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TOXICITY AND RISKS WITH T-2 AND HT-2 TOXINS IN CEREALS

ABSTRACT

The trichothecenes T-2 and HT-2 toxins have during recent years been found frequently in cereals grown in Europe. They are mainly produced by *Fusarium langsethiae*. High concentrations of the toxins are most commonly found in oats, but they are also detected frequently at lower concentrations in barley. Wheat is only rarely contaminated. Yearly surveys of T-2 and HT-2 toxins in oats from Northern Europe have shown that the occurrence and levels have increased from 2002, with very high levels in 2005-2007, followed by a decrease in 2008-2009.

Raw oats delivered to mills for processing to food have also been highly contaminated with T-2 and HT-2 toxins during the period 2006-2009. The processing of oats in the mills by sorting-sieving and dehulling reduce the toxin concentrations in the final food products, flakes and meals, with more than 80 % even at high levels in the raw oat. The concentrations of the toxins in the by-products from the process are instead increased. The by-products are mainly used as feed components.

The toxic effects of T-2 and HT-2 toxins in animals and the toxicological information used in the risk evaluations are briefly described. Risk evaluations of the toxins in cereals for human consumption have been conducted by both EU-Scientific Committee on Food and by JECFA in 2001. Both evaluations resulted in the same temporary tolerable daily intake (t-TDI) for the sum of T-2 and HT-2 toxins. The group TDI for T-2 and HT-2 toxins, alone or in combination, became 60 ng/kg bw and day.

The intake of T-2 and HT-2 toxins through oats is calculated from median concentrations in oat products and median consumption data from Norway. The intake was found to be 1.5-5.4 % of the t-TDI.

The toxic effects studied or expected in farm animals, horses and ruminants, consuming high amounts of oat in their feed are described and discussed.

Key words: Fusarium langsethiae, HT-2 toxin, oats, T-2 toxin, toxin contamination, toxicity, risk

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INTRODUCTION

Cereal plants are worldwide infected with different *Fusarium* species and some of them e.g. *F. graminearum*, *F. culmorum* are associated with plant diseases like Fusarium Head Blight and grain contamination with toxins. Other Fusarium species e.g. *F. poae, F. langsethiae* do not produced clear pathogenic symptoms but may still produce toxins.

The trichothecene deoxynivalenol mainly produced by *F. graminearum* is the most frequently found fusarium toxin and present at the highest concentrations in especially wheat. The more toxic trichothecenes T-2 and HT-2 toxins have during recent years been found also frequently in cereals grown in Europe (Edwards *et al.* 2009, Pettersson *et al.* 2008). They are mainly associated with *F. langsethiae*, but may be produced also by *F. sporotrichioides* in cereals from East and South Europe. T-2 and HT-2 toxins have most frequently been found at highest concentrations in oats followed by barley. Wheat is much less contaminated.

Tricothecenes in cereals were risk evaluated by the EU Scientific Committee on Food (SCF 2001) and JECFA (Joint FAO/WHO Expert Committee on Food Additives) in 2001. a combined temporary tolerable daily intake (t-TDI) of 0.06 µg/kg body weight and day was established for T-2 and HT-2 toxins, since T-2 toxin is readably converted into HT-2 toxin after consumption.

The European Union has introduced maximal tolerable levels of deoxynivalenol in cereals intended for food and recommendation on guidance levels in feed (EC 2006a,b). There are currently no legal limits for T-2 and HT -2 toxins in food or feed, although the intention to introduce such is indicated in the legislation. The time table for introduction has been prolonged, partly due to the high occurrence of the toxins in oats.

This paper will give a review of the occurrence of T-2 and HT-2 toxins in European cereals, effect of processing, their toxicity and risks for human and animals.

OCCURRENCE

Surveys of T-2 and HT-2 toxins in European cereals during the 1990-ties as reported by SCOOP 2003 and JECFA 2001 showed that the toxins occurred most frequently in oats followed by barley and maize. Wheat was much less contaminated. The mean levels for the sum of T-2 and HT-2 toxins were generally relatively low (< 100 µg/kg) although some max values in certain oat samples exceeded 1000 µg T-2+HT-2/kg. The surveys of trichothecenes in cereals continued in Scandinavia and started in UK during the period 2000 to 2009. Results from the surveys of T-2 and HT-2 toxins in oats are presented in Table 1. High and increasing levels of T-2 and HT-

2 toxins were found in oats from Scandinavia and UK in 2002 to 2006. Thirty-three to 44 % of the samples from UK, Finland, and Sweden exceeded 500 µg T-2+HT-2/kg during at least one year. Median levels above 200 µg/kg were recorded and max concentrations up to 9990 µg/kg were found. The levels decreased in oats from all survey countries during the period 2007-2009.

Table 1

T-2 and HT-2 toxins in surveys of oats 2000-2009. (after Pettersson 2010)

Year	Country	Number of Samples	Percentage of			Mean	Median	Max	Reference
			>10 [ppb]	>50 [ppb]	>500 [ppb]	[µg/kg]	[µg/kg]	[µg/kg]	
1994	Sweden	34		24	3	81	25	871	Pettersson 2000
1996	Sweden	80		18	0	57	20	390	Pettersson 2000
	Norway	14	100	50		190		718	Langseth *et al.* 2001
1996-98	Norway	178	70	33		108		1260	Langseth & Rundberget 1999
	Finland	51		4	2	<50	<50	856	Hietaniemi *et al.*. 2004
1997	Sweden	84		20	0	39	15	216	Pettersson 2000
	Norway	84	71	38		132		1260	Langseth *et al.* 2001
	Finland	52		2	0	<50	<50	116	Hietaniemi *et al.*. 2004
1998	Finland	13		15	0	20	10	116	Eskola *et al.*. 2000
	Sweden	33		27	0	33	15	134	Pettersson 2000
	Norway	80	63	18		68		585	Langseth *et al.* 2001
	Finland	59		7	0	<50	<50	240	Hietaniemi *et al.*. 2004
1999	Finland	10		0	0	10	10	10	Yli-Mattila *et al.*. 2004
	Norway	20		85	0	117		330	Langseth *et al.* 2001
2000	Finland	25		36	8	137	25	1369	Hietaniemi 2006
	Norway	22		73	5	86	53	564	SCOOP 2003
2001	Finland	37		27	0	59	25	273	Hietaniemi 2006
	Norway	24		0	0	10	10	10	SCOOP 2003
2002	Finland	30		37	0	78	38	427	Hietaniemi 2006
	UK	92	85	70	16	311	106	4844	Edwards 2006
2003	Finland	30		63	13	305	116	1647	Hietaniemi 2006
	UK	104	90	69	33	727	204	9990	Edwards 2006
	Finland	30		57	10	282	104	2850	Hietaniemi 2006
2004	Norway	56		70	0	106	86	334	Clasen 2006
	UK	128	94	80	24	500	202	6997	Edwards 2006
	Finland	60		63	33	440	186	3500	Hietaniemi 2006
	Sweden	41		61	17	255	90	1165	Pettersson 2006
2005	Norway	126		87	13	283	180	2041	Clasen 2006
	Denmark	18	100	94	6	312	221	2560	Biselli 2006
	UK	134	97	88	44	694	403	3188	Edwards 2006

Table 1

T-2 and HT-2 toxins in surveys of oats 2000-2009. (after Pettersson 2010) — continued

Year	Country	Number of Samples	Percentage of			Mean	Median	Max	Reference
			>10 [ppb]	>50 [ppb]	>500 [ppb]	[µg/kg]	[µg/kg]	[µg/kg]	
2006	Finland	59		53	5	163	47	1283	Hietaniemi 2007
	Sweden	71		90	44	465	376	1416	Pettersson 2007
	Norway	102		78	9	218	145	1675	Clasen 2006
	UK	100	97	96	43	795	404	6261	Edwards 2007
2007	Finland	80		53	5	121	64	863	Hietaniemi 2007
	Sweden	58		91	10	255	90	1165	Pettersson 2008
	Norway	32		94	6	217	177	980	Clasen 2008
	UK	103		77	18	438	169	8399	Edwards 2008
2008	Finland	80		38	5	100	32	1932	Hietaniemi 2009
	Sweden	70		34	0	57	34	493	Pettersson 2009
	Norway	33		64	0	62	55	145	Clasen 2009
	UK	90			7	120	47	1190	Edwards 2009
2009	Finland	80		39	4	85	25	1020	Hietaniemi 2010
	Sweden	27		33	4	82	35	886	Pettersson 2010

The European Breakfast Cereal Association (CEEREAL) has analyzed T-2 and HT-2 toxins in 235 samples of raw oats delivered to their mills during 2006-2009 (Pettersson 2010). The overall median level was only 44 µg T-2+HT-2/kg with a max value of 841µg/kg in 2006. The decrease in the levels during 2008-2009 compared to 2006-2007 was clear.

Barley and wheat have also been analyzed for T-2 and HT-2 toxins in Scandinavia, UK and France during several years in the period 2000-2009. Concentrations above 50 µg T-2+HT-2/kg have only rarely been detected in wheat. Barley samples above that level occurred more frequently, but most positive samples had a concentration below. In the French surveys of spring barley such low levels were frequently detected (Orlando *et al.* 2010). The adjusted mean concentrations for the years 2006-2008 were between 19 and 22 µg T-2+HT-2/kg. The toxins were much less frequently detected in winter barley although fewer samples had been analyzed.

All oats for human consumption are processed in mills. Oats are cleaned by screening, dehulled, sorted and flaked or milled. T-2 and HT-2 toxin concentration in the final products used for food are reduced by an average of 80% during especially the dehulling step. The effect of processing on the toxin levels in oats from UK mills are in detail described by Scudamore *et al.* 2007. The toxin levels in the by-products (husks, debris, small kernels) often used for feed will instead increase by on an average up to 3 times compared to the raw oats.

The CEEREAL has also analyzed T-2 and HT-2 toxins in the oat-flakes and oat by-products obtained in their mills during 2005-2009 (Pettersson 2010). The concentra-

tions in the raw oats, oat-flakes and oat by-products from the mills are given in Table 2. The mean and median concentrations in oat-flakes decrease by 81 and 73 % respectively compared to raw oats and increased by 307 and 345 % in the oat-byproducts.

Table 2

T-2 and HT-2 toxins in oats and oat products from European mills in the CEEREAL study 2005-2009. (after Pettersson 2010)

Product	Number of samples	Percentage of samples				Mean [µg/kg]	Median [µg/kg]	90th % ile [µg/kg]	Max [µg/kg]
		>50 [ppb]	>200 [ppb]	>500 [ppb]	>1000 [ppb]				
Oats raw	235	43	12	2	0	96	44	212	841
Oat flakes	435	8	0	0	0	18	12	41	197
Oat by-product	208	86	46	15	10	295	152	663	1711

TOXICITY

T-2 and HT-2 toxins exhibit their toxicity mainly by inhibiting DNA, RNA and protein synthesis, the latter at the ribosomal level. The toxins are therefore highly cytotoxic and more toxic compared to the other trichothecenes partly due to their more lipophilic character and membrane permeability. T-2 toxin is rapidly converted into HT-2 toxin after ingestion by animals. The toxicity of T-2 and HT-2 toxins in animals is thus considered to be similar.

Several studies in mice and rats show that T-2 toxin causes cytotoxicity and proliferative changes in the oesophagus- and forestomach epithelium. Several tests for genotoxicity *in vitro* and in rodents *in vivo*, especially for clastogenic effects, were positive for T-2 and HT-2. There is, however, limited evidence for carcinogenicity in experimental animals. It induced hepatocellular- and pulmonary adenomas in male mouse (Schiefer *et al.* 1987).

The most important toxicity studies identified by the EU Scientific Committee on Food (SCF, 2001) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2001) in their evaluation of T-2 and HT-2 toxicity are given in Table 3. The LOAEL (Lowest Observed Adverse Effect Levels) or NOAEL (No Observed Adverse Effect Levels) are given for the critical effects. Both Committees, the JECFA and the SCF, used the haematotoxicity and immunotoxicity of T-2 toxin in the subacute toxicity study in pigs by Rafai *et al.* 1995a as the bases for their safety assessment. There are deficiencies in the toxicity studies, e.g study duration, pair feeding of control animals, comparative studies on metabolism and toxicokinetics. To account for this and the use of a LOAEL, the Committes included an extra uncertainty factor of 5, giving an overall uncertainty factor of 500. a temporary or provisional maximal Tolerable

Daily Intake (t-TDI or PMTDI) of 0.06 µg/ kg bodyweight and day was thus established for the sum of T-2 and HT-2 toxins.

Table 3

Critical Toxicology studies on T-2 toxin identified by SCF in 2001. (after Slatter 2004)

Study	Critical effect	NOAEL/LOAEL [mg/kg b.w./Day]	Reference
Mouse, 16 months	Pulmonary adenomas Hepatocellular adenomas Forestomach epithelial hyperplasi	0.23 (NOAEL) 0.23 (NOAEL) 0.23 (NOAEL)	Schiefer *et al.* 1987
Rat, 4 week	Forestomach epithelial hyperplasi	0.5 (NOAEL)	Ohtsubo and Saito
Mouse, 5 days	Thymus athrophy, decreased number of	0.75 (LOAEL)	Smith *et al.* 1994
Pig, 3 weeks (subacute)	Reduced number of leukocytes, lymphocytes and antibody production against horse globulin. Decrease in size	0.03 (LOAEL)	Rafai *et al.* 1995
Monkey (15 days by	Leukopenia	0.1 (LOAEL)	Rukimini *et al.*
Mouse, CD-1, two generations. No dose	Embryo- or foetotoxicity	0.45 (NOAEL)	Rosseaux and Schiefer 1987
Rat, single dose	Neurotoxicity	0.4 (NOAEL)	Sirkka *et al.* 1992

The toxicity of T-2 and HT-2 toxins in farm animals was evaluated by Eriksen and Pettersson 2004. The lowest effect level in feed for certain toxic effects in major feeding studies with pigs and chickens are given in Table 4. Guidance values for the highest T-2 and HT-2 concentrations in feed for pigs and chicken was suggested to 0.2 and 0.5 µg/kg respectively.

Table 4

Lowest effect level of T-2 toxin in feed for pigs and chicken.

Animals	Lowest Effect level	Toxic Effect	Reference
Pig	0.5	Reduced immunedefence	Rafai *et al.* 1995b
	1-2	Reduced growth and feed intake	Rafai *et al.* 1995a, Friend *et al.* 1992, Weaver *et al.* 1978
Chicken	0.4-1	Mucosa erosion	Wyatt *et al.* 1972, 1973
	2	Reduced feed consumption and growth	Wyatt *et al.* 1972, 1973

There are hardly any reports on toxic effects in ruminants fed T-2 and HT-2 toxins in controlled studies. This may be due to that trichothecenes including T-2 and HT-2 toxins are rapidly degraded and detoxified by mi-

croorganisms in the rumen. They are deacetylated and de-epoxidated. The removal of the epoxide is the main detoxification of trichothecenes. De-epoxidation activities have also been found in faeces from pigs and horses (Eriksen *et al.* 2002; Pettersson *et al.* 2007), but it is unclear if this reaction in the lower part of the gastro-intestinal tract may have an influence on the eventual toxic effects.

Horses may be highly exposed to T-2 and HT-2 toxins but there are only few case reports on their eventual toxic effects in horses. Most cases are from East Europe but T-2 toxin has also been the cause of bean-hull poisoning of horses in Japan. Toxic effects described are CNS toxicity, muscle contraction, tachycardia and colic. The exposure of trotter horse to T-2 and HT-2 toxins through oats has been studied in Sweden (Pettersson *et al.* 2007). Horses consuming an average of 2.6 mg T-2+HT-2 per day were compared with a group consuming 0.7 mg toxins per day. No clear effects were seen on health and performance of the horses.

RISKS

Estimation of human intake of T-2 and HT-2 toxins through oats and comparison with the established t-TDI can provide information on the risks with the toxins in food oats. JECFA (2001) made intake calculations for the trichothecenes based on the toxin database available for each cereal at that time and different cereal consumption information. The calculated intakes were high for many population groups and the intake for the sum of T-2 and HT-2 toxins exceeded the combined t-TDI in most high cereal consumption groups. The toxin portion from oats was about 50% of the intake. The mean concentration used for oats in the calculations was a weight mean (21 µg T-2/kg, 35 µg HT-2/kg) of all European analysis on unprocessed oats. This is not an appropriate concentration value to use in the calculations since unprocessed oats are not consumed and processing decrease the toxin concentrations with more than 80%.

The median concentration of T-2 and HT-2 toxins in oat-flakes for the year 2005-2009 from the study by CEEREAL are more correct to use. This concentration has been used together with the detailed Norwegian oat consumption data for the calculation of intake in Table 5. Oat consumption in Norway is relatively high and a median consumption has been used in the calculations. The intake of T-2 and HT-2 toxins from oats is then 1.5-5.4 % of the t-TDI depending on groups and much lower than in the JECFA calculations. If the intake is calculated for high oat consumers (95^{th} percentile consumption) and high toxin concentration (90^{th} percentile) in the oat-flakes, the toxin intake will become 48-77 % of the t-TDI.

About 75 % of the European oat crop is used in animal feed. Oats are mainly used in feed for ruminants and horses. It is less popular in feeds for pigs and

poultry due to the relative high fibre content and low energy value. Oat by-products are only used in horse and ruminant feed.

Table 5

Intake of T-2 and HT-2 toxins from oats calculated on consumption data from Norway. Median consumption and median toxin concentration from CEEREAL study

Population group	Body weight [kg]	Median Toxin concentration [µg/kg]	Median Consumption			
			Grain	Toxin intake		% of TDI
			[g/person per day]	[ng/person per day]	[ng/kg b.w. per day]	
			Children			
6 years	23	12	6.2	74.4	3.23	5.4
10 years	35	12	8.2	98.4	2.81	4.7
			Males			
16-29 years	75	12	7.5	90	1.20	2.0
30-59 years	83	12	7.6	91.2	1.10	1.8
60-79 years	79	12	6.5	78	0.99	1.6
			Females			
16-29 years	63	12	6.3	75.6	1.20	2.0
30-59 years	65	12	5.8	69.6	1.07	1.8
60-79 years	69	12	5.1	61.2	0.89	1.5

Oats with median T-2 and HT-2 toxin concentrations (Survey mean 90 µg/kg, CEEREAL 42 µg/kg) can be used in feed to pigs and poultry without restrictions due to toxin content and risk for exceeding feed guidance levels. The oat component in their feeds rarely exceeds 50% of the diet. Oats containing high toxin levels equal to the 90th percentile (208 µg/kg) in the CEEREAL study could also be used, but oats with concentrations above 1000 µg T-2+HT-2/kg may cause adverse effects.

In adult ruminants even the highest T-2 and HT-2 toxin concentrations in oats are expected to be degraded and detoxified by the rumen microbes. The highest toxin concentrations may have a local contact effect causing erosions on the muzzle and in the mouth. This has however not been described.

Athletic or working horses may be fed up to 6 kg oats per day in addition to the roughage. If oats with a median toxin concentration (90 or 42 µg/kg) is used the daily intake will be only 0.25-0.54 mg/day or calculated on a body weight of 500kg give 0.5-1.1 µg/kg b.w. and day. The lowest adverse effect level of T-2 and HT-2 toxins in horses is not known, but this daily amount will probably not cause adverse effects. Oats with T-2 and HT-2 concentrations above 1000 µg/kg will give a daily consumption of more than 6 mg/day or more than 12 µg/ kg b.w. and day. These amounts are expected to cause toxic effects in the horses, although it was not noticed in the study on trotter horses in Sweden. An explanation could be the degradation of trichothecenes in intestinal and feces content of horses fed oats. a local cytotoxic contact effects caused by high toxin concen-

trations could also be expected in the muzzel, mouth, stomach and upper intestine of the horses. T-2 and HT-2 toxins are highly cytotoxic and cause cell death at concentrations from 0.3-20 ng/ml in cell culture studies.

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