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CODEX ALIMENTARIUS COMMISSION

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World Health Organization

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JOINT FAO/WHO FOOD STANDARDS PROGRAMME

CODEX COMMITTEE ON CONTAMINANTS IN FOODS

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DISCUSSION PAPER ON FURAN

(Prepared by Electronic Working Group led by the United States of America)

BACKGROUND

1. The 4th Session of the Codex Committee on Contaminants in Food (CCCF) agreed to establish an Electronic Working Group, led by the United States, to prepare a discussion paper on furan in food.[1] The list of participants of the electronic working group is attached as Appendix I.

2. The discussion paper was proposed to include a review of furan exposure, furan toxicities, and available technologies to reduce furan in foods, with a view to exploring the possibility of developing a code of practice (COP).

3. Since the ultimate goal of a COP is to provide information on reducing furan levels in food, this paper will focus on information related to furan formation and mitigation. Shorter discussions on toxicology, analysis, and exposure are also included.

INTRODUCTION

4. Furan (C_4H_4O; CAS No. 110-00-9) is a highly volatile, heterocyclic, lipophilic compound used as an intermediate in the production of industrial and agricultural chemicals. Furan can be found in engine exhaust, wood and tobacco smoke, and the products of coal combustion and gasification (*1, 2*).

Furan, C_4H_4O

5. Furan can form in foods as a result of heating (*3-6*) or exposure to ionizing or ultraviolet radiation (*4, 7-8*). Potential precursors of furan include amino acids, sugars, polyunsaturated fatty acids (PUFAs), ascorbic acid, and carotenoids (*5-6*). Furan-based compounds have long been linked to food flavour and aroma (*3*) and prior to 2004, furan itself was known to be present in a limited number of foods (*3,9-11*). In 2004, scientists at the United States Food and Drug Administration (U.S. FDA) reported finding significant levels of furan in a wide range of foods, particularly coffee and foods subjected to retorting in cans and jars (*4*). Furan was subsequently identified in certain low moisture foods as well, such as toast, crackers, potato chips, and tortilla chips (*12-13).*

[1] ALINORM 10/33/41

TOXICOLOGY and EPIDEMIOLOGY

6. Furan in food is a concern because furan is a known rodent carcinogen (*14*). Furan was classified by the International Agency for Research on Cancer (IARC) as Group 2B, possibly carcinogenic to humans (*1*).

7. The Joint WHO/FAO Expert Committee on Food Additives (JECFA) considered furan at its 72nd meeting in Rome, 16-25 February 2010. The following paragraphs (paras. 7-11), taken directly from the report of the 72nd Meeting, provide information on furan toxicokinetics and toxicological data.

Absorption, distribution, metabolism and excretion

8. Following oral administration to mice and rats, furan is rapidly absorbed, metabolized and eliminated in urine and faeces as metabolites and exhaled in air as unchanged furan and carbon dioxide formed as a result of ring opening. The initial ring-opened metabolite is *cis*-2-butene-1,4-dial (BDA), which is formed in the liver in a reaction catalysed by CYP2E1. Furan-derived products are most abundant in the liver of dosed animals. A variety of identified urinary metabolites could arise from amino acid or protein crosslinking (*15*).

Toxicological data

9. The toxicity of orally administered furan has been extensively studied in mice and rats over a wide dose range. The primary site of toxicity of furan is the liver, although the kidneys and lungs are also affected at high doses (>30 mg/kg-bw per day). In addition, changes in some haematological and hormonal parameters occur at doses as low as 0.12 mg/kg-bw per day administered 5 days/week (*15*).

10. Regarding hepatotoxicity, uncoupling of hepatocyte mitochrondrial oxidative phosphorylation is an early critical event in cytolethality. Liver cell injury, including oxidative stress, progresses to cell death. This, in turn, gives rise to regenerative responses, including increased hepatocellular proliferation in mice and rats and, notably in the rat, an early proliferative reaction involving the biliary epithelium, referred to as cholangiofibrosis. These proliferative changes may be the basis for liver tumorigenicity, either alone or in combination with DNA alteration. Although furan is not genotoxic in a number of test systems and binding to rat liver DNA was not detectable, the metabolite BDA is highly reactive and binds to proteins and nucleic acids. BDA produced DNA strand breaks in cultured mammalian cells and was mutagenic in bacteria and cultured mammalian cells; being a dialdehyde, it also formed crosslinks with DNA of cultured cells. The *in vitro* genotoxicity of BDA allows the possibility that BDA formed *in vivo* from furan could react with DNA (*15*).

11. Several cancer bioassays of orally (gavage) administered furan in mice and rats have been performed. In mice, doses of 8 and 15 mg/kg-bw per day, 5 days/week, and 0.5, 1.0, 2.0, 4.0 and 8.0 mg/kg-bw per day, 5 days/week, were used. In rats, doses of 2, 4 and 8 mg/kg-bw per day, 5 days/week, were administered. In livers of male and female rats, high incidences of cholangiocarcinomas were induced at all doses in the U.S. National Toxicology Program (NTP) study, accompanied by biliary tract hyperplasia, metaplasia and fibrosis. Hepatocellular neoplasms were increased at lower incidences. In both sexes of rat, furan also increased the incidences of mononuclear cell leukaemia, albeit against unusually low background incidences in control groups. In male and female mice in both studies, only hepatocellular neoplasms were increased (*15*).

12. No epidemiological studies on furan in humans are available (*15*).

JECFA conclusions

13. JECFA calculated the following dietary exposures for furan: 1 µg/kg-bw/d for the general population (average exposure), and 2 µg/kg-bw/d for consumers with high exposure to furan. These estimates cover potential dietary exposure for children as well as adults (*15-16*).

14. JECFA considered induction of hepatocellular adenomas and carcinomas in female mice as the relevant endpoint and calculated a $BMDL_{10}$[2] of 1.3 mg/kg-bw/d, corresponding to 0.96 mg/kg-bw/d when adjusted from a 5 day/week dosing schedule to an average daily dose. At the average dietary exposure, the margin of exposure (MOE) was 960. For high dietary exposure, the MOE was 480. JECFA considered that

[2] $BMDL_{10}$, lower limit on the benchmark dose for a 10% response

these MOEs indicate a human health concern for a carcinogenic compound that might act via a deoxyribonucleic acid (DNA)-reactive genotoxic metabolite (*16*).

Additional information

15. A two-year carcinogenicity bioassay of furan in F344 rats is currently being conducted as part of a new NTP study at furan doses of 0, 0.02, 0.044, 0.092, 0.20, 0.44, 0.92, and 2.0 mg/kg-bw/day. The assay is intended to determine the dose-response relationship for the carcinogenicity of furan in F344 rats and provide information on lower doses than tested previously. The predicted final report date for the bioassay is 2013. Related ongoing studies will address toxicokinetics and biomarkers (dose-response for liver furan-DNA adduct formation at furan doses ≥ 0.1 mg/kg-bw, adduct accumulation and removal, evaluation of hemoglobin adducts and urinary mercapturates as biomarkers of furan exposure, and physiologically based pharmacokinetic modeling) and mechanistic questions (Big Blue rat mutagenesis, dose-response for subchronic furan hepatotoxicity, reversibility of hepatotoxicity, and epigenetics) (*17*).

16. Epidemiological studies suggest that coffee is associated with a reduced risk of liver cancer in humans (*18-19*), despite coffee containing high levels of furan.

ANALYSIS

17. The JECFA 72nd Report provided the following information on furan analysis: Gas chromatography-mass spectrometry (GC-MS) has been shown to be the most suitable technique for the reliable detection of low levels of furan in foods. GC-MS is usually preceded by headspace (HS) extraction or headspace solid-phase microextraction (HS-SPME). Both HS and HS-SPME approaches are simple and convenient and give satisfactory results for analyses of volatiles. Owing to the high volatility of furan, food samples and standards need to be chilled and handled quickly. Pureed liquid samples or reconstituted powdered samples can be transferred directly to HS vials, whereas solid samples have to be homogenized. Most published methods include the use of deuterium-labelled furan as an internal standard, which is normally added to the homogenized sample before the extraction. Limits of detection (LODs) and limits of quantification (LOQs) from 0.1 to 5 µg/kg and from 0.4 to 13 µg/kg, respectively, have been reported for methods based on HS extraction. Lower LODs and LOQs are reported for methods using HS-SPME. No certified reference material is currently available (*15-16*).

18. Table 1 lists a variety of methods that have been developed since the U.S. FDA published its original method in 2004. The initial U.S. FDA method called for incubating headspace vials at 80 °C, but after reports of furan formation at lower temperatures (*20-24*), subsequent recommendations were to incubate headspace vials at 60 °C (*24-25*) or 50 °C or lower (*26*). Comprehensive reviews on furan analysis methodology can be found in the following recent references (*23, 27)*.

Table 1: Typical methods for analysis of furan in different matrices

Reference	Method	Reported LOD (µg/kg)	Reported LOQ (µg/kg)	Food matrix	Quantification method
Altaki et al., 2007 (*28*)	HS-SPME/GC-IT-MS(1)	0.008 – 0.070	0.030 – 0.250	Apple juice, honey, soup, coffee, baby foods	External calibration curve
Becalski and Seaman, 2005 (*5*)	HS/GC-MS(2)	1	___	Model systems	External calibration curve
Becalski et al., 2010 (*29*)	HS/GC-MS(2)	0.1	___	Fruit products (juices, canned fruits), vegetable products (juices, canned vegetables), mixed products (baked beans, pasta, chili con carne), meat products (beef stew, luncheon meat, canned	External calibration curve

				fish), coffee, baby foods	
Bianchi et al., 2006 (*30*)	HS-SPME/GC-MS(3)	0.0257	0.0417	Baby foods	External calibration curve
Goldmann et al., 2005 (*31*)	HS-SPME/GC-MS(3)	0.034	0.086	Coffee, pet foods, juices, baby foods	External calibration curve
Ho et al., 2005 (*32*)	HS-SPME/GC-MS(3)	0.3	0.8	Brewed coffee; coffee drinks	External calibration curve
Ridgway et al., 2010 (*33*)	SBSE/GC-MS(4)	2	10	Coffee, baby food	Standard addition
US FDA, 2004 (*34*); Nyman et al., 2006 (*20*); Nyman et al., 2008 (*25*)	HS/GC-MS(2)	0.2-4.4	0.6-13	Apple juice, chicken broth, peanut butter, infant formula, canned green beans, pretzels, graham crackers, potato chips	Standard addition
Yoshida et al., 2007 (*24*)	HS/GC-MS(2)	0.2-0.5	0.5-2.0	Baby food, infant formula	External calibration curve

(1) Headspace-solid-phase microextraction/gas chromatography-ion trap-mass spectrometry

(2) Headspace/gas chromatography-mass spectrometry

(3) Headspace-solid-phase microextraction/gas chromatography-mass spectrometry

(4) Stir bar sorptive extraction (SBSE)/ gas chromatography-mass spectrometry

OCCURRENCE AND EXPOSURE

Occurrence

19. Furan has been found in a wide range of thermally treated foods. Initial investigations focused on heated foods sealed in cans and jars, such as baby foods, infant formulas, canned vegetables, baked beans, soups, sauces, stews, and canned meats and fishes (*4*,*12*). Furan has also been found in coffee, beer, fruit and vegetable juices, soy sauce, nutritional drinks, and cereal-based foods, such as cookies (biscuits), crackers, breakfast cereals, and bread (*7*,*13*,*27*,*35*-*36*).

20. Levels of furan in foods for adults typically range from non-detectable to less than 100 µg/kg, although levels in some foods range into the hundreds of µg/kg. Based on data from Australia, Brazil, Canada, the European Union (EU), Japan, Republic of Korea, Switzerland and the U.S., JECFA reported the following ranges for national mean levels of furan in foods with the highest contamination levels: roasted coffee (powder), 814–4590 µg/kg; instant coffee (powder), 90–783 µg/kg; brewed roasted coffee, 34–113 µg/kg; jarred baby foods, 19–96 µg/kg; soy sauce, 16–52 µg/kg; canned fish, 6–76 µg/kg; and baked beans, 27–581 µg/kg (*15*).

21. Roasted coffee (in unbrewed dry form) is particularly high in furan. While furan levels in brewed coffee are typically near or below 100 µg/kg (e.g.,*7*,*36*), levels of furan in roasted whole coffee beans or ground coffee can approach thousands of µg/kg (*36*). EFSA (*36*) provided the following mean (upper bound) values for five coffee categories: instant coffee, 602 µg/kg; coffee, roasted beans, 3611 µg/kg; roasted ground coffee, 1807 µg/kg; coffee, not specified, 1855 µg/kg; and coffee ready-to-drink, 102-104 µg/kg. Coffee values reported by the U.S. FDA for coffee as drunk were lower: 42-52 µg/kg for brewed coffee (*7*).

22. Baby foods have been extensively studied, because of relatively high furan levels, concerns about the sensitivity of infants/toddlers to furan, and because commercially prepared baby foods may comprise a large portion of infant/toddler diets. Freshly prepared/homemade baby foods contain little or no furan (*30*, *37*). Commercial baby foods have been reported to contain non-detectable to greater than 150 µg/kg furan (*7*, *13*,

24, 27, 35, 38). Baby foods containing vegetables or vegetable and meat mixtures have consistently been reported to have higher furan levels than baby foods containing fruit only, meat only, or meat and starches (*13,24,37,39-40*). Zoller et al. (*13*) identified the following ranges (and means) for jarred baby foods containing the following ingredients: meat with no vegetables, 3 to 8 µg/kg (no mean given); vegetables, 4 to 153 µg/kg (mean of 40 µg/kg); and fruit, 1 to 16 µg/kg (mean of 4 µg/kg). Based on European monitoring data, EFSA (*36*) identified the mean furan content in six baby food categories as follows: cereal based, 19 µg/kg; meat and vegetables, 39-40 µg/kg; vegetables only, 39-40 µg/kg; fruits and vegetables, 10-12 µg/kg; fruits only, 2.5-5 µg/kg; and non-classified, 31-32 µg/kg.

Exposure

23. Exposure estimates for furan for Europe, Denmark, U.S., and Brazil from the JECFA assessment are shown in Table 2. Mean exposures for adults ranged between 0.25 and 1.17 µg/kg-bw/d and upper percentile exposures ranged from 0.60 and 2.22 µg/kg-bw/d. As noted in paragraph 12, JECFA chose an exposure of 1 µg/kg-bw/d for the average consumer and 2 µg/kg-bw/d for the high consumer as the basis of its MOE calculation.

Table 2: JECFA estimates of dietary exposure to furan[a]

Country	Dietary exposure estimate (µg/kg-bw per day)	
	Mean	Upper percentile
Europe Europe[b]	 0.29–1.17 adults 0.27–1.01 infants 3–12 months	 0.60–2.22 adults (95th) 1.14–1.34 infants 6–9 months (95th)
Denmark[c]	0.95–1.02 adults 0.08 children 4–6 years	2.10–2.19 adults (95th)
North America U.S.[d]	 0.25–0.26 adults 0.23 children 2–5 years 0.41 infants 0–12 months	 0.61 adults (90th) 0.99 infants 0–12 months (90th)
South America Brazil[e]	 0.46 infants 6–11 months	 1.34 infants 6–11 months (99th)

[a] Adapted from (*15*).

[b] Individual dietary records for 14 European countries from the Concise European Food Consumption Database; analysed furan values from 2004–2009.

[c] Individual dietary records from the Danish National Nutrition Survey; new furan data for some heat-processed foods; EFSA data for other foods.

[d] Individual dietary records from the U.S. 1994–1996, 1998 supplementary CSFII; analysed furan values from 2003 and 2007 surveys.

[e] Individual dietary records for infants; analysed data for baby food.

24. Table 3 shows some additional published exposure estimates for furan in food. Estimates of average exposure are similar to Table 2, with the exception of estimates for Korea, which were much lower.

Table 3: Additional exposure estimates for furan in food

Country/region	**Average Exposure (µg/kg-bw/d), Exposure Category**	**Reference**
Canada	0.37, 20 + year olds 1.12, 1-4 year olds	*29*
Korea	0.0106, adults 0.0174, babies	*38*

Taiwan	0.299, male adults 0.177, female adults 0.47, 6-month-old infants	*41*
Germany	0.5, 6-month-old infants	*37*
Finland	0.1-2.1, infants	*42*

25. Coffee is the major contributor to furan dietary exposure for adults in Europe and North America (*7, 15, 39*). For children, JECFA reported that breakfast cereals were the major contributor to exposure (*15*).

FORMATION

26. Furan is formed in foods as a result of thermal treatment (*3-6*). Furan formation has also been reported in foods treated with ionizing radiation (*4,7-8*) or ultraviolet radiation (*45-46*).

27. Maga (*3*) reviewed early work on the formation of furan and furan derivatives in thermally treated food, identifying the primary source of furans in food as thermal degradation and rearrangement of organic compounds, particularly carbohydrates. Maga identified a number of experimental systems known to produce furan (or derivatized furan) in food, including heating of sugars, heating of sugars in the presence of amino acids or protein, and thermal degradation of vitamins including ascorbic acid (*3-4,22*).

28. Since the identification of furan in a wide range of foods in 2004 (*4*), new studies in model systems have confirmed or identified key pathways to thermally induced formation of furan: (1) thermal oxidation of ascorbic acid, ascorbic acid derivatives, polyunsaturated fatty acids (PUFAs), triglycerides, and carotenoids, (2) thermal degradation of reducing sugars in the absence or presence of amino acids, and (3) thermal degradation of amino acids (*5-6,43-44,47-48*). Fructose was identified as a key precursor in UVC irradiation studies (*45-46*).

29. Based on studies in model systems of thermally induced furan formation, Perez and Yaylayan (*6*) proposed a series of formation pathways for furan in food from sugars, amino acids, ascorbic acid and ascorbic acid derivatives, and PUFAs. Ascorbic acid had the highest furan formation potential of the precursors examined in simple model systems (*6,22*). Mark et al. (*43*) and Limacher et al. (*44*) have elaborated further on probable reaction pathways from ascorbic acid to furan.

30. Becalski and Seaman (*5*) confirmed oxidation of PUFAs at elevated temperatures and decomposition of ascorbic acid derivatives as sources of furan in model systems. They also identified carotenoids as potential precursors to furan.

31. A number of chemical factors have been reported to affect the formation of furan in model studies of thermally induced furan formation. Furan production from PUFAs and ascorbic acid is reportedly suppressed by antioxidants, reducing agents, or limited oxygen availability (*5,43*). Phosphate generally increased thermally induced furan formation from sugars, ascorbic acids, and linoleic acid, while pH had variable effects, depending on the precursor (*49*).

32. Furan production in simple model systems has been reported both to be enhanced (*50*) and reduced by the presence of multiple precursors or other ingredients (*43-44*). Therefore, predictions of furan production from simple model systems should be interpreted cautiously (*43-44*).

33. Based on model studies, and considering the wide range of foods in which furan occurs, it is likely that there are multiple mechanisms of formation in actual foods (*7,35*). There are also likely multiple competing reactions that can decrease or increase furan levels (*23,43-44*). This situation may complicate efforts to identify mitigation opportunities for furan.

MITIGATION RESEARCH

Introduction

34. To date, research on furan has not been successful in identifying practical and consistently effective solutions for decreasing furan in food. Reasons for this include the existence of multiple, complex pathways for furan formation; the importance of thermal processing techniques for food safety and the development of

desirable flavour and aroma; and the complex effects of the food matrix on furan retention in food. Although a "toolbox" of solutions is not yet available, extensive research has been conducted in the areas of food handling, coffee preparation, baby foods, and model systems. This section will review these experiments with the intent of identifying possible material for a future COP. Some experiments describe food handling conditions (e.g., prolonged incubations) that are unrealistic, but the results may still be useful for increasing understanding of furan stability and furan retention in foods.

Food handling: jarred and canned foods

35. Some authors have found a reduction in furan levels by heating and/or stirring prepared foods. Roberts et al. (*51*) tested the effects on furan levels of heating canned and jarred foods in saucepans, microwaves, and hot water baths. The authors found that saucepan heating decreased furan levels more reliably than microwave heating, but not in all samples. Stirring canned samples and jarred baby foods enhanced the release of furan compared with simply letting foods stand. To reduce furan levels, they recommended leaving food to stand as long as possible with regular stirring.

36. Fromberg et al. (*52*) found that heating a variety of ready to eat foods reduced furan content by about half across different foods, with no difference observed between microwave and saucepan heating. Higher temperatures during heating were associated with greater furan reductions in soups and canned foods. No further declines in furan levels were seen in samples left to cool for 1 hour at room temperature.

37. Kim et al. (*53*) found that heating canned meats to 50-70 ºC reduced furan levels 26 to 46 percent. They recommended heating canned meats before consumption, as well as leaving canned foods open for 1 minute prior to eating.

38. Zoller et al. (*13*) reported that heating open jars of baby food in a microwave for 45 seconds and stirring for 10 seconds reduced furan levels 29 percent. When the authors microwaved and stirred samples a second time, furan decreased to 55 percent of original levels.

39. Goldmann et al. (*31*) found that atypical home heating conditions (i.e., heating open jars of baby food to 75 ºC over 5.5 hours) caused an 85 percent decrease in furan. Furan levels also declined about 50 percent in unheated samples over the same time period. The authors concluded that furan is not stable in foods after preparing or opening commercial products, and that the extent of furan loss is related to the temperature of the product and time of exposure to the atmosphere.

40. Other researchers have not found consistent reductions in furan levels from heating and/or stirring prepared foods. Hasnip et al. (*22*) analyzed furan levels before and after heating prepared foods by microwaving, stovetop cooking, and warming in hot water (baby foods), under different stirring conditions. They reported that the heating processes generally did not lead to significant decreases in furan levels.

41. Lachenmeier et al. (*37*) reported that heating commercial baby food jars in a baby food warmer did not show a consistent trend toward increasing or decreasing furan levels, although two potato-based products incurred increased furan levels (6-7 µg/kg) after heating. Heating open jars with stirring also did not cause consistent changes in furan levels. The authors concluded that furan evaporation is hindered by its slow diffusion within the food matrix, and made a preliminary recommendation to heat baby foods in a larger pan or bowl.

Food handling: coffee

42. Goldmann et al. (*31*) found that furan in coffee declined about 50 percent after researchers simulated the transfer of coffee from a pot to a cup and let the coffee stand for about 4 hours. Furan levels also declined approximately 20 percent in 1 hour without simulated transfer. Zoller et al. (*13*) reported comparable declines of furan in coffee by 50 percent after 1 hour resting at room temperature.

43. Guenther et al. (*54*) reported that pouring brewed coffee in cups and letting the cups stand at room temperature reduced furan levels by 25 percent after 30 minutes. Based on these results, they estimated that furan levels would decline by 10 percent within the first few minutes. For coffee prepared in a filter drip machine and kept warm on a hotplate, furan levels fell 50 percent by 1 hour. The authors estimated that furan levels in coffee kept warm on a hotplate would decline 35 percent by 30 minutes.

44. Kim et al. (*53*) analyzed a small number of coffee samples, and found that furan levels decreased in both instant and brewed coffee when samples were left to stand at room temperature for up to 20 minutes with and without lids.

45. Al-Taher et al. (*55*) reported that furan levels in brewed coffee decreased significantly when coffee brews were heated in an open carafe for 1 hour.

46. Fritz et al. (*56*) reported that furan levels in coffee drinks declined almost 50 percent over 30 minutes holding time in a coffee machine.

Coffee preparation

47. Furan exposure from liquid coffee may be affected by factors including roasting procedures (time, temperature), furan content of ground coffee or coffee powders, brewing/extraction procedure (e.g., automatic machine, home brewing, instant), ingredients added to coffee (e.g., cream), amount of ground coffee or coffee powders used per cup, and volume of coffee consumed (e.g., espresso portion versus larger portion). Furan levels can decline significantly during multiple steps in the roasting-to-drinking process (*54*).

48. Furan levels have been reported to be highest in roasted coffee beans versus instant coffee powder or brewed or instant coffee (*13,22,36*). Furan levels have been reported to be higher in brewed coffee than in instant coffee (*7,13,22*). Also, espresso-brewed coffee has higher concentrations of furan than standard brewed coffee (*13,54,57*).

49. Zoller et al. (*13*) reported that espresso-type machines (semi- or fully automatic) gave the highest furan concentrations, and filter brewing (especially into a warmed pot) gave the lowest concentrations.

50. Crews (*58*) found that higher furan levels were associated with commercial bean-to-cup machines versus instant coffee or percolator-brewed coffee, because exposure to air in the commercial machines was limited, minimizing furan loss by evaporation.

51. Kuballa et al. (*59*; reviewed in *60*) also reported finding the highest levels of furan with automatic (bean-to-cup) machines, and attributed this finding to increased retention of furan in the closed system. Home coffee-making machines and manual brewing produced lower levels of furan.

52. La Pera et al. (*60*) found that moka brewing and automatic espresso brewing caused greater reductions in furan (67 percent and 63.3 percent) than infusion in hot water (57 percent).

53. Crews (*58*) found that latte coffee had higher furan levels than espresso coffee, which the authors attributed to greater furan retention from larger drink volume, the presence of milk fat, or the froth on top of the drink. Consistent with the milk fat finding, Van Lancker et al. (*61*) observed decreased furan retention in defatted coffee versus untreated coffee.

54. Guenther et al. (*54*) reported that darker (longer) coffee roasts have higher furan levels than lighter (shorter) roasts, but that decreasing roast time is not a practical option for reducing furan levels, because roast time is an important determinant of coffee flavour and because longer roast times decrease concentrations of another process contaminant, acrylamide. La Pera et al. (*60*) also pointed out that the need to roast coffee at high temperatures (>200 °C) and the inability to purge furan from roasted samples without also purging flavour and aroma-producing chemicals would complicate attempts to reduce furan in coffee.

Toasting bread

55. Furan has been found in both untoasted and toasted breads, but toasting caused furan levels to increase (*13,22*). Furan has also been reported to be concentrated in the crust of breads (*13*).

Ingredients and processing: Baby foods and juices

56. Baby foods are typically thermally processed at high temperatures in sealed containers, increasing susceptibility to furan formation. As noted in para. 21, baby foods containing vegetables or vegetable-meat mixtures typically have higher furan levels than fruit-only baby foods.

57. Understanding why furan levels are higher in vegetable-based baby foods than in fruit-based baby foods may help identify opportunities for furan reduction. Two possible factors are higher furfural levels (furfural is a furan precursor) and higher pH in vegetable foods (*13,62-64*).

58. Vitamin C (ascorbic acid) may also be a factor. Vitamin C is a precursor of furan and baby foods may be fortified with and contain naturally occurring vitamin C (*65*). Mesias-Garcia et al. (*62*) suggested increased breakdown of vitamin C in vegetable-based baby foods as a possible reason for increased furan levels relative to fruit-based foods. Vitamin C may also increase furan formation from other precursors (*37,44*). Both Lachenmeier et al. (*37*) and Limacher et al. (*44*) recommended against adding vitamin C to thermally treated (canned and jarred) products, especially certain baby foods. On the otherhand, Mesias-Garcia et al. (*62*) noted that vitamin C fortification of fruit-based baby foods does not appear to contribute to enhanced furan formation, and Owczarek-Fendor et al. (*65*) did not observe effects on furan levels when changing vitamin C concentrations in a baby food model system (see the following section on Model Systems for more information on vitamin C in baby foods).

59. Bianchi et al. (*30*) observed that fruit-based baby foods are generally pasteurized whereas vegetable-based baby foods are sterilized. Wegener et al. (*64*) found that furan levels were higher in carrot juice products intended for infants that were sterilized compared with similar products that were pasteurized at lower temperatures. The higher furan levels were also associated with a higher pH.

60. Van Lancker et al. (*61*) examined the effects of oil on retention of furan in baby foods heated prior to consumption. Of four baby food products examined, "spinach" and "meat and vegetables," which contained added oil, had higher retention of furan than "carrots" or "garden vegetables," which did not have added oil. Based on the limited number of samples examined, the authors concluded that the amount of oil added had more effect than the inherent fat content. They also concluded that because eliminating oils from baby food is not nutritionally suitable, it would be better to add oils after heat processing, immediately before consumption.

Model systems

61. Van Lancker et al. (*61*) studied the effects of food matrix on furan retention in model systems and domestically heated prepared foods. Starch did not generally increase furan retention relative to water in a model system, despite the fact that starch can form gels containing inclusion bodies. Limited retention was noted only with a high-viscosity potato matrix, suggesting that matrix viscosity does not affect furan retention significantly. The presence of oils was also associated with a significant decrease in furan release from baby foods (irrespective of degree of oil saturation), suggesting that oils can decrease volatilization of furan. Decreased furan retention was also seen in defatted coffee compared with untreated coffee.

62. Owczarek-Fendor et al. (*65*) used a model system based on heating vials containing starch gels to simulate baby foods. They reported that furan generation was much higher in incompletely filled vials, suggesting that oxygen may enhance furan formation; however, no practical effects were expected in commercially available jarred baby foods, which show little variation in headspace volume. The authors also found that changing vitamin C concentrations from 0.1 to 4.5 mg/g had no effect on furan levels. Since baby foods contain 0.02 to 0.15 mg/g vitamin C, Owczarek-Fendor et al. (*65*) predicted that changing vitamin C supplementation levels would not be expected to affect furan levels in baby food. The same model system was used to examine the effects of oils on furan formation. The generation of furan from unoxidized oils was very limited. Oxidized oils containing alpha-linolenic acid generated furan, but only when the oils were oxidized at levels unacceptable in practical use (*66*).

63. Limacher et al. (*44*) studied furan formation in model food systems consisting of pumpkin puree and vegetable and fruit juices heated in pressure cookers under sterilization conditions. They found that supplementing puree and juices with vitamin C can cause significant increases in furan levels, and noted that vitamin C may function in these systems as a pro-oxidant promoting furan formation, rather than as a precursor. They recommended against vitamin C fortification of foods containing furan precursors before thermal treatment, particularly foods containing polyunsaturated lipids.

64. Lachenmeier et al. (*37*) studied the effects of heating conditions and vitamin C in a potato puree baby food model, and concluded that vitamin C had the potential to increase furan formation. They recommended not fortifying canned or jarred foods with vitamin C before thermal treatment.

MITIGATION OPTIONS AND RECOMMENDATIONS

65. To date, research on furan has not been successful in identifying practical and consistently effective solutions for decreasing furan in food. The interventions in the scientific literature on furan are mostly targeted at the level of the consumer, i.e., at the level of handling of prepared foods, rather than production methods. Although formation and mitigation research suggests the potential for interventions in the areas of ingredient addition and thermal processing, such interventions could have serious nutritional or microbiological effects (e.g., changing thermal profiles) and cannot be taken lightly. For these reasons, the Working Group considers it premature to develop a Code of Practice at this time.

66. The Working Group suggests that the following material be considered as an optional consumer education section in a Code of Practice in the future. It can also be used separately as possible advice for consumers by national authorities.

a. Heat canned or jarred foods with stirring to allow partial volatilization and dissipation of furan. Stovetop heating, microwave heating, and heating jars in water have all been shown to reduce furan in some cases, but there is some evidence that stovetop heating may be more effective than microwave heating.

b. Consumers who wish to reduce furan intake from coffee can moderate coffee intake or choose a coffee brewing method that results in lower furan levels (instant coffee < filter drip < bean-to-cup machine). Consumers may also wish to let coffee stand for several minutes after pouring to allow furan release before adding cream.

c. Include homemade foods in the diet (e.g., baby foods, soup, baked beans) as alternatives to prepackaged foods.

d. Include fresh and frozen vegetables in the diet, along with canned vegetables.

e. Toast bread to light brown, rather than dark brown, levels.

67. Ongoing or future research may provide more practical solutions that could form the basis of a Code of Practice. The Working Group recommends that national authorities and food processors research novel mitigation approaches for furan, especially for food production. Such research should consider organoleptic qualities and overall safety profiles of foods. Possible examples include:

a. Investigate potential changes in thermal processing profiles, in the context of microbiological risks.

b. Investigate furan formation in fish, bean, and other products, for which furan formation pathways may be unclear.

c. Investigate whether changes in added ingredients (e.g., vitamin C, oils) can mitigate furan formation and/or enhance furan release.

d. Investigate ways to minimize furan formation or retention in dry foods.

e. For consumers, investigate additional techniques for reducing furan levels in prepared foods.

f. Consider including furan analogues that are of toxicological relevance to humans (e.g., 2-methylfuran, 3-methylfuran) in mitigation studies.

g. Pursue international alignment of testing methodology for furan (e.g., sampling, sample preparation, analytical methodology).

68. The Working Group recommends that CCCF re-establish the Electronic Working Group to revise and update the furan discussion paper when adequate new data are available.

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