of acrylamide, looking at the pH dependence, reduction by addition of enzymes in model systems e.g. asparaginase in dough and potato models[21]. Studies in model systems have also shown that the elimination of acrylamide can be accelerated by addition of heated (caramelised) sugars[13,22]. Addition of sugars not only promotes acrylamide formation by providing a carbonyl source in the Maillard reaction but may also reduce acrylamide under certain conditions.

The addition of proteins to model systems has been investigated using fish[23], meat and chickpea proteins[19] and has resulted in lower acrylamide levels. It has been demonstrated that coating potato slices with chickpea batter before frying results in a reduction in acrylamide levels[19]. The mechanism is still unknown, however suggestions include the chemical elimination of acrylamide or the formation of a thermal barrier. These observations may explain the low levels of acrylamide observed in high protein foods.

4.1.3 Gaps Highlighted and Potential Areas of Research in Acrylamide Formation

- Maillard Reaction:
    - Fundamental research on the mechanistic chemistry of acrylamide outside of the known food systems and the Maillard reaction.
    - What is the efficiency of the Maillard reaction (reducing sugars and carbonyls) to produce acrylamide? Why is the yield of acrylamide formation observed in model systems high in comparison to other Maillard reaction products (as observed in many foods such as roasted nuts, coffee and certain cereals), taking into consideration that elimination reactions commence already at temperatures above 120°C? What limits the acrylamide formation?

Dependent on the conditions, in many foods a significant proportion of free asparagine and sugars remain unreacted.
  - How does the addition of heated sugars influence the final acrylamide levels?
  - Work on potato model systems showed that acrylamide levels decreased initially at about 120°C[6], this effect is more prominent in coffee that is roasted at temperatures above 200°C[24]. It has been suggested that there is a reduction of acrylamide at high temperatures due to the lack of available reducing sugars. Further work is required to investigate whether there are other mechanisms contributing.
  - Are there other precursors that have not yet been identified? Kinetic modelling will assist in determining the rate-limiting steps and thus provide a means of potentially controlling acrylamide formation.
- Amino Acid Mixtures:
  - The competitive effect of free amino acid mixtures must be investigated and linked to the free amino acid pool of the food matrix.
  - There is a need to map the total free amino acid and sugar profiles in crops and raw materials and how this influences acrylamide formation, this could also be extended to other specific amino acids such as lysine and glycine.
  - Kinetic modelling could be used to understand the role of asparagine versus the role of the total amino acids or other specific amino acids.

As a result of these discussions, a need was identified to better understand the fundamental chemistry of acrylamide formation, elucidate the fundamental steps of the reaction and then assess under real food processing conditions, which of the possible pathways are dominant. This understanding should then be translated to food systems and the chemistry that governs industrial food processing, domestic and catering food preparation practices, so that the benefits of the Maillard reaction can be realised without producing acrylamide.

4.2 Physical Parameters

The groups discussed the role of the food matrix and in particular starch and proteins involved in acrylamide formation. Acrylamide formation has been associated with starch-rich foods, however, it has not been shown thus far that starch itself is involved in the formation of acrylamide in food. It has been hypothesised that the starch matrix could entrap, in some manner, acrylamide precursors, intermediates or acrylamide itself, or that the dry matter content of the food effects formation. Another hypothesis is that starch provides an inert matrix, which does not promote elimination of acrylamide; therefore rates of formation are greater than elimination. It should also be considered that starch may have no correlation with acrylamide formation, but it is just that foods containing high levels of asparagine and reducing sugars are also starch-rich.

Temperature has an important role in the formation and elimination of acrylamide. It is well known that acrylamide forms in foods that are cooked at high temperatures, however, when temperatures are raised further an increase in acrylamide destruction is apparent[6,7]. In cereal products the more often a product is heated the higher the destruction of acrylamide, and may be related to the secondary heating effects. It was recommended that further work should be carried out in order to support this hypothesis. In some cases higher baking temperatures are associated with less acrylamide, suggesting that there is a balance of simultaneous reactions forming and destroying acrylamide[13]. There may be a critical temperature/time zone where acrylamide is formed at a greater rate than it is destroyed, at temperatures outside of this zone no/little acrylamide is present. In an attempt to reduce the length of time that foods are cooked at critical temperatures, the use of flash frying and rapid cooling could be used to reduce acrylamide formation. However, it has been suggested that these processes do not produce products with optimum organoleptic properties.

Using thermal imaging techniques, the distribution of temperature in food as it bakes has been studied for some types of cereal biscuit. The imaging shows graphically what is well known to experts in the energy efficiency of baking. The loss of water as the food dries during baking cools it and the bulk of the product is at a temperature very much lower than that of the oven. Temperature, time and moisture are key drivers of acrylamide formation, but the temperature of the food is not that of the oven and the moisture content is at a gradient from centre to crust. Small scale chemistry research needs to embrace the physics of heat and water transport in baking if results are to be meaningfully interpreted and transferred to a manufacturing scale. However, these products are not homogeneous and the observed results will therefore vary considerably.

It was agreed that the water content and the physical state of the food matrix could affect the mechanistic pathway for acrylamide formation. Water affects the chemical route as well as the mobility of the chemical constituents in polymeric matrices such as starch[14], i.e. the transition from the rubbery to glassy state. A small increase in the final water content (from 1% to 2%) has been shown to reduce acrylamide formation in potato crisps[21]. In potato crisps it is thought that the low water content is one of the key contributors to high acrylamide levels[13]. Water management may be a key factor in controlling acrylamide in foods and warrants study in both industrial and domestic processing.

In order to determine how to reduce acrylamide levels effectively, it is important to know whether the formation of acrylamide is controlled by chemical or physical processes, and to gain further understanding of the acrylamide formation process and the Maillard reaction.

Several areas were identified which require further research:

- It has been suggested that acrylamide may only be present at high levels within a critical temperature zone, where the formation reaction is greater than elimination. Further work is required to determine whether altering processing techniques could avoid this critical temperature zone.
- Water content could be a key factor to controlling acrylamide levels, but little is still known about the effects of water content and the physical state of the food matrix on acrylamide formation.

4.3. Processing Techniques and Recipes

Processing techniques as well as the composition of the raw materials determine product characteristics (e.g. colour, flavour, and texture) and influence acrylamide levels in foodstuffs. Several researchers to date have shown that there is a relationship between product colour and acrylamide levels[25,26], however, there must be a colour/texture balance in order to have a product with acceptable organoleptic properties. Conversely, other researchers believe that product colour cannot be relied on as a good indicator of acrylamide levels.

In experiments looking at the production of roasted potato products, it has been shown that reducing sugar levels of 1g/kg and 2g/kg in fresh weight potatoes resulted in acrylamide levels of approximately 500ppb and 1000ppb respectively[27]. These researchers therefore concluded that potatoes with less than 1 g/kg reducing sugar are desired to retain low levels of acrylamide in roasted or fried potatoes. It has been seen that acrylamide levels can be significantly reduced by decreasing the reducing sugar content. However, because potato products are not uniform, both acrylamide and reducing sugar levels can vary considerably between products and therefore it is not possible to fix a maximum level of reducing sugars in fresh potatoes destined for cooked potato products.

In a Swiss study participants were asked to prepare French fries following preprepared instructions. This guidance detailed methods of preparing the fries to minimise acrylamide levels, without compromising product quality. 63 % of the participants produced fries with less than 100 ppb.

It was pointed out that processing techniques are much more complex in other sectors, such as the baking industry, where several unique and complex processes/recipe combinations are employed for individual product types. A much better understanding of the chemistry is required before significant changes can consistently be made.

Processing temperature alone is an inadequate parameter to compare different processing techniques. Heat flux allows the measurement of the energy transferred to the food from conductive, convective and radiative processes in an oven, and is therefore a more accurate representation of the processes occurring in the oven. The rapid cooling of low density, fried snack products following cooking can be demonstrated to lower acrylamide levels. In this instance rapid cooling prevents further cooking post frying and hence additional acrylamide generation.

Based on industrial baking trials and model experiments, it has been observed that the use of ammonium carbonate as a baking aid can increase acrylamide formation[13]. It is not obvious what role ammonia plays in acrylamide formation; when ammonium carbonate was added to a glucose–asparagine system (without a food matrix) no increase in acrylamide was observed. However, in some model experiments the addition of ammonium carbonate has resulted in an increased yield[13]. Reducing the amount of the raising agent ammonium bicarbonate was shown to reduce the acrylamide levels in plain flour matrices and the addition of lactic acid had a similar effect. Yung et al showed that the addition of citric acid to both French fries (1-2 %) and corn chips (0.1 – 0.2%) reduced acrylamide levels[28]. However, citric acid accelerates the degradation of the frying oil that consequently leads to off-flavours and unacceptable quality of the products.

The role of ammonia needs to be explored and this was identified as a gap in the current knowledge. In the meantime it was felt that there is a need to investigate other CO_2-releasing agents that are compatible with food processing technology and will not compromise the desired organoleptic characteristics. The addition of SO_2 as an antioxidant was discussed as an effective means of reducing acrylamide levels during processing, although its use is limited by its potential allergenic properties[29].

Other processing techniques which have been seen to produce a reduction in acrylamide levels, include the chemical or enzymatic reduction of asparagine, or the addition of amino acids other than asparagine. Addition of cysteine has been shown to be most effective in the reduction of acrylamide, although it produced an unpleasant off-flavour in the food. Blanching potatoes before cooking leaches out sugars from the potato and therefore reduces the acrylamide formation potential[26].

The affect of cooking oil has also been investigated, but due to the water-soluble nature of acrylamide it is not thought to be important; in a recent study it has been shown that acrylamide is not found in the oil following cooking. One question that remains is the effect of using old cooking oils on the level of acrylamide, and the potential contribution from the accumulation of particulates on the oil filters during frying. However, further work is required to establish how significant this effect would be.

Areas for further investigation:

- The role of ammonia in acrylamide formation.
- The consequences of high temperatures and the addition of sugars as elimination options.
- Process-related parameters (high temperature, high sugar) and different forms of cooking processes that result in high acrylamide levels.
- Feasibility of acrylamide reduction in coffee and other commodities.

For all heating processes the formation of acrylamide is related to the three physical factors, temperature, time and water content, and this may in turn affect the safety and organoleptic qualities of the food. Therefore when changing processing techniques to alter acrylamide formation, processors must also consider the expectations and safety of the consumer.

4.4. Agricultural Effects

Variation in raw materials and ingredients play an important role in acrylamide formation due to natural variation in levels of asparagine and reducing sugars. Reducing sugar levels in potatoes vary considerably with a number of factors including crop variety, seasonal changes, growing conditions (e.g. weather and type of soil) and storage conditions. In cereals it appears that variation in asparagine levels could be an important factor determining the acrylamide formation potential, although further data are required. Potato crops also show variation in reducing sugar and asparagine levels both between and within batches[15], hence this is an important problem.

In both cereals and potatoes, it has been seen that varying the crops growing conditions will effect the variation in precursors, these differences are more significant in potatoes. It is thought that there is a higher homogeneity of precursors within a batch of grain than in potatoes, however, further work is needed to confirm these observations. The selection of crop varieties with lower reducing sugar levels provides a limited reduction in the levels of acrylamide and is currently being used in some areas of the cereal market. Millers blend all kinds of grain and use wide varieties of flours, and also add minerals and other additives; this makes the selection of cereal products based on crop type more difficult. Asparagine levels can vary depending on the degree of milling, for example, dark flours can contain twice as much asparagine as white flour[30], however, in alternative experiments no significant difference has been observed.

Genetic modification of plant materials could provide a quick and effective reduction of reducing sugars and therefore the potential for acrylamide formation, for example, inhibiting the enzyme invertase to reduce the formation of reducing sugars in potatoes. This would avoid the lengthy process of crop breeding programmes, but due to other considerations it is not currently possible to use genetically engineered products.

The use of asparaginase in yeast during bread production was also discussed and is said to successfully reduce levels of acrylamide in bread, although the fermentation time is significantly increased. This is an important area for manufacturers of leavened dough products and further investigations are required to discover how it effects acrylamide formation.

Asparagine levels vary between varieties of cereals and little is known about what affects these levels. Potatoes produced using organic fertilisers have been shown to result in potatoes with slightly higher asparagine levels. Additionally the nitrogen content of the soil also appears to have a stronger link to the amino acid content in potatoes than it does in cereals, however, some experiments have shown that nitrogen fertilisers have no effect on the levels of asparagine[6,15].

The time that potatoes are harvested may also have a significant effect on the potential for acrylamide formation. The maturity stage of the potato tubers affects the reducing sugar levels. If two crops of the same variety, grown under the same conditions were harvested at different times, the more immature potatoes would have higher levels of reducing sugar. This relative difference in sugar levels will remain the same if the potatoes are kept under the same storage conditions[31].

In order to develop a sustainable approach to reducing acrylamide levels in the long term, it was felt that information on the effect of the fundamental chemistry of the precursors on acrylamide levels (e.g. free amino acid and sugar profiles), must be translated into plant breeding programs. However, it was noted that the benefits from such programmes may take more than 10 years to be realised. The challenge will be to consistently achieve the desired levels of precursors crop after crop within seasonal and climatic variations.

Comparatively little is known about cereals and other commodities such as coffee and the effects different agricultural practices have on the levels of acrylamide in the final foods. Further work is required on different crop varieties, critical components and processing parameters effecting the formation of acrylamide in coffee. It is also necessary to identify other potential commodities that may produce high levels of acrylamide.

Further research is required to determine the free amino acid pool and reducing sugar content for targeted raw materials e.g. wheat, other cereals, coffee and cocoa, and the associated natural variations within a single crop, within a season and over a number of years. For example what are the effects of seasons with low levels of precipitation on the levels of acrylamide formed in the final processed foodstuff?

Areas for further investigation for the development of a plant-breeding programme:

- Bio-agricultural research is needed to understand the metabolic profiles and develop fingerprints for the key precursors, and how this affects the composition of priority raw materials and hence acrylamide formation.
- Environmental affects on the composition of raw materials and how this affects acrylamide formation potential, for example, the use of fertilisers, climatic variation and natural variation, both between crops and from fluctuations between years and seasons.

4.5. Storage Conditions

Controlling storage conditions of potatoes could be a simple method for reducing acrylamide levels in cooked potato products[32]. It has been widely recognised that the storage conditions of potatoes can contribute significantly to the potential for acrylamide formation. By carrying out a systematic assessment of storage parameters, such as, temperature, humidity and light on factors such as levels of asparagine, reducing sugars and the associated product quality, this may provide information on reducing the potential for acrylamide formation. Storage of potatoes at temperatures below 8°C and storage over long periods of time have been shown to increase the concentration of reducing sugars and asparagine[21], which consequently increases the potential for acrylamide formation. It was also suggested that asparagine is not effected by storage conditions, therefore further work is recommended to confirm these suggestions. Recommendations were made for research to assess the associated risk of increasing storage temperatures above 4°C, including the potential for disease and the effects of using sprout inhibitors on product quality and safety. It was thought that some of these factors could be overcome by selecting crops that were suited for particular storage conditions.

It was suggested that potatoes destined for industrial processing are currently kept under controlled storage conditions, whereas fresh potatoes to be sold for domestic use are stored at lower temperatures, therefore increasing the potential for high reducing sugar levels and therefore the formation of acrylamide in domestically prepared potato products.

It has been found that reconditioning potatoes by storing them at higher temperatures for 2-3 weeks will lower levels of reducing sugars and consequently the potential for acrylamide formation. When considering this it must be acknowledged that it generally takes at least 2 weeks from delivery to processing in the home, which could provide the necessary reconditioning. However, reconditioning for 2-3 weeks will not reduce reducing sugar levels to the original levels[32].

As well as attempting to lower reducing sugar levels and therefore the potential for acrylamide formation, it may also be possible, by monitoring levels of reducing sugars in batches of raw potatoes, to recommend products suitable for particular processes.

It is currently thought that the storage conditions of cereals do not have a significant effect on the potential for acrylamide formation. Little is known about the effects on other commodities and this would therefore benefit from additional research.

During discussions the following areas were highlighted as requiring further research:

- The systematic assessment of storage parameters, such as, temperature, light and humidity on acrylamide precursor levels.
- Associated risk of changing storage conditions on product safety and quality, and the potential effects of using sprout inhibitors on potatoes.

4.7. Communication and Information Exchange

Continued use should be made of the systems already in place, for example, populating the EC JRC Monitoring Database on Acrylamide Levels[33] with data generated from national surveillance programmes and other analyses. Also keeping updated the Acrylamide Information Base of Research Activities in the EU[34] and the FAO/WHO Acrylamide Infonet[35].

The format for the discussion and exchange of new ideas was not discussed. Closer contact and interaction should be made with potato research institutes, e.g. The Federal Research Centre for Nutrition and Food, Germany (formerly The Federal Centre for Cereal Potato and Lipid Research), Wageningen UR or Agrotechnology and Food Innovations, Netherlands. A project on selection of cultivars and storage conditions to supply potatoes for roasting, baking and frying is being carried out by the Swiss Federal Research Station for Agroecology and Agriculture FAL, Reckenholz-Zurich.

Efforts should be made to exchange information on the formation of acrylamide through communication with the EC 6th Framework Programme HEATOX project[36], via its dissemination package. Also the University of Newcastle is carrying out a study on Low Input Farming as part of the EC 6th Framework Programme[36]. This project aims to lead to new technologies and systems for organic and low input production systems, the research will include potatoes and cereals.

5. CONCLUSIONS

The key conclusion highlighted by many participants of the workshop was that further research was required to better understand the fundamental chemistry of acrylamide formation. It was noted by several participants that for a number of the relevant foods there is insufficient information available to be able to consistently lower the levels of acrylamide formed. There is a need to elucidate the fundamental steps of the reaction and then assess under real food processing conditions, which of the possible pathways are dominant. This understanding should then be translated to food systems and the chemistry that governs industrial food processing, domestic and catering food preparation practices; so that the benefits of the Maillard reaction can be realised without producing acrylamide and adversely affecting other safety/nutritional factors.

In addition to the research needs listed below other recommendations were:

- Continue the co-ordination of acrylamide activities via the Acrylamide Information Base of Research Activities in the EU and the FAO/WHO Acrylamide Infonet.

- Provide regular updates on research activities and the EC 6th Framework Programme Heatox Project.
- Liase with the EC's DG Agriculture on relevant issues such as, potential plant breeding programmes, and collaborate with farmers, agriculture and research institutes.

During the discussions a number of areas were highlighted for further research:

5.1. Chemistry of Formation:

5.1.1. Maillard Reaction:

- Fundamental research on the mechanistic chemistry of acrylamide outside of the known food systems and the Maillard reaction.
- Investigate further the mechanism for acrylamide destruction at high temperatures.
- Identification of other potential acrylamide precursors.
- Investigate why low levels of acrylamide are observed in high protein foods.

5.1.2. Amino Acid Mixtures:

- Map the total free amino acid and sugar profiles in crops and raw materials and how this influences acrylamide formation.
- Kinetic modelling could be used to understand the role of asparagine versus the role of other amino acids.

5.2. Physical Parameters:

- Further work is required to determine whether altering processing techniques could avoid temperatures where the rate of acrylamide formation is greater than the rate of destruction.
- The effects of water content and the physical state of the food matrix on acrylamide formation.
- The physics of heat and water transport in baking.

5.3. Processing Techniques:

- The role of ammonia in acrylamide formation.
- Process-related parameters (high temperature, high sugar) and different forms of cooking processes that result in high acrylamide levels.
- The effect of using old cooking oils on the level of acrylamide, and the potential contribution from the accumulation of particulates on the oil filters during frying.

5.4. Agricultural Effects:

- Understand the metabolic profiles and develop fingerprints for the key precursors, and how this affects the composition of priority raw materials and hence acrylamide formation.
- Environmental affects on the composition of raw materials and how this affects acrylamide formation potential.

5.5. Storage Conditions:

- The systematic assessment of storage parameters, such as, temperature, light and humidity on acrylamide precursor levels.
- Associated risk of changing storage conditions on product safety and quality, including the use of sprout inhibitors on potatoes.

Annex I **Glossary of Terms and Abbreviations**

Annex II **Attendance List - EFSA Workshop on Acrylamide Formation in Food**

Annex III **Agenda - EFSA Workshop on Acrylamide Formation in Food**

References

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[36] EC 6th Framework Programme: http://europa.eu.int/comm/research/fp6/index_en.html

Glossary of Terms & Abbreviations

CIAA	Confederation des Industries Agro-Alimentaries (Confederation of Food and Drink industries of the European Union)
CO_2	Carbon dioxide
DG	Directorate-General
EC	European Commission
EFSA	European Food Safety Authority
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FSA	Food Standards Agency, UK
JRC	EC Joint Research Centre
ppb	Parts per billion
SCF	EC Scientific Committee on Food
SO_2	Sulphur dioxide
US JIFSAN	United States Joint Institute for Food Safety and Applied Nutrition
VWA	Voedsel-en Waren Autoriteit (Dutch Food and Consumer Product Safety Authority)
WHO	World Health Organisation

Transition from the rubbery to glassy state: Polymers can exist in three physical states (glassy, rubbery and viscous flow state), between the glassy and rubbery state is the glass-to-rubber transition zone. At low temperatures the polymer is in the glassy state (rigid and brittle), molecular motion is restricted to vibrations and the chains are unable rotate or move in space. As the polymer is heated the chains are able to move, and the polymer becomes rubbery (soft and flexible). Each polymer will have a different transition temperature.

European Food Safety Authority

Workshop on Acrylamide Formation in Food - 17 Nov 03, Brussels

List of Participants

Name	*Organisation*	*Email Address*
Chair:		
Herman Koëter	European Food Safety Authority (EFSA)	herman.KOETER@efsa.eu.int
Co-ordinators:		
Claudia Heppner	European Food Safety Authority (EFSA)	claudia.HEPPNER@efsa.eu.int
Karen Goonan	Food Standards Agency, UK	karen.goonan@foodstandards.gsi.gov.uk
Wendy Matthews	Food Standards Agency, UK	wendy.matthews@foodstandards .gsi.gov.uk
Wim Ooms	Dutch Food and Consumer Product Safety Authority (VWA)	wim.ooms@vwa.nl

Annex II

Name	*Organisation*	*Email Address*
Group A		
Richard Stadler (Chair)	Nestle, Switzerland	richard.stadler@rdls.nestle.com
Erik Konings (Co-rapporteur)	Dutch Food and Consumer Product Safety Authority (VWA)	Erik.konings@kvw.nl
Sam Lalljie (Co-rapporteur)	Unilever	sam.lalljie@unilever.com
Achim Boenke	EC DG Research	Achim.Boenke@cec.eu.int
Barbara Gallani	EC DG-SANCO	Barbara.GALLANI@cec.eu.int
Bob Foot	European Snack Association, UK	rfoot@esa.org.uk
David Lineback	Joint Institute for Food Safety and Applied Nutrition (JIFSAN), US	lineback@umd.edu
Didac Garcia Carrete	Hotrec Catering Sector, Belgium	didac.garcia@hotrec.org
Don Mottram	Reading University, UK	d.s.mottram@reading.ac.uk
Ernst Reimerdes	German Institute for Food Technology	e.reimerdes@dil-ev.de
Ian Slaiding	Brewing Research International, UK	islaidin@brewingresearch.co.uk
Ingegerd Sjoholm	Lund University, Sweden	Ingegerd.Sjoholm@livstek.lth.se
Janny van Gijssel	Wageningen UR, Agrotechnology and Food Innovations	Janny.vangijssel@wur.nl
Julia Gelbert	German Federation of Food Law and Food Science (BLL)	jgelbert@bll-online.de
Karl-Erik Hellenäs	National Food Administration (SLV), Sweden	kahe@slv.se
Konrad Grob	Food Control Authority, Switzerland	Konrad.Grob@klzh.ch
Laurence Castle	Central Science Laboratory (CSL), UK	l.castle@csl.gov.uk
Leif Busk	National Food Administraton (SLV), Sweden	leif.busk@slv.se
Lutz Dehne	Federal Institute for Risk Assessment (BfR), Germany	l.dehne@bfr.bund.de
Paul van Eijck	McCain Foods Ltd, Canada	pvaneijc@mccain.ca
Peter Sadd	RHM Technology Ltd. UK	pasadd@rhmtech.co.uk
Philippe Verger	INRA Safe Consortium, Belgium	philippe.verger@safeconsortium.org
Pietro Realini	Zweifel Pomy-Chips Ltd, Switzerland	Pietro.realini@zweifel.ch
Songün Demirel	Food Science and Techology Research Institute (FSTRI), Turkey	Songun.Demirel@posta.mam.gov.tr
Thomas Wenzl	EC DG-JRC, IRMM	Thomas.WENZL@cec.eu.int

Name	*Organisation*	*Email Address*
Group B		
Norbert Hasse (Chair)	Federal Centre for Cereal, Potato and Lipid Research, Germany	potato@bagkf.de
Colin Hamlet (Co-rapporteur)	RHM Technology Ltd, UK	cghamlet@rhmtech.co.uk
Eugène Schijvens (Co-rapporteur)	Wageningen UR, Agrotechnology and Food Innovations, Netherlands	Eugene.schijvens@wur.nl
Anne-Mette Jensen	CIAA	a.jensen@ciaa.be
Brian Hanley	Leatherhead Food International, UK	Bhanley@LeatherheadFood.com
Denise Baxter	Brewing Research International, UK	dbaxter@brewingresearch.co.uk
Detlef Muller	Procter & Gamble, Germany	muller.d@pg.com
Frederic Mestdagh	Ghent University, Belgium	frederic.mestdagh@Ugent.be
Gerhard von Campenhausen	Union der Deutschen Kartoffelwirtschaft (UNIKA), Germany	info@kartoffelwirtschaft.de (h.simonin@bauernverband.net)
Hülya Olmez	Food Science and Technology Research Institute (FSTRI), Turkey	Hulya.Olmez@posta.mam.gov.tr
Iona Pratt	Food Safety Authority of Ireland	ipratt@fsai.ie
James Williams	Campden and Chorleywood Food Research Association, UK	j.williams@campden.co.uk
Jana Hajslová	Institute of Chemical Technology, Czech Republic	jana.hajslova@vscht.cz
Katrin Hoenicke	WEJ GmbH, Germany	katrin.hoenicke@wej.de
Kerstin Skog	Lund University, Sweden	Kerstin.Skog@inl.lth.se
Kristina Bagdonaite	Graz University, Austria	bakrista@sbox.tugraz.at
John O'Brien	Danone, France	John.O'BRIEN@danone.com
Maaike Bilau	Ghent University, Belgium	Maaike.Bilau@Ugent.be
Marco Dalla Rosa	University of Bologna, Italy	mdrosa@foodsci.unibo.it
Martin Slayne	DG-SANCO, EC	Martin.Slayne@cec.eu.int
Peter Ashby	Cereal Partners Worldwide, UK	peter.ashby@uk.nestle.com
Pierre Gonde	McCain Continental Europe, France	pigonde@mccain.ca
Roland Grossgut	Austrian Agency Health & Food Safety	roland.grossgut@ages.at
Svein Knutsen	Matforsk, Norway	svein.knutsen@matforsk.no
Thomas Amrein	Swiss Federal Institute of Technology (ETH Zurich), Switzerland	thomas.amrein@ilw.agrl.ethz.ch

European Food Safety Authority

Workshop on Acrylamide Formation in Food

17 November 2003, Brussels – Sofitel Brussels Airport Hotel

Final Agenda

1. **09.30 – 10.00 Registration and Coffee**

2. **10.00 Introduction**
   - Introduction to workshop, including the aims, expected outcomes, EFSA's role & an overview of the 28 March 03 Acrylamide Meeting: Dr. Herman Koëter, EFSA (10 mins)
   - Update from 20/21 October European Commission workshop: Dr. Martin Slayne, European Commission DG SANCO (10 mins)
   - Update from EC JRC on acrylamide activities. Dr. Thomas Wenzl, JRC (10 mins)
   - An overview on the EC 6th Framework programme Heatox project: Dr. Kerstin Skog, University of Lund, Lund, SE (5 mins)
   - Overview of EU database on research activities: Dr. Claudia Heppner, EFSA (10 mins)
   - Update on international research efforts: Dr. David Lineback (Joint Institute for Food Safety and Applied Nutrition, USA) (15 mins)
   - CIAA update on research: Dr Richard Stadler, CIAA (10 mins)

3. **11.15 Discussion Groups: Session I**
   - Discussion of scientific information and opinions on formation of acrylamide in foods, including information on available results. Any topic on the formation of acrylamide can be discussed during the session. Topics such as chemical mechanisms of formation, the effect on formation of raw commodity variety/storage/cooking method etc are likely to be included.

4. **13.00 – 14.00 Buffet Lunch**

5. **14.00 Group Feedback Session**
   - Group chairs will provide a summary of the mornings discussions.
   - Highlight gaps in knowledge and research for discussion in session II.

6. **14.30 Discussion Groups: Session II**
   - Continuation of the morning session, taking account of outcome of other groups as presented in feedback session.
   - Focus on current gaps in knowledge and how we can approach filling these gaps and possibly generate ideas for future research.

7. **16.15 Coffee Break**

8. **16.30 Plenary Session**
   - Discussion group chairs will provide a summary of key points highlighted during the day
   - Discussion on key points raised and how they can be taken forward
   - Discussion of facilitation of further discussion/information exchange
   - Recommendations
   - AOB

9. **17.30 Closing Remarks from Chair**