Iodine in animal nutrition and Iodine transfer from feed into food of animal origin

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Introduction

Iodine is an essential trace element for humans and animals. More than 95 % of total iodine is accumulated in the thyroid gland. The only known roles of iodine in metabolism are its incorporation into the thyroid hormones, thyroxine (T_4) and triiodothyronine (T_3), and into the precursor iodotyrosines. Both hormones have multiple functions in the energy metabolism of cells, in the growth, as a transmitter of nervous stimuli, and as an important factor in brain development (Mc Dowell, 2003; Underwood and Suttle, 2001). Iodine deficiency reduces the production of thyroid hormones in humans and animals, leading to morphological and functional changes of the thyroid gland and reduction of the formation of thyroxin (ICCIDD, 2001). A high proportion of the population in Western and Central Europe is still at risk of iodine deficiency (Delange, 2002; Vitti et al., 2003; Delange and Dunn, 2004). Globally about 800 Mio people still suffer from iodine deficiency. Therefore improvement of iodine supply is still a great challenge for nutritionists (Lauerberg, 2004).

Numerous measures have, therefore, been undertaken to improve the iodine supply to human diets, e.g., using iodized salts (e.g., Lind et al., 2002; Zimmermann, 2004), other vehicles for iodine (e.g., Dunn, 2003) supplementation of foods of plant or animal origin (e.g. Schöne et al., 2003; Zimmermann et al., 2005), or supplementing iodine to animal feed in order to increase the iodine content of food of animal origin (e.g., Kaufmann and Rambeck, 1998; Flachowsky et al., 2006; Schöne et al., 2006).

During the last few years, the status of iodine nutrition in some European countries has improved (Lind et al., 2002, Thamm et al. 2007) thanks to the use of various possibilities of adding iodine to human diets. But there are still problems with the contributions of various iodine sources.

Iodine requirements of food producing animals

The iodine requirements of food producing animals vary between 0.15 and 0.6 mg/kg dry matter (DM) of feed according to various scientific committees (Table 1).

Table 1: Iodine requirements of food producing animals by the German Society of Nutrition Physiology (GfE) and the National Research Council in the USA (NRC in mg/kg DM)

Species/ Categories	GfE (German Society of Nutrion Physiology) (1999, 2001, 2004, 2006)	NRC (National Research Council) (1994, 1998, 2001)
Cattle		
Dairy cows	0.5	0.5
Beef cattle	0.3	0.4
Pigs		
Fattening pigs	0.15	0.16
Breeding sows	0.5 - 0.6	0.16
Poultry		
Poulets	0.4	0.33 - 0.35
Laying hens	0.5	0.32 - 0.48
Broiler	0.5	0.35
Turkey	0.5	0.40

Human needs and upper levels

The iodine requirements of humans depend on age, physiological stage and scientific committee (Table 2).

Table 2: Iodine requirements of humans depending on age, physiological stage and scientific committee (in µg per day)

Age/ physiological stage	Scientific committee		
	WHO (2001)	USA DRI (2001)	D - A - CH (2000)
0 - 1 year		110 - 130	40 - 80
0 - 6 years	90		
1 - 8 years		90	
1 - 15 years			100 - 200
6 - 12 years	120		
9 - 13 years		120	
14 - 18 years/adults	150	150	180 - 200
Pregnancy		220	
Pregnancy/lactation	200		
Lactation		290	260

It increases from 50-100 to 200 µg and more per day. Pregnancy and lactation require more iodine. The iodine concentration in human food (≈ 0.4 – 0.5 mg/kg DM) is adequate to animal requirements under consideration of DM-intake of humans (compare Tables 1 and 2).

There is a considerable variation in the tolerable upper levels of iodine intake of healthy humans (Table 3).

Table 3: Tolerable upper levels (UL) of iodine intake of healthy humans depending on age, physiological stage and scientific committee (in µg per day)

Age/ physiological stage	Scientific committee			
	USA- FNB (2001)	SCF (2002)	WHO (1994)	D - A - CH (2000)
1 - 3 years	200	200	< 1 mg (1000 µg) per day are considered as safe	< 500 µg per day are considered as safe
4 - 6 years	-	250		
4 - 8 years	300	-		
7 - 10 years	-	300		
9 - 13 years	600	-		
11 - 14 years	-	450		
14 - 18 years	900	-		
15 - 17 years	-	500		
> 19 / adults	1100	600		
Pregnancy	900	600		
Lactation	1100	600		

Iodine is characterized by a high risk of deficiency in human nutrition (Delange 2002, Delange and Dunn, 2004), but there is a low difference between requirements (Table 2, ≈ 200 µg/day for adults) and the UL (Table 3, ≈ 600 µg/day, SCF 2002).

That means the range between requirements and UL is only about 1 : 3. Therefore iodine belongs to the trace elements of the Supply Category I (high risk of deficiency from the global view) and of the High Risk Category (high risk of excess; BfR, 2004; EFSA, 2006; Gassmann 2006). Therefore, more information is necessary to avoid deficiencies and to prevent iodine excess in human nutrition.

Objectives of the report

Recently the EFSA (2005) dealt with this problem, esp. with the use of iodine in animal nutrition and with the transfer from feed into food of animal origin. The following conclusions were given:

- More dose-response studies with food producing animals are necessary,
- Iodine requirements of modern breeds of animals should be revised,
- Assessment of further iodine inputs in food of animal origin is recommended.

During the last few years, some studies were done to overcome those weaknesses. The present paper informed about some recent dose-response studies with animals and contributions of food of animal origin to overcome iodine deficiency and to avoid iodine excess.

Dose-Response-Studies

Some dose-response-studies with food producing animals were carried out at the Institute of Animal Nutrition of the FAL during the last few years, further studies are still underway. Iodine in feed, body samples, milk and eggs were analysed by ICP-MS.

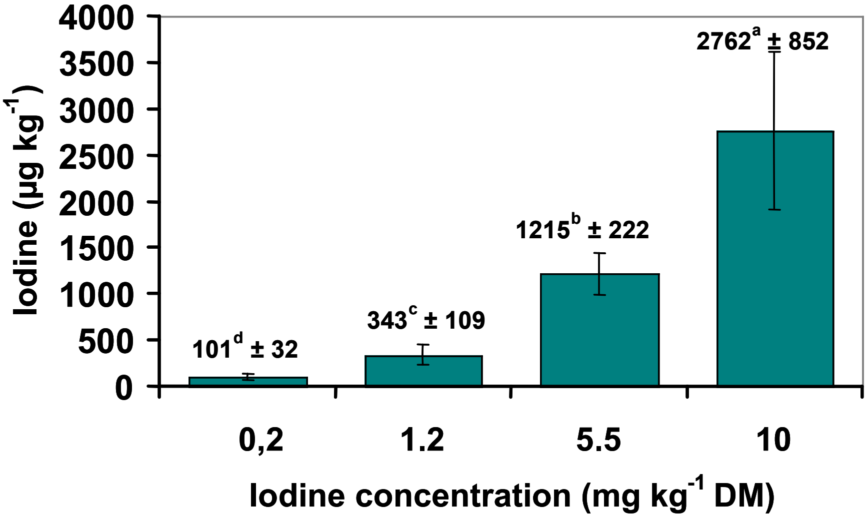
The paper informs about results from studies with dairy cows, growing bulls and growing pigs.

Dairy cows

In a preliminary test a grass - maize silage concentrate ration (0.2 mg I/kg DM) was supplemented with 0, 1, 4 or 10 mg I/kg DM and fed to five late lactating cows over 14 days (average milk yield: 22.1 ± 2.0 kg/day).

Figure 1 shows the dramatic increase of iodine concentration in milk.

Figure 1: Iodine concentration of milk (µg/kg) depending on the iodine concentration of feed (5 cows, 14 days of treatment; Flachowsky et al., 2006)



Beef cattle

A dose-response-study was carried out with 34 growing bulls of the German-Friesian breed (223-550 kg BW). The bulls consumed 3 kg concentrate per day and maize silage ad libitum. The bulls were divided into three groups and the diets were supplemented with 0.5, 4 and 10 mg/kg DM (11/11/12 bulls per treatment). At the end of the study, all bulls were slaughtered and the iodine concentration in some body samples was analysed.

Iodine did not significantly influence the weight gain of bulls, but the daily weight gain of the most highly supplemented animal was 110 g lower than those of the control group (Table 4). Apart from the thyroid, the weights of body samples were not significantly influenced by iodine supplementation.

Table 4: Influence of iodine supplementation on selected live and carcass traits of bulls (fattened from 223 to 550 kg) and the iodine content in various body samples (n = 11/11/12; Meyer et al., 2007)

Iodine supplementation analysed iodine concentration in feed (mg/kg DM)	0.5/0.79	4.0/3.52	10.0/8.31
Feed intake (kg DM/day)	7.79 ± 0.64	7.66 ± 0.45	7.70 ± 0.60
Weight gain (g/day)	1453 ± 179	1419 ± 172	1343 ± 208
Feed efficiency (kg DM/kg body weight)	5.32 ± 0.61	5.35 ± 0.65	5.70 ± 0.63
Carcass yield (% of live weight)	52.0 ± 0.8	52.3 ± 1.0	52.4 ± 1.3
Thyroid weight (g)	32[a] ± 11	26[a] ± 6	42[b] ± 10
Iodine concentration (µg/kg fresh weight; thyroid: µg/g fresh weight)			
Liver	73[a] ± 10	138[b] ± 15	245[c] ± 6
Kidney	93[a] ± 16	231[b] ± 43	450[c] ± 67
Thyroid	378[a] ± 91	495[a] ± 125	844[b] ± 558
Musc.long.dorsi	16[a] ± 3	45[b] ± 11	80c ± 20
Musc. gluteaus medius	32[c] ± 25	83[b] ± 27	147[c] ± 34

[a, b, c] Various letters in one line show significant differences ($p<0.05$)

Iodine concentration in organs and tissue samples increased significantly with iodine supplementation (Table 4), but much less than in milk (see Figure 1).

Fattening pigs

70 growing pigs were divided into 5 groups and supplemented with 0, 0.5, 1, 2 and 5 mg iodine per kg dry feed. All pigs were slaughtered with a final weight of 120 kg. The native iodine content of feed amounted to 0.17 mg/kg, which is in accordance with the present iodine requirements of growing pigs (Table 1).

Iodine supplementations did not influence (p >0.05) feed intake and weight gain of pigs (Table 5).

Table 5: Influence of iodine supplementation on pigs fattened from 27 to 120 kg (n = 14; Berk et al., 2004)

Iodine supplementation/Iodine content of feed (mg/kg)	0 / 0.17	0.5 / 0.41	1.0 / 0.99	2.0 / 2.20	5.0 / 4.38
Feed intake (kg/day)	2.60 ± 0.10	2.24 ± 0.13	2.21 ± 0.10	2.24 ± 0.13	2.26 ± 0.10
Daily weight gain (g/day)	837 ± 70	819 ± 99	811 ± 93	851 ± 84	867 ± 63
Energy efficiency (MJ ME/kg weight gain)	37.4 ± 2.9	38.3 ± 3.7	37.8 ± 3.8	36.4 ± 2.5	36.0 ± 2.1

The iodine concentration in all body samples increased significantly after iodine supplementation (Table 6), but the concentration was much lower than in milk (see Figure 1).

Table 6: Influence of iodine supplementation on iodine content in various body samples (n = 4; Franke et al., 2006)

Iodine supplementation/Iodine content of feed (mg/kg)	0 / 0.17	0.5 / 0.41	1.0 / 0.99	2.0 / 2.20	5.0 / 4.38
Muscle/fat (µg/kg fresh weight)	3.9^{a} ± 0.6	6.0^{a} ± 1.9	8.5^{b} ± 1.9	10.8^{b} ± 1.2	17.1^{c} ± 1.5
Thyroid (µg/g fresh weight)	620^{a} ± 71	1054^{b} ± 280	1154^{b} ± 191	1699^{c} ± 184	1645^{c} ± 159
Body samples (liver, kidney, heart, spleen; µg/kg fresh weight)	94^{a} ± 61	63^{a} ± 40	$138^{a,b}$ ± 73	230^{b} ± 145	226^{b} ± 38

$^{a, b, c}$ Various letters in one line show significant differences (p<0.05)

Iodine transfer

These results demonstrate that there are large differences in transfer of iodine from feed into pork (≈ 0.3 %) and beef (< 1 %) compared to milk from dairy cows (30-40 %) on the other hand.
Iodine transfer from feed into eggs is also much higher (10 – 20 %) than from feed into meat as shown by dose-response-studies by Richter (1995) and Yalcin et al. (2004).

Based on the differences in transfer, large differences also exist in the iodine concentration of various food of animal origin (Table 7).

Especially the iodine concentration in milk and eggs of low supplemented animals is much higher (Table 7) than values given in the present food tables (Table 8). Also results from field studies (Table 10 to 14) show higher iodine concentrations than the food tables (Table 8).

Table 7: Iodine content in food of animal origin (µg/kg fresh matter) depending on iodine supplementation in feed

Food and animal origin	Iodine in feed (mg/kg DM)					
	Native 0.1 - 0.25	0.5	1 - 2.2	2	4 - 5	10
Milk[1)]	101	-	393	-	1215	2692
Beef[1)]	-	16	-	-	45	80
Pork[1)]	3.9	6.0	8.5	11	17	-
Poultry meat[2)]	6	-	(20)	-	-	(100)
Eggs[2)]	-	140	330	-	1460	-

[1)] Data from Institute of Animal Nutrition [2)] Data from literature

Table 8: Iodine content in food of animal origin according to food value tables (Souci et al., 2000)

Food and animal origin	Iodine content (µg/kg fresh matter) $\bar{x}$	(Range)
Ruminants		
Milk, cow	27	(20 - 60)
Milk, goats	41	(21 - 110)
Veal	26	(25 - 28)
Beef	54	(17 - 68)
Mutton	18	(-)
Pigs		
Muscle	45	(26 - 52)
Heart	30	(-)
Liver	140	(-)
Poultry		
Geese, meat	40	(-)
Eggs	95	(10 - 400)
Egg yolk	120	(80 - 160)

Iodine entry in milk via teat dipping of cows

Five late-lactating cows of the German Friesian breed were used for the study. The iodine content of the diet amounted to 0.2 mg/kg DM. After milking in the morning and evening, the teats were dipped in a teat disinfection solution containing Nonoxinol (9)-Iodine with 3 g available iodine per kg.

Teat dipping with the disinfectant significantly increased the iodine concentration of milk (Figure 2), which is in agreement with other authors (Table 9).

Figure 2: Iodine concentration of milk without and with teat dipping (iodine content of dipping substances: 3 g l^{-1}, dipping after milking; Flachowsky et al., 2007)

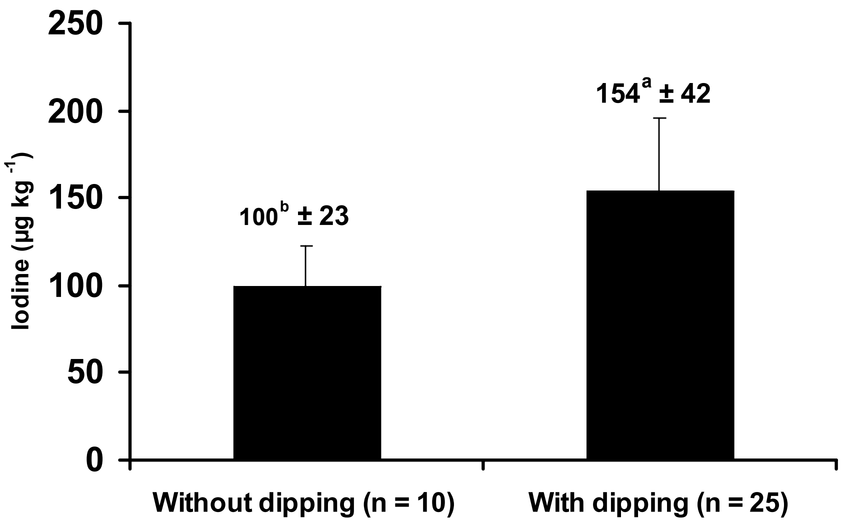


Table 9: Influence of teat dipping on iodine concentration in milk

Iodine in dipping solution (g/l)	Dipping before (B) or after (A) milking	Increase of iodine concentration in milk (µg/kg)	References
1	A	35	Galton et al. (1986)
2	A	11 - 60	van Ryssen et al. (1985)
2.7	B	30	Falkenberg (2002)
3	A	54	Flachowsky et al. (2007)
5	A	27 - 32	Galton (2004)
5	A	36	Galton et al. (1984)
5	A	120	Hamann and Heeschen (1982)
10	A	46	Swanson et al. (1990)
10	A	76	Galton et al. (1986)
10	A	90	Galton et al. (1984)
10	B/A	110	Galton et al. (1986)
10	B/A	150	Galton et al. (1984)

Three to five grams available iodine per litre disinfectant, and dipping after milking, increase the iodine content in milk by 50-60 µg per litre and contribute to the iodine supply of humans.

Field measurements

Apart from the dose-response-studies there some field measurements also exist on the iodine concentration in milk (Tables 10 and 11), poultry meat (Table 12) and eggs (Tables 13 and 14).

Milk

The iodine concentration in milk increased in many European countries during the last few years (Table 10).

Milk contains more than 100 µg/l in many countries (Table 11), exceeding 300 µg/l in England and the Czech Republic.

Such high concentrations could be a real problem under consideration of human needs (Table 2) and upper levels (Table 3), esp. for children.

Table 10: Iodine content in milk from various field samples

Authors		Iodine content (µg/kg)	
Binnerts (1986, NL)		35 - 53	
Dahl et al. (2003, Norway)	1971:	Summer:	65
		Winter:	120
	2000:	Summer:	88
		Winter:	232
Kursa et al. (2004, CZ)		324 (70 - 2542)	
Launer and Richter (2005; Samples 1996-2004)		74 - 210	
Leiterer et al. (2001)		160	
MAFF (2000)	1991/1992:	Summer:	90
		Winter:	210
	2000:	Summer:	200
		Winter:	430
Philipps et al. (1998, UK)		130 - 200	
Preis et al. (1997)		84 - 180 (During the year)	
Zimmerman et al. (2005)			
Cow milk		175	
Goat milk		384	

Table 11: Iodine concentration in milk in various European countries (Ryšava et al., 2007)

Country	Iodine concentration (µg/kg)	(Range)
Austria	74	(45 - 92)
Poland	90	(86 - 93)
Switzerland	90	(79 - 106)
Germany	130	(93 - 159)
Belgium	158	(158)
France	207	(192 - 221)
Slovakia	240	(180 - 310)
England	325	(305 - 345)
Czech Rep.	472	(387 - 601)

Poultry meat

The iodine concentration of poultry meat is relatively low (Table 12) and comparable with pork. Previous data by Groppel et al. (1991) show higher values, but on the basis of DM.

Table 12: Iodine content of poultry meat by various authors

Iodine supplementation		Body tissue				Author
		Beast-muscle	Heart (µg/kg DM)	Liver	Kidney	Groppel et al. (1991)
Feeding studies with various Iodine sources/ amounts	(0.03 mg I/kg DM)	32	354	30	88	
	+ 0.1 mg I/kg DM (KIO_3)	57	459	45	97	
	+ 1 mg I/kg DM (KIO_3)	73	518	71	126	
	+ 10 mg I/kg DM (KIO_3)	385	1295	525	558	
	+ 10 mg I/kg DM (KI)	302	1148	901	646	
		(µg/kg fresh matter)				
Laying hens from field						Stibilj and Holcman (2002)
- Free range	0.18 mg I/kg feed	6.8 (5.6-8.5)	-	23 (16-35)	27 (22-32)	
- Indoor	0.66 mg I/kg feed	5.8		32	35	Vadujal (1996)
Samples from Supermarket	no date	Broiler 23.2 - 29.1				Hassanein et al. (2000)

Eggs

Table 13: Iodine content in egg albumen and egg yolk from field samples

	Iodine content (mg/kg feed)	Egg albumen	Egg yolk	Authors
Free range	0.18	6.7 ± 2.2	114 ± 21	Stibilj and Holcman (2002)
Indoor	0.18	7.5 ± 2.0	268 ± 42	Savski (1999)
	0.66	37.5 ± 3.9	740 ± 22	Vadujal (1996)

The iodine concentration in egg yolk is much higher than in albumen (e.g. 856 and 16.2 µg/kg; Travnicek et al., 2006, Table 13).

Assuming that the egg yolk weight is 18 g and the albumen weight is 34 g, one egg produced in large flocks in the Czech Republic (see Table 14) contained 31.2 µg (≈ 15 %) and in small flocks about 10 µg iodine (≈ 5 % of iodine requirements of adults, see Table 2).

Feed supplementation

Based on previous results and the preventive consumer protection, the iodine upper level in feeding-stuffs for dairy cows and laying hens was reduced from 10 to 5 mg per kg in 2005 (EU 2005).

Table 14: Iodine content in the yolk of eggs from large and small flocks in the Czech Rep. (Travnicek et al., 2006)

Flock	Year (Number of flocks)	Eggs (n)	Iodine content in the yolk (µg/kg fresh matter)
Large[1)]	2004 (9)	54	1014 ± 357
	2005 (10)	135	1664 ± 1080
Small	2004 (16)	96	307 ± 256
	2005 (15)	114	502 ± 508

1) Mostly higher I-supplementation of feed (≈ 1 mg/kg DM) in comparison to small flocks (0.3-0.5 mg/kg DM)

Table 15: Iodine concentration in feeding stuffs for cattle, pigs and laying hens (field samples, Grünewald et al., 2006)

	Dairy cows	Beef cattle	Fattening pigs	Laying hens
Samples (n)	51	8	46	24
Average (mg/kg DM)	1.27	1.48	2.27	1.27
Min. (mg/kg DM)	0.49	0.25	0.32	0.54
Max. (mg/kg DM)	5.70	4.58	8.48	2.64

10 mg iodine per kg feedingstuffs are still permitted for other food producing animals (fish: 20 mg). The upper limits are much higher than the present iodine supplementation of various feedingstuffs under farm conditions (Table 15). But nevertheless, there is an iodine supplementation on the average between 1 and 2 mg kg^{-1} dry matter. This iodine concentration in field samples (e.g., Tables 10, 11 and 14) responses to the iodine supplementation in comparison to previous values (Table 8) and is in agreement with data from dose-response studies (see Table 7).

Summary

Many people still suffer from iodine deficiency all over the world, but there is only a small range between human requirements and upper levels (≈ 1 : 3). Therefore iodine belongs to the trace elements of the Supply Category I (high risk of deficiency) and of the High Risk Category (high risk of excess). Food of animal origin should contribute to improve the iodine supply to humans, but excesses have to be avoided.

Some dose-response studies were carried out to assess the iodine transfer from feed into food of animal origin. Mainly the transfer from feed into meat is below 1 % of supplemented iodine, but it can be increased up to 30 % in the case of milk and eggs. In consequence of the high transfer, the EU-commission decreased the iodine-maximum level for dairy cows and laying hens from 10 to 5 mg kg^{-1} feed

More dose-response studies seem to be necessary with dairy cows and laying hens under consideration of the iodine supply of humans and the preventive consumer protection.

Zusammenfassung

Jod in der Tierernährung und Jodtransfer von Futter in Lebensmittel tierischer Herkunft

Weltweit leiden immer noch viele Menschen an Jodmangel. Andererseits besteht jedoch eine geringe Spanne zwischen Jodbedarf des Menschen und möglichem Überschuss (≈ 1 : 3). Jod gehört deshalb zu den Spurenelementen der Versorgungskategorie I (hohes Risiko eines Defizits) und zur Risikokategorie Hoch (hohes Risiko eines Überschusses). Lebensmittel tierischer Herkunft sollen zur Verbesserung der Jodversorgung der Menschen beitragen; Überversorgungen sind jedoch zu vermeiden. Verschiedene Dosis-Wirkungs-Studien zur Beurteilung des Jodtransfers vom Futter in Lebensmittel tierischer Herkunft wurden durchgeführt. Dabei zeigte sich, dass der Transfer vom Futter in Fleisch bei unter 1 % liegt, während in Eier und vor allem in Milch bis zu 30 % des zugesetzten Jods übergehen können.

Unter Berücksichtigung dieses hohen Transfers hat die EU-Kommission die Jod-Höchstgehalte im Futter von Legehennen und Milchkühen von 10 auf 5 mg/kg Futter gesenkt. Weitere Dosis-Wirkungsstudien mit Legehennen und Milchkühen sind vor allem unter dem Aspekt des vorbeugenden Verbraucherschutzes notwendig.

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