European Food Safety Authority

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SCIENTIFIC OPINION

Flavouring Group Evaluation 220: alpha,beta-Unsaturated ketones and precursors from chemical subgroup 4.4 of FGE.19: 3(2H)-Furanones[1]

Scientific Opinion of the Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids (CEF)

(Question No EFSA-Q-2008-763)

Adopted on 29 january 2009

PANEL MEMBERS

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SUMMARY

The Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids (the Panel) was asked to provide scientific advice to the Commission on the implications for human health of chemically defined flavouring substances used in or on foodstuffs in the Member States. In particular, the Panel was asked to evaluate flavouring substances using the Procedure as referred to in the Commission Regulation (EC) No 1565/2000.

The present Flavouring Group Evaluation 220 (FGE.220) concerns 10 substances, corresponding to subgroup 4.4 of FGE.19. The 10 substances are alpha,beta-unsaturated 3(2H)-furanones [FL-no: 13.010, 13.084, 13.085, 13.089, 13.099, 13.117, 13.119, 13.157, 13.175 and 13.176]. The

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substances in this FGE.220 were further subdivided into two subgroups as five of the 10 substances can only exist as alpha, beta-unsaturated ketones (subgroub 4.4a) while in the other five substances, the alpha,beta double bond can be involved in keto-enol tautomerism (subgroup 4.4b).

For the substances in subgroup 4.4a [FL-no: 13.089, 13.117, 13.119, 13.157 and 13.175], the Panel considered that presently the available data on genotoxicity are too limited to evaluate these substances through the Procedure. Additional studies are needed as outlined in the Genotoxicity Test Strategy for Substances belonging to Subgroups of FGE.19 (EFSA, 2008bb).

For the substances in subgroup 4.4b [FL-no: 13.010, 13.084, 13.085, 13.099 and 13.176], evidence for genotoxicity was obtained *in vitro* and *in vivo*. Evidence is available from *in vitro* studies that the genotoxicity of the candidate substances in this subgroup may be caused by indirect (thresholded) mechanisms of action (in particular generation of reactive oxygen species). The concern for carcinogenicity is alleviated, since one of the substances, for which positive genotoxicity data in mice were obtained, was not carcinogenic in a valid chronic assay in rats. Therefore, no further genotoxicity tests in somatic cells are required. However, some evidence was also available that this substance might elicit genotoxic effects in germ cells, which theoretically may result in reduced reproductive capacity or in inheritable genetic damage. Reduced reproductive capacity and inheritable genetic damage are toxicological endpoints which differ from carcinogenicity and therefore, the negative results for the carcinogenicity study cannot be used to overrule this concern. It is not clear if (and if so to what extent) the thresholded mechanism mentioned above would be relevant for genotoxic effects in the germ cells. Therefore, the Panel concluded that presently these five substances cannot be evaluated through the Procedure.

The Panel recognised that the studies which provided indications for germ cell genotoxicity are of limited validity. For that reason a robust GLP-controlled cytogenetic investigation in mouse spermatocytes according to the OECD guideline 483 is requested.

KEY WORDS: alpha,beta-unsaturated ketones, 3(2h)-furanones, flavouring substances, safety evaluation.

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BACKGROUND

Regulation (EC) No 2232/96 of the European Parliament and the Council (EC, 1996) lays down a Procedure for the establishment of a list of flavouring substances, the use of which will be authorised to the exclusion of all other flavouring substances in the EU. In application of that Regulation, a Register of flavouring substances used in or on foodstuffs in the Member States was adopted by Commission Decision 1999/217/EC (EC, 1999a), as last amended by Commission Decision 2008/478/EC (EC, 2008a). Each flavouring substance is attributed a FLAVIS-number (FL-number) and all substances are divided into 34 chemical groups. Substances within a group should have some metabolic and biological behaviour in common.

Substances which are listed in the Register are to be evaluated according to the evaluation programme laid down in Commission Regulation (EC) No 1565/2000 (EC, 2000a), which is broadly based on the Opinion of the Scientific Committee on Food (SCF, 1999). For the submission of data by the manufacturer, deadlines have been established by Commission Regulation (EC) No 622/2002 (EC, 2002b).

After the completion of the evaluation programme the community list of flavouring substances for use in or on foods in the EU shall be adopted (Article 5 (1) of Regulation (EC) No 2232/96) (EC, 1996).

Flavouring Group Evaluation 19 (FGE.19) contains 360 flavouring substances from the EU Register being alpha,beta-unsaturated aldehydes or ketones and precursors which could give rise to such carbonyl substances via hydrolysis and/or oxidation (EFSA, 2008b).

The alpha,beta-unsaturated aldehyde and ketone structures were considered by the Panel to be structural alerts for genotoxicity. The Panel noted that there were limited genotoxicity data on these flavouring substances but that positive genotoxicity studies were identified for some substances in the group.

The alpha, beta-unsaturated carbonyls were subdivided into 28 subgroups on the basis of structural similarity (EFSA, 2008b). In an attempt to decide which of the substances could go through the Procedure, a (quantitative) structure-activity relationship (Q)SAR prediction of the genotoxicity of these substances was undertaken considering a number of models (DEREKfW, TOPKAT, DTU-NFI MultiCASE Models and ISS Local Models, (Gry et al., 2007)).

The Panel noted that for most of these models internal and external validation has been performed, but considered that the outcome of these validations was not always extensive enough to appreciate the validity of the predictions of these models for these alpha,beta-unsaturated carbonyls. Therefore, the Panel considered it inappropriate to totally rely on (Q)SAR predictions at this point in time and decided not to take substances through the Procedure based on negative (Q)SAR predictions only.

The Panel took note of the (Q)SAR predictions by using two ISS Local Models (Benigni & Netzeva, 2007a; Benigni & Netzeva, 2007b) and four DTU-NFI MultiCASE Models (Gry et al., 2007; Nikolov et al., 2007) and the fact that there are available data on genotoxicity, *in vitro* and *in vivo*, as well as data on carcinogenicity for several substances. The Panel decided that 11 subgroups (1.1.2, 1.1.3, 1.1.4, 2.4, 2.6, 2.7, 3.1, 3.3, 4.1, 4.2 and 4.4) (EFSA, 2008b) should be further

examined to determine whether evaluation through the Procedure is feasible. Corresponding to these 11 subgroups 11 Flavouring Group Evaluations (FGEs) were established (FGE.201, 202, 203, 210, 212, 213, 214, 216, 217, 218 and 220). If the Panel concludes for any substances in these 11 FGEs that they cannot be evaluated using the Procedure then it has to be decided if there is a safety concern for certain substances or if additional data are required in order to finalise the evaluation. If the Panel concludes that a genotoxic potential can be ruled out for the substances they will be merged with structurally related substances in other FGEs and evaluated using the Procedure.

TERMS OF REFERENCE

European Food Safety Authority (EFSA) is requested to carry out a risk assessment on flavouring substances prior to their authorisation and inclusion in a community list according to Commission Regulation (EC) No 1565/2000 (EC, 2000a).

ACKNOWLEDGEMENTS

European Food Safety Authority wishes to thank the members of the Working Groups on Flavourings and ac hoc experts for the preparation of this Opinion: Ulla Beckman Sundh, Vibe Beltoft, Wilfried Bursch, Angelo Carere, Riccardo Crebelli, Karl-Heinz Engel, Henrik Frandsen, Jørn Gry, Rainer Gürtler, Frances Hill, Trine Husøy, John Christian Larsen, Catherine Leclercq, Pia Lund, Wim Mennes, Gerard Mulder, Karin Nørby, Francesca Pacchierotti, Gerard Pascal, Iona Pratt, Gerrit Speijers, Harriet Wallin.

ASSESSMENT

1. Presentation of the Substances in the Flavouring Group Evaluation 220

1.1. Description

The present Flavouring Group Evaluation 220 (FGE.220) concerns 10 substances, which are presented in Table 1. The 10 substances correspond to subgroup 4.4 of FGE.19 (EFSA, 2008b). These substances are all alpha,beta-unsaturated 3(2H)-furanones [FL-no: 13.010, 13.084, 13.085, 13.089, 13.099, 13.117, 13.119, 13.157, 13.175 and 13.176]. Five of the 10 substances can only exist as ketones [FL-no: 13.089, 13.117, 13.119, 13.157 and 13.175] (subgroub 4.4a). In the remaining five substances, the alpha,beta double bond can be involved in keto-enol tautomerism as such [FL-no: 13.010, 13.084 and 13.085] or after hydrolysis of the ester moiety [13.099 and 13.176] (subgroup 4.4b). Two substances possess alkoxy groups as side chains [FL-no: 13.089 and 13.117], two are mono- and di-methylated furanones [FL-no: 13.119 and 13.157] and one is a dimethylated furanone with an additional acetyl group as substituent [FL-no: 13.175].

A summary of their current evaluation status by the JECFA is given in Table 2 (JECFA, 2006a).

The alpha,beta-unsaturated aldehyde and ketone structures are considered by the Panel to be structural alerts for genotoxicity (EFSA, 2008b). Accordingly, the available data on genotoxic or carcinogenic activity for the 10 ketones in FGE.220 will be considered in this FGE.

The Panel has also taken into consideration the outcome of the predictions from five selected (Q)SAR models (Benigni & Netzeva, 2007a; Gry et al., 2007; Nikolov et al., 2007) on the ketones in the present FGE. The 10 alpha,beta-unsaturated ketones and their (Q)SAR predictions are shown in Table 3.

2. Toxicity

2.1. (Q)SAR Predictions

In Table 3 the outcomes of the (Q)SAR predictions for possible genotoxic activity in five *in vitro* (Q)SAR models (ISS Local Model-Ames test, DTU-NFI MultiCASE-Ames test, -Chromosomal aberration test in Chinese hamster ovary cells (CHO), -Chromosomal aberration test in Chinese hamster lung cells (CHL), and -Mouse lymphoma test) are presented.

For none of the candidate substances in this FGE a prediction was obtained with the ISS Local Model for gene mutations in *Salmonella* TA100, as all substances were out of domain. The DTU-NFI MultiCase models for mutagenicity predicted negative (no genotoxic potential) in the Ames test for all 10 substances, and also for three substances (all three in subgroup 4.4b) in the Mouse lymphoma assay. For one substance [FL-no: 13.157] from subgroup 4.4a, a positive response in this assay was predicted. The other candidate substances were out of domain. All but four substances were out of domain for both the Chromosomal aberration CHO and CHL models. Four substances from subgroup 4.4b were in the domain of the Chromosomal aberrations CHL model and for these four the application of the model resulted in a negative prediction.

It is concluded that these models except for the negative predictions for the substance in the DTU-NFI MultiCASE model for Ames test do not seem to generate a reliable and reproducible pattern of preditions for this group. Negative predictions in mammalian cells were only available for four of the substances in subgroup 4.4b (Furan-3(2H)-ones in which the alpha,beta double bond can be involved in keto-enol tautomerism). One positive prediction was available for genotoxic activity in mammalian cells for a substance in subgroup 4.4a (Furan-3(2H)-ones).

2.2. Carcinogenicity Studies

A carcinogenicity study with chronic exposure is available for one substance in subgroup 4.4b

In an OECD guideline 451 and GLP compliant study, groups of 60 male and 60 female Sprague-Dawley rats were fed diets containing 0 (controls), 100, 200 or 400 mg 4-hydroxy-2,5-dimethylfuran-3(2H)-one [FL-no: 13.010] per kg body weight (bw)/day for two years. Mean body weights and body weight gains of male and female rats exposed to 400 mg 4-hydroxy-2,5-dimethyl-3(2H)-furanone/kg bw/day were decreased compared to those of the controls in the last part of the study. No neoplasms or non-neoplastic lesions were attributed to exposure to 4-hydroxy-5-dimethyl-3(2H)-furanone. The NOAEL was 200 mg/kg bw/day (Kelly & Bolte, 2003).

The Panel concluded that the study on 4-hydroxy-2,5-dimethylfuran-3(2H)-one [FL-no: 13.010] was valid and did not show a carcinogenic potential in rats.

Study validation and results are presented in Table 4.

2.3. Genotoxicity Studies

Studies are available for four of the candidate substances in FGE.220.

Subgroup 4.4a (Furan-3(2H)-ones)

For one substance in subgroup 4.4a (2,5-dimethyl-3(2H)-furanone [FL-no: 13.119]) no mutagenic activity was observed in *S. typhimurium* in a valid assay. No experimental data were available for any of the other substances in this subgroup.

Subgroup 4.4b (Furan-3(2H)-ones in which the alpha,beta double bond can be involved in keto-enol tautomerism)

For the three remaining substances, which belong to subgroup 4.4b, the following results have been reported:

4-hydroxy-2,5-dimethylfuran-3(2H)-one [FL-no: 13.010]

For 4-hydroxy-2,5-dimethylfuran-3(2H)-one [FL-no: 13.010] publications on *in vitro* and *in vivo* studies are available. In three studies the potential of the test substance to induce gene mutations in *S. typhimurium* was studied. The substance was found positive in two valid studies and in one study with limited validity. The substance did not cause gene mutations in a valid study in *Escherichia coli* WP2 uvrA$^-$. It was also observed that the substance caused DNA repair in a less relevant bacterial test and single strand breaks in purified DNA.

All *in vivo* studies provided indications for a genotoxic potential. Two studies showing micronucleus formation in peripheral blood cells were considered valid (Hiramoto et al., 1996b: Hiramoto et al., 1998); in a third study similar evidence but of limited validity was obtained (Xing et al., 1988). The latter authors also reported an increase in sister chromatid exchanges (SCE) in mouse bone marrow, but the validity of that observation could not be assessed. In addition, this endpoint is of questionable relevance for the assessment of genotoxicity.

In addition to the genotoxicity observed in somatic cells, three studies provided evidence for genotoxicity in germ cells.

The evidence of chromosome aberration induction in mouse germ cells provided in the study by Xing et al. (1988) is poor because it is essentially based on an increase of premature disjunction of sex chromosomes and autosomes at metaphase I. This effect could be considered at most an alert of possible subsequent missegregation events; even so, data have been published (Liang & Pacchierotti, 1988) showing the lack of correlation between univalents at metaphase I and aneuploidy at metaphase II.

Tian et al. (1992) reported an induction of SCE in spermatogonia. Incomplete information is given on the experimental protocol. There is a dose-dependent increase of SCE/cell, with each dose group significantly higher than the negative control. For these reasons, these data seem to be convincing although obtained on a small (3) number of animals/group. The relevance of SCE in spermatogonia as an indicator of heritable genetic damage is limited.

In the same paper Tian et al. (1992) reported the induction of micronuclei in early sperm cells. This test measures the induction of DNA lesions in preleptotene spermatocytes that can lead to breaks and fragments several days later, at the first or second meiotic division. The test has not been standardised and validated for routine regulatory application, but has been conducted by more than one laboratory in the world with consistent results. The study seems adequately performed. Staining with Giemsa is not optimal and does not allow to distinguish among phases of spermatid differentiation as recommended by the guidelines (Russo, 2000). However, this drawback could hardly produce an overestimation of the effect, more likely, if any, an underestimation.

4-hydroxy-5-methylfuran-3(2H)-one [FL-no: 13.085] and 2-ethyl-4-hydroxy-5-methyl-3(2H)-furanone [FL-no: 13.084]

Reverse mutations were also observed in *S. typhimurium* TA100, but not TA98 with 4-hydroxy-5-methylfuran-3(2H)-one [FL-no: 13.085] and with 2-ethyl-4-hydroxy-5-methyl-3(2H)-furanone [FL-no: 13.084]. The other strains were not tested. The same substances could induce single strand breaks in purified DNA. With 2-ethyl-4-hydroxy-5-methyl-3(2H)-furanone [FL-no: 13.084] also induction of micronuclei in peripheral erythrocytes was observed in two valid *in vivo* assays.

Mechanistic data

For the substances in subgroup 4.4b also mechanistic studies have been carried out with [FL-no: 13.010, 13.084 and 13.085], all considered valid. These substances were identified as Maillard reaction products in soy sauce. When the substance [FL-no: 13.085] was incubated with supercoiled pBR 322 plasmid DNA, single strand breaks were observed at pH 4.4, but not at pH 7.4. When a spin trap was also present, formation of hydroxy radicals together with a carbon-centered radical could be demonstrated. Subsequent addition of superoxide dismutase and catalase inhibited the DNA breaking showing involvement of hydrogen peroxide. Potassium iodide, mannitol, sodium

azide, and ethanol were also inhibitory to the DNA breaking showing involvement of hydroxy radicals. Spin trapping agents and thiol compounds and metal chelators also effectively inhibited the breaking of DNA (Hiramoto et al., 1996a). Similar studies were carried out with [FL-no: 13.010 and 13.084] with the same results and it was also demonstrated that these substances are capable to reduce Fe^{3+} at neutral or alkaline pH (Li et al., 1998).

Study validation and results are presented in Table 5 and 6.

2.4. Conclusion on Genotoxicity and Carcinogenicity

Apart from the negative predictions for the substances in the DTU-NFI MultiCASE model for the Ames test, the (Q)SAR models do not seem to generate a reliable and reproducible pattern of preditions on the genotoxicity for the substances in this FGE.

For one substance in subgroup 4.4a (2,5-dimethyl-3(2H)-furanone [FL-no: 13.119]) no mutagenic activity was observed in *S. typhimurium* in a valid assay. This study result is insufficient to reach a conclusion as to the (absence) of genotoxicity for this subgroup.

With several substances in subgroup 4.4b indications have been obtained in *in vitro* studies that the genetic damage they cause is related to the generation of reactive oxygen species, as a result of redox cycling in combination with metal ions present in the media. The valid positive *in vivo* data were obtained with high dose levels that may be anticipated to have exhausted the anti-oxidant capacity of the target cells. This, in combination with the absence of carcinogenicity observed in a valid carcinogenicity study in rats with one of the substances [FL-no: 13.010], which was tested positive in the genotoxicity assays, takes away a concern for genotoxic events resulting in carcinogenicity in somatic cells.

For two of the studies in which genotoxic effects were observed in germ cells *in vivo* the studies had limited validity and/or address endpoints that may have limited relevance for the assessment of genotoxic potential. The Panel noted that a positive result was obtained in a micronucleus study in early sperm cells. However, a micronucleus test does not discriminate between aneuploidy or chromosomal breakage. The observed effects in the germ cells could be the result of the malsegratation of chromosomes which is generally considered a thresholded event. They may alternatively be the result of the (thresholded) generation of reactive oxygen species.

3. Conclusions

For the substances in subgroup 4.4a [FL-no: 13.089, 13.117, 13.119, 13.157 and 13.175], the Panel considered that presently the available data on genotoxicity are too limited to evaluate these substances through the Procedure. Additional studies are needed as outlined in the Genotoxicity Test Strategy for Substances belonging to Subgroups of FGE.19 (EFSA, 2008bb)

For the substances in subgroup 4.4b [FL-no: 13.010, 13.084, 13.085, 13.099 and 13.176], evidence for genotoxicity was obtained *in vitro* and *in vivo*. Evidence is available from *in vitro* studies that the genotoxicity of the candidate substances in this subgroup may be caused by indirect (thresholded) mechanisms of action (in particular generation of reactive oxygen species). The concern for carcinogenicity is alleviated, since one of the substances, for which positive genotoxicity data in mice were obtained, was not carcinogenic in a valid chronic assay in rats. Therefore, no further genotoxicity tests in somatic cells are required. However, some evidence was

also available that this substance might elicit genotoxic effects in germ cells, which theoretically may result in reduced reproductive capacity or in inheritable genetic damage. Reduced reproductive capacity and inheritable genetic damage are toxicological endpoints which differ from carcinogenicity and therefore, the negative results for the carcinogenicity study cannot be used to overrule this concern. Also it is not clear if (and if so to what extent) the thresholded mechanism mentioned above would be relevant for genotoxic effects in the germ cells. Therefore, the Panel concluded that presently these five substances cannot be evaluated through the Procedure.

The Panel recognised that the studies which provided indications for germ cell genotoxicity are of limited validity. For that reason a robust GLP-controlled cytogenetic investigation in mouse spermatocytes according to the OECD guideline 483 is requested.

TABLE 1: SPECIFICATION SUMMARY OF THE SUBSTANCES IN THE FLAVOURING GROUP EVALUATION 220 (JECFA, 2006A)

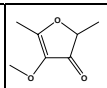
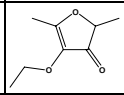
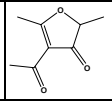
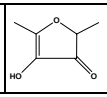
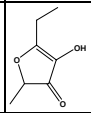
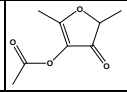
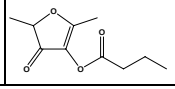
Table 1: Specification Summary of the Substances in the Flavouring Group Evaluation 220 (JECFA, 2006a)							
FL-no JECFA-no	**EU Register name**	**Structural formula**	**FEMA no CoE no CAS no**	**Phys.form Mol.formula Mol.weight**	**Solubility 1) Solubility in ethanol 2)**	**Boiling point, °C 3) Melting point, °C ID test Assay minimum**	**Refrac. Index 4) Spec.gravity 5)**
Substances in subgroup 4.4a (Furan-3(2H)-ones)							
13.089 1451	2,5-Dimethyl-4-methoxyfuran-3(2H)-one		3664 4077-47-8	Liquid $C_7H_{10}O_3$ 142.15	Insoluble Soluble	61-63 (0.4 hPa) NMR 97 %	1.475-1.481 1.091-1.097
13.117	2,5-Dimethyl-4-ethoxyfuran-3(2H)-one		 65330-49-6	Solid $C_8H_{12}O_3$ 156.18	1 ml in 1 ml	251 60 95 %	n.a. n.a.
13.119	2,5-Dimethylfuran-3(2H)-one		 11066 14400-67-0	Liquid $C_6H_8O_2$ 112.13	1 ml in 1 ml	68 (16 hPa) 95 %	1.473-1.479 1.050-1.060
13.157	5-Methylfuran-3(2H)-one		 3511-32-8	Liquid $C_5H_6O_2$ 98.10	1 ml in 1 ml	59 (13 hPa) 95 %	1.492-1.498
13.175	4-Acetyl-2,5-dimethylfuran-3(2H)-one		 	Solid $C_8H_{10}O_3$ 154.17	1 ml in 1 ml	283 34 95 %	n.a. n.a.
Substances in subgroup 4.4b (Furan-3(2H)-ones in which the alpha,beta-unsaturated double bond can be involved in keto-enol tautomerism)							
13.010 1446	4-Hydroxy-2,5-dimethylfuran-3(2H)-one		3174 536 3658-77-3	Solid $C_6H_8O_3$ 128.13	Insoluble Soluble	n.a. 78-80 IR 98 %	n.a. n.a.

Table 1: Specification Summary of the Substances in the Flavouring Group Evaluation 220 (JECFA, 2006a)

FL-no JECFA-no	EU Register name	Structural formula	FEMA no CoE no CAS no	Phys.form Mol.formula Mol.weight	Solubility 1) Solubility in ethanol 2)	Boiling point, °C 3) Melting point, °C ID test Assay minimum	Refrac. Index 4) Spec.gravity 5)
13.084 1449	2-Ethyl-4-hydroxy-5-methyl-3(2H)-furanone		3623 27538-09-6	Liquid $C_7H_{10}O_3$ 142.15	Soluble Soluble	103 (20 hPa) NMR 96 %	1.509-1.514 1.133-1.143
13.085 1450	4-Hydroxy-5-methylfuran-3(2H)-one		3635 11785 19322-27-1	Solid $C_5H_6O_3$ 114.10	Soluble Soluble	n.a. 126-133 NMR 97 %	n.a. n.a.
13.099 1456	4-Acetoxy-2,5-dimethylfuran-3(2H)-one		3797 4166-20-5	Liquid $C_8H_{10}O_4$ 170.17	Slightly soluble Soluble	243 NMR 85 %	1.476-1.480 1.159-1.167
13.176 1519	Furaneyl butyrate		3970	Liquid $C_{10}H_{14}O_4$ 198.22	Insoluble Soluble	287 NMR 93 %	1.467-1.473 1.095-1.103

1) Solubility in water, if not otherwise stated.

2) Solubility in 95% ethanol, if not otherwise stated.

3) At 1013.25 hPa, if not otherwise stated.

4) At 20°C, if not otherwise stated.

5) At 25°C, if not otherwise stated.

n.a.: not applicable.

TABLE 2: SUMMARY OF SAFETY EVALUATION APPLYING THE PROCEDURE (BASED ON INTAKES CALCULATED BY THE MSDI APPROACH) (JECFA, 2006A)

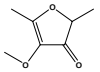
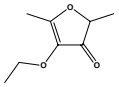
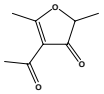
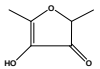
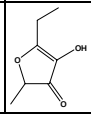
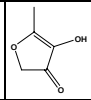
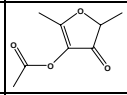
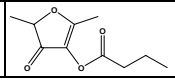
Table 2: Summary of Safety Evaluation Applying the Procedure (based on intakes calculated by the MSDI approach) (JECFA, 2006a)					
FL-no JECFA-no	**EU Register name**	**Structural formula**	**MSDI 1) (μg/*capita*/day) EU USA**	**Class 2) Evaluation procedure path 3)**	**Outcome on the named compound [4) or 5)]**
Substances in subgroup 4.4a (Furan-3(2H)-ones)					
13.089 1451	2,5-Dimethyl-4-methoxyfuran-3(2H)-one		12 0.7	Class II A3: Intake below threshold	4)
13.117	2,5-Dimethyl-4-ethoxyfuran-3(2H)-one		0.018		Not evaluated by JECFA
13.119	2,5-Dimethylfuran-3(2H)-one		1.9		Not evaluated by JECFA
13.157	5-Methylfuran-3(2H)-one		0.0061		Not evaluated by JECFA
13.175	4-Acetyl-2,5-dimethylfuran-3(2H)-one		1.3		Not evaluated by JECFA
Substances in subgroup 4.4b (Furan-3(2H)-ones in which the alpha,beta-unsaturated double bond can be involved in keto-enol tautomerism)					
13.010 1446	4-Hydroxy-2,5-dimethylfuran-3(2H)-one		4483 5203	Class II A3: Intake above threshold, A4: Not endogenous, A5: Adequate NOAEL exists	4)

Table 2: Summary of Safety Evaluation Applying the Procedure (based on intakes calculated by the MSDI approach) (JECFA, 2006a)

FL-no JECFA-no	EU Register name	Structural formula	MSDI 1) (µg/*capita*/day) EU USA	Class 2) Evaluation procedure path 3)	Outcome on the named compound [4) or 5)]
13.084 1449	2-Ethyl-4-hydroxy-5-methyl-3(2H)-furanone		203 13	Class II A3: Intake below threshold	4)
13.085 1450	4-Hydroxy-5-methylfuran-3(2H)-one		47.8 0.07	Class II A3: Intake below threshold	4)
13.099 1456	4-Acetoxy-2,5-dimethylfuran-3(2H)-one		ND 8	Class II A3: Intake below threshold	4)
13.176 1519	Furaneyl butyrate				Evaluation deferred by the JECFA.

1) EU MSDI: Amount added to food as flavour in (kg / year) x 10E9 / (0.1 x population in Europe (= 375 x 10E6) x 0.6 x 365) = µg/capita/day.

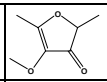
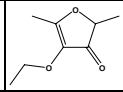
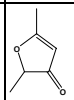
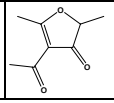
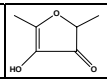
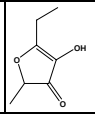
2) Thresholds of concern: Class I = 1800, Class II = 540, Class III = 90 µg/person/day.

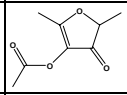
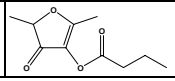
3) Procedure path A substances can be predicted to be metabolised to innocuous products. Procedure path B substances cannot.

4) No safety concern based on intake calculated by the MSDI approach of the named compound.

5) Data must be available on the substance or closely related substances to perform a safety evaluation.

TABLE 3: QSAR PREDICTIONS ON MUTAGENICITY IN FIVE MODELS FOR 10 KETONES FROM SUBGROUP 4.4

FL-no JECFA-no	Sub-group	EU Register name	Structural formula	FEMA no CoE no CAS no	ISS Local Model Ames Test TA100	MultiCASE Ames test	MultiCASE Mouse lymphoma test	MultiCASE Chromosomal aberration test in CHO	MultiCASE Chromosomal aberration test in CHL
Substances in subgroup 4.4a (Furan-3(2H)-ones)									
13.089 1451	4.4	2,5-Dimethyl-4-methoxyfuran-3(2H)-one		3664 - 4077-47-8	OD*	NEG	OD*	OD*	OD*
13.117	4.4	2,5-Dimethyl-4-ethoxyfuran-3(2H)-one		- - 65330-49-6	OD*	NEG	OD*	OD*	OD*
13.119	4.4	2,5-Dimethylfuran-3(2H)-one		- 11066 14400-67-0	OD*	NEG	OD*	OD*	OD*
13.157	4.4	5-Methylfuran-3(2H)-one		- - 3511-32-8	OD*	NEG	POS	OD*	OD*
13.175	4.4	4-Acetyl-2,5-dimethylfuran-3(2H)-one		- - -	OD*	NEG	OD*	OD*	OD*
Substances in subgroup 4.4b (Furan-3(2H)-ones in which the alpha,beta-unsaturated double bond can be involved in keto-enol tautomerism)									
13.010 1446	4.4	4-Hydroxy-2,5-dimethylfuran-3(2H)-one		3174 536 3658-77-3	OD*	NEG	NEG	OD*	NEG
13.084 1449	4.4	2-Ethyl-4-hydroxy-5-methyl-3(2H)-furanone		3623 - 27538-09-6	OD*	NEG	NEG	OD*	NEG

FL-no JECFA-no	Sub-group	EU Register name	Structural formula	FEMA no CoE no CAS no	ISS Local Model Ames Test TA100	MultiCASE Ames test	MultiCASE Mouse lymphoma test	MultiCASE Chromosomal aberration test in CHO	MultiCASE Chromosomal aberration test in CHL
13.085 1450	4.4	4-Hydroxy-5-methylfuran-3(2H)-one		3635 11785 19322-27-1	OD*	NEG	NEG	OD*	NEG
13.099 1456	4.4	4-Acetoxy-2,5-dimethylfuran-3(2H)-one		3797 - 4166-20-5	OD*	NEG	OD*	OD*	OD*
13.176	4.4	Furaneyl butyrate		3970 - -	OD*	NEG	OD*	OD*	NEG

Column 2: Structure group 4.4: alpha,beta-unsaturated ketones.

Column 6: Local model on aldehydes and ketones, Ames TA100 (NEG: Negative; POS: Positive; OD: Out of domain).*

Column 7: MultiCase Ames test (OD: Out of domain; POS: Positive; NEG: Negative; EQU: Equivocal).*

Column 8: MultiCase Mouse Lymphoma test (OD: Out of domain; POS: Positive; NEG: Negative; EQU: Equivocal).*

Column 9: MultiCase Chromosomal aberration in CHO (OD: Out of domain; POS: Positive; NEG: Negative; EQU: Equivocal).*

Column 10: MultiCase Chromosomal aberration in CHL (OD: Out of domain; POS: Positive; NEG: Negative; EQU: Equivocal).*

** OD, out of applicability domain: not matching the range of conditions where a reliable prediction can be obtained in this model. These conditions may be physicochemical, structural, biological, etc.*

TABLE 4: CARCINOGENICITY STUDIES

Table 4: Carcinogenicity Studies

Chemical Name [FL-no]	Species; Sex No./Group	Route	Dose levels	Duration	Results	Reference	Comments
4-hydroxy-2,5-dimethylfuran-3(2H)-one [13.010]	Rats; Male, Female 60/sex/group	Diet	0, 100, 200, or 400 mg/kg bw/day	2 years	Males: No increase in tumour incidences Females: No increases in tumour incidences	(Kelly & Bolte, 2003)	Valid . (GLP/OECD compliant). The NOAEL was 200 mg/kg bw/day based on reduced mean body weight at the highest dose.

TABLE 5: GENOTOXICITY (*IN VITRO*)

Table 5: GENOTOXICITY (*in vitro*)

Chemical Name [FL-no]	Test System	Test Object	Concentration	Reported Result	Reference	Comments [e]
4-hydroxy-2,5-dimethylfuran-3(2H)-one [13.010]	Reversed mutation	*S. typhimurium* TA1535, TA1537, TA1538, TA100 and TA98	10.0, 33.3, 100.0, 333.3, 1000, 2000, 3300, 4000, 6000, 8000 µg/plate	Positive[a, b]	(Gilroy et al., 1978)	Valid. Unpublished non-GLP study. The report contains sufficient details. Result is considered valid.
	Reversed mutation	*S. typhimurium* TA100 and TA98	0 – 10000 µg/plate	Positive[a, b]	(Hiramoto et al., 1996b)	Valid. Positive in TA100 + and – S9; negative in TA98 (+/- S9).
	Reversed mutation	*S. typhimurium* TA100, TA102, TA98 and TA97	500 – 4000 µg/plate	Positive[a, c]	(Xing et al., 1988)	Limited validity. No methodological details, but stated to be performed according to Maron and Ames, 1983. Some errors reduce the trustworthiness of the paper.
	Reversed mutation	*E. coli* WP2 uvrA$^-$	10.0, 33.3, 100.0, 333.3, 1000, 3300 µg/plate	Negative	(Gilroy et al., 1978)	Valid. Unpublished non-GLP study. The report contains sufficient details. Result is considered valid.
	DNA damage	*B. subtilis* H17 (Rec$^+$) and M45 (Rec$^-$)	20, 40, 60, 80, 120 µg/disc	Positive	(Xing et al., 1988)	Validity cannot be evaluated. Test system with low predictive value for genotoxicity). No methodological details, but stated to be performed according to Kada et al. (1972).
	DNA strand breaks	pBR322 DNA	2.6 – 780 µmol/l (0.3 – 100 mg/l)	Positive	(Hiramoto et al., 1996b)	Valid. Single strand breaks caused by redox cycling of the substance in combination with metal ions, generating reactive oxygen species.
4-Hydroxy-5-methylfuran-3(2H)-one [13.085]	Reversed mutation	*S. typhimurium* TA100 and TA98	0 – 5000 µg/plate	Positive[a, b]	(Hiramoto et al., 1996a)	Limited validity. Limited due to uncertainty of test substance. Positive in TA100 + and – S9; negative in TA98 (+/- S9).
	DNA strand breaks	pBR322 DNA	0 -900 µmol/l (0 – 103mg/l)	Positive[a, d]	(Hiramoto et al., 1996a)	Valid. Single strand breaks caused by redox cycling of the substance in combination with metal ions, generating reactive oxygen species.
2,5-Dimethyl-3(2H)-Furanone [13.119]	Reverse mutation	*S. typhimurium* TA1535, TA1537, TA98, TA100 and TA102	0 – 5000 µg/plate	Negative	(RCC - CCR, 2007)	Valid.. According to current guidelines.
2-ethyl-4-hydroxy-5-methyl-3(2H)-furanone [13.084]	Reversed mutation	*S. typhimurium* TA100 and TA98	0 – 10000 µg/plate	Positive[a, b]	(Li et al., 1998)	Valid. + with and without S9 in TA100; negative in TA98 (+/- S9).
	DNA strand breaks	pBR322 DNA	0-2000 µM	Positive[d]	(Li et al., 1998)	Valid. Single strand breaks caused by redox cycling of the substance in combination with metal ions, generating reactive oxygen species.

a: With and without metabolic activation provided by S9 (9000 x g supernatant from rodent liver).

b: Positive results only observed in TA100.

c: Positive results in all strains at the highest dose tested.

d: Only positive without inhibitors of redox cycling and ROS scavengers.

e: Validity of genotoxicity studies:

Valid.

Limited validity (e.g. if certain aspects are not in accordance with OECD guidelines or current standards and / or limited documentation).

Insufficient validity (e.g. if main aspects are not in accordance with any recognised guidelines (e.g. OECD) or current standards and/or inappropriate test system).

Validity cannot be evaluated (e.g. insufficient documentation, short abstract only, too little experimental details provided).

TABLE 6: GENOTOXICITY (*IN VIVO*)

Table 6: GENOTOXICITY (*in vivo*)

Chemical Name [FL-no]	Test System	Test Object	Route	Dose	Reported Result	Reference	Comments [a]
4-hydroxy-2,5-dimethylfuran-3(2H)-one [13.010]	Micronucleus formation	Mouse, bone marrow	Not stated	0, 186, 232 or 309 mg/kg bw	Positive	(Xing et al., 1988)	Limited validity. Important data not given; Reference to methodological description could not be traced.
	Chromosomal aberration	Mouse spermatocytes	Not stated	0, 232, 464 or 928 mg/kg bw	Positive	(Xing et al., 1988)	Limited validity. Important data not given; Reference to methodological description could not be traced. Predominant aberration: malsegregation of chromosomes.
	Sister chromatid exchange	Mouse, bone marrow	Intra-abdominal injection	0, 185, 232, 303 mg/kg	Positive	(Xing et al., 1988)	Validity cannot be assessed. Dose-related increase; statistically significant at all dose levels, but max increase < 2-fold. Effect not adequately specified; very intense exposure to BrdU. Non-validated protocol. Relevance for the evaluation of genotoxicity questionable.
	Sister chromatid exchange	Mouse spermatocytes	Oral (gavage)	200, 400 or 800 mg/kg bw	Positive	(Tian et al., 1992)	Limited validity. Relevance for the evaluation of genotoxicity questionable; non- validated test protocol.
	Micronucleus formation	Mouse early sperm cells	Oral (gavage)	200, 400 or 800 mg/kg bw	Positive	(Tian et al., 1992)	Limited validity. Non-validated test protocol.
	Micronucleus formation	Mouse peripheral blood cells	gavage	1000, 2000 3000 mg/kg bw	Positive	(Hiramoto et al., 1998)	Valid.
	Micronucleus formation	Male mice peripheral erythrocytes	i.p.	500, 1000, 1500mg/kg bw	Positive	(Hiramoto et al., 1996b)	Valid.
2-ethyl-4-hydroxy-5-methyl-3(2H)-furanone [13.084]	Micronucleus formation	Mouse peripheral blood cells	gavage	0, 1000, 2000, and 3000 mg/kg bw	positive	(Hiramoto et al., 1998)	Valid.
	Micronucleus formation	Male mice peripheral erythrocytes	i.p.	0, 500 and 1000 mg/kg bw	positive	(Li et al., 1998)	Valid.

a: Validity of genotoxicity studies:

Valid.

Limited validity (e.g. if certain aspects are not in accordance with OECD guidelines or current standards and / or limited documentation).

Insufficient validity (e.g. if main aspects are not in accordance with any recognised guidelines (e.g. OECD) or current standards and/or inappropriate test system).

Validity cannot be evaluated (e.g. insufficient documentation, short abstract only, too little experimental details provided).

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ABBREVIATIONS

CAS	Chemical Abstract Service
CHL	Chinese hamster lung cell(s)
CHO	Chinese hamster ovary cell(s)
CoE	Council of Europe
DNA	Deoxyribonucleic acid
DTU-NFI	Danish Technical University – National Food Institute
EC	European Commission
EFSA	The European Food Safety Authority
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FEMA	Flavor and Extract Manufacturers Association
FGE	Flavouring Group Evaluation
FLAVIS	Flavour Information System database
GLP	Good Laboratory Practise
ID	Identity
IR	Infrared spectroscopy
ISS	Istituto Superiore di Sanita
JECFA	The Joint FAO/WHO Expert Committee on Food Additives
MSDI	Maximum Survey-derived Daily Intake
NMR	Nuclear magnetic resonance
No	number
NOAEL	No observed adverse effect level
OECD	Organisation for Economic Co-operation and Development
(Q)SAR	(Quantitative) structure-activity relationship
SCE	Sister chromatid exchange
SCF	Scientific Committee on Food
WHO	World Health Organisation