codex alimentarius commission

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

WORLD HEALTH ORGANIZATION

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Agenda Item 12 **CX/CF 07/1/15**

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JOINT FAO/WHO FOOD STANDARDS PROGRAMME
CODEX COMMITTEE ON CONTAMINANTS IN FOODS
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PROPOSED DRAFT CODE OF PRACTICE FOR THE REDUCTION OF ACRYLAMIDE IN FOOD **(N06-2006)**

(At Step 3 of the Elaboration Procedure)

Governments and international organizations are invited to submit comments on the following subject matters no later than 1 March 2007, preferably in electronic format, for the attention of Ms. Tanja Åkesson, the Netherlands Secretariat of the Codex Committee on Contaminants in Foods, Fax No.:+31 70 3786141; E-mail:info@codexalimentarius.nl with a copy to the Secretary, Codex Alimentarius Commission, Joint FAO/WHO Food Standards Programme, Viale delle Terme di Caracalla, 00153 Rome, Italy (Fax +39.06.5705.4593; E-mail: Codex@fao.org).

BACKGROUND

1. The Codex Committee on Food Additives and Contaminants, at its 38th Session, agreed to start new work to elaborate a Code of Practice for the Reduction of Acrylamide in Food and agreed to establish an electronic working group for preparation of an initial draft of the Code of Practice (ALINORM 06/29/12 para. 185 and Appendix XXIX)[1].

2. The new work proposal was approved by the 29th Session of the Codex Alimentarius Commission as N06-2006 (ALINORM 06/29/41, Appendix VIII)[2].

3. The Codex Committee on Contaminants in Foods is invited to discuss the initial draft Code of Practice for the Reduction of Acrylamide in Foods prepared by the electronic working group as presented in ANNEX to this document. The Committee is also invited to draw its attention to the report of the electronic working group as presented in paras 4 – 8.

REPORT OF THE ELECTRONIC WORKING GROUP

4. As agreed by the Codex Committee on Food Additives and Contaminants at its 38th Session[1], the electronic working group led by the United States and the United Kingdom elaborated the Proposed Draft Code of Practice for the Reduction of Acrylamide in Foods. Canada, China, Denmark, European Community, Germany, Indonesia, Japan, Netherlands, Republic of Korea, Sweden, Thailand, United Kingdom, United States, WHO, CIAA, ICGMA, IFT and INC participated in the electronic working group.

5. More information was requested on the levels of acrylamide from developing countries, in particular on national foods.

6. This draft Code of Practice is being developed as a means of disseminating strategies that will facilitate the reduction of acrylamide in internationally traded foodstuffs. The draft Code of Practice

discusses those established minimisation techniques that have been demonstrated to be effective in a commercial setting. Several potential strategies that are still at the research stage are also discussed.

7. The focus of this draft Code of Practice is predominantly on foods produced from potatoes and cereals, reflecting their importance in terms of dietary exposure to acrylamide. It builds upon the substantial body of information that now exists with respect to these products. Although coffee is also an important contributor to acrylamide exposure, effective minimisation strategies for coffee are not currently available.

8. This Code of Practice draws on a number of activities already undertaken, such as the "CIAA Acrylamide Toolbox", a document produced by the Confederation of the Food and Drink Industries of the EU (CIAA), which contains potential acrylamide mitigation measures relevant to many food sectors.[3] The Toolbox is updated on a regular basis as new knowledge and progress in the different food sectors are reported.

ANNEX

PROPOSED DRAFT CODE OF PRACTICE FOR THE REDUCTION OF ACRYLAMIDE IN FOOD

INTRODUCTION

1. Recent concern over the presence of acrylamide in food dates from 2002. Swedish scientists[4] reported that up to mg/kg quantities of acrylamide could be formed in carbohydrate-rich foods during high-temperature cooking, e.g., during frying and baking. These findings were rapidly confirmed by other researchers;[5] subsequently, major international efforts have been mounted to investigate the principal sources of dietary exposure, assess the associated health risks and develop risk management strategies.[6,7,8,9,10,11] Details of these global research initiatives are provided on the WHO/FAO Acrylamide Information Network (http://www.acrylamide-food.org/) and the EU Acrylamide in Food Database of Activities (http://ec.europa.eu/food/food/chemicalsafety/contaminants/acrylamide_en.htm).

2. Acrylamide is mainly formed in food by the reaction of asparagine (an amino acid) with reducing sugars (particularly glucose and fructose) as part of the Maillard Reaction;[12,13] acrylamide may also be formed *via* reactions involving 3-aminopropionamide.[14,15] Acrylamide formation primarily takes place under conditions of high temperature (usually in excess of 120 °C) and low moisture.

3. The Joint FAO/WHO Expert Committee on Food Additives (JECFA)[7] has undertaken a comprehensive analysis of acrylamide occurrence data from 24 countries, the majority originating from Europe and North America. It was concluded that the major contributing food groups were French fries[a], potato crisps[b], coffee, biscuits[c]/pastries, bread and rolls/toasted bread.

TOXICOLOGY

4. JECFA reviewed acrylamide at the request of CCFAC in 2005.[7] The following section summarises the major conclusions of the JECFA review.

5. Acrylamide is an important industrial chemical used since the mid 1950s as a chemical intermediate in the production of polyacrylamides, which are used as flocculants for clarifying drinking water and in other industrial applications. The neurotoxicity of acrylamide in humans is well known from occupational and accidental exposures. In addition, experimental studies with acrylamide in animals have shown reproductive, genotoxic, and carcinogenic properties.

6. JECFA analysed acrylamide occurrence data from 24 countries and national dietary intake data from 17 countries. The committee identified average acrylamide intakes in the range 0.3 – 2.0µg/kg bw/day, with a mean of 1µg/kg bw/day for the general population and intakes in the range 0.6 –5.1µg/kg bw/day, with a mean of 4µg/kg bw/day for high-level consumers (90 – 99th percentile).

7. To assess the risk of cancer from acrylamide in food, JECFA calculated a Benchmark Dose Lower Limit (BMDL) for mammary tumour formation from rodent carcinogenicity studies and then calculated the margin of exposure (MOE) between the BMDL and human acrylamide intake. For average intakes (1µg/kg bw/day), the MOE was 300; for high intakes (4 µg/kg bw/day), the MOE was 75. JECFA considered these MOEs to be low for a compound that is genotoxic and carcinogenic and concluded that the MOEs may indicate a human health concern.

8. JECFA also calculated MOEs for neurological effects of 200 and 50 for average and high intakes; for reproductive, developmental, and other non-neoplastic effects, JECFA calculated MOEs of 2000 and 500 for average and high intakes. Based on these MOEs, JECFA concluded that adverse neurological, reproductive, and developmental effects are unlikely for the average consumer, but that morphological changes in nerves cannot be excluded for some individuals with very high intake.

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[a] Potato products that are thickly sliced and fried (referred to as French fries in some regions including North America, or as chips in the UK).

[b] Potato snack product that is thinly sliced and fried (includes foods called potato chips in some regions including North America).

[c] Baked cereal products (referred to as cookies in some regions, including North America).

9. In summary, JECFA concluded that the pivotal effects of acrylamide for risk assessment are genotoxicity and carcinogenicity. The Committee also stated that ongoing studies of neurotoxicity and neurodevelopmental effects in rats will more clearly define whether neurotoxic or neurodevelopmental effects may arise from long-term, low doses of acrylamide.

10. JECFA made the following recommendations:

    i. acrylamide should be re-evaluated when results of ongoing carcinogenicity and long-term neurotoxicity studies become available,

    ii. work should be continued on using pharmacologically based pharmacokinetic (PBPK) modelling to better link human biomarker data with exposure assessments and toxicological effects in experimental animals,

    iii. appropriate efforts to reduce acrylamide concentrations in food should continue, and

    iv. it would be useful to have occurrence data on acrylamide in foods as consumed in developing countries.

11. A number of studies have been commissioned following the JECFA review of acrylamide. At the time this draft Code of Practice was prepared, these studies had not been completed. As outlined in its Action Plan for Acrylamide in Food,[16] the United States Food and Drug Administration (FDA) and associated agencies are conducting a suite of studies on both acrylamide and glycidamide. Short-term studies on toxicokinetics, bioavailability, DNA adduct formation, and acrylamide in rodent feed have been completed,[17,18,19,20,21,22] but the results of long-term carcinogenicity assays and a developmental neurotoxicity assessment will not be available until 2008. The FDA has completed research for a physiologically based pharmacokinetic model (PBPK) for acrylamide in rodents and humans. This model will allow better estimates of the levels of DNA damage resulting from dietary exposures to acrylamide and better extrapolation of human cancer risks from rodent carcinogenicity studies.[23] The first large, prospective epidemiological cohort study recently reported no association between acrylamide intake and colorectal cancer, and intake of specific foods high in acrylamide was not associated with elevated risk.[24] Other groups are also continuing work on acrylamide toxicology, including recent work on adducts and urinary metabolites.[25,26]

RECOMMENDED PRACTICES

12. In broad terms there are three main strategies for reducing acrylamide formation in a particular product:

    i. raw materials — reduction of the levels of asparagine and/or reducing sugars in the raw materials;

    ii. control/addition of other ingredients — reduction of the effective concentration of asparagine and/or reducing sugars during the early stages of food processing *via* careful control/addition of other ingredients, and

    iii. food processing and heating — modification/careful control of food processing, and the thermal profile of cooking, to minimise conditions that result in excessive heat and low moisture.

13. For the purposes of this draft Code of Practice, the recommended practices are divided up according to food groups.

POTATOES

Raw materials

14. The concentration of reducing sugars is the most important factor related to raw materials that can be used practically to influence acrylamide formation in potatoes and potato products. There is a strong correlation between reducing sugar content and cooking-mediated formation of acrylamide in potatoes.[27] Moreover, the concentration of reducing sugars exerts a greater effect on final acrylamide levels than does the asparagine concentration.[28] A number of factors influence reducing sugar levels including climatic conditions, cultivar,[28] storage temperature and time,[29] reconditioning temperature and time,[29] tuber size,[30] and fertilizer application rate.[31] Concentrations of reducing sugars in potatoes can vary by up to two orders of magnitude,[28] depending, in particular, on cultivar and storage history. Exploitation of the variation in the reducing sugar content represents a major opportunity for reducing acrylamide formation during cooking. Agronomical and genetic factors may be varied to produce potato tubers with low levels of asparagine and/or reducing sugars; however, such approaches are likely to have a significant lead time and other factors, such as yield and resistance to fungal infections (field mycotoxin formation), would need to be considered.

15. Some cultivars are inherently more prone to higher levels of reducing sugars than others, and should be avoided if at all possible for high temperature cooking processes such as frying and baking. In particular, cultivars should be selected with reducing sugar contents of less than 0.3 % on a wet weight basis.[3] The European Cultivated Potato Database has information on the suitability of potatoes for French fry usage and includes information on the suitability for crisping.[32]

16. Storage of potatoes below 9 – 10 °C enhances the formation of reducing sugars.[33] Generally, low-temperature sweetening occurs if tubers are stored at, or below, about 9 – 10 °C, with resultant increases of an order of magnitude (or more) in the reducing sugar content. Some cultivars are less prone than others to low temperature sweetening.[34,35] Information on such cultivars is contained in a database available from the German Federal Office of Plant Varieties.[36] Where feasible, potatoes for frying or roasting should be stored in a manner so as to minimise low-temperature sweetening.

17. When potatoes that have been stored at low temperatures are reconditioned over a period of a few weeks at higher temperatures (e.g., 12 – 25 °C), the reducing sugar content decreases again, although not to pre-storage levels.[29] Reconditioning has been associated with an increased variability of fry colour, i.e., one tuber in a batch may recondition better than another, and some tissues (of a tuber) recondition better than others. Fry defects should be expected to be higher in crisps and chips made from reconditioned potatoes. Potatoes that have been subject to excessive low-temperature sweetening during storage should be avoided for frying, roasting and oven-baking. However, low-temperature storage may be unavoidable because at higher temperatures potatoes become more susceptible to sprouting and to certain diseases. Indeed, storage at low temperatures is of fundamental importance in maintaining the low disease levels required to keep pre-packaged potatoes in a saleable condition. Sprout suppressant is often essential in stores held at temperatures over 7 °C,[37] although regional regulations in some cases do not permit the use of sprout suppressants. The need to use sprout suppressant treatments is dependent on the variety of tuber, length and time of storage, and the season. In short-dormant cultivars, sprout suppressants may be required, even during storage at 3.5 °C.

18. Manufacturers of French fries and potato crisps should select potato cultivars that are low in reducing sugars, screen incoming lots by measuring sugar content or assessing the colour of a fried sample, and control storage conditions from farm to factory.[3]

Control/addition of other ingredients

19. For reconstituted or formed potato-based snacks produced from potato doughs, it may be possible to include other ingredients with lower reducing sugar/asparagine content to replace some of the potato. The practicality of this option will depend on organoleptic properties and subsequent consumer acceptability.

20. Addition of the enzyme asparaginase has been shown to reduce asparagine and thus acrylamide levels in potato products made from potato doughs.[38,39] Although asparaginase treatment is not yet in commercial use, a US patent has been awarded for this process and two companies have filed notices informing the US FDA of their view that the use of asparaginase in certain foods is Generally Recognized as Safe (GRAS). Asparaginase may be best suited for food products manufactured from liquidised or slurried materials.[38]

21. Treatment with various other reagents prior to the frying stage has also been demonstrated to reduce acrylamide formation. Nevertheless, these experimental minimisation procedures have yet to be applied in a full commercial setting, and the issue of whether such pre-treatments may cause an adverse impact on the organoleptic qualities of the final product has not, in the main, been addressed. Similarly, the practicality of these procedures in the context of a commercial setting, such as a catering establishment, has not been studied in depth. Techniques that fall into this experimental category include: treatment of French fries with amino acids[40,41] or sodium acid pyrophosphate,[3] treatment with calcium salts, and the salts of a number of other di- and trivalent cations (this method has been shown to reduce acrylamide formation in French fries made from potato dough[42]) and blanching in sodium chloride solution[43] (though this method may increase dietary exposure to salt). In addition to the caveats over organoleptic issues, and practicality in a commercial setting, it should also be noted that a number of these procedures may require regulatory approval.

22. Acrylamide has also been found in taro, a root vegetable commonly used in Chinese cooking. Laboratory studies have indicated that coating taro in a thin starch batter can reduce acrylamide formation.[44]

Food processing and heating

23. Acrylamide levels in fried or roasted potatoes can be reduced by decreasing the surface area; for example, by cutting potatoes into thicker slices or removal of fines (fine pieces of potato) before or after frying.[45,46]

24. Washing, blanching or par-boiling treatments may be employed to leach the asparagine/reducing sugar reactants from the surface of the potato before the cooking step, as has been demonstrated for potato slices.[47,48] Blanching is a standard processing step in the manufacture of French fries to manage sugar levels at the surface of the product. However, it should be noted that excessive blanch times may adversely affect flavour and texture. Blanching may not be suitable for some products, e.g., potato crisps, because it may cause unacceptable moisture uptake, leading to a loss of consistency/crispness or possible microbiological spoilage.[49]

25. Acrylamide levels in potato crisps can be reduced by controlling the thermal input.[3] Vacuum frying might offer the opportunity to reduce acrylamide levels in crisps made from potatoes with high sugar content. Rapid cooling crisps that are cooked by flash frying can also reduce levels of acrylamide in the final product. The use of in-line optical sorting to remove dark coloured crisps has been proved to be an effective measure to reduce acrylamide.[3]

26. Significant reductions in the acrylamide content of French fries can be achieved by setting the temperature of the oil at the start of frying to no more than 175 °C and cooking to a golden-yellow rather than a golden-brown colour.[50,51] However, it is essential to ensure that the final product is properly cooked. Depending on the relative proportions of raw potato to cooking oil, the temperature of the frying oil will drop after the raw French fries are added. Such a decrease in temperature may help to reduce acrylamide formation, although too great a temperature drop will adversely affect the culinary quality of the product.[52] Therefore, a maximum load of 100 g food per litre of oil is recommended.[53] Laboratory-based experiments have shown that removing some residual heat from French fries after frying (by rapid cooling in liquid nitrogen) may help to limit acrylamide formation.[54] Manufacturers that use flash frying to produce potato crisps have found that rapid cooling of the crisps following cooking can help to reduce acrylamide levels in the final product.[3]

27. Similar reductions are achievable for frozen "Oven" French fries (i.e., products that are blanched, par-fried and frozen by the manufacturer and intended to be oven cooked, or fried by the consumer), by cooking to a golden-yellow colour[55] and not overcooking. "Oven" French fry manufacturers should ensure that their on-pack cooking instructions are consistent with the need to minimise acrylamide formation.[3] Where frying is one of the on-pack suggestions for "Oven" French fries, the recommended frying temperature should not be greater than 175 °C and the maximum load should not exceed 100 g per litre of oil.[53] The cooking instructions should also mention that consumers should reduce the cooking time when cooking small amounts.[3] Again it is essential to ensure that the French fries are properly cooked.

28. Some "Oven" French fries or prefabricated potato products are manufactured with a view to storage under refrigerated conditions rather than frozen conditions. Storage at these temperatures may be conducive to low-temperature sweetening.[56] Should this be the case, measures will need to be devised to eliminate the residual amylase activity, which causes low-temperature sweetening. Concerned users can also avoid storing fresh "oven" French fries or prefabricated potato products for long periods of time at these temperatures, or should use frozen products instead.

29. The use of sugar dips to give par-cooked potato products an even golden colour should be avoided because the sugar in these dips can enhance acrylamide formation.[49]

CEREALS

Raw materials

30. For cereals and cereal-based products such as bread, biscuits and breakfast cereals, the asparagine content is the most important raw material determinant of acrylamide formation. Limited amounts of data are available regarding the asparagine content of different cereals and their associated cultivars. Typically, asparagine can range from 75 to 2200 mg/kg in wheat, from 50 to 1400 mg/kg in oats, from 70 to 3000 mg/kg in maize, from 319 to 880 mg/kg in rye[57] and from 15 to 25 mg/kg in rice.[55] This level of variation suggests that there may be scope for reducing acrylamide by exploiting the variability of asparagine content in the cultivar pool. However, as in the similar case for potatoes, such approaches are likely to have a significant lead time, and other factors, such as yield and resistance to fungal infections (field mycotoxin formation), would need to be considered. Thought should also be given to the type of flours used in products. Light flours contain significantly less asparagine than wholemeal flours. However, lowering the wholemeal content will reduce the nutritional benefits of the final product.

31. Deficiencies in the sulphur content of soil can cause an increase in asparagines levels in wheat and barley.[58] Therefore, sulphur deficient soil should be avoided, or well fertilised.

Control/addition of other ingredients

32. Raising agents are commonly used in biscuit production, and usually consist of a combination of sodium and ammonium hydrogen carbonate. Tests on model baked products and gingerbread have demonstrated that the presence of ammonium hydrogen carbonate has a significant effect in increasing acrylamide formation in biscuits and other baked products.[59] Thus, manufacturers should consider whether the use of ammonium-containing raising agents can be reduced, for example, by replacing them with sodium-containing raising agents. However, manufacturers should also consider the possibility that this change may increase dietary exposure to sodium or adversely affect the physical or organoleptic qualities of the baked products.[3]

33. Sugars (sucrose, glucose, fructose and/or high fructose corn syrup) are commonly used in biscuit production for colour and flavour development. Of these sugars, only glucose and fructose are reducing sugars. If, for a given total sugar content, the proportion of reducing sugar in the recipe is increased, higher levels of acrylamide will be found in the finished product.[55] In addition, greater amounts of acrylamide are formed if the reducing sugar is fructose rather than glucose. Therefore, manufacturers should minimise the usage of reducing sugars in biscuit production where practical. Alternatively, replacing fructose with glucose may be an effective option; where glucose syrup (also known as corn syrup in North America) is necessary, the level of fructose should be kept as low as possible.[3]

34. Care should also be exercised in the usage of reducing sugars during the manufacture of breakfast cereals. When such sugars are used they are usually added after the baking process, in which case no additional acrylamide formation will occur. However, addition of reducing sugars prior to baking represents an avoidable source of acrylamide formation.

35. Other minor ingredients may also have an influence. Increases in acrylamide formation have been shown to occur in some recipes when ingredients such as ginger, honey and cardamom are added during biscuit production.[55] Conversely, nutmeg has been shown, in some cases, to result in a decrease in acrylamide.[60] In order to reduce acrylamide levels in final products, manufacturers could investigate the effect of different spices in their own recipes.

36. In mixed cereal products, there may be scope for reducing the proportion of the predominant source of acrylamide by incorporating cereals with lower asparagine content. For example, this strategy could include replacing rye and wheat with rice; however, nutritional and organoleptic implications must be considered.

37. Experimental studies indicate that treatment with selected amino acids, calcium salts and the enzyme asparaginase may reduce acrylamide formation in cereal-based products. However, it should be noted that these treatments have not been fully tested in a commercial setting, and may require regulatory approval.[3]

38. Use of rework (the practice of re-using scraps) has been shown to increase acrylamide levels in some cases, but not in others.[3] Manufacturers should consider examining production processes for individual products to determine whether reducing rework can be used to mitigate acrylamide levels in their products.

Food processing and heating

39. Yeast fermentation of wheat bread doughs reduces the free asparagine content.[61] Fermentation for two hours utilises most of the asparagine in wheat flour dough models; shorter times are less effective, as is sourdough fermentation.

40. The extent of acrylamide formation during baking is critically dependent upon the time and temperature of the baking regime and the moisture content of the product during baking.[55] As a general rule, the higher the water content the less acrylamide formation will occur. Acrylamide formation can be reduced by modifying the time–temperature profile of the baking process,[62] in particular by decreasing the temperature of the final stages when the product reaches the crucially vulnerable, low moisture phase. Compensation by increasing the temperature of the earlier stages of baking should not lead to a significant increase in acrylamide, since the moisture content at this stage should be sufficiently great so as to prevent acrylamide formation. Careful control of oven temperatures and time profiles can be effective in reducing acrylamide levels. These principles have been applied successfully in both a biscuit model and in non-fermented crisp-breads.[55] In addition, where the crisp-bread is very dry it may be possible to increase the moisture specification without loss of product quality.

41. Whilst the degree of browning of a cereal product can often be taken as an indicator of the extent of acrylamide formation, there are a few cases where this is not a reliable guide. For example, in some breakfast cereals, a darker colour may be associated with less acrylamide owing to degradation or loss of previously formed acrylamide.[63]

42. Acrylamide is also formed when bread is toasted, but this can be significantly minimised by toasting to a lighter colour.[3]

COFFEE

43. Recent work indicates that asparagine is most probably the major determinant of acrylamide in coffee. Owing to the higher processing temperatures of roasting, other pathways of formation may also contribute to a small extent.[64]

44. Work on the mechanisms of formation of acrylamide in coffee shows that acrylamide is formed rapidly during the early stages of roasting, and that levels then significantly decrease towards the end of the roasting cycle as a result of decomposition or volatilisation.[3,63,64] Asparagine concentrations in green coffee have been shown to lie within a narrow range, so that a reduction in acrylamide levels in roasted coffee cannot be achieved by selecting specific green coffee types.[3,64] Studies have also shown that acrylamide is not stable in coffee powder in closed containers over extended storage periods[3,65,66,67] and work is underway to identify the underlying mechanisms that may provide future opportunities for mitigation. However, any changes to the roasting profile, or deliberate use of extended storage, to decrease acrylamide levels are likely to have a significant impact on the organoleptic properties and consumer acceptability of the product.[3,60,64]

CONSTRAINTS IN DEVELOPING PREVENTATIVE MEASURES

45. Measures aimed at reducing levels of acrylamide cannot be taken in isolation from other considerations. Precautions need to be taken to avoid compromising the existing chemical and microbiological safety of the food. The nutritional qualities of products also need to remain unimpaired, together with their organoleptic properties and associated consumer acceptability. Examples can be found in the following paragraphs. In addition, potential new additives and processing aids, such as asparaginase, may require formal safety assessment and efficacy-in-use demonstration prior to regulatory approval.

46. In developing a particular minimisation strategy a step-wise approach will be required, whereby results obtained in a laboratory setting are scaled up to pilot plant, and only then applied at production level. It should be noted that the extent of acrylamide formation can be quite variable within a production batch. For example, the acrylamide content of different packets of biscuits, sampled from the same production line, can vary by more than a factor of two.[63] Such inherent variability is clearly undesirable when attempting to investigate the impact of different processing/cooking conditions on acrylamide formation. This underlines the need to ensure that the bulk raw material is homogenous with respect to asparagine and reducing sugars, and that heating elements/devices are well controlled, before attempting to investigate possible minimisation strategies.

47. There are a number of other contaminants that may, in certain circumstances, be formed when foods are processed and cooked. These include N-nitrosamines,[68] polycyclic aromatic hydrocarbons,[69] chloropropanols,[70] ethyl carbamate,[71] furan,[72] heterocyclic aromatic amines and amino acid pyrolysates.[73] When preventative measures for acrylamide are considered, checks should be made to ensure that they will not result in an increase in other process contaminants.

48. It is essential that preventative measures devised for acrylamide do not compromise the microbiological stability of the final product. In this context it is worth noting that acrylamide formation during biscuit manufacture is crucially dependent upon the precise details of the temperature/time/moisture profile, particularly during the later, low-moisture stages of the baking process. Any palliative measure that results in too great an increase in the moisture content of the final product, and which thereby reduces its microbiological stability, is undesirable.

49. When assessing a particular minimisation strategy, the benefits should be weighed against any possible adverse effects on the nutritional properties of the food. For example, although blanching or soaking potatoes may reduce acrylamide levels, leaching of vitamin C and minerals from potatoes during immersion in water is well known. However, a blanching step before frying/roasting is known to lower the fat content of the final product.[74] Conversely, the frying of fried potato products at too low a temperature may lead to an increased fat content of the final product. Replacement of ammonium-containing raising agents with those containing sodium may increase dietary exposure to the latter, and may also adversely affect the physical properties of gingerbread and the organoleptic qualities of biscuits.[3]

50. Precautions should be taken to avoid detrimental changes to the organoleptic properties of the final product. Acrylamide is formed as part of the Maillard reaction between compounds containing amino groups and those bearing carbonyl moieties. The Maillard reaction itself is at the heart of the heat-induced generation of the characteristic colour, flavour and aroma of cooked foods. Any changes that, in an attempt to minimise acrylamide, also reduce consumer acceptance of the product will be counter-productive. Proposed changes to cooking conditions, or indeed raw materials and other ingredients, must be assessed from the perspective of the acceptability of the final product to the consumer.

51. The predictability and consistency of results with any mitigation measure must be adequate, i.e., variation must be within an acceptable range. Currently, wide variations are often observed even on repetition of a specific mitigation measure under controlled conditions, e.g., between different batches of a product made within the same manufacturing plant, or between manufacturing plants using the same process, ingredients and formulations. The sources of these variations are not yet understood. More research on this specific point is required, as the variability in acrylamide levels has very significant implications for the estimation of dietary exposures and risks.

CONSUMER PRACTICES

52. National and local authorities should consider advising domestic consumers to avoid over-heating potato and cereal-based foodstuffs when using high temperature cooking processes. Such advice could include recommendations that French fries and roast potatoes be cooked to a golden-yellow rather than golden-brown colour, whilst still ensuring that the food is fully cooked. Similarly, the consumer could be advised to aim for a light brown colour when toasting bread and related products.

53. National and local authorities should also consider encouraging consumers to avoid storing potatoes intended for high-temperature cooking under cold and/or refrigerated conditions. Retailers should also review their storage procedures in order to avoid low temperatures for such potatoes.

REFERENCES

1. *ALINORM 06/29/12* (2006)

2. *ALINORM 06/29/41* (2006)

3. Confederation of the Food and Drink Industries of the EU (CIAA): The CIAA Acrylamide "Toolbox". (2006) Available at: http://www.ciaa.be/documents/brochures/CIAA_Acrylamide_Toolbox_Oct2006.pdf

4. E.Tareke, P.Rydberg, P.Karisson, S.Ericksson, and M.Tornqvist: Analysis of acrylamide, a carcinogen formed in heated foodstuffs. *J.Agric.Food Chem.*, 51, 4998 - 5006 (2002)

5. J.S.Ahn, L.Castle, A.Clarke, M.Lloyd, and D.Speck: Verification of the findings of acrylamide in heated foods. *Food Add.Contam.*, 19, 1116 - 1124 (2002)

6. Food Standards Agency: *Analysis of Total Diet Samples for acrylamide*. Food Survey Information Sheet, No. 71/05 (2005) Available at: http://www.food.gov.uk/multimedia/pdfs/fsis712005.pdf

7. Joint FAO/WHO Expert Committee on Food Additives (JECFA): *Report on 64th meeting (Rome, 8-17 February 2005).* Joint FAO/WHO Expert Committee on Food Additives (2005) Available at: http://www.who.int/ipcs/food/jecfa/summaries/en/summary_report_64_final.pdf

8. M.A.Slayne and D.R.Lineback: Acrylamide: consideration for risk management. *J.AOAC Int.*, 88, 227 - 233 (2006)

9. A.Göbel and A.Kliemant:The German minimisation concept for acrylamide. *Food Add.Contam.* (in press)

10. A.Kliemant and A.Göbel: Acrylamide minimisation concept - a risk management tool in Thermal processing of food - potential health benefits and risks. Ed.: Senate Commission on Food Safety SKLM. Wiley-VCH, Weinheim (2007)

11. German Federeal Office of Consumer Protection and Food Safety (BVL): The German minimisation concept for acrylamide. (2006) Available at: http://www.bvl.bund.de/cln_027/nn_521172/EN/01__Food/04__Acrylamid__en/00__Minimierungskonzept__en/minimierungskonzept__node.html__nnn=true

12. D.S.Mottram, B.L.Wedzicha, and A.T.Dodson: Acrylamide is formed in the Maillard reaction. *Nature*, 419, 448 - 449 (2002)

13. R.Stadler, I.Blank, N.Varga, F.Robert, J.Hau, Ph.Guy, M.C.Robert, and S.Riedicker: Food Chemistry: acrylamide from Maillard reaction products. *Nature*, 419, 449 - 450 (2002)

14. D.V.Zyzak, R.A.Sanders, M.Stojanovic, D.H.Tallmadge, B.L.Eberhart, D.K.Ewald, D.C.Gruber, T.R.Morsch, M.A.Strothers, G.P.Rizzi, and M.D.Villagran: Acrylamie formation mechanism in heated foods. *J.Agric.Food Chem.*, 51, 4782 - 4787 (2003)

15. M.Granvogl, M.Jezussek, P.Koehler, and P.Schieberle: Quantitation of 3-aminopropionamide in potatoes - a minor but potent precursor in acrylamide formation. *J.Agric.Food Chem.*, 52, 4715 - 4757 (2004)

16. United States Food and Drug Administration: FDA Action plan for acrylamide in food. (2004) Available at: http://www.cfsan.fda.gov/~dms/acrypla3.html

17. G.Gamboa da Costa, M.I.Churchwell, L.P.Hamilton, F.A.Beland, M.M.Marques, and D.R.Doerge: DNA adduct formation from acrylamide via conversion to glycidamide in adult and neonatal mice. *Chem.Res.Toxicol.*, 16, 1328 - 1337 (2003)

18. D.R.Doerge, J.F.Young, L.P.McDaniel, N.C.Twaddle, and M.I.Churchwell: Toxicokinetics of acrylamide in glycidamide in Fischer 344 rats. *Toxicol.Appl.Pharmacol.*, 208, 199 - 209 (2005)

19. I.Maniere, T.Godard, D.R.Doerge, M.I.Churchwell, M.Guffory, M.Laurentie, and J.M Poul: DNA damage and DNA adduct formation in rate tissues following oral administration of acrylamide. *Mutat.Res.*, 580, 119 - 129 (2005)

20. N.C.Twaddle, M.I.Churchwell, L.P.McDaniel, and D.R.Doerge: Autoclave sterilization produces acrylamide in rodent diets: implications for toxicity testing. *J.Agric.Food Chem.*, 52, 4344 - 4349 (2004)

21. N.C.Twaddle, L.P.McDaniel, G.Gamboa da Costa, M.I.Churchwell, F.A.Beland, and D.R.Doerge: Determination of acrylamide and glycidamide serum toxicokinetics in B6C3F1 mice using LC-ES/MS/MS. *Cancer Lett.*, 207, 9 - 17 (2004)

22. E.Tareke, L.P.McDaniel, M.I.Churchwell, N.C.Twaddle, and D.R.Doerge: Relationship between biomarkers of exposure and toxicokinetics in Fischer 344 rats and B6C3F1 mice administered single doses of acrylamide and glycidamide and multiple doses of acrylamide. *Toxicol.Appl.Pharmacol.*, 63 - 75 (2006)

23. D.R.Doerge: FDA/NTP Toxicology Studies: GeneTox, Metabolism, PBPK and Chronic Studies with Acrylamide. 31st Annual Sumer Toxicology Forum, Aspen, Colorado. (2005) Available at: http://www.toxforum.org/html/summer_meeting_2005.html

24. L.A.Mucci, H.-O.Adami, and A.Wolk: Prospective study of dietary acrylamide and risk of colorectal cancer among women. *Int.J.Cancer*, 118, 169 - 173 (2006)

25. T.R.Fennell, S.C.Sumner, R.W.Snyder, J.Burgess, R.Spicer, W.E Bridson, and M.A.Friedman: Metabolism and haemoglobin adduct formation of acrylamide in humans. *Toxicological Sciences*, 85, 447 - 459 (2005)

26. T.R.Fennell, S.C.Sumner, R.W.Snyder, J.Burgess, and M.A.Friedman: Kinetics of elimination of urinary metabolites of acrylamide in humans. *Toxicological Sciences*, 93, 256 - 267 (2006)

27. T.M.Amrein, B.Schonbachler, F.Rohner, H.Lukac, H.Schneider, A.Keiser, F.Escher, and R.Amado: Potential for acrylamide formation in potatoes: data from the 2003 harvest. *Eur.Food Res.Technol*, 219, 572 - 578 (2004)

28. T.M.Amrein, S.Bachmann, A.Noti, M.Biedermann, M.F.Barbosa, S.Biedermann-Brem, K.Grob, A.Keiser, P.Realini, F.Escher, and R.Amado: Potential of acrylamide formation, sugars, and free asparagine in potatoes: a comparison of cultivars and farming systems. *J.Agric.Food Chem.*, 51, 5556 - 5560 (2003)

29. A.Noti, S.Biedermann-Brem, M.Biedermann, K.Grob, P.Albisser, and P.Realini: Storage of potatoes at low temperature should be avoided to prevent increased acrylamide formation during frying and roasting. *Mitt.Lebensm.Hyg*, 94, 167 - 180 (2003)

30. T.De Wilde, B.De Meulenaer, F.Mestdagh, Y.Govaert, W.Ooghe, S.Fraselle, K.Demeulemeester, C.Van Peteghem, A.Calus, J.M.Degroodt, and R.Verhe: Selection criteria for potato tubers to minimize acrylamide formation during frying. *J.Agric.Food Chem.*, 54, 2199 - 2205 (2006)

31. T.De Wilde, B.De Meulenaer, F.Mestdagh, Y.Govaert, S.Vandeburie, W.Ooghe, S.Fraselle, K.Demeulemeester, C.Van Peteghem, A.Calus, J.M.Degroodt, and R.Verhe: Influence of fertilization on acrylamide formation during frying of potatoes harvested in 2003. *J.Agric.Food Chem.*, 54, 404 - 408 (2006)

32. European Cultivated Potato Database. (2006) Available at: http://www.europotato.org/menu.php

33. R.H.Coffin, R.Y.Yada, K.L.Parkin, B.Grodzinski, and D.W.Stanley: Effect of low temperature *storage* on sugar concentrations and chip color of certain processing potato cultivars and selections. *J.Food Sci.*, 52, 639 - 645 (1987)

34. R.W.Blenkinsop, L.J.Copp, R.Y.Yada, and A.G.Marangoni: Changes in compositional parameters of tubers of potato *(Solanum tuberosum)* during low temperature storage and their relationship to chip processing quality. *J.Agric.Food Chem.*, 50, 4545 - 4553 (2002)

35. B.Putz: Erste 4 °C - typen bei Kartoffeln aus deutscher Züchtung. *Kartoffelbau*, 48, 280 - 282 (1997)

36. Bundessortenamt: Database of descriptive variety lists. (2006) Available at: www.bundessortenamt.de

37. British Potato Council: BPC Store Managers' Guide. (2001)

38. 2nd International Acrylamide in Food Workshop, Chicago: *Working Group #1: Mechanisms of formation and methods of mitigation (April 13 - 15 2004)* (2004) Available at: http://www. jifsan.umd.edu/presentations/acryl2004/acryl_2004_wg1_report.pdf and http://www.jifsan.umd.edu/presentations/acryl2004/wg1_2004.pdf

39. V.A.Elder, J.G.Fulcher, K-H.H.Leung, and M.G.Topor: Method for reducing acrylamide formation in thermally processed foods. WO 2004/075657 A2 (2004)

40. E.Brathen, A.Kita, S.H.Knutsen, and T.Wicklund: Addition of glycine reduces the content of acrylamide in cereal and potato products. *J.Agric.Food Chem.*, 53, 3259 - 3264 (2005)

41. P.Rydberg, S.Eriksson, E.Tareke, P.Karlsson, L.Ehrenberg, and M.Tornqvist: Investigation of factors that influence the acrylamide content of heated foodstuffs. *J.Agric.Food Chem.*, 51, 7012 - 7018 (2003)

42. P.J.Corrigan: Method for reducing acrylamide in foods, foods having reduced levels of acrylamide and article of commerce. WO 2005/034649 A1 (2005)

43. F.Pedreschi, O.Bustos, D.Mery, P.Moyano, K.Kaack, and K.Granby: Color kinetics and acrylamide formation in NaCl soaked potato chips. *J.Food Eng.*, 79, 989 - 997 (2007)

44. Centre for Food Safety: Acrylamide in fried and baked food. (2006) Available at: www.cfs.gov.hk/cfs_news2_acryl.html

45. D.Taubert, S.Harlfinger, L.Henkes, R.Berkels, and E.Schomig: Influence of processing parameters on acrylamide formation during frying of potatoes. *J.Agric.Food Chem.*, 52, 2735 - 2739 (2004)

46. B.Matthaus, N.U.Haase, and K.Vosmann: Factors affecting the concentration of acrylamide during deep-fat frying of potatoes. *Eur.J.Lipid Technol*, 106, 793 - 801 (2004)

47. A.Kita, E.Brathen, S.H.Knutsen, and T.Wicklund: Effective ways to decrease acrylamide content in potato crisps during processing. *J.Agric.Food Chem.*, 52, 7011 - 7016 (2004)

48. F.Pedreschi, P.Moyano, K.Kaack, and K.Granby: Color changes and acrylamide formation in fried potato slices. *Food Res.Int.*, 38, 1 - 9 (2005)

49. Euproean Commission: Note of the meeting of experts on industrial contaminants in food, Acrylamide workshop: information on ways to lower the levels of acrylamide formed in food. (2003) Available at: http://europa.eu.int/comm/food/food/chemicalsafety/contaminants/acryl_guidance.pdf

50. F.Pedreschi, K.Kaack, and K.Granby: Reduction of acrylamide formation in potato slices during frying. *Lebensm.-Wiss.U.Technol.*, 37, 679 - 685 (2004)

51. K.Grob: Reduction of exposure to acrylamide: achievements, potential of optimisation, and problems encountered from the perspectives of a Swiss enforcement laboratory. *J.AOAC Int.*, 88, 253 - 261 (2005)

52. K.Fiselier, D.Bazzocco, F.Gama-Baumgartner, and K.Grob: Influence of the frying temperature on acrylamide formation in French fries. *Eur.Food Res.Technol.*, 222, 414 - 419 (2006)

53. K.Grob, M.Biedermann, S.Biedermann-Brem, A.Noti, D.Imhof, T.Amrein, A.Pfefferle, and D.Bazzocco: French fries with less than 100 mg/kg acrylamide. A collaboration between cooks and analysts. *Eur.Food Res.Technol.*, 217, 185 - 194 (2003)

54. K.Ishihara, A.Matsunaga, K.Nakamura, K.Sakuma, and H.Koga:Examination of conditions inhibiting the formation of acrylamide in the model system of fried potato. *Biosci.Biotechnol.Biochem.* (in press)

55. Confederation of the Food and Drink Industries of the EU (CIAA): *A summary of the efforts and progress achieved to date by the European food and drink industry (CIAA) in lowering levels of acrylamide in food*. Acrylamide status report December 2004 (2004)

56. K.Fiselier, A.Hartmann, A.Fiscalini, and K.Grob: Higher acrylamide contents in French fries prepared from 'fresh' prefabricates. *Eur.Food Res.Technol.*, 221, 376 - 381 (2005)

57. A.Habel, A.Lehrack, and M.Spriner U.Tietz: Development of new technologies to minimize acrylamide in food. (2005) Available at: www.ilu-ev.de/berichte/acrylamide_bll_fei-veoeffenlichung_final.pdf

58. N.Muttucumaru, N.G.Halford, J.S.Elmore, A.T.Dodson, M.Parry, P.R.Shewry, and D.S.Mottram: The formation of high levels of acrylamide during the processing of flour derived from sulfate-deprived wheat. *J.Agric.Food Chem.*, 54, 8951 - 8955 (2006)

59. M.Biedermann and K.Grob: Model studies on acrylamide formation in potato, wheat flour and corn starch; ways to reduce acrylamide contents in bakery ware. *Mitt.Lebensm.Hyg*, 94, 406 - 422 (2003)

60. D.Taeymans, A.Anderson, P.Ashby, I.Blank, P.Gonde, P.Van Eijck, V.Faivre, S.P.D.Lalljie, H.Lingert, M.Lindblom, R.Matissek, D.Muller, R.H.Stadler, A.Studer, D.Silvani, D.Tallmadge, G.Thompson, T.Whitmore, J.Wood, and D.Zyzak: Acrylamide: update on selected research activities conducted by the European food and drink industry. *J.AOAC Int.*, 88, 234 - 241 (2005)

61. H.Fredriksson, J.Tallving, J.Rosen, and P.Aman: Fermentation reduces free asparagine in dough and acrylamide in bread. *Cereal Chem.*, 81, 650 - 653 (2004)

62. Association of the Chocolate, Biscuits and Confectionery Industries of the EU CAOBISCO: Review of acrylamide mitigation in biscuits, crackers and crispbread. (2006) Available at: www.caobisco.com/english/pdf/7254-639e.pdf

63. D.Taeymans, J.Wood, P.Ashby, I.Blank, A.Studer, R.H.Stadler, P.Gonde, P.Van Eijck, S.P.D.Lalljie, H.Lingert, M.Lindblom, R.Matissek, D.Muller, D.Tallmadge, J.O'Brien, S.Thompson, D.Silvani, and T.Whitmore: A review of acrylamide: an industry perspective on research, analysis, formation and control. *Crit.Rev.Food Sci.Nutr.*, 44, 323 - 347 (2004)

64. R.H.Stadler and G.S.Scholz: Acrylamide: an update on current knowledge in analysis, levels in food, mechanisms of formation, and potential strategies of control. *Nutr.Revs*, 62, 449 - 467 (2004)

65. T.Delatour, A.Perisset, T.Goldmann, S.Riedicker, and R.H.Stadler: Improved sample preparation to determine acrylamide in difficult matrixes such as chocolate powder, cocoa, and coffee by liquid chromatography tandem mass spectroscopy. *J.Agric.Food Chem.*, 52, 4625 - 4631 (2004)

66. K.Hoenicke and R.Gatermann: Stability of acrylamide in food during storage. *Czech J.Food Sci.*, 88, 268 - 272 (2004)

67. D.Andrzejewski, J.A.Roach, M.L.Gay, and S.M.Musser: Analysis of coffee for the presence of acrylamide by LC-MS/MS. *J.Agric.Food Chem.*, 52, 1996 - 2002 (2004)

68. Ministry of Agriculture, Fisheries and Food: *Nitrate, nitrite and N-nitroso compounds in food: second report*. Food Surveillance Paper No. 32., HMSO London (1992)

69. M.J.Dennis, R.C.Massey, G.Cripps, I.Venn, N.Howarth, and G.Lee: Factors affecting the polycyclic aromatic hydrocarbon content of cereals, fats and other food products. *Food Add.Contam.*, 8, 517 - 530 (1991)

70. Food Standards Agency: *Survey of 3-monochloropropane-1,2-diol (3-MCPD) in selected food groups*. Food Survey Information Sheet, No. 01/03 (2001) Available at: http://www.food.gov.uk/science/surveillance/fsis-2001/3-mcpdsel

71. R.Battaglia, H.B.S.Conacher, and B.D.Page: Ethyl carbamate (urethane) in alcoholic beverages and foods: a review. *Food Add.Contam.*, 7, 477 - 496 (1990)

72. U.S.Food and Drug Administration: Exploratory data on furan in food. (2004) Available at: http://www.cfsan.fda.gov/~dms/furandat.html

73. R.C.Massey and M.J.Dennis: The formation and occurrence of amino acid pyrolysates and related mutagens in cooked foods. *Food Add.Contam.*, 4, 27 - 36 (1987)

74. G.Lisiñska: Manufacture of potato chips and French fries in Potato science and technology. Ed.: G.Lisiñska and W.Leszczyñski. Elsevier Science Publishers Ltd, New York (1989)