codex alimentarius commission

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

WORLD HEALTH ORGANIZATION

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Agenda Item 14 (g)

CX/FAC 06/38/35
March 2006

JOINT FAO/WHO FOOD STANDARDS PROGRAMME

CODEX COMMITTEE ON FOOD ADDITIVES AND CONTAMINANTS

Thirty-eighth Session

The Hague, the Netherlands, 24 – 28 April 2006

DISCUSSION PAPER ON ACRYLAMIDE

(prepared by United Kingdom and the United States with the assistance of Canada, Norway, Sweden, Switzerland and CIAA)

Governments and international organizations in Observer status with the Codex Alimentarius Commission wishing to submit comments on the following subject matter are invited to do so **no later than 7 April 2006** as follows: Netherlands Codex Contact Point, Ministry of Agriculture, Nature and Food Quality, P.O. Box 20401, 2500 E.K., The Hague, The Netherlands (Telefax: +31.70.378.6141; E-mail: info@codexalimentarius.nl - ***preferably***), with a copy to the Secretary, Codex Alimentarius Commission, Joint FAO/WHO Food Standards Programme, Viale delle Terme di Caracalla, 00100 Rome, Italy (Telefax: +39.06.5705.4593; E-mail: Codex@fao.org - ***preferably***).

BACKGROUND

1. The 37th session of the Codex Committee on Food Additives and Contaminants (CCFAC) agreed that the Discussion Paper on Acrylamide[1] should be revised, taking into account the 64th Joint Expert Committee on Food Additives (JECFA) evaluation of acrylamide; national mitigation strategies; and the role of food processors, catering services, and consumers. The Committee also agreed that the Discussion Paper should also include an outline of a Code of Practice and a project document for starting new work on the elaboration of the Code of Practice for possible future submission to the Commission.

2. The Committee agreed to establish a Working Group, led by the United Kingdom and the United States, to revise the Discussion Paper, taking into consideration the above discussion, for circulation, comments and consideration at its next session.

INTRODUCTION

3. 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[2]. 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[3-6].

4. 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[7].

5. The discovery that acrylamide is formed in some cooked foods is a concern because acrylamide is a probable human carcinogen[8]. It is a known carcinogen and germ cell mutagen in rodents and a known human neurotoxicant; based on high-dose animal studies, it is a potential human carcinogen and genotoxicant[7, 9, 10]. 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)[11].

6. Population-based case-control studies have found no positive association between acrylamide food exposure or food sources and cancer risk, at a variety of organ sites, some unrelated to those identified in rats[12]. 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[13, 14]. 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.

7. 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[15-17]. Acrylamide has not been detected in boiled foods[18, 19]. 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[20-24]. Other precursors that have been suggested to account for some fraction of acrylamide in food include 3-aminopropionamide, acrylic acid, and ammonia[25, 26].

TOXICOLOGY AND EPIDEMIOLOGY

Genotoxicity and carcinogenicity

8. Acrylamide has been classified by the International Agency for Research on Cancer (IARC) as "probably carcinogenic for humans"[8] and recognized by the European Union (EU) Scientific Committee on Food (SCF) as a genotoxic carcinogen[27]. In two long-term studies in rats, acrylamide increased the incidence of a number of benign and malignant tumours in a variety of organs[7,8]. Acrylamide also induced lung and skin tumors in a series of non-standard carcinogenicity bioassays in mice[28]. 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[29]. No increases in cancer have been observed in humans occupationally exposed to acrylamide, with the possible exception of an increase in pancreatic cancer[13, 14].

9. Acrylamide is metabolized in vivo to glycidamide, a chemically reactive epoxide that accounts for acrylamide's observed genotoxic effects. Examples of genotoxic findings for acrylamide include the induction of genetic mutations and chromosomal abnormalities in cultured cells in vitro[8] germ cell mutagenicity in dominant lethality studies in male rodents[39] and in vivo mutagenicity in Big Blue Mouse study with glycidamide and acrylamide[122]. Both acrylamide and glycidamide react with nucleophilic compounds via Michael addition to form adducts on DNA (glycidamide) and protein (acrylamide and glycidamide). 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[7, 27]. 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[30, 31].

Neurotoxicity and Reproductive and Developmental Toxicity

10. Neurotoxicity (from occupational and other high-level non-food exposures) is the only recognized adverse effect of acrylamide exposure in humans[7]. Human occupational studies do not provide information to define a dose response relationship[7]. 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[7, 27].

11. 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[7].

12. 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[32].

Ongoing studies

13. There are a number of ongoing studies on the toxicology of acrylamide, details of which are available on the WHO/FAO Acrylamide Infonet[33]. As outlined in its Action Plan for Acrylamide in Food[34], 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[35-38], but the results of long-term carcinogenicity assays and a developmental neurotoxicity assessment will not be available until 2008. The JECFA evaluation requested by CCFAC will therefore not be concluded until these carcinogenicity and neurotoxicity studies have been completed and the results assessed.

JECFA evaluation

14. The 64th JECFA meeting evaluated acrylamide, summarizing information on acrylamide bioavailability, metabolism, toxicology, exposure, and formation[39]. JECFA characterized the carcinogenic risk of acrylamide by calculating the margins of exposure (MOEs) between a benchmark dose lower limit for mammary gland tumors in rats and estimated acrylamide intakes for consumers with average (1 µg/kg-bw/day) and high-level (4 µg/kg-bw/day) acrylamide consumption (see also the Exposure section of this paper). The MOEs were 300 for the average consumer and 75 for the high-level consumer. The Committee considered these MOEs to be low for a compound that is genotoxic and carcinogenic and concluded that they may indicate a human health concern.

15. JECFA also calculated MOEs for neurological endpoints. Based on these MOEs, the Committee affirmed that adverse neurological effects are unlikely at the estimated intakes, but also said that morphological changes in nerves cannot be excluded for some individuals with very high intake. JECFA stated that ongoing studies of neurotoxicity and neurodevelopmental effects in rats will more clearly define whether effects may arise from long-term low doses of acrylamide.

16. JECFA made the following recommendations: (1) Acrylamide should be reevaluated when results of ongoing carcinogenicity and long-term neurotoxicity studies become available, (2) work should be continued on using pharmacologically based pharmacokinetic (PBPK) modeling to better link human biomarker data with exposure assessments and toxicological effects in experimental animals, (3) appropriate efforts to reduce acrylamide concentrations in food should continue, and (4) it would be useful to have occurrence data on acrylamide in foods as consumed in developing countries.

Epidemiological studies

17. 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 stated 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[12].

18. JIFSAN concluded that existing epidemiological studies do not have the statistical power to detect cancer risk from dietary acrylamide exposure at the levels suggested by toxicological studies[12]. JECFA likewise concluded that the results available from epidemiological studies that estimate oral exposure to acrylamide are not suitable for use in risk assessment of acrylamide[39].

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 or underivatized analyte), (GC-MS) and high performance liquid chromatography/tandem mass spectrometry (HPLC-MS/MS) detection using a stable isotope labeled internal standard[40, 41,82].

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[33]. 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[41]. 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[42].

22. The status of acrylamide methodology as of April 2004 was reviewed at the JIFSAN Acrylamide in Food Workshop[43]. 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[43].

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[42]. 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[44], 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).

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[43].

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. 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[6]	3770[45]
	Chips/French fries[b, c]	59[46]	5200[47]
	Potatoes (raw)	<10[48]	<50[47]
	Potato Fritters/Rosti (fried)	42[45]	2779[45]
Cereal Products	Corn crisps	120[2]	220[6]
	Bakery products & biscuits	18[49]	3324[45]
	Gingerbread	<20[45]	7834[45]
	Bread	<10[6]	130[6]
	Bread (toast)	25[47]	1430[50]
	Breakfast cereals (non-infant)	11[6]	1057[6]
	Crisp bread	<30[2]	2838[45]
	Diabetic cakes & biscuits	20[45]	3044[45]
	Popcorn (sweet & salted)	57[45]	300[45]
	Sesame Snacks	55[45]	160[45]
Rice and Noodles	Fried noodles	3[51]	581[49]
	Fried rice	<3[51]	67[51]
	Instant noodle soup	<3[51]	152[6]
	Rice crackers, grilled or fried	17[49]	500[52]
Fruit and Vegetables	Canned black olives	123[53]	1925[6]
	Bottled prune juice	53[53]	267[6]
	Fried vegetable (including tempura vegetables)	34[49]	34[49]
Nuts	Nuts, including peanut butter	28[6]	339[6]
Fried composite foods	Deep fried Asian delicacies - dumplings, rolls, fritters	<3[51]	190[51]
	Deep fried Asian savoury snacks (lentils, ‘bombay mix’)	33[45]	120[45]
Fish & Meat	Fish and seafood products, crumbed or battered	<2[49]	39[7]
	Meat/Poultry products, crumbed or battered (fried)	<10[6]	64[7]
	Carcass Meat, Poultry and Fish (fried)	<5[18]	52[18]
Cocoa based products	Chocolate products	<2[46]	826[45]
	Cocoa powder[d]	<10[6]	909[6]
Beverages	Coffee (roasted)[e]	45[6]	975[45]
	Coffee substitute[f]	116[45]	5399[6]
	Coffee extract/powder[e]	195[45]	4948[45]
	Roasted Tea (hoji-cha) and Oolong Tea[g]	<9[52]	567[52]
	Roasted barley grains (for tea)	140[7]	578[49]
	Beer	<6[46]	<30[50]
Infant/Baby foods	Infant biscuits/rusks	<20[45]	910[45]
	Jarred/canned baby foods	<10[6]	121[6]

[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[47].

[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 µg/kg, respectively. Samples of Green Tea, Tea (Black) and Pu’er tea either did not contain detectable acrylamide [<9 µg/kg] and / or contained trace levels [9 to 30 µg/kg][52].

27. As summarized in Table 2 (see references in Table), 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. 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[7]	0.3 - 0.8
EU SCF[27]	0.2-0.4
BfR, Germany[54]	1.1 – 3.4
BAG, Switzerland[55]	0.28
SNT, Norway[56]	0.32 – 1.35
AFSSA, France[57]	0.5 – 2.9
SNFA, Sweden[58,114]	0.45 – 1.03
NFCS, Netherlands[50]	0.48 – 1.1
USA[59]	0.43-2.31
UK[60]	0.3 – 1.8
JECFA[39]	1-4

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

28. The FDA found that eight food categories (potato crisps[a], regular French fries (chips)[b], oven baked French fries (chips), 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[61]. 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[60]. 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[11] and smoking[9, 62], and the presence of residual acrylamide in polyacrylamide used in products such as cosmetics, soil conditioners, and coagulants and flocculents used in water treatment[11]. Allowable limits for acrylamide in cosmetics and water have been set[11, 63, 64].

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[24]. 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[20-24, 65, 66]. Foods rich in both of these precursors are largely derived from plant sources, e.g., potatoes and cereal grains[67]. In many cooking processes the Maillard cascade is the predominant chemical process producing products which determine the colour, flavour, aroma and texture of cooked foods, based on the highly complex reactions between amino acids and sugars.

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[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).

33. Based on mechanistic studies, additional formation pathways for acrylamide from food have been hypothesized[25, 26]: (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[68], (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. However, in the majority of cases, the main pathway involves the high-temperature reaction between asparagine and reducing sugars[69, 70].

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[6, 53, 71-73]. Intensive work has been conducted to understand the formation of acrylamide in coffee during roasting[120]. Investigations indicate that asparagine is most probably the main determinant of acrylamide in coffee[23,66]. But other pathways of formation may provide a contribution to the acrylamide formation due to higher processing temperatures used compared to other food sectors[26, 68]. It is known that acrylamide forms early in the roasting process, and then declines, with about 70 percent of the acrylamide being 'lost' or degraded during the later stages of roasting before reaching the final degree of roast of typical commercial roast coffee products. It has also been established that acrylamide levels are lower in dark roasts[71, 121]. 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.

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[53]. Research on the formation of acrylamide during home cooking is under way in the U.S. and the U.K.[33, 76, 77].

36. 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 a precursor for the development of a future Code of Practice for reducing levels of acrylamide in food. An outline of the proposed Code of Practice is shown in Annex 1 and the project document for the proposal for new work is in Annex 2.

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. For a given concentration of sugar and asparagine, more acrylamide is formed in potato than in wheat flour and corn starch. This indicates that there could be other factors involved such as the availability of ammonia [22,119].

40. 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[16]. Cultivar type and storage conditions are key factors in determining the amount of reducing sugars[15-17, 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[15, 75, 84]. Even potato cultivars with low levels of sugar at harvest have been reported to 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/chips) 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]. One report has found that French fries (chips) for the chilled convenience market, which are pre-treated (e.g. blanched, pre-fried), can produce higher levels of acrylamide than frozen French fries (chips), as a result of the liberation of reducing sugar during storage.

41. 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].

42. 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[16, 22]. 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[51] and for baked and fried French fries (chips)[15]. 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 (chips) may lower their acrylamide content, but may also increase their fat content[15]. Finally, increasing cooking time has also been shown to decrease acrylamide in certain products, by promoting elimination of acrylamide[75, 87].

43. 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[17, 89, 90].

44. 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].

45. 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[16, 17, 23, 76, 94, 95]. Asparaginase has been used successfully to obtain significant reductions of acrylamide levels in potato flakes and French fries (chips), but commercialization is thought to be several years away[24,66]. 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].

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

47. There have been recent reports that suggest a positive correlation between antioxidant formation (which can be a nutritional benefit) and acrylamide levels in cookies and coffee[118], both being a result of the Maillard reaction.

Strategies for reducing acrylamide formation in food

48. 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 (Confederation of the Food and Drink Industries of the EU) 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]. A public version of the toolbox was released on the CIAA website in September 2005[98].

Potato based products

49. 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[16, 84].

50. 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[a] or French fries (chips)[b] as this leads to a lighter coloured product[15, 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].

51. 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[15, 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, 99].

52. Soaking or blanching potatoes intended for frying or roasting in water will lower acrylamide levels in the final product by removing acrylamide precursors[15, 76]. Such treatment may delay browning and crust formation, however, leading to longer cooking and hence similar acrylamide levels[15, 97]. Washing in an acidic rinse, vinegar: water[76] or citric acid[15] 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 (chips) 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.

53. Addition of amino acids has been reported to be beneficial in reducing acrylamide levels in fried potato products[17, 100]. However, their effectiveness is not consistent across different products; for example, addition of amino acids during blanching may reduce acrylamide formation in potato crisps, but have no apparent effect for French fries (chips).

54. The presence of calcium ions may also be effective in reducing acrylamide formation. A recent patent application[101] has described laboratory-based studies in which the calcium cation reduces the acrylamide concentration in a number of products, including French fries (chips) and prefabricated potato crisps.

55. 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[15, 91, 97].

56. A promising strategy for minimising exposure to acrylamide involves the use of the enzyme asparaginase. Whilst commercial application of this approach is some way off, preliminary studies are encouraging. For example, laboratory-based experiments have revealed decreases in acrylamide formation of 97 percent in potato crisps and 80 percent in French fries (chips)[24, 102].

57. Formulated potato snacks are based on doughs made predominantly from potato flakes. It is feasible to lower the acrylamide content of such products by partial replacement of the potato ingredients, with other ingredients such as wheat, maize and rice, which have a lower reducing sugar/asparagine content[75].

58. Acrylamide levels can also be controlled by avoiding excessive browning[91, 103]. Endpoints discussed for French fries (chips) are when fries are crispy and golden, and slightly browned at the tips or edges[15, 76] or a golden-yellow color, without surface browning[87].

59. Using lower thermal input into the cooking process, either by decreasing cooking temperatures or duration of cooking, can also help to reduce acrylamide levels[15, 76, 87]. Using lower cooking temperatures for French fries (chips) 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[15, 97]. However, lower cooking temperatures may not equate to lower acrylamide contents for all foods or under all conditions (e.g., references [51, 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 (chips)[76]. Lower oil temperatures can also increase moisture and oil levels in finished fried products, potentially causing quality and food health concerns[15, 87].

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

Cereal-based products

61. 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 temperature and cooking time 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].

62. 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].

63. 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 by catalysing the reaction in experimental systems[87, 89,119] . Such changes may affect the taste of products and require modifications in other ingredients[79, 89].

64. Yeast fermentation of wheat bread doughs is known to reduce the free asparagine content[104]. Fermentation for two hours is reported to utilize most of the asparagine in wheat flour dough models, but shorter times are less effective[105]. Nevertheless, it is apparent that the fermentation process may be one of the parameters that can be manipulated in order to reduce acrylamide formation.

65. Acrylamide levels in toasted bread appear to increase with color[47, 75, 76].

66. 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].

67. 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

68. 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[33] and government-initiated mitigation programs (e.g., Germany)[106, 107].

69. 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[46, 108]. 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[108]. In spring 2005, Health Canada updated its recommendations to suggest that Canadian consumers have fried or deep-fried foods and snacks such as French fries (chips) and potato chips less often while choosing a healthy diet, including a variety of foods from each food group. Health Canada also provided suggestions on how consumers could reduce acrylamide exposure, e.g., by cooking fries to certain color and temperature conditions, by soaking potato slices before cooking, and by toasting bread to a light color[109].

70. The FAO/WHO consultation on acrylamide advised consumers that food should not be cooked excessively, i.e., 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[7].

71. 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[106].

72. In Japan, the Ministry of Health, Labour and Welfare gave the same advice to 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.

73. Following the recommendations made in 2004 by the Swiss Federal Authorities, Swiss food retailers have introduced a specific packaging line for fresh potatoes indicating that their most appropriate forms of preparation (roasting, frying and baking)[115.]. In the Canton of Zurich, after having been trained on how to reduce the acrylamide content in foodstuffs, professional producers of French fries (chips) (restaurants, hospitals, schools etc.) were invited to send French fries (chips) of good quality and low acrylamide content to the Cantonal authorities for analysis. Recommendations were also given in a leaflet, on how acrylamide formation could be reduced. The authorities received 157 products. The median acrylamide concentration was 76µg/kg, whereby the French fries (chips) prepared from fresh prefabricates had an approximately doubled content compared to those from frozen ones. The widely published results prompted the gastronomy sector to produce French fries (chips) with less acrylamide and also gave them an indication of the acrylamide reduction achievable in their field with practical tips[116, 117.]

INTERNATIONAL ACTIVITIES

74. 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"[7]
Ongoing	FAO/WHO Acrylamide Infonet[33]
November 2003	EFSA workshop on the formation of acrylamide in food[110]
March 2004	American Chemical Society symposium on "Chemistry and Safety of Acrylamide in Food[111]
April 2004	2nd JIFSAN Acrylamide in Food Workshop[112]
Ongoing	EC JRC database of acrylamide levels in food in the EU[45]
2002—Ongoing	U.S. FDA Action Plan for Acrylamide in Food[34], Database of acrylamide levels in food in the U.S.[6, 53]
Ongoing	European Commission Research Framework Programme project (HEATOX)[44, 113]
January 2005	European Commission meeting of experts and stakeholders on acrylamide in food [77]
February 2005	JECFA risk assessment of acrylamide in food[39]

CONCLUSIONS

75. 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.

76. There are uncertainties about the impact of acrylamide in food on public health. The JECFA analysis in February 2005 stated that the MOEs for acrylamide intake and cancer risk were low for a compound that is genotoxic and carcinogenic, and that these MOEs may indicate a human health concern.

77. 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.

78. 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

79. It is recommended that CCFAC determine whether it is appropriate to continue further elaboration of this Discussion Paper or whether the Discussion Paper, project document, and Outline Code of Practice should be forwarded to the Codex Alimentarius Commission for consideration of development of a Code of Practice.

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ANNEX 1: OUTLINE 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[1] reported that up to mg/kg amounts of acrylamide could be formed in carbohydrate-rich foods during cooking, at temperatures that occur during frying and baking. These findings were rapidly confirmed in other countries[2], and major international efforts have subsequently been mounted to investigate the principal sources of dietary exposure, assess the associated health risks and develop risk management strategies[3, 4, 5]. 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:europa.eu.int/comm/food/food/chemicalsafety/contaminants/acrylamide_en.htm).

2. Considerable research effort has been undertaken since the discovery of the widespread presence of acrylamide in the diet. A wealth of information now exists regarding factors that influence acrylamide formation, and some approaches that may be employed to minimise its occurrence. The principal aim of this Code of Practice is to disseminate strategies that will facilitate the reduction of acrylamide in internationally traded foodstuffs. It is important to note that some of the approaches mentioned in this Code are still at a research stage, rather than commercially proven. A number of the concepts will also be relevant to catering establishments and domestic consumers.

3. The focus of the Code of Practice is predominantly on foods produced from potatoes and cereals, reflecting their importance in terms of dietary exposure to acrylamide. The Code of Practice builds upon the substantial amount of information that now exists with respect to these products. Although coffee is also an important contributor to acrylamide exposure, it is presently not feasible to identify comprehensive minimisation strategies for coffee.

4. This Code of Practice draws on the 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. The toolbox document is updated on a regular basis as new knowledge and progress in the different food sectors are reported.

5. When the Code of Practice is elaborated, the sections set out here will be expanded to take over information currently in the Discussion Paper and information drawn from all other available sources. It is anticipated that new mitigation measures will be developed as the field evolves.

PREVENTATIVE MEASURES

Overview

6. In broad terms there are four options for reducing acrylamide formation in a particular product: i) decrease the levels of asparagine and/or reducing sugars in the raw materials; ii) reduce the effective concentration of these reactants during the early stages of food processing; iii) minimise those heating conditions that result in excessive heat/low moisture and iv) modify the thermal profile of the cooking process.

Potatoes

Raw Material

7. Reducing sugars are the most important factor influencing acrylamide formation in potatoes; i.e., they exert greater effect than the asparagine concentration. There is a strong correlation between reducing sugar content and cooking-mediated formation of acrylamide[6]. Concentrations of reducing sugars in potatoes can vary by up to two orders of magnitude[7], depending upon cultivar and storage history. Exploitation of the variation in the reducing sugar content represents a major opportunity for reducing acrylamide formation during cooking.

8. Some cultivars are inherently more prone to high levels of reducing sugars than others and should be avoided for high temperature cooking processes.

9. In addition, storage of potatoes below 6 to 10°C enhances the formation of reducing sugars. Low temperature sweetening occurs if tubers are stored at or below about 6 to 8°C, with resultant increases of up to an order of magnitude, or more, in the reducing sugar content. Potatoes that have been subject to excessive low temperature sweetening during storage should be avoided if possible for frying, roasting and oven-baking. Low temperature storage may however be unavoidable as, at higher temperatures, potatoes become more susceptible to sprouting and to certain diseases; sprout suppressant is often essential in stores held at temperatures over 7°C[8].

More information in future papers will be included on:

- Growing Conditions
- Selection of Varieties
- Time of Harvest
- Maturity of Tubers at Harvest
- Storage
- Reconditioning
- Screening Procedures Used for Potatoes

Information on the above aspects are requested

10. Manufacturers of French fries (chips)[a] and potato crisps/potato chips[b] should, where feasible, select potato cultivars that are low in reducing sugars, screen incoming lots for reducing sugar content, and aim to control storage conditions from farm to factory[9].

Other Ingredients

11. For reconstituted or formed potato-based snacks, based on a potato dough, it may be feasible to include other ingredients with lower reducing sugar/asparagine content.

Food Processing and Heating

12. 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[10, 11, 12].

13. Alternatively, 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[13, 14].

14. Treatment of French fries (chips) with amino acids[15, 17, 18] or sodium acid pyrophosphate[9] (added during the last stages of blanching) can be effective, to varying degrees, in reducing acrylamide formation, although such treatment is still experimental.

15. The use of antioxidants may reduce acrylamide formation in some situations, however it is difficult to draw firm conclusions[19, 20] as reports regarding their effects are conflicting.

16. In some situations the asparagine content may be reduced by treatment with the asparaginase enzyme. This technique has shown good potential, both for dough-based potato crisps (potato chips)[15] and for French fries (chips). However, it may be best suited to food products manufactured from liquidised or slurried materials.

17. Treatment with calcium salts, and the salts of a number of other di- and trivalent cations, has been proposed for use in a patent application French fries (chips) made from potato dough, to reduce acrylamide formation[21, 22].

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[a] Potato products that are more thickly sliced (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)

18. The issue of whether such pre-treatments cause an adverse impact on the organoleptic qualities of the fried/baked potato have not in the main been addressed. Similarly, the question of their practicality in the context of a commercial setting, such as a catering establishment, has not been studied in depth.

19. Significant reductions in the acrylamide content of French fries (chips) can be achieved by maintaining the temperature of the frying oil at no more than 175^{o}C, and cooking to a *golden yellow* rather than a *golden brown* colour[16, 23]. Local and national authorities should consider recommending that French fries (chips) prepared in catering establishments, and domestically, are fried to a *golden yellow* colour. However, it is essential to ensure that the French fries (chips) are properly cooked through.

20. Similar reductions are achievable for oven-ready (par-fried) French fries (chips), by cooking to a *golden yellow* colour[24] and not overcooking. A number of oven chip manufacturers have modified their on-pack cooking instructions for frying in order to reduce acrylamide formation[9], and in particular have reduced the recommended frying temperature to 175^{o}C. Again it is essential to ensure that the French fries (chips) are properly cooked through. No changes have been made for the instructions for oven baking.

21. The use of sugar dips to give par-cooked potato products an even golden colour should be reconsidered, as the sugar in these dips can enhance acrylamide formation[25].

Cereals

Raw Material

22. For cereals and cereal-based products such as bread, biscuits (cookies) and breakfast cereals, the asparagine content is the most important determinant of acrylamide formation, i.e., rather than glucose and fructose. A limited amount of data is 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 and from 15 to 25 mg/kg in rice[24]. This level of variation suggests that there may be scope for reducing acrylamide by exploiting the variability in asparagine in the cultivar pool. However, such approaches are likely to have a significant lead time, and the other factors, such as yield and resistance to fungal infections (field mycotoxin formation) should be considered.

23. Raising agents are commonly used in biscuit (cookie) production, and usually consist of a combination of sodium and ammonium bicarbonate. Tests on model baked products and gingerbread have demonstrated that the presence of ammonium bicarbonate has a significant effect in increasing acrylamide formation in biscuits (cookies), and other baked products[35] and manufacturers can consider whether ammonium-containing raising agents can be reduced, e.g., by replacing with sodium-containing raising agents. However, manufacturers should also consider the possibility that this change will increase dietary exposure to sodium or adversely affect the physical or organoleptic qualities of the baked products.[9]

24. Sugars are commonly used in biscuit (cookie) production; specifically sucrose, glucose and occasionally fructose. Of these, 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 are found in the finished product[24]. In addition, higher amounts are formed if the reducing sugar is fructose rather than glucose.

25. Glucose syrup is also often added in biscuit (cookie) production for colour and flavour development. In view of the foregoing, manufacturers should consider using glucose syrups with fructose levels as low as possible.

26. 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 (cookie) production[24] . Conversely, nutmeg has been shown in some cases to result in a decrease in acrylamide[18]. Manufacturers should consider investigating the effect of different spices in their own recipes.

27. An alternative preventative strategy, in terms of ingredient manipulation, may be to increase the content of those ingredients that actively *prevent* acrylamide formation. Addition of selected amino acids may reduce acrylamide by competing with asparagine for the available reducing sugar.

28. Treatment with the enzyme asparaginase may also reduce the asparagine levels. Similarly, 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.

Food Processing and Heating

29. Yeast fermentation of wheat bread doughs reduces the free asparagine content[27]. Fermentation for two hours utilises most of the asparagine in wheat flour dough models, but shorter times are less effective, as is sourdough fermentation.

30. 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[24]. At any one point in the baking cycle, acrylamide formation depends upon both the temperature and the moisture content. As a general rule, the higher the water content the less acrylamide formation will occur. However, as the temperature is increased, the threshold moisture content preventing acrylamide formation drops. In principal, as the temperature increases, the formation of acrylamide is able to occur at lower and lower moisture contents. Acrylamide formation can be reduced by modifying the time/temperature profile of the baking process, in particular by decreasing the temperature of the last stages when the product reaches the crucial, low moisture region. 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 is above the level needed to prevent acrylamide. Tight control of oven temperatures and time profiles can also be effective in reducing acrylamide levels[24]. These principles have been applied successfully in both a biscuit model and in non-fermented crisp-breads[24].

31. 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. In some cases a darker colour may be associated with less acrylamide, as in the case of some breakfast cereals [28].

32. Acrylamide is also formed when bread is toasted, but this can be significantly minimised by toasting to a lighter colour[24].

Coffee

33. Recent work indicates that asparagine is most probably the major determinant of acrylamide in coffee. Due to the higher processing temperatures at roasting other pathways of formation may contribute to a smaller extent[19]. Asparagine levels in green coffee have been analysed in relatively narrow range (300-900 mg/kg) not offering an opportunity to influence the acrylamide levels in roasted coffee[24].

34. Work on the mechanisms of formation of acrylamide in coffee shows that acrylamide is formed rapidly during the early stages of roasting and then the concentration is significantly reduced due to elimination toward the end of the roasting cycle [19,28,36]. Asparagine levels 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[19,36] . Studies have also shown that acrylamide is not stable in coffee powder in closed containers over extended storage periods [36,37,38] 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 will have significant impact on the important organoleptic properties and acceptability of the product [18,19,36].

CONSTRAINTS IN DEVELOPING PREVENTATIVE MEASURES

35. 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. In addition, potential new additives and processing aids, such as asparaginase, will require formal safety assessment and efficacy-in-use demonstration prior to regulatory approval.

36. The development and implementation of measures to reduce acrylamide in a particular foodstuff need careful planning. There are a raft of issues involved including: i) the choice of physico-chemical approach; ii) its practical effectiveness in terms of decreasing acrylamide in a consistently reliable manner; iii) organisational issues associated with any necessary re-design of the manufacturing step, or processing/cooking stage; iv) any microbiological and/or chemical safety implications and/or nutritional implications arising from the introduction of the preventative measure; v) the organoleptic acceptability of the final product to the consumer. Alterations to processing and or/cooking conditions must be practical from the viewpoint of the user. For example, new regimes for soaking French fries (chips) prior to frying must be practical in a commercial kitchen environment, i.e., in restaurants, catering establishments and take-away outlets.

37. Generally, 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.

38. It should also 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 (cookies), sampled from the same production line, can vary by more than a factor of two[28]. 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 such studies to eliminate this as a cause of variability.

Chemical and Microbiological Food Safety

39. There are a number of other contaminants that may, in certain circumstances, be formed when foods are processed and cooked. These include N-nitrosamines[29], polycyclic aromatic hydrocarbons[30], chloropropanols[31], ethyl carbamate[32], furan[33] and amino acid pyrolysates[34]. When preventative measures for acrylamide are considered, checks should be considered to ensure that they will not result in an increase in other contaminants.

40. 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 (cookie) 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 an increase in the moisture content of the final product, and which thereby reduces its microbiological stability, is undesirable.

Nutritional Issues

41. Adverse effects on the nutritional properties of a foodstuff should be weighed against the potential benefits of reducing acrylamide levels. For example, although blanching or soaking potatoes may reduce acrylamide levels, leaching of vitamin C from potatoes during immersion in water is well known, and par boiling/soaking of potatoes before frying/roasting may lead to an increased fat content of the final product. Similarly, replacement of ammonium-containing raising agents with those containing sodium will increase dietary exposure to the latter, and may also adversely affect the physical properties of gingerbread and the organoleptic qualities of biscuits (cookies)[9].

Consumer Acceptance

42. 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, must be assessed from the perspective of the acceptability of the final product to the consumer.

CONSUMER PRACTICES

43. 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 (chips) and roast potatoes be cooked to a *golden yellow* rather than *golden* brown colour, whilst 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.

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

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ANNEX 2 : Project Document

PROPOSAL FOR NEW WORK ON A CODE OF PRACTICE FOR THE REDUCTION OF ACRYLAMIDE IN FOOD

The purposes and the scope of the standard

To develop a draft Code of Practice for the reduction of acrylamide in food. The Code will cover major aspects of commercial production of food, including agricultural practices, storage, raw ingredients, and processing and preparation of food (thermal input, temperature profile, pH, recipe, etc.). The United Kingdom, in consultation with other member countries, will write a first draft of the Code of Practice.

Its relevance and timeliness

Conditions that can be controlled during the production of food, such as agricultural practices, storage conditions, thermal input, temperature profile, pH and recipe, can affect the concentration of acrylamide in the final product. JECFA (2005) has stated that acrylamide may be a human health concern at the levels found in food. A Code of Practice will provide a means of reducing the concentration of the process contaminant acrylamide.

The main aspects to be covered

The draft Code of Practice will cover the parameters that can be controlled and the conditions that have been shown to be effective for these parameters. It will present potential methods for reducing acrylamide in the areas of agronomics, product composition, process conditions and final preparation. It will include an assessment of the effect of these methods on finished product characteristics, both positive and negative. It will also emphasize previous successful and failed mitigation strategies. The Code of Practice will carry forward information included in previous discussion papers on acrylamide.

An assessment against the Criteria for the Establishment of Work Priorities

This proposal is consistent with the following Criteria for the Establishment of Work Priorities:

a) Consumer protection from the point of view of health and fraudulent practices. (By reducing consumer dietary exposure to acrylamide from food).

Relevance to the Codex strategic objectives

This proposal is consistent with the Strategic Vision statement of the Strategic Framework 2003-2007

Information on the relation between the proposal and other existing Codex documents

This new work is recommended in the Discussion Paper on Acrylamide (CX/FAC 05/37/33), the Report of the 37th Session of the Codex Committee on Food Additives and Contaminants (ALINORM 05/28/12) and the revised Discussion Paper on Acrylamide to be presented at the 38th CCFAC Session.

Identification of any requirements for and availability of expert scientific advice

None.

Identification of any need for technical input to the standard from external bodies so that this can be planned for.

None

The proposed timeline for completion of the new work, including the start date, the proposed date for adoption at the Step 5, and the proposed date for adoption by the Commission; the timeframe for developing a standard should not normally exceed five years.

If the Commission approves, in 2006, that the proposal for this New Work should proceed, the draft Code of Practice will be circulated for consideration at Step 3 at the 39th Session of the CCFAC. Advancement to Step 5 is planned for 2009 and an additional Session of the CCFAC might be necessary to finalise the revision for adoption at Step 8 by the subsequent Session of the Codex Alimentarius Commission.