



# Risk assessment of furan in commercially jarred baby foods and insights into furan occurrence and formation in freshly home-cooked foods for infants and young children

Dirk W Lachenmeier, Helmut Reusch, Thomas Kuballa

## ► To cite this version:

Dirk W Lachenmeier, Helmut Reusch, Thomas Kuballa. Risk assessment of furan in commercially jarred baby foods and insights into furan occurrence and formation in freshly home-cooked foods for infants and young children. Food Additives and Contaminants, 2009, 26 (06), pp.776-785. 10.1080/02652030802714018 . hal-00577364

**HAL Id: hal-00577364**

**<https://hal.science/hal-00577364>**

Submitted on 17 Mar 2011

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



**Risk assessment of furan in commercially jarred baby foods and insights into furan occurrence and formation in freshly home-cooked foods for infants and young children**

Journal:	<i>Food Additives and Contaminants</i>
Manuscript ID:	TFAC-2008-341.R1
Manuscript Type:	Original Research Paper
Date Submitted by the Author:	22-Dec-2008
Complete List of Authors:	Lachenmeier, Dirk; Chemisches und Veterinäruntersuchungsamt Karlsruhe Reusch, Helmut; Chemisches und Veterinäruntersuchungsamt Karlsruhe Kuballa, Thomas; Chemisches und Veterinäruntersuchungsamt Karlsruhe
Methods/Techniques:	Chromatography - GC/MS, Exposure assessment, GC/MS, Risk assessment
Additives/Contaminants:	Process contaminants, Volatiles
Food Types:	Baby food, Cereals, Potatoes, Vegetables

SCHOLARONE™  
Manuscripts

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1     **Risk assessment of furan in commercially jarred baby foods,**  
2     **insights into furan occurrence and formation in freshly home-**  
3     **cooked foods for infants and young children**

5     **Abstract**

6     Furan is a possible human carcinogen (IARC group 2B) with widespread occurrence in  
7     many types of foods. In this study, a survey of furan contamination in 230  
8     commercially-jarred ready-to-eat infant food products was conducted using headspace  
9     sampling in combination with gas chromatography and mass spectrometry (HS-GC/MS)  
10    with a detection limit of 0.2 µg kg<sup>-1</sup>. The incidence of furan contamination in jarred  
11    infant beverages, cereals and fruits was relatively low, with average concentrations  
12    below 10 µg kg<sup>-1</sup>. Significantly higher concentrations were found in pasta (34.8 ± 14.5  
13    µg kg<sup>-1</sup>), meals containing meat (28.2 ± 15.0 µg kg<sup>-1</sup>), and meals containing vegetables  
14    (31.2 ± 17.3 µg kg<sup>-1</sup>). The average exposure of 6-month old infants to furan was  
15    estimated to be 0.2 µg per kg bodyweight per day. The margin of exposure calculated  
16    using the T25 dose descriptor would be 2692, which points to a possible public health risk. In  
17    contrast to commercially jarred food products, none of 20 freshly home-prepared baby foods  
18    contained furan above the limit of detection. Only after re-heating in closed vessels was furan  
19    found to have formed. Furan was especially prevalent in reheated foods containing potatoes,  
20    with values ranging between 2.3 and 29.2 µg kg<sup>-1</sup>. The formation of furan in potato-  
21    containing baby foods was increased by addition of ascorbic acid, by longer heating  
22    times above 1 h and by temperatures above 50°C. Research regarding reduction of  
23    furan in commercial baby foods should be conducted, with a priority aimed at reducing

24 this heat-induced contaminant without concomitantly increasing the microbiological  
25 risk.

26

27 **Keywords:** Furan, carcinogens, gas chromatography, mass spectrometry, food  
28 contamination, food analysis, baby food, infant food, risk assessment

For Peer Review Only

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

29 Introduction

30 Furan ( $C_4H_4O$ ), a very volatile and colourless liquid, has been classified by the  
31 International Agency for Research on Cancer (IARC 1995) as a possible human  
32 carcinogen (group 2B). However, it is still a matter of debate whether the carcinogenic  
33 effects are caused by a genotoxic mechanism (Durling et al. 2007). Other chronic effects  
34 in humans may include hepatotoxicity (Jun et al. 2008). Due to its widespread  
35 occurrence in many types of food products, concerns have been raised that furan might  
36 become a serious problem, similar to that seen for acrylamide (Yaylayan 2006).

37  
38 Furan generation in food is multi-factorial (Yaylayan 2006). A number of model tests  
39 have shown that furan is produced through heating of reducing carbohydrates through  
40 the Maillard reaction (Maga 1979; Perez Locas and Yaylayan 2004). Furan generation  
41 has also been determined in the presence of ascorbic acid (Fan 2005; Becalski and  
42 Seaman 2005) or certain amino acids (Perez Locas and Yaylayan 2004; Märk et al.  
43 2006; Limacher et al. 2008). The pathway from ascorbic acid is of special importance as  
44 many foods are fortified with vitamin C as part of processing. Possible intermediates in  
45 the formation from ascorbic acid are 2-deoxyaldotetroses, 2-furoic acid and 2-  
46 furaldehyde (Limacher et al. 2007). The oxidation of poly-unsaturated fatty acids may  
47 also represent a means of furan generation (Becalski and Seaman 2005; Senyuva and  
48 Gökmen 2007).

49  
50 There are currently a large number of analytical methods for the determination of furan  
51 in foods, developed over the past few years, and the analytical problems first reported

for furan appear to have been resolved (Senyuva and Gökmen 2005; Crews et al. 2007; Wenzl et al. 2007; Crews and Castle 2007b).

In our current study, we have focused on furan in foods intended to be consumed by infants, because they are the most susceptible consumer group (Suk et al. 2003) and because relatively high amounts of furan were previously detected in commercial baby foods. Heppner and Schlatter (2007) summarized the data from a number of sources (including data from the US FDA) and found that the concentration of furan in baby foods ranged from non-detectable to as much as  $112 \mu\text{g kg}^{-1}$ . Taking into consideration a consumption of 234 g per day of canned baby food (Kersting et al. 1998), Heppner and Schlatter (2007) assumed an exposure range of  $<0.03\text{--}3.5 \mu\text{g}$  per kg body weight (bw) per day, assuming a body weight of 7.5 kg for a 6-month-old baby. Yoshida et al. (2007) reported levels of furan in a similar range of 1.4 to  $90 \mu\text{g kg}^{-1}$  in 15 baby foods from the Japanese market. Most recently, the US FDA reported furan in ready-to-eat baby foods from the USA in ranges between 2.5 and  $112 \mu\text{g kg}^{-1}$  were found (Morehouse et al. 2008).

The European Food Safety Authority's (EFSA) Scientific Panel on Contaminants in the Food Chain noted an absence of information on freshly prepared foods in home cooking and catering in general (Heppner and Schlatter 2007). A first indication of the effect of consumer cooking on furan in convenience food showed that the levels decreased in most canned and jarred foods after heating due to simple evaporation (Roberts et al. 2008). In contrast, other researchers found furan to be relatively persistent in food (Crews and Castle 2007a) and that it is not lost to a very significant extent when the foods are simply warmed to be ready to eat (Hasnip et al. 2006). At this point in time,

only one study has researched furan in home-prepared baby foods and it showed that all seven preparations examined had significantly lower levels of furan in comparison with commercial baby foods (Bianchi et al. 2006). However, the results were described to be insufficient to make a definite conclusion regarding furan content and home cooking. In the context of EFSA's open call for scientific data on furan in food and beverages (EFSA 2006), we have analyzed a large collection of commercial jarred baby food products from the German market and have evaluated the influence of domestic heating procedures on the furan content of the jars. In addition, we have analyzed freshly prepared baby foods prepared according to typical baby food recipes using fresh fruits and vegetables. Finally, we provide some insight into the pathway of formation of furan in baby foods.

**Materials and Methods**

*Samples*

The survey of commercial ready-to-eat baby foods included 230 products sampled and analyzed between 2004 and 2007. As part of official food control in the German federal state of Baden-Württemberg, our institute covers the district of Karlsruhe in North Baden (Germany) with a population of approximately 2.7 million. The sampling was carried out by local authorities directly at the food producers or at retail trade establishments including pharmacies and organic food stores. The samples were randomly selected and collected by government food inspectors. Only products intended for use as foods specifically for infants and young children, in the sense of Commission Directive 2006/125/EC, were included in the survey (European Commission 2006).

The ingredients for home preparation of baby foods were purchased in May and June 2008 at local farmer's markets and organic food stores. In the initial experiment concerning different product groups, only ingredients classifiable as organic according to Council Regulation (EEC) No 2092/91 were chosen (European Council 2001). The second experiment, which focused on potato-based baby foods, was conducted with organic as well as conventionally produced ingredients.

#### *Quantitative determination of furan*

For the survey, a headspace-gas chromatography-mass spectrometry (HS-GC/MS) method with deuterated furan as internal standard and standard addition for quantification was used, which was based on a FDA method (FDA, 2004). The HS-GC/MS method was previously described in detail (Kuballa et al. 2005; Kuballa 2007).

The HS-GC/MS method was validated for the determination of baby foods and accredited to ISO 17025. The precision of the method never exceeded 6.4% (relative standard deviation,  $n=5$ ) and the average recovery was 105% ( $n=8$ ). Determined according to DIN 32645, the limit of detection (LOD) was  $0.20 \mu\text{g kg}^{-1}$  and the limit of quantification (LOQ) was  $0.60 \mu\text{g kg}^{-1}$ .

Because of the extremely high time effort of the HS-GC/MS method due to standard addition, the home preparation and formation experiments were evaluated using purge-and-trap-GC/MS procedure. Deuterated furan was used as internal standard, but the quantification was conducted using a more efficient external calibration.



1  
2  
3  
4  
5 123  
6  
7  
8 124 The purge-and-trap system used for analysis was an Eclipse 4660 Purge-and-Trap  
9  
10 125 Sample Concentrator in combination with a model 4552 water/soil autosampler (OI  
11  
12 126 Analytical, College Station, TX, USA). The trap was #10 (8 cm, tenax, silica gel, carbon  
13  
14  
15 127 molecular sieve) provided by the manufacturer. The sample temperature was 40°C. The  
16  
17 128 sample was purged for 5 min. The desorption was conducted for 4 min at 190°C,  
18  
19 129 followed by a bake time of 20 min at 210°C to avoid carry over.  
20  
21  
22 130  
23  
24  
25 131 The purge-and-trap system was combined with an Agilent model 6890 Series Plus gas  
26  
27 132 chromatograph and an Agilent 5973N mass selective detector (Agilent, Waldbronn,  
28  
29 133 Germany). Data acquisition and analysis were performed using standard software  
30  
31 134 supplied by the manufacturer. Substances were separated on a fused silica capillary  
32  
33 135 column (HP Plot Q, 30 m x 0.32 mm I.D., film thickness 0.25 µm). Temperature  
34  
35 136 program: 90°C hold for 1 min, 10°C min<sup>-1</sup> up to 225°C, hold for 15 min. The  
36  
37 137 temperatures for the ion source, quadrupole and interface were set at 230°C, 150°C, and  
38  
39 138 225°C, respectively. Helium with a constant flow rate of 1.5 ml min<sup>-1</sup> as carrier gas was  
40  
41 139 used. For quantification, the mass fragments *m/z* 68 and *m/z* 72 were used for furan and  
42  
43 140 furan-d<sub>4</sub>, respectively.  
44  
45  
46  
47  
48  
49  
50 141  
51  
52  
53 142 The purge-and-trap method was validated similar to the HS-GC/MS method. The  
54  
55 143 precision of the purge-and-trap method never exceeded 3.7% (relative standard  
56  
57 144 deviation, n=8) and the average recovery was 106 % (n=8). The LOD was 0.15 µg kg<sup>-1</sup>  
58  
59 145 and the LOQ was 0.44 µg kg<sup>-1</sup>. No artifactual furan formation was observed during the  
60

purge-and-trap step, as e.g. proven by results below LOD in unheated samples containing furan precursors.

### *Experiments for home preparation of baby foods*

The home preparation experiments were aimed to simulate typical home cooking as closely as possible. We used only standard kitchen equipment, e.g. a kitchen stove and a household blender. The recipes were taken from a cookbook intended for parents preparing foods for babies between five and 10 months of age, i.e. the time period of adjustment from breast feeding to normal solid foods (von Mandelsloh 2007). These foods are generally prepared as a puree (so-called 'Babybrei' in German) using hand or table-top blenders to achieve a consistency that allows easy ingestion by the babies. In Germany, potatoes are typical ingredients, alone or in combination with carrots and other vegetables or meat. In general, we cooked the ingredients in boiling water until done, then the ingredients were blended, with addition of water to adjust the consistency to correspond with that of typical commercial baby foods. No other additives were used. The food groups under investigation are shown in Table 1. Besides the direct analysis of the freshly prepared food, we have stored the foods overnight at 8°C, followed by a re-heating in closed vessels for 1 h in a water bath at 70°C. Finally, we have added 2-furan carboxylic acid (80 mg kg<sup>-1</sup>, purity 98%) and re-heated similarly.

As it became evident in the first experiment that potatoes, in particular, appeared to have the capacity to form furan, we conducted a second experiment with potato purees specifically. Potatoes of different origins and agricultural production methods were used

(Table 2). In this experiment, we also performed additional tests involving the addition of ascorbic acid (500 mg kg<sup>-1</sup>) to the ingredients.

***Preparation experiments involving commercial baby foods***

To assess possible changes in furan content during normal home preparation of commercial baby foods, we chose 10 products of which we had more than one jar of the same production lot, and analyzed them as opened, as well as following heating with a baby food warmer. The warmer was a PTC baby food warmer type 702 by Reer-Kindersicherheit, Leonberg, Germany. The baby food jar is placed into the device, which is then filled with water, so that the jar is indirectly heated by the water. To assess the maximal furan formation capacity, we have used extreme conditions for the heating, including a maximum temperature setting of the device (80°C water temperature, own measurement), a 1 h heating time, and closed jars. In two cases, we had three jars of one lot, so we were also able to assess the effect of heating in an open jar, with regular stirring during the heating process.

***Experiment on influences on furan formation in potato puree baby foods***

In order to evaluate possible furan formation mechanisms in potato puree baby foods, with a minimum number of experiments, the information gleaned from each experiment and the relationships between the experiments have to be fully exploited. This was done using a D-optimal design type (Box et al. 2005; Montgomery 2005). The D-optimal algorithm was used because it chooses an ideal subset of all possible combinations and significantly reduces the number of required experiments when compared to standard design types.

1  
2  
3  
4  
5 193  
6

7 194 The potato puree used in this experiment was freshly prepared from organic potatoes  
8  
9 195 (Nicola from Egypt) using the same methods described above for the home preparation  
10  
11 196 of baby foods. The preparations were then re-heated using the following conditions. The  
12  
13 197 heating temperature and heating time were studied at two levels (50°C, 100°C; 1 h, 2 h)  
14  
15 198 whereas the ascorbic acid concentration was assessed as numeric factor between 0 and  
16  
17 199 1000 mg kg<sup>-1</sup>.  
18  
19  
20  
21  
22

23  
24 200

### 25 201 *Approach for risk assessment*

26 202 Risk assessment was conducted according to the harmonised approach of the European  
27  
28 203 Food Safety Authority (EFSA) for the risk assessment of substances which are  
29  
30 204 genotoxic and carcinogenic (EFSA 2005). The EFSA has developed and recommends  
31  
32 205 an approach known as the margin of exposure (MOE). This approach uses the value of  
33  
34 206 doses of substances that have been observed to cause low but measurably harmful  
35  
36 207 responses in animals as a reference point, which is then compared with relevant  
37  
38 208 substance-specific dietary intake estimates in humans, taking into account differences in  
39  
40 209 consumption patterns. For this case of commercial ready-to-eat baby foods, we used the  
41  
42 210 consumption data provided by Kersting et al. (1998).  
43  
44  
45  
46  
47  
48  
49

50 211

51 212 To obtain the MOE, the Benchmark Dose Lower Confidence Limit (BMDL) of 10%  
52  
53 213 was suggested. In cases where the data are unsuitable for obtaining a BMDL, the EFSA  
54  
55 214 recommends the use of the T25 calculation, wherein the dose corresponding to a 25%  
56  
57 215 incidence of tumours, after correction for spontaneous incidence, is represented. Since  
58  
59 216 the dose-response modelling of a BMDL would have gone beyond the scope of this  
60

article, we therefore chose the T25 of  $1.4 \text{ mg kg bw}^{-1} \text{ day}^{-1}$ , as tabulated by Sanner et al. (2001), to provide a preliminary risk assessment.

**Statistics**

The experimental designs and calculations were done using the Software Package Design Expert v7 (Stat-Ease Inc., Minneapolis, MN, USA). The experiments were evaluated using Analysis of Variance (ANOVA) to find the significance of variables and their interactions in the models. The models were checked for consistency by looking at the lack of fit and possible outliers.

The survey data were evaluated using Origin Pro v7.5 (OriginLab Corporation, Northampton, MA, USA). Statistical significance was assumed at below the 0.05 probability level. Groups of two cases were compared using t-tests. One-way ANOVA was used to test whether three or more cases had the same mean, including the Bonferroni post hoc means comparison. Pearson's test was used to evaluate the significance of linear relations. Box and whisker plots were used for visualization of data (box 25<sup>th</sup> - 75<sup>th</sup> percentile, line in the box: median, whiskers: minimum and maximum (max. 1.5 times the length of the inner quartiles), data points outside are outliers).

To assess the influence of ingredients in commercial jarred baby foods on furan content, the 230 products in the survey were categorized according to their ingredients lists as to whether they contained potatoes, carrots, other vegetables, meats, fruits or cereals. A data matrix was compiled containing the binary classification (0 if the ingredient was not contained, and 1 if it was contained) as well as the furan content of the product. A

1  
2  
3  
4  
5 241 partial least squares (PLS) analysis was conducted using the binary classifications as x-  
6  
7 242 variables and the furan content as y-variable, with the aim of visualizing correlation  
8  
9 243 between the variables. A multivariate PLS analysis was conducted using the software  
10  
11 244 Unscrambler v9.7 (CAMO Process AS, Oslo, Norway).  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

**Results and Discussion**

*Furan in freshly homeprepared baby foods*

A major finding of our study is the fact that self-prepared baby food does not contain furan. Furan was below the limit of detection in all of the ten different foods prepared (Table 1). Our results are in agreement with those of Bianchi et al. (2006) who detected none or only very low concentrations in seven home-made baby foods. We think that the available literature now conclusively supports the assumption of a very low risk of furan in home prepared baby foods.

In our study, only after storage and re-heating was furan detectable, in three cases in concentrations between 4.5 and 10.0  $\mu\text{g kg}^{-1}$  (Table 1). However, it must be stressed that our re-heating conditions (70°C, 1 h, closed vessel) were extreme compared to normal household conditions. Furan was formed in five cases, at concentrations between 1.8 and 51.8  $\mu\text{g kg}^{-1}$ , after the addition of 2-furan carboxylic acid, a possible precursor of furan (Yaylayan 2006; Limacher et al. 2007). As the formation capability appears to have been highest in samples containing potatoes, we have studied potato baby foods in more detail (Table 2). Again, furan was below the limit of detection in all freshly prepared samples. After re-heating, amounts between 2.3 and 29.2  $\mu\text{g kg}^{-1}$  were formed. No significant differences could be detected between organically and conventionally produced potatoes ( $p=0.1306$ ) or between potatoes with origins in Germany and Egypt ( $p=0.8600$ ). If ascorbic acid was added to the potato baby foods, the furan content increased in every case, ranging between 8.3 and 58.3  $\mu\text{g kg}^{-1}$ . The furan contents of the re-heated samples before and after ascorbic acid addition show a significant linear

relation ( $y=5.7+1.8x$ ;  $p=0.0001$ ), which proves that other factors besides ascorbic acid are involved in the formation mechanism. Otherwise, the same amount should have been formed in every sample, had ascorbic acid been the only factor involved. This finding is in agreement with Limacher et al. (2007), who also suggested that other compounds must be functioning as precursors and who deduced that transformation of these into furan is being accelerated by the presence of ascorbic acid.

A more detailed insight into the furan formation in potato baby foods is provided by our formation experiment (Figure 1). The ANOVA for the response surface two factor interaction model implies that the model is highly significant ( $p<0.0001$ ). Significant influences on furan formation were temperature ( $p<0.0001$ ), ascorbic acid content ( $p<0.0001$ ) and heating time ( $p=0.0093$ ). Significant interactions occurred between ascorbic acid and temperature ( $p<0.0001$ ) and between temperature and heating time ( $p=0.0212$ ). Figure 1 shows that, at  $50^{\circ}\text{C}$ , the furan content stays almost constant and there are no differences between 1 and 2 h heating nor between the different ascorbic acid additions. The picture changes at  $100^{\circ}\text{C}$ , when furan shows a linear increase with rising ascorbic acid concentrations, and higher concentrations were found at 2 hours of heating than at 1 hour.

We conclude from our results that furan content in freshly home-cooked baby foods is not an issue. The problem may only arise if self-prepared foods are stored and then reheated. Especially when they contain potatoes, baby foods should only be mildly reheated to avoid furan formation. The experiments also show that ascorbic acid, a common ingredient and additive in foods, has the potential to increase furan formation



1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

292 or act itself as a precursor. We can only stress the warning of Limacher et al. (2007)  
293 who concluded that it is not recommended to fortify canned and jarred food products  
294 with vitamin C before thermal treatment.

295

296 ***Behaviour of furan during heating of commercial baby food jars***

297 The heating of commercial baby food jars in a typical baby food warmer showed no  
298 consistent trend (Table 3). Only two products containing potatoes (potato-carrot puree,  
299 cream potatoes) again showed increases in furan, at 7.4 and 6.1  $\mu\text{g kg}^{-1}$ . The eight other  
300 products showed no significant increase or decrease due to heating, but results were  
301 identical within the method uncertainty. Heating of opened jars with stirring also  
302 showed no consistent trend. In the case of a potato-carrot-puree, a slight decrease of 4.9  
303  $\mu\text{g kg}^{-1}$  was detectable, and in the case of a vegetable puree a slight, but not significant,  
304 increase of 0.7  $\mu\text{g kg}^{-1}$  was noted. Further research is required to evaluate the influence  
305 of stirring and other influences during heating, with the aim of determining the best  
306 methodology for reducing furan during household preparation of baby foods.

307

308 There is still an ongoing discussion concerning to what extent consumer cooking may  
309 influence the furan levels in foods. Some researchers have found that furan persists  
310 during the normal heating practices that precede consumption (Hasnip et al. 2006),  
311 whereas other studies reported losses of 29-55% in vegetable purees during different  
312 warming procedures in microwave ovens (Zoller et al. 2007). Losses of up to 85% were  
313 reported during heating of opened jars over a period of 5.5 h in boiling water, and a  
314 reduction of ca. 50% if the baby food jar was opened but not heated (Goldmann et al.

2005). However, such significant furan losses were not evident at more moderate heating or storage conditions.

Our results are in agreement with those of Crews et al. (2007a), which indicate that the removal of furan is not as easy as has been sometimes assumed on the basis of its volatility. Furan appears to be well dissolved within the matrix of the baby food and opening of the jars exposes only a relatively small surface area. Therefore, despite its volatility, the evaporation of furan appears to be hindered due to its apparently slow diffusion inside the food matrix. The same observations were made by Roberts et al. (2008), who demonstrated larger declines of furan in baby foods heated in a saucepan under stirring. A preliminary recommendation could therefore be to transfer the baby foods into a larger pan or bowl to increase the surface area for furan evaporation. However, due to the unknown conditions of household preparation, we currently cannot assume a significant reduction of risk due to evaporation. We agree with Crews et al. (2007a) that these initial thoughts proved to be naïve, and our results show, in accordance with Hasnip et al. (2006), that there is even the possibility of additional formation, which could balance the potential evaporative losses.

#### *Survey of commercial ready-to-eat baby foods*

Table 4 shows the results of our survey of 230 jarred baby foods, which is so far the largest overview of furan in this food group in Germany. We have classified the baby foods into five broad groups and ANOVA shows that the groups have highly significant differences in furan content ( $p < 0.0001$ ), as shown in the distribution patterns in Figure 2. The highest average content was found in pasta products (i.e. spaghetti or other pasta meals), followed by vegetable meals and meals with meat. Lower

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

339 concentrations were found in beverages and in meals that were comprised of cereals.

340 Preparations containing only fruits had the lowest furan content and the majority of

341 samples in this group were below the detection limit. Our results correspond well to the

342 ranges reported in previous surveys in Europe (Heppner and Schlatter 2007), Japan

343 (Yoshida et al. 2007), Switzerland (Zoller et al. 2007), and the USA (Morehouse et al.

344 2008).

345 As the classification of the foods into the five broad groups only allows limited

346 conclusions regarding the ingredients attributable to furan formation (e.g. most meals

347 with meat also contain vegetables and potatoes), we have also separately evaluated the

348 ingredients lists of all products as to whether they contain fruits, cereals, carrots,

349 potatoes, meat or other vegetables. The PLS correlation loadings plot in Figure 3 shows

350 that furan is closely correlated with the presence of carrots, potatoes, meat and other

351 vegetables, while cereals and fruits appear to have no such influence. As our PLS

352 evaluation is based only on qualitative data (we had no information regarding the

353 quantity of each ingredient in each jar), this result can only be interpreted as

354 preliminary, but it does allow the setting of a research focus and of possible preventive

355 measures on foods containing these suspect ingredients. Currently, we cannot point

356 specifically to other vegetables besides potatoes and possibly carrots, because the

357 sample size for each vegetable was too low to acquire statistically significant

358 information. This type of analysis would also be confounded by the multi-component

359 vegetable mixtures that occur in commercial baby foods. Further research, with the aim

360 of studying each vegetable type separately, possibly in a realistic pilot plant setting,

361 would be required to identify vegetable groups that may be especially prone to furan

362 formation.

363

364 *Preliminary risk assessment of furan in baby foods*

365 The EFSA (2005) recommends that risk assessments provide different exposure  
366 scenarios (e.g. for entire, or specific groups of populations) along with their inherent  
367 uncertainties. Other than the mean and median, intakes from highly exposed individuals  
368 (due to high consumption or to average consumption of highly contaminated foods)  
369 should be considered as represented by the 90<sup>th</sup>, 95<sup>th</sup>, 97.5<sup>th</sup> and 99<sup>th</sup> percentiles.

370 The intake of commercial food products intended for infants in Germany is available  
371 from the DONALD (Dortmund Nutritional and Anthropometrical Longitudinally  
372 Designed) study (Kersting et al. 1998). The DONALD study also provided separate data  
373 for ready-to-eat or -drink baby foods (without consideration of infant formulas, follow-  
374 on formulas and dry cereal-based foods), so we can directly take the DONALD intake  
375 data to evaluate our commercial ready-to-eat baby foods. We selected four different  
376 exposure scenarios (3 months, 6 months, 9 months and 12 months). Because of their  
377 lower body weights, we chose the data for girls from the DONALD study. The four  
378 scenarios, corresponding body weights, and intake of ready-to-eat baby foods are shown  
379 in Table 5. This table also shows the calculated exposures to furan for mean and median  
380 concentrations and the percentiles. The statistical data for this exposure evaluation were  
381 calculated from all 230 commercial baby foods investigated in our study.

382

383 The exposure data from Table 5 were then used to characterize risk using the margin of  
384 exposure (MOE) calculated from T25 (table 6). MOEs can be used by risk managers for  
385 setting priority, with a small MOE representing a higher risk than a larger one.

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

386 In our case of furan in baby foods, the MOEs were below 10,000 in all cases, a finding  
387 which signifies a potential public health concern for this contaminant (EFSA, 2005).  
388 These values would still be below this threshold even if we were to assume a 30%  
389 evaporation during food preparation. In addition, an additional safety factor of 10 for  
390 exposures to children between 0 and 2 years of age could be required (Barton et al.  
391 2005) because the MOE threshold of 10,000 was deduced for adults.  
392  
393 Uncertainties in the evaluation include the T25 as reference point, as it is calculated  
394 from only one data point in an animal experiment, and there is no clear information of  
395 the raw data (i.e. study type, animal species, exposure route, endpoint) from which the  
396 T25 of furan was derived in the Sanner et al. (2001) study. Nonetheless, we believe that  
397 our preliminary MOEs more than justify priority research with the aim of finding  
398 measures to reduce furan in baby foods. This would be required anyway, according to  
399 the ALARA-principle ("As low as reasonably achievable"), introduced into the *Codex*  
400 *Alimentarius* standards for dealing with contaminants and toxins (Codex alimentarius  
401 1997) and the corresponding EU legislation (Council of the European Communities  
402 1993). The European baby food directive also demands that baby foods shall not contain  
403 any substance in such quantity as to endanger the health of infants and young children  
404 (European Commission 2006). As the EFSA is still in the process of toxicological  
405 evaluation of furan, we cannot finally decide at the present time if the levels detected in  
406 our baby foods endanger the health of the children. In our view, baby foods from other  
407 European countries should be included as priority food group in the data collection of  
408 EFSA mentioned in the introduction, in order to provide exposure data for a final risk  
409 assessment of foods available to this vulnerable consumer group.

410

## 411 Conclusion

412 The current recommendation for consumers can only be to include freshly cooked foods  
413 in the diet of their babies. As furan formation is a heat-induced process, we cannot give  
414 recommendations for the industry at this stage because a reduction in temperature would  
415 possibly increase the microbiological risk of the products, which might far outweigh the  
416 risk of furan toxicity. For the same reason, at this stage of data gathering, the  
417 governmental food control agencies currently can only inform the producers and give  
418 recommendations. In our view, any measures to reduce furan in baby food must include  
419 a weighing of the risks presented by the chemical versus the microbiological factors –  
420 and possibly also nutritional factors. The baby food industry should advance this type of  
421 research with priority. We hope that our paper will stimulate industry, other member  
422 states and other research groups to further the research into furan in baby foods.

423

## 424 Acknowledgments

425 H. Mann is thanked for excellent technical assistance.

426

## 427 References

428

- 429 Barton AH, Coglianò VJ, Flowers L, Valcovic L, Setzer RW, Woodruff TJ. 2005.  
430 Assessing susceptibility from early-life exposures to carcinogens. *Environmental*  
431 *Health Perspectives* 113:1125-1133.
- 432 Becalski A, Seaman S. 2005. Furan precursors in food: A model study and development  
433 of a simple headspace method for determination of furan. *Journal of AOAC*  
434 *International* 88:102-106.

- 435 Bianchi F, Careri M, Mangia A, Musci M. 2006. Development and validation of a solid  
436 phase micro-extraction-gas chromatography-mass spectrometry method for the  
437 determination of furan in baby-food. *Journal of Chromatography A* 1102:268-272.
- 438 Box GEP, Hunter JS, Hunter WG. 2005. *Statistics for Experimenters*. John Wiley &  
439 Sons, Hoboken, New Jersey, USA
- 440 Codex alimentarius. Codex general standard for contaminants and toxins in foods  
441 (CODEX STAN 193-1995, Rev.1-1997). [www.codexalimentarius.net](http://www.codexalimentarius.net) (accessed on:  
442 2008/07/31). 1997.
- 443 Council of the European Communities. 1993. Council Regulation (EEC) No 315/93  
444 laying down Community procedures for contaminants in food. *Official Journal of the*  
445 *European Communities* L37:1-3.
- 446 Crews C, Castle L. 2007b. The determination of furan in foods - Challenges and  
447 solutions. *LC GC Europe* 20:498-503.
- 448 Crews C, Castle L. 2007a. A review of the occurrence, formation and analysis of furan  
449 in heat-processed foods. *Trends in Food Science & Technology* 18:365-372.
- 450 Crews C, Hasnip S, Roberts DPT, Castle L. 2007. Factors affecting the analysis of furan  
451 in heated foods. *Food Additives and Contaminants* 24:108-113.
- 452 Durling LJK, Svensson K, bramsson-Zetterberg L. 2007. Furan is not genotoxic in the  
453 micronucleus assay in vivo or in vitro. *Toxicology Letters* 169:43-50.
- 454 EFSA. 2005. Opinion of the Scientific Committee on a request from EFSA related to a  
455 harmonised approach for risk assessment of substances which are both genotoxic and  
456 carcinogenic. *EFSA Journal* 282:1-31.
- 457 EFSA. 2006. Call for scientific data on furan in food and beverages. European Food  
458 Safety Authority, Parma, Italy
- 459 European Commission. 2006. Commission Directive 2006/125/EC of 5 December 2006  
460 on processed cereal-based foods and baby foods for infants and young children.  
461 *Official Journal* L339:16-35.
- 462 European Council. 2001. Council Regulation (EEC) No 2092/91 of 24 June 1991 on  
463 organic production of agricultural products and indications referring thereto on  
464 agricultural products and foodstuffs. *Official Journal* L198:1-15.
- 465 FDA. 2004. Determination of furan in foods. Available:  
466 <http://www.cfsan.fda.gov/~dms/furan.html>. Accessed 13 October 2008.
- 467 Fan XT. 2005. Formation of furan from carbohydrates and ascorbic acid following  
468 exposure to ionizing radiation and thermal processing. *Journal of Agricultural and*  
469 *Food Chemistry* 53:7826-7831.



- Goldmann T, Périsset A, Scanlan F, Stadler RH. 2005. Rapid determination of furan in heated foodstuffs by isotope dilution solid phase micro-extraction-gas chromatography - mass spectrometry (SPME-GC-MS). *Analyst* 130:878-883.
- Hasnip S, Crews C, Castle L. 2006. Some factors affecting the formation of furan in heated foods. *Food Additives and Contaminants* 23:219-227.
- Heppner CW, Schlatter JR. 2007. Data requirements for risk assessment of furan in food. *Food Additives and Contaminants* 24:114-121.
- IARC. 1995. Furan. In: IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 63, Dry Cleaning, Some Chlorinated Solvents and Other Industrial Chemicals. International Agency for Research on Cancer, Lyon, France
- Jun HJ, Lee KG, Lee YK, Woo GJ, Park YS, Lee SJ. 2008. Correlation of urinary furan with plasma gamma-glutamyltranspeptidase levels in healthy men and women. *Food and Chemical Toxicology* 46:1753-1759.
- Kersting M, Alexy U, Sichert-Hellert W, Manz F, Schoch G. 1998. Measured consumption of commercial infant food products in German infants: results from the DONALD study. *Journal of Pediatric Gastroenterology and Nutrition* 27:547-552.
- Kuballa T. 2007. Furan in coffee and other foods. *Journal für Verbraucherschutz und Lebensmittelsicherheit* 2:429-433.
- Kuballa T, Stier S, Strichow N. 2005. Furan concentrations in coffee and coffee beverages. *Deutsche Lebensmittel-Rundschau* 101:229-235.
- Limacher A, Kerler J, Conde-Petit B, Blank I. 2007. Formation of furan and methylfuran from ascorbic acid in model systems and food. *Food Additives and Contaminants* 24:122-135.
- Limacher A, Kerler J, Davidek T, Schmalzried F, Blank I. 2008. Formation of furan and methylfuran by Maillard-type reactions in model systems and food. *Journal of Agricultural and Food Chemistry* 56:3639-3647.
- Maga JA. 1979. Furan in foods. *CRC Critical Reviews in Food Science and Nutrition* 11:355-400.
- Märk J, Pollien P, Lindinger C, Blank I, Märk T. 2006. Quantitation of furan and methylfuran formed in different precursor systems by proton transfer reaction mass spectrometry. *Journal of Agricultural and Food Chemistry* 54:2786-2793.
- Montgomery DC. 2005. Design and Analysis of Experiments. John Wiley & Sons, Hoboken, New Jersey, USA
- Morehouse KM, Nyman PJ, Mcneal TP, Dinovi MJ, Perfetti GA. 2008. Survey of furan in heat processed foods by headspace gas chromatography/mass spectrometry and estimated adult exposure. *Food Additives and Contaminants* 25:259-264.



- 506 Perez Locas C, Yaylayan VA. 2004. Origin and mechanistic pathways of formation of  
507 the parent furan - A food toxicant. *Journal of Agricultural and Food Chemistry*  
508 52:6830-6836.
- 509 Roberts D, Crews C, Grundy H, Mills C, Matthews W. 2008. Effect of consumer  
510 cooking on furan in convenience foods. *Food Additives and Contaminants* 25:25-31.
- 511 Sanner T, Dybing E, Willems MI, Kroese ED. 2001. A simple method for quantitative  
512 risk assessment of non-threshold carcinogens based on the dose descriptor T25.  
513 *Pharmacology & Toxicology* 88:331-341.
- 514 Senyuva HZ, Gökmen V. 2007. Potential of furan formation in hazelnuts during heat  
515 treatment. *Food Additives and Contaminants* 24:136-142.
- 516 Senyuva HZ, Gökmen V. 2005. Analysis of furan in foods. Is headspace sampling a fit-  
517 for-purpose technique? *Food Additives and Contaminants* 22:1198-1202.
- 518 Suk WA, Murray K, Avakian MD. 2003. Environmental hazards to children's health in  
519 the modern world. *Mutation Research* 544:235-242.
- 520 von Mandelsloh N. 2007. *Babybreie selbst gemacht*. Area Verlag, Erfstadt, Germany
- 521 Wenzl T, Lachenmeier DW, Gökmen V. 2007. Analysis of heat-induced contaminants  
522 (acrylamide, chloropropanols and furan) in carbohydrate-rich food. *Analytical and*  
523 *Bioanalytical Chemistry* 389:119-137.
- 524 Yaylayan VA. 2006. Precursors, Formation and Determination of Furan in Food.  
525 *Journal für Verbraucherschutz und Lebensmittelsicherheit* 1:5-9.
- 526 Yoshida I, Isagawa S, Kibune N, Hamano-Nagaoka M, Maitani T. 2007. Rapid and  
527 improved determination of furan in baby foods and infant formulas by headspace  
528 GC/MS. *Journal of the Food Hygienic Society of Japan* 48:83-89.
- 529 Zoller O, Sager F, Reinhard H. 2007. Furan in food: Headspace method and product  
530 survey. *Food Additives and Contaminants* 24:91-107.  
531

532 **Figure captions**

533 *Figure 1. Influence of ascorbic acid concentration, heating temperature and time on the*  
534 *furan content in potato puree baby food.*

535

536 *Figure 2. Box-plots for the furan concentrations in different types of commercial ready-*  
537 *to-eat babyfoods (analyzed as bought without prior heating).*

538

539 *Figure 3. PLS correlation loadings plot of a dataset of 230 commercial baby food*  
540 *products analyzed for furan content. Furan is predominantly found in products*  
541 *containing carrots, potatoes, other vegetables or meat.*

1     *Table 1. Furan in freshly homeprepared vegetable, cereal, and fruit-based baby foods*  
2     *(all ingredients from organic production).*

Product	Furan [ $\mu\text{g kg}^{-1}$ ]		
	Freshly prepared, directly analysed	Re-heated (1 h, 70°C) in closed jar after storage over night at 8°C	Re-heated (1 h, 70°C) in closed jar after storage over night at 8°C and addition of 2-furan carboxylic acid (60 mg kg <sup>-1</sup> )
Potato Puree	n.d.	10.0	51.8
Carrot Puree	n.d.	n.d.	n.d.
Potato-Carrot Puree	n.d.	6.7	3.3
Spinach Puree	n.d.	n.d.	n.d.
Broccoli Puree	n.d.	4.5	2.5
Spaghetti, mashed	n.d.	n.d.	2.7
Semolina-milk pudding	n.d.	n.d.	n.d.
Rice porridge	n.d.	n.d.	n.d.
Apple puree	n.d.	n.d.	1.8
Chicken puree	n.d.	n.d.	n.d.

3     n.d. not detectable ( $< 0.15 \mu\text{g kg}^{-1}$ )

4 Table 2. Furan in freshly homeprepared potato puree baby foods.

Potato variety	Potato origin	Method of agricultural production *	Furan [ $\mu\text{g kg}^{-1}$ ]		
			Freshly prepared, directly analysed	Re-heated (1 h, 70°C) in closed jar after storage over night at 8°C	Re-heated (1 h, 70°C) in closed jar after storage over night at 8°C and addition of ascorbic acid (500 mg $\text{kg}^{-1}$ )
Rosetta	Egypt	organic	n.d.	4.1	11.6
Nicola	Italy	organic	n.d.	6.0	19.7
Nicola	Egypt	organic	n.d.	6.2	32.1
Astoria	Germany	organic	n.d.	8.6	15.8
Nicola	Egypt	organic	n.d.	10.1	17.3
Christa	Germany	organic	n.d.	11.9	21.7
Gloria	Germany	organic	n.d.	16.1	40.0
Nicola	Egypt	organic	n.d.	29.2	58.3
Nicola	Egypt	conventional	n.d.	2.3	10.6
Princess	Egypt	conventional	n.d.	2.8	8.3
Princess	Germany	conventional	n.d.	4.6	14.2
Berber	Germany	conventional	n.d.	6.2	19.3
Marabel	Israel	conventional	n.d.	7.0	16.4
Atlas	Egypt	conventional	n.d.	7.2	19.3
Annabelle	Cyprus	conventional	n.d.	7.6	15.9
Monalisa	Germany	conventional	n.d.	7.9	15.1
Berber	Germany	conventional	n.d.	16.8	37.2
Convenience pre-boiled potatoes	(unknown)	conventional	n.d.	6.5	18.4

5 \* According to label. Organic production was assumed when labelling requirements  
6 were in accordance with Council Regulation (EEC) No 2092/91 (European Council  
7 2001). Conventional production was assumed when no information on production  
8 method was provided on the label.

Table 3. Furan in commercial baby food jars analyzed without preparation and heating in a typical baby food warmer.

Product	Furan [ $\mu\text{g kg}^{-1}$ ]		
	unprepared	Heated with baby food warmer, closed (1 h, 80°C)	Heated with baby food warmer, opened jar, periodical stirring
Potato-Carrot Puree	39.6	47.0	34.7
Mixed Vegetable Puree	66.8	67.0	67.5
Vegetables with chicken and pasta	28.7	29.7	-*
Muesli	10.0	8.5	-
Cream potatoes with cauliflower and veal	73.5	79.6	-
Rigatoni Napoli	92.0	89.5	-
Vegetables with beef	25.4	27.6	-
Spaghetti Bolognese	44.0	45.9	-
Mixed vegetables with chicken	27.5	28.5	-
Potato-vegetables with pork	47.5	48.0	-

\* *experiment not conducted*

13 Table 4. Incidence of occurrence of furan in commercial ready-to-eat babyfoods

14 (analyzed as bought without prior heating)

Sample matrix	Numbers of samples in the range [ $\mu\text{g kg}^{-1}$ ]								Furan concentrations [ $\mu\text{g kg}^{-1}$ ] <sup>a</sup>		
	< 2	2-5	5-10	10-20	20-30	30-40	40-50	>50	Mean $\pm$ SD	Median	95 <sup>th</sup> percentile
Baby beverages	7	4	1	0	2	1	1	0	9.6 $\pm$ 14.8	2	45
Fruit-only dishes	30	3	15	1	0	0	0	1	3.5 $\pm$ 8.4	0.2	9
Meals with cereals	5	9	5	4	1	1	0	0	6.6 $\pm$ 7.2	4	20
Pasta	0	0	0	1	3	4	1	2	34.8 $\pm$ 14.5	35	63
Meals with meat	0	0	2	15	21	8	6	5	28.2 $\pm$ 15.0	26	59
Vegetable meals (without meat)	3	0	1	13	17	18	8	11	31.2 $\pm$ 17.3	30	63

15 <sup>a</sup> Samples below LOD were calculated as zero

Table 5. Exposure with furan from commercial ready-to-eat baby foods. The exposure scenarios were derived using the mean, median and percentiles of the furan concentrations in all ready-to-eat baby foods and beverages in our survey (n=230)

Intake scenarios <sup>a</sup>			Exposure scenarios for different furan concentrations in the foods [µg kg bw <sup>-1</sup> day <sup>-1</sup> ]				
Age (months)	Body weight (kg)	Intake of baby foods (g day <sup>-1</sup> )	Mean (20 µg kg <sup>-1</sup> )	Median (18 µg kg <sup>-1</sup> )	90th percentile (44 µg kg <sup>-1</sup> )	95th percentile (54 µg kg <sup>-1</sup> )	99th percentile (68 µg kg <sup>-1</sup> )
3	5.8	67	0.2	0.2	0.5	0.6	0.8
6	7.5	195	0.5	0.5	1.1	1.4	1.8
9	8.6	234	0.5	0.5	1.2	1.5	1.9
12	9.4	208	0.4	0.4	1.0	1.2	1.5

<sup>a</sup> Data from Kersting et al. (1998). Only ready-to-eat baby foods and beverages were included in the consumption estimate (dry infant formulae and dry processed cereal-based foods were not included in this evaluation)

Table 6. Margin of Exposure (MOE) for furan in the different exposure scenarios (MOE = T25 / Exposure). Calculated with T25 of 1.4 mg kg bw<sup>-1</sup> day<sup>-1</sup> from Sanner et al. (2001).

Age (months)	MOE for different exposure scenarios				
	Mean (20 µg kg <sup>-1</sup> )	Median (18 µg kg <sup>-1</sup> )	90th percentile (44 µg kg <sup>-1</sup> )	95th percentile (54 µg kg <sup>-1</sup> )	99th percentile (68 µg kg <sup>-1</sup> )
3	6060	6733	2754	2244	1782
6	2692	2991	1224	997	792
9	2573	2858	1169	953	757
12	3163	3515	1438	1172	930

□ Heating time = 1 h

○ Heating time = 2 h





