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FOOD AND AGRICULTURE
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CODEX COMMITTEE ON FOOD ADDITIVES AND CONTAMINANTS

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DISCUSSION PAPER ON ACRYLAMIDE

BACKGROUND

1. The 36th session of the Codex Committee on Food Additives and Contaminants (CCFAC) agreed that the Discussion Paper on Acrylamide[1] would be revised, taking into account comments submitted and discussions in the Session, by a working group led by the United Kingdom and the United States, with the assistance of the EC, Japan, Korea, Sweden, the Confederation of Food and Drink Industries of the European Union (CIAA), the International Council of Grocery Manufacturers Associations (ICGMA), and the International Nut Council (INC) for circulation, comments, and further consideration at its 37th Session[2]. Germany joined the working group after the Session.

2. The Committee noted the importance of reducing the level of acrylamide in foods and noted that progress had already been made to reduce these levels in certain commodities based on current information[2].

3. The Committee also agreed to forward to FAO and WHO terms of reference for a planned evaluation on acrylamide by the Joint Expert Committee on Food Additives (JECFA) at its 64th meeting in February 2005[2].

4. Acrylamide research is an active, fast-moving field. This paper does not reflect developments after January 2005, including the JECFA evaluation. The areas to be considered by JECFA such as dietary exposure, toxicology and epidemiology are briefly summarised in this paper. These are not covered in detail as they will have been considered as part of JECFA’s risk assessment.

INTRODUCTION

5. In April 2002, researchers from the Swedish National Food Administration (SNFA) and the University of Stockholm announced that acrylamide is formed in a variety of baked and fried foods cooked at high temperatures[3]. Since the Swedish report, similar findings that acrylamide is formed primarily in carbohydrate-rich foods of plant origin prepared or cooked at high temperatures have been reported in numerous other countries[4-7].

6. In 2002, the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) held a consultation on the “Health implications of acrylamide in food” and made a number of recommendations[8].

7. The discovery that acrylamide is unintentionally formed in some cooked foods is a concern because acrylamide is a probable human carcinogen[9]. It is a known carcinogen and germ cell mutagen in rodents, a potential human carcinogen and genotoxicant based on high-dose animal studies, and a known human neurotoxicant[8,10,11]. In animals it increases the incidence of a number of benign and malignant tumours identified in a variety of organs (e.g., mammary gland, tunica vaginalis, thyroid, and adrenals)[12]. The potential carcinogenicity of acrylamide has not been thoroughly investigated in humans[12], particularly after chronic dietary exposure to humans.

8. Population-based case-control studies have found no positive association between acrylamide food exposure or food sources and cancer risk[13]. Also, no increases in cancer have been observed in cohort studies of humans exposed to acrylamide occupationally, with the possible exception of an increase in pancreatic cancer[14,15]. However, epidemiology studies have limited power to detect small increases in tumour incidence; therefore, the absence of a positive association can not be interpreted as proof that the substance cannot induce cancer in humans.

9. Studies conducted to date suggest that acrylamide formation is particularly likely in carbohydrate-rich foods cooked (i.e., baked or fried) at temperatures above approximately 120 ^{o}C[16-18]. Acrylamide has not been detected in boiled foods[19,20]. The mechanisms leading to the formation of acrylamide are not yet fully understood. The pathway that appears to account for most of the acrylamide in food involves a chemical reaction termed the Maillard reaction, and in particular a reaction between the amino acid asparagine and reducing sugars, which are found naturally in foodstuffs[21-25]. Other precursors that have been suggested to account for some fraction of acrylamide in food include 3-aminopropionamide, acrylic acid, and ammonia[26,27].

TOXICOLOGY

10. There are a number of ongoing studies on the toxicology of acrylamide, details of which are available on the WHO/FAO Acrylamide Infonet[28]. This includes new information from the U.S. FDA on toxicokinetics, bioavailability, DNA adduct formation, and acrylamide in rodent feeds[29-33]. Progress in toxicology research since 2002 was characterized by the Joint Institute for Food Safety and Applied Nutrition (JIFSAN) 2004 Acrylamide in Food Workshop[34]. The working group noted that "significant progress has been made towards understanding the toxicology and metabolism of acrylamide"[34]. The JECFA evaluation will have interim endpoints, as key toxicology data (e.g., neurotoxicity data, data from chronic animal studies) are still being gathered. JECFA's characterization of acrylamide will likely be a key component of future versions of this discussion paper.

11. Acrylamide has been classified by the International Agency for Research on Cancer (IARC) as "probably carcinogenic for humans"[9] and recognized by the European Union (EU) Scientific Committee on Food (SCF) as a genotoxic carcinogen[35]. In two long-term studies in rats, acrylamide increased the incidence of a number of benign and malignant tumours in a variety of organs[8,9]. Acrylamide also induced lung and skin tumors in a series of non-standard carcinogenicity bioassays in mice[36]. Acrylamide is thought to be a genotoxic carcinogen, although there are some suggestions that additional modes of action might contribute to the observed spectrum of tumors seen in acrylamide-treated rats, especially tumors of hormone-responsive tissues[37]. No increases in cancer have been observed in humans occupationally exposed to acrylamide, with the possible exception of an increase in pancreatic cancer[14,15].

12. Acrylamide is metabolized *in vivo* to glycidamide, a chemically reactive epoxide that may account for most of acrylamide's observed genotoxic and carcinogenic effects. Examples of genotoxic findings for acrylamide include the induction of genetic mutations and chromosomal abnormalities in cultured cells *in vitro*[9] and positive results in *in vivo* genotoxicity studies[35]. Both acrylamide and glycidamide react with nucleophilic compounds via Michael addition to form adducts on DNA and protein. Acrylamide and glycidamide adducts at the N-terminal valine of hemoglobin are not toxic, but serve as a useful marker of *in vivo* exposure to acrylamide[8,35]. Three DNA adducts have been demonstrated to result from *in vivo* exposure to glycidamide, and other adducted bases have been identified in *in vitro* reactions with acrylamide[31,38].

Neurotoxicity and Reproductive and Developmental Toxicity

13. Neurotoxicity (from occupational and other high-level non-food exposures) is the only recognized adverse effect of acrylamide exposure in humans[8]. Human occupational studies do not provide information to define a dose response relationship[8]. It is unclear whether the neurotoxic effects of acrylamide are attributable to acrylamide itself or its metabolite glycidamide. Both the WHO and the SCF concluded that no neurotoxic effects were to be expected from the levels of acrylamide encountered in food[8,35].

14. Acrylamide has been shown to be a reproductive and developmental toxicant in animal studies. As with neurotoxicity, reproductive and developmental effects are believed to occur at doses much higher than those encountered in foods. The WHO Expert Consultation stated that the no observed adverse effect level (NOAEL) for fertility effects was four times higher than for neurotoxicity (neuropathy), and that controlling for neurotoxicity would control for fertility effects[8].

15. In 2004, a U.S. National Toxicology Program (NTP) Expert Panel reviewed the reproductive and developmental toxicity of acrylamide and identified lowest observable adverse effect levels (LOAELs) ranging from 4 to 45 mg/kg bw/day for developmental toxicity and male reproductive toxicity in mice and rats. Considering the low level of estimated human exposures to acrylamide (including food exposures), the Expert Panel expressed negligible concern for adverse reproductive and developmental effects and minimal concern for acrylamide-induced heritable effects in the general population[39].

16. As outlined in its Action Plan for Acrylamide in Food[40], the U.S. 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[29,30,32,33], but the results of long-term carcinogenicity assays and a developmental neurotoxicity assessment will not be available until 2008.

17. CCFAC has requested that the JECFA evaluation consider interim endpoints, as key toxicology data (e.g., neurotoxicity data, data from chronic animal studies) are still being gathered. The JECFA evaluation will have interim endpoints, as key toxicology data (e.g., neurotoxicity data, data from chronic animal studies) are still being gathered.

Epidemiological studies

18. The JIFSAN 2004 Acrylamide in Food Workshop Working Group on exposure and biomarkers reviewed the available epidemiological studies on acrylamide (both dietary and occupational exposure). The Workshop concluded that although the studies available to date do not provide conclusive evidence of an association between dietary exposure to acrylamide and cancer risk, this does not necessarily indicate that no relationship exists. Existing epidemiological studies do not have the statistical power to detect cancer risk from dietary acrylamide exposure at the levels suggested by toxicological studies[13].

ANALYTICAL METHODS

19. Several analytical methods have been used to quantify acrylamide in food. The most commonly used methods are based on gas chromatography/mass spectrometry (derivatized analyte), (GC-MS) and high performance liquid chromatography/tandem mass spectrometry (HPLC-MS/MS) detection[41,42].

20. The Acrylamide Infonet, operated by the Joint Institute for Food Safety and Nutrition for the FAO/WHO, functions as a global resource and inventory of ongoing research on acrylamide in food[28]. The Infonet contains information (or links to information) on various analytical methodologies.

21. Methods and sample preparation techniques for measuring acrylamide in food were recently reviewed[42]. The review covers information on methods from peer-reviewed articles and other sources (for example, a survey carried out among official and private laboratories of the Member States of the EU). The authors concluded that the influence of different extraction techniques or extraction solvents has not yet been fully investigated and that methods should be viewed critically with respect to their performance criteria[43].

22. The status of acrylamide methodology as of April 2004 was reviewed at the JIFSAN Acrylamide in Food Workshop[44]. Among the conclusions reached by the working group on analytical methodology were the following: (1) there is reasonable coverage of all matrices of concern, but limited information about the performance of methods across a range of food products, (2) there is confidence in the identification of detected compounds as acrylamide, (3) numerical results are generally satisfactory, depending on concentration and matrix, and (4) there are regular, ongoing proficiency tests, but there is a need for certified reference materials and interlaboratory validation of methods. The working group also identified elements to ensure that methodology is properly applied[44].

23. The EC Joint Research Centre’s (JRC) task force on acrylamide methods continues to review requirements for the analytical methods. JRC has conducted a series of proficiency testing exercises on acrylamide determination in a range of matrices[43]. A recent test on crispbread samples showed poor performance ($z > 2$) for approximately 30% of the laboratories that participated for at least one of the five samples analysed. As part of the EC Heatox project[45], the JRC is planning to validate two methods for acrylamide determination in selected food matrices. JRC, in conjunction with the German Institute for Materials Research and Testing, is currently preparing certified reference materials for acrylamide (toasted bread and crispbread), to be available in late 2005.

24. In the U.S., the National Food Processors Association (NFPA) has conducted three ring trials to evaluate the analytical performance of government and commercial laboratories conducting acrylamide testing. Both North American and European laboratories have participated in the trials and a range of methods has been represented. Results from the latest round of testing, which was comprised of samples of cereal, peanut butter, chocolate, and coffee, can be viewed at the JIFSAN site[44].

DIETARY EXPOSURE

25. Acrylamide has been detected in foods prepared by commercial processing and domestic cooking. The broad range of foods susceptible to acrylamide formation includes dietary staples and foods that are nutritionally important in the diet.

26. Table 1 gives a summary of selected results of analyses of acrylamide in food to date. There are limited numbers of analyses conducted for some of these food groups. Significant variability of acrylamide levels among foods within particular categories and within batches of products processed under the same conditions has been observed. This summary is of occurrence data produced since April 2002; as such it does not necessarily reflect the current levels of acrylamide in these commodities.

Table 1: Summary of reported levels of acrylamide in food

Food Group	**Food Product Group**	**Acrylamide levels (µg/kg)**	
		Minimum	**Maximum**
Potatoes	Potato crisps[a]	117[7]	3770[46]
	Chips/French fries[b, c]	59[47]	5200[48]
	Potatoes (raw)	<10[49]	<50[48]
	Potato Fritters/Rosti (fried)	42[46]	2779[46]
Cereal Products	Corn crisps	120[3]	220[7]
	Bakery products & biscuits	18[50]	3324[46]
	Gingerbread	<20[46]	7834[46]
	Bread	<10[7]	130[7]
	Bread (toast)	25[48]	1430[51]
	Breakfast cereals (non-infant)	11[7]	1057[7]
	Crisp bread	<30[3]	2838[46]
	Diabetic cakes & biscuits	20[46]	3044[46]
	Popcorn (sweet & salted)	57[46]	300[46]
	Sesame Snacks	55[46]	160[46]
Rice and Noodles	Fried noodles	3[52]	581[50]
	Fried rice	<3[52]	67[52]
	Instant noodle soup	<3[52]	152[7]
	Rice crackers, grilled or fried	17[50]	500[53]

Food Group	Food Product Group	Acrylamide levels (µg/kg)	
		Minimum	Maximum
Fruit and Vegetables	Canned black olives	123[54]	1925[7]
	Bottled prune juice	53[54]	267[7]
	Fried vegetable (including tempura vegetables)	34[50]	34[50]
Nuts	Nuts, including peanut butter	28[7]	339[7]
Fried composite foods	Deep fried Asian delicacies - dumplings, rolls, fritters	<3[52]	190[52]
	Deep fried Asian savoury snacks (lentils, 'bombay mix')	33[46]	120[46]
Fish & Meat	Fish and seafood products, crumbed or battered	<2[50]	39[8]
	Meat/Poultry products, crumbed or battered (fried)	<10[7]	64[8]
	Carcass Meat, Poultry and Fish (fried)	<5[19]	52[19]
Cocoa based products	Chocolate products	<2[47]	826[46]
	Cocoa powder[d]	<10[7]	909[7]
Beverages	Coffee (roasted)[e]	45[7]	975[46]
	Coffee substitute[f]	116[46]	5399[7]
	Coffee extract/powder[e]	195[46]	4948[46]
	Roasted Tea (hoji-cha) and Oolong Tea[g]	<9[53]	567[53]
	Roasted barley grains (for tea)	140[8]	578[50]
	Beer	<6[47]	<30[51]
Infant/Baby foods	Infant biscuits/rusks	<20[46]	910[46]
	Jarred/canned baby foods	<10[7]	121[7]

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

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

[c] Higher levels have been reported in overcooked home prepared products, such as the overcooked French fries sample reported with an acrylamide level of 12800[48].

[d] Cocoa powder for baking.

[e] Analysed as sold (as roasted/instant coffee/coffee extract powder), not prepared for consumption.

[f] It is not clear whether the sample for the minimum value was analyzed as sold or as prepared for consumption. The sample for the maximum value was analysed as sold, not prepared for consumption.

[g] Roasted tea (hoij tea) contained 519 to 567 ng/g and Oolong tea ranged from <9 to 142 ng /g, respectively. Samples of Green Tea, Tea (Black) and Pu'er tea either did not contain detectable acrylamide [<9 ng/g] and / or contained trace levels [9 to 30 ng/g][53].

27. A number of studies have been carried out to estimate dietary exposure to acrylamide. Short-term intake estimates ranged from 0.2 µg/kg bw/day for the average consumer to 3.4 µg/kg bw/day for the high level consumer[55]. These levels are summarised in Table 2. It should be noted that various methods have been used to provide acrylamide occurrence data and food consumption data, and to estimate dietary exposures.

Table 2: Summary of estimated acrylamide dietary intake

Country/Organisation	Estimated Acrylamide Dietary Intake (µg/kg bw/day)*
FAO/WHO[8]	0.3 - 0.8
EU SCF[35]	0.2-0.4
BfR, Germany[56]	1.1 – 3.4
BAG, Switzerland[57]	0.28
SNT, Norway[58]	0.32 – 1.35
AFSSA, France[59]	0.5 – 2.9

SNFA, Sweden[60]	0.45 – 1.03
NFCS, Netherlands[51]	0.48 – 1.1
USA[61]	0.43-2.31
UK[62]	0.3 – 1.8

*ranges include mean and high consumption exposure levels where these have been estimated

28. The FDA found that eight food categories (potato crisps[1], regular French fries[2], oven baked French fries, breakfast cereals, toast, cookies, soft bread, coffee) contribute more than 80 percent of the mean population acrylamide intake and that no one food accounts for the majority of the mean population acrylamide intake[63]. The dietary exposure estimates conducted in the UK show that cereal-based products and potatoes are also the main sources of acrylamide in the UK diet[62]. The main food groups contributing to acrylamide exposure appear to be similar for North America and Europe.

29. The contribution from home cooking to overall exposure has not been established.

Non-dietary sources of exposure

30. Other possible sources of potential exposure to acrylamide include occupational exposure[12] and smoking[10,64], and the presence of residual acrylamide in polyacrylamide used in products such as cosmetics, soil conditioners, and coagulants and flocculents used in water treatment[12]. Allowable limits for acrylamide in cosmetics and water have been set[12,65,66].

FORMATION IN FOOD

31. Acrylamide has been detected in foods prepared by thermal treatments in commercial processing and domestic cooking.

32. A number of theoretical mechanisms of acrylamide formation have been identified, including pathways from amino acids only, from acrolein intermediates, from acrylic acid intermediates and from Maillard browning precursors[25]. The pathway that appears to account for most of the acrylamide in most of the foods in which acrylamide has been detected involves a high-temperature-induced chemical reaction termed the Maillard reaction between the amino acid asparagine and certain reducing sugars, both of which are found naturally in foods[21-25,67,68]. Foods rich in both of these precursors are largely derived from plant sources, e.g., potatoes and cereal grains[69]. Other precursors that have been suggested to account for some fraction of acrylamide in food include 3-aminopropionamide, acrylic acid, and ammonia[26,27].

33. Based on mechanistic studies, additional formation pathways for acrylamide from food have been hypothesized[26,27]: (a) heating at 180 °C of either asparagine or glutamine forms acrylamide from thermal degradation, albeit at trace levels, (b) ammonia produced from alpha-amino acids via Strecker degradation reacts with acrylic acid, formed from acrolein during lipid degradation or from aspartic acid via an analogous route[70], (c) an acrylic acid radical from high-temperature heating of acrolein reacts with an amine radical formed from high-temperature heating of an amino acid, and (d) 3-aminopropionamide formed from enzymatic decarboxylation of asparagine (e.g., in potatoes) degrades into acrylamide during heating.

34. Acrylamide has also been found in coffee, canned black ripe olives, nuts, chocolate, some fish/meat products, roasted vegetables (peppers, onions, broccoli), and prunes[7,54,71-73]. The formation of acrylamide in coffee is not well understood. It is known that acrylamide forms early in the roasting process, and then declines; that acrylamide levels are lower in dark roasts[71,74,75]. The detection of acrylamide in olives and prunes was unexpected, and the mechanisms of formation for these foods have not been established[72]. Other factors, such as use of ferrous gluconate, may play a role in acrylamide formation in canned black olives[74], but could not be confirmed.

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

[2] Potato products that is more thickly sliced (Referred to as French fries, in some regions including North America, or Chips, in the UK)

35. Results of studies on the effect of home cooking suggest acrylamide is present in home-prepared foods such as fries and toast, but that levels can be minimized (reviewed in the Mitigation section)[76]. The U.S. FDA has also analyzed acrylamide in hundreds of samples of food from the FDA Total Diet Study, which includes foods as prepared by consumers[54]. Research on the formation of acrylamide during home cooking is under way in the U.S. and the U.K.[28,76,77].

36. Acrylamide formation in other food groups is still under investigation. The formation of acrylamide in coffee shows a different pattern to some heated food products with about 70 percent of the acrylamide formed being 'lost' or degraded during roasting[75]. Studies of stability of acrylamide in foods have shown that acrylamide is not stable in some foods over time. Acrylamide levels have been observed to decline in coffee, cocoa, biscuits, gingerbread and liquorice during storage[74,78-80].

MITIGATION OF ACRYLAMIDE LEVELS IN FOOD

37. This section of the Discussion Paper is intended to serve as the basis for potential development of any future Code of Practice. The sections below indicate a number of factors that influence acrylamide formation and highlight some of the factors that should be considered in developing strategies to minimise acrylamide levels in food. Any additional effect such measures may have on characteristics of a food should be assessed when utilising these measures to reduce acrylamide levels in a particular food. In particular, characteristics that need to be considered include microbial safety, organoleptic properties, nutritional quality and other chemical changes.

Factors affecting acrylamide formation

38. Factors affecting acrylamide formation have been characterized primarily in potato and cereal- (grain-) based foods. Key factors that have been identified include the presence of acrylamide precursors (most importantly asparagine and reducing sugars), cooking temperature and time, and other reaction conditions or parameters, such as pH, water activity, surface area, and extent of browning. Some of these factors have the potential to be manipulated in order to reduce acrylamide levels.

39. In potato-based foods, the amount of reducing sugars is a key factor affecting acrylamide formation, while asparagine levels are less important. A number of factors affect the sugar content of potatoes, including variety, growing temperature, soil moisture content and storage conditions[17]. Cultivar type and storage conditions are key factors in determining the amount of reducing sugars[16-18,81-86]. Several research groups[83,85] have found that reducing sugar levels in a variety of potato cultivars varied by a factor of 32, while free asparagine contents varied only within a narrow range. It has been reported that storage at low temperatures (4-6 °C), even for short time periods, can dramatically increase levels of sugars in potatoes[16,75,84]. Even potato cultivars with low levels of sugar at harvest have been reported to can undergo significant increases in sugar levels during low-temperature storage[84]. The processed potato industry stores potatoes at 6-8°C (for potatoes for French fries) or 8-10°C (for potatoes for crisps) for long periods (up to 9 months) to prevent high sugar build up[75]. In the processed potato industry, potatoes are often reconditioned for two to three weeks after extended 6-8°C storage; the reconditioning lowers sugar levels due to increased respiration[75].

40. For cereal-based foods, inherent levels of reducing sugars are lower and less subject to variation than in potatoes[87]. The asparagine levels in the raw material together with the method of processing appear to be the main determinant of the amount of acrylamide in the final product[75,87].

41. The combination of temperature and duration of cooking also affect the level of acrylamide in food. It has been suggested that when the temperature of a food rises above 120 ºC, the rate of acrylamide formation increases rapidly with temperature over a limited range[88]. At temperatures above 160-170 ºC, the rate of acrylamide elimination increases significantly for some foods and model systems[17,23]. While reducing exposure to high temperatures or long cooking times will often reduce acrylamide levels, it is not always clear whether shortening time or temperature will have the most impact, or be most appropriate, as different results have been reported for different foods. For example, higher acrylamide levels with shorter cooking times/higher temperatures were reported for fried Chinese fritters[52] and for baked and fried French fries[16]. Conversely higher acrylamide levels have been reported for gingerbread cooking under longer times/lower temperature conditions[83]. Also, it may not be possible to shorten time and temperature beyond a certain point without affecting the desirability or quality of foods. For example, lowering the frying temperature of French fries may lower their acrylamide content, but may also increase their fat content[16]. Finally, increasing cooking time has also been shown to decrease acrylamide in certain products, by promoting elimination of acrylamide[75,87].

42. Other factors shown to affect acrylamide formation include pH, water activity, surface area, and extent of surface browning. Acrylamide formation from asparagine appears to occur optimally at pH 7-8, and researchers have tested the ability of various acids (e.g., citric acid) to reduce acrylamide formation in heated foods[18,89,90].

43. The extent of surface browning of some cooked foods (e.g., bread crusts, toasted bread, potato) appears to be related to acrylamide levels in a given product and cooking foods under conditions that limit surface browning may result in lower acrylamide formation in that given product[91-93]. Although a correlation between food colour and acrylamide level has been seen for certain products, it may not be possible to establish a general rule for all products. Surface area is related to browning, in that increases in surface area increase the area in which acrylamide-forming browning reactions can occur; reducing surface area may limit acrylamide formation[91].

44. The effects of various additives on reducing acrylamide formation in potato products have been explored, but these approaches are considered preliminary[76]. Examples of additives that may reduce acrylamide include citric and lactic acids, amino acids, rosemary, calcium chloride, phytate, a flavonoid spice mix, and rosemary[17,18,24,76,94,95]. Asparaginase has been used successfully to obtain significant reductions of acrylamide levels in potato flakes and French fries, but commercialization is thought to be several years away[25,68]. The commercial production of asparaginase is the subject of two patents currently under review. Approval for the use of asparaginase as a processing aid would have to be given by the appropriate authority. Other additives, such as BHT, sesamol, and vitamin E, appeared to enhance acrylamide formation in meat[96]. Similarly, acrylamide formation appears to increase when vegetable oil is added to potatoes an effect thought to be due to antioxidants in the oil[96].

45. The cooking oil used in processing has been found to result in no significant differences in acrylamide formation in the fried food[97].

Strategies for reducing acrylamide formation in food

46. It is possible to alter some of the parameters/factors known to affect acrylamide formation in order to reduce acrylamide in the final product. Consideration to some of these alterations is given in this section. The CIAA has developed a ‘toolbox’ of measures applicable to specific food groups. The toolbox presents potential methods of reducing acrylamide in the areas of: natural parameters (e.g., agronomic factors, biological and chemical parameters of raw materials), product composition (e.g., recipe changes), process conditions (e.g., thermal input or pre-treatment of product or ingredients) and assessment of the effect of these methods on finished product characteristics (e.g., taste, colour, shelf life, etc.)[75]. This approach was detailed at a European Commission stakeholder meeting in January 2005 and builds upon the earlier progress on ways to lower the levels of acrylamide formed in food, as highlighted at the European Commission stakeholder meeting in October 2003[77,87].

Potato based products

47. Strategies for minimizing acrylamide formation in potato products focus on reducing the levels of the precursor reducing sugars in the potato tuber and minimising the conversion of these sugars to acrylamide during heat treatment. Strategies include selection of potato cultivars with low levels of reducing sugars, storage of potatoes at temperatures 8-10°C or greater and the use of moderate cooking temperatures and times[17,84].

48. Choice of potato cultivar for both commercial processing and retail of fresh potatoes depends on the use for the potato. The food industry selects potatoes with specific qualities including low reducing sugar levels for preparation of potato crisps[3] or French fries[4], as this leads to a lighter coloured product[16,81,85]. In general, use of potatoes low in reducing sugars for cooking processes likely to form acrylamide, such as frying and roasting, should be considered as part of strategies to minimize acrylamide in food[81,83].

49. Since storage below 6-10°C enhances formation of reducing sugars, acrylamide can be minimized by not storing potatoes under refrigeration conditions (4-6°C) if they may be used for frying, roasting, or other high-temperature cooking processes[81,83,84,93,97]. Storage at 8-10 °C or above should be considered from farm to consumption, since refrigeration for even brief periods (e.g., several days) may increase sugar levels[16,84]. Consumer information about storage conditions for potatoes, including not using refrigerated storage, should be considered[81]. Consideration of using storage temperatures to control sugar levels needs to be balanced against the positive role of low temperature storage in helping to control sprout formation and disease and allowing year round access to potatoes and reduced residues of chemical sprout suppressants[84,98].

50. Soaking or blanching potatoes intended for frying or roasting in water will lower acrylamide levels in the final product by removing acrylamide precursors[16,76]. Such treatment may delay browning, however, leading to longer cooking and hence similar acrylamide levels[16,97]. Washing in an acidic rinse, vinegar:water[76] or citric acid[16] may enhance the reduction in acrylamide, although at the levels of addition required to be effective these treatments may also affect taste and texture and may also have a negative effect on the quality of the cooking oil. Blanching is a standard processing step in French fries manufacturing to manage sugar levels at the surface of the product. In developing acrylamide minimisation strategies for such products, consideration needs to be given to other effects of soaking potatoes before frying. For example, leaching of vitamin C from potatoes during immersion in water is well known and the par boiling/soaking of potatoes before frying/roasting may lead to an increased fat content in the final product.

51. Acrylamide levels in fried or roasted products can also be reduced by reducing surface area, for example, by cutting potatoes into thicker slices or removal of fines (fine pieces of potato) before or after frying[16,91,97].

52. Acrylamide levels can also be controlled by avoiding excessive browning[91,99]. Endpoints discussed for French fries are when fries are crispy and golden, and slightly browned at the tips or edges[16,76] or a golden-yellow color, without surface browning[87].

53. Using lower thermal input into the cooking process, either by decreasing cooking temperatures or duration of cooking, can also help to reduce acrylamide levels[16,76,87]. Using lower cooking temperatures for French fries can help to reduce acrylamide levels by avoiding the rapid increase in acrylamide at the end of the cooking process, particularly at higher temperatures, where it is easier to overshoot ideal cooking conditions[16,97]. However, lower cooking temperatures may not equate to lower acrylamide contents for all foods or under all conditions (e.g.,[52,91]), including when cooking time is increased to compensate for lower temperatures[76]. Browning may be a more important criterion to follow than temperature when cooking French fries[76]. Lower oil temperatures can also increase moisture and oil levels in finished fried products, potentially causing quality and food health concerns[16,87].

54. The use of sugar dips to give par-cooked potato products (such as French fries) an even golden color should be reconsidered, as the sugar in these dips can enhance acrylamide formation[87].

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

[4] Potato products that is more thickly sliced (Referred to as French fries, in some regions including North America, or Chips, in the UK)

Cereal-based products

55. Baking temperature and cooking time are also important target areas for reducing acrylamide levels in cereal products. As a general rule, baking of cereal products should proceed until the proper moisture levels are obtained and minimum browning in the crust or surface occurs[76]. Reducing these may lower acrylamide levels in some products; however, for other products, longer baking times and higher temperatures may decrease acrylamide levels (due to elimination of previously formed acrylamide), and manufacturers will have to assess baking conditions for each product[87]. The need to maintain low moisture levels for dry, crisp products (e.g., crispbread) to maintain a desirable texture and to avoid spoilage is a major consideration for these products[87].

56. Using ingredients with low levels of free asparagine or low levels of reducing sugars may help to reduce acrylamide levels in finished cereal products[87,89,92]. The use of such ingredients may introduce other problems, for example, substitution of reducing sugars with non-reducing sugar could affect the product color and flavor, as in the case of gingerbread[89]. Also, it has been suggested that unrefined flours (which retain the bran) may yield higher acrylamide levels than refined flours. However, these flours have greater nutritional benefits[75,87]. No strategy to reduce free asparagine content in cereal ingredients is currently available[87,92]. As a long term strategy, plant breeders could be encouraged to monitor asparagine and to treat low asparagine content as a desirable trait [75].

57. Using alternatives to ammonium bicarbonate as a leavening agent in sweetened bakery products may also reduce the acrylamide levels in these products as it has been shown to contribute to high acrylamide levels[87,89]. Such changes may affect the taste of products and require modifications in other ingredients[79,89].

58. Acrylamide levels in toasted bread appear to increase with color[48,75,76].

59. There is a great deal of variation in acrylamide levels between batches of the same breakfast cereals processed under the same conditions. The benefits of the modifications tested to date have not been as great as the batch to batch variation. A greater understanding of the formation mechanisms is needed to consistently realise reductions in acrylamide levels[93].

60. Variation in mean asparagine content from one season’s crop to the next can influence the extent of acrylamide formation in breakfast cereals[75].

Current approaches to acrylamide mitigation by governments

61. The approach by governments and governmental organizations to acrylamide mitigation has included issuing advice to consumers (U.S., Canada, United Kingdom, FAO/WHO), conducting research to inform risk assessment and risk management measures[28] and government-initiated mitigation programs (e.g., Germany)[100,101].

62. In North America, both the FDA and Health Canada advised consumers not to make major dietary changes, but to continue to eat a balanced diet in line with each government’s dietary recommendations. FDA’s recommendation states that until more is known, FDA continues to recommend that consumers eat a balanced diet, choosing a variety of foods that are low in trans fat and saturated fat, and rich in high-fiber grains, fruits, and vegetables[47,102].

63. The FAO/WHO consultation on acrylamide advised consumers that food should not be cooked excessively-for too long or at too high a temperature. The consultation also recommended cooking all food thoroughly, particularly meat and meat products, to destroy foodborne pathogens, such as bacteria and viruses. The consultation further advised that consumers eat a balanced and varied diet, which includes plenty of fruit and vegetables, and should moderate their consumption of fried and fatty foods[8].

64. In Germany a ‘minimisation concept’ was introduced in August 2002 whereby regularly calculated ‘signal levels’ have been developed for selected food groups. Where monitoring of these acrylamide levels in food shows that these levels are being contravened producers are requested to reduce levels in their products. Guidance on frying and roasting potatoes has also been issued to consumers in Germany[100].

65. In Japan, the Ministry of Health, Labour and Welfare gave the same advice consumers as the FAO/WHO consultation on acrylamide. A government-initiated research project, aiming to reduce the formation of acrylamide in processed foods and to mitigate the toxicity of acrylamide, is in progress.

INTERNATIONAL ACTIVITIES

66. Some important activities on acrylamide are summarized in Table 3.

Table 3: Summary of international activities on acrylamide

2002	FAO/WHO consultation on "Health implications of acrylamide in food"[8]
Ongoing	FAO/WHO Acrylamide Infonet[28]
November 2003	EFSA workshop on the formation of acrylamide in food[103]
March 2004	American Chemical Society symposium on "Chemistry and Safety of Acrylamide in Food[104]
April 2004	2nd JIFSAN Acrylamide in Food Workshop[105]
Ongoing	EC JRC database of acrylamide levels in food in the EU[46]
2002--Ongoing	U.S. FDA Action Plan for acrylamide in food[40], Database of acrylamide levels in food in the U.S.[7,54]
Ongoing	European Commission Research Framework Programme project (HEATOX)[45,106]
January 2005	European Commission meeting of experts and stakeholders on acrylamide in food [77]
February 2005	JECFA risk assessment of acrylamide in food[107]

CONCLUSIONS

67. A great deal of research has been completed internationally which has provided further information on the toxicology, analytical methodology, formation and potential methods of reducing acrylamide in foods.

68. There are uncertainties about the impact of acrylamide in food on public health. To better address the risk of acrylamide JECFA will begin to address this issue in 2005, the results of this assessment of acrylamide in foods will be used to inform the risk to public health and hence risk management.

69. Although the risk of acrylamide in food and the overall effects of risk management options are still uncertain, governments and organizations have started to recommend limited modifications to food processing techniques that may reduce acrylamide formation. It is important that any suggested modifications to decrease acrylamide levels do not negatively affect the safety of foods and diets by compromising nutritional properties or the microbiological safety of the food (e.g., by increasing fat content). Also, not enough is known about all routes of acrylamide formation to identify modifications that will be helpful in all foods.

70. The FAO/WHO consultation in June 2002 concluded that the presence of acrylamide in food is a major concern, and recommended more research such as on mechanisms of formation and toxicity. The consultation recommended that people continue to eat a balanced diet rich in fruits and vegetables, and advised that food should not be cooked excessively, i.e., for too long a time or at too high a temperature. It noted however, that it is important to cook all food thoroughly, particularly meat and meat products to destroy foodborne pathogens (bacteria, virus, etc.) that might be present.

RECOMMENDATION

71. It is recommended that CCFAC review JECFA's February 2005 evaluation of acrylamide in food before further elaboration of this discussion paper or further considering risk management options.

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