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Dioxins. Effect on human nutrition

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SUMMARY – Chemical structure of dioxins and furans and its sources and origin are explained. The toxic compounds of this group and the Toxic Equivalent Factor (TEF) concept is introduced. The Tolerated Daily Intake (TDI) and results from the EU are given. The recent episodes of foodstuff contamination and the European Directives which will limit the dioxin contents are also discussed.

Key words: Dioxins, contamination, toxicity, foodstuff, European Directives.

RESUME – *"Les dioxines. Leur effet sur la nutrition animale". La structure chimique des dioxines et des furanes et leurs sources et origine sont expliquées. Les composés toxiques de ce groupe et le concept de facteur d'équivalent toxique (TEF) sont présentés. L'ingestion quotidienne tolérée (TDI) et les résultats de l'UE sont exposés. Les épisodes récents de contamination de denrées alimentaires et les directives européennes qui limiteront les teneurs en dioxines sont également débattus.*

Mots-clés : *Dioxines, contamination, toxicité, denrées alimentaires, directives européennes.*

Introduction

In the latest decades significant achievements have been obtained in "Quality of Life" standards, leading to an increase in the life expectancy. In this sense, a major efforts to study the effects of bio-accumulation of harmful substances, requires more and more attention every day and studies that, in other times would be refereed as out-of-place, are now totally justified.

In some people's daily practices, as smoking, the personal choice is freely accepted, and the risk quota (benzopyrene ingestion) for the users' health could be avoided completely. In some other cases, ubiquity of the contamination substances, and the ingestion paths, makes necessary a general approach to control and reduce them.

Dioxins are among these chemical substances. They are undesirable, and should be always avoidable in food.

General considerations about dioxins and furans

Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDDs/PCDFs) form two groups of halogenated aromatic hydrocarbons with 210 compounds.

The basic structure of these substances is based on two benzene rings bonded by one or two heteroatoms of oxygen. Each ring can have a different degree of chlorination, from 1 to 8 chlorine atoms for the whole molecule. Chlorine atoms are able to hold different positions for each chlorination degree, giving place to different isomers. There are 75 possible PCDDs and 135 PCDFs.

PCDDs and PCDFs have a strong thermal stability and are chemically inert. These compounds are lipophylic and very insoluble in water. Chemical stability and lipophylic behavior gives to these compounds the property of bioaccumulation and biomagnification through the trophic chain and can finally end in humans.

Toxicity of dioxins and furans

Some dioxins and furans are highly toxic at extremely low levels. Two factors rules the degree of toxicity:

(i) Chlorination degree.

(ii) The position of the chlorine atoms.

From animal laboratory studies it has found that the compounds with higher toxicity are those chlorine-substituted in 2,3,7,8 positions (Fig. 1). Only 17 compounds out of the 210 isomers of the dioxin and furans family show this configuration (7 dioxins and 10 furans).

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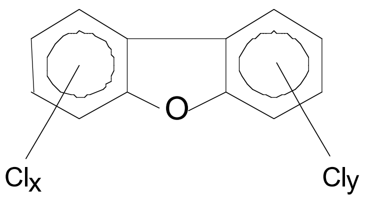
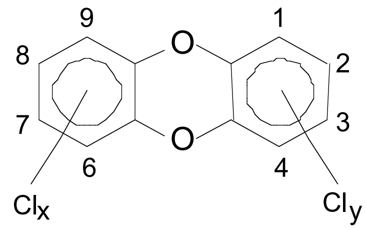
Polychlorinated dibenzofurans (PCDFs)



Polychlorinated dibenzo-p-dioxins (PCDDs)



x + y = 1 – 8

PCDD's exemple: 2,3,7,8-Tetrachlor dibenzo-p-dioxin (2,3,7,8-TCDD)

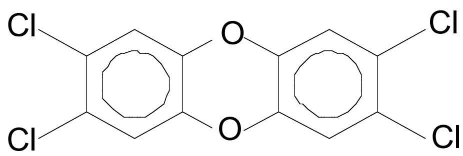


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Fig. 1. Polychlorinated dibenzofurans and dibenzo-p-dioxins chiral structure.

The first studies of 2,3,7,8-TCDD toxicity, made by Kociba and collaborators in 1978 with Laboratory Guinea pigs, had given a LD_{50} of 0.6 micrograms/kg. Several studies have demonstrated the capacity of these compounds to develop such effects as cancer, mutations and foetal malformations in different species.

Origin and sources of dioxins and furans

PCDDs/Fs have a strong anthropogenic nature, appearing to be as undesirable by-products in particular industrial activities. As PCBs and pesticides, dioxins and furans are founded frequently in the environment, however dioxins and furans have never been produced neither commercialised. Besides of study purposes, there is not known any practical application. Schematically, the sources of dioxins and furans can be divided into two great groups, natural and anthropogenic, as shown in Table 1.

Table 1. Sources of dioxins and furans

Natural
Forest fire

Volcano eruptions
Enzymatic reactions of natural substrates
Photolytic reactions of natural substrates

Anthropogenic

(i) Combustion processes. "De novo" synthesis
- Urban, industrial and hospital solid waste incinerators
- Thermic powerhouse
- Combustion engines
- Domestic heating systems
- Cigarettes combustion

(ii) Industrial and chemical processes
- Organochlorinated compounds manufacturing (PCP, pesticides, etc.)
- Metal manufacturing and recycling
- Chlorine water whitening
- Electrochemical chlorine productions with graphite electrodes
- Fire retardants manufacturing
- Textile industry
- Composting of organic matter
- Recycling

(iii) Wastes
- Sludges from water work plants and waste water treatment plants
- Dumping site lixiviates
- Domestic waste waters
- Flying ashes and slags

(iv) Incidents
- Building and similar fires

Human exposure to dioxins and furans

In the last ten years, the development of analytical techniques in sample concentration, standards availability and improvement of sensibility and specificity of instrumentation, have given the majority of human samples PCDDs/Fs content results.

The ubiquity of these pollutants shows the evidence that exposure to PCDDs/Fs for humans is due, in lesser and higher degree, to the background pollution. This is particularly true for industrial on urban areas where concentrations levels are higher than in rural areas. In the other hand, a small part of population has been exposed occasionally to higher levels, are cases of accident or workplaces exposure.

The I-TEF and I-TEQ concept

Quantification of PCDDs/PCDFs requires a special treatment in order to take into account the degree and order of chlorination. In fact, the major objective is to obtain the toxicological potential of the dioxins and furans mix found in samples. Usually, in real samples there is not just an isomer, but a profile of toxic (the 2,3,7,8 chlorine-substituted) and non-toxic isomers.

The Toxic Equivalent Factor (TEF) concept was suggested in 1988 and it is based in two proven facts:

(i) All the 2,3,7,8 chlorine-substituted compounds have the same action mechanism (in qualitative terms), but the toxic potential can vary from one to another.
(ii) The response has an additive behaviour whenever we work with a mixture of these substances, which it is the usual situation.

Based in these two statements, a Toxic Equivalence Factor is assigned to each congener isolated. This Factor is related to the most toxic compound, the 2,3,7,8-TCDD, assigned with a 1 value (Table 2).

Table 2. Toxic Equivalence Factors of the 2,2,7,8-substituted PCDDs/PCDFs

PCDFs	I-TEF	PCDDs	I-TEF
2,3,7,8-TCDF	0.1	2,3,7,8-TCDD	1
1,2,3,7,8-PeCDF	0.05	1,2,3,7,8-PeCDD	0.5
2,3,4,7,8-PeCDF	0.5		
1,2,3,4,7,8-HxCDF	0.1	1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDF	0.1	1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDF	0.1	1,2,3,7,8,9-HxCDD	0.1
2,3,4,6,7,8-HxCDF	0.1		
1,2,3,4,6,7,8-HpCDF	0.01	1,2,3,4,7,8,9-HpCDD	0.01
1,2,3,4,7,8,9-HpCDF	0.01		
OCDF	0.001	OCDD	0.001

Another important concept is the I-TEQ (International Toxic Equivalent Quantity) which is the result from multiplying the congeners concentration by its I-TEF, and adds them all. Mixture toxicity of PCDDs/Fs is expressed as the I-TEQs addition obtained from each one of the 17 isomers, getting an indicative unique value.

A new equivalence factor proposed by the World Health Organisation (WHO) is being used in biological and health studies, bringing some changes in values for some of the congeners related to I-TEF and includes equivalence factors for some of the non-orto and mono-orto PCBs substituted.

The Tolerated Daily Intake (TDI) concept

The ingestion paths for human population to get these pollutants in their bodies are listed for significance order ingestion, inhalation and dermal contact. Ingestion is the most important pathway, estimated in the 90-05% from the total.

In 1990 the WHO meeting in Bilthoven about dioxins, achieved an agreement about the Tolerated Daily Intake (TDI) for PCDDs/Fs to be in 10 picograms I-TEQ for kg body weight and day (WHO-EURO, 1990). Based in the relation dose-response for the more significant adverse effects, the WHO has recently proposed a TDI for humans of 1-4 pg TEQ/kg body weight/day for PCDDs, PCDFs and "dioxin-like" PCBs.

There are many data compilations about dioxin and furans contents in environmental, food (specially milk), biological material, etc. that shows the average levels of daily intake by food (Liem and Theelen, 1997; EU, 1999a).

The following table shows the average exposure for PCDDs/Fs through dietary intake in several European countries, assigning 70 kg as the average weight. It is worth to say that this values are made for dioxins and furans, but that "dioxins-like PCBs" are not taken into account, which could be as much ass the PCDDs/Fs, showing that the European consumer is having a higher exposure than the WHO suggested (1-4 pg TEQ/kg bw/day) (Table 3).

With this data available, a requirement to reduce food and environmental levels to minimize the daily intake will force in the incoming years to be lowered to protect the consumers' health.

Table 3. Total dietary exposure estimates across the EU. Source: EU (1999a)

	Denmark	Finland	France	Germany	Netherlands	Spain	Sweden	UK
	1995	1991	nd	1995	1991	1996	1990	1992

Average total diet exposure estimate pg I-TEQ/day	171	95	nd	69.6	65	210	126.5	69
Average total diet exposure estimate pg I-TEQ/kg bw/day (assuming 70 kg bw)	2.44	1.36	2.21[†]	0.99	0.93	3.0	1.81	0.86-1.3
High level consumer exposure pg I-TEQ/kg bw/day			5.66[†]		2.3			1.5-2.2

[†]Unknown average bodyweight assumption.
nd = no data available/not known.

Contamination episodes in food and European directives development

The data supplied shows chronical levels, or the occasional knowledge of industrial processes of dioxin sources. There are two examples of dioxin sources; chlorine whitening in paper manufacturing and the urban solid waste incineration. Recently, two episodes of PCDDs/Fs contamination of food through animal foodstuffs have opened a research field of PCDDs/Fs determination in foodstuff components. This is the case of citric pulp (Malisch, 1998) and fraudulent or accidental uses of contaminated matter (Verkest Belgium) (EU, 1999b).

European directives have been made for the processes with dioxins and furans presence in the case of emission in incineration (EU, 1994) or in the addition of PCDDs/Fs in the wastewater sludge Directive. Several drafts of directives are being made in "maximum levels of particular pollutants in food" (EU, 2000) (Table 4).

Table 4. Maximum levels for dioxins in foodstuffs

Foodstuff	Maximum level pg WHO-PCDD/F-TEQ/g (upper bound determination limit)
Fat of Cow's milk (liquid, as consumed)	3
Fat of poultry meat	3
Fat of beef meat	5
Fat of pork meat	2
Egg fat	5
Fish (whole product)	3

From the episodes mentioned and because of the additive samples (kaolinitic clay) with an undesirable content of PCDDs/Fs, from unknown origin, has driven to develop a Directive about undesirable products and substances in animal foodstuff and a Regulation about "the conditions of authorization of the additives belonging to the group of binders, anti-caking and coagulants in animal foodstuff".

A limit of 500 pg WHO-TEQ/kg could be forced for those additives that do not demonstrate to be free of these compounds by analytical results.

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