

# Utilisation of iodine from different sources by sows and their progeny

Tomáš BAŇOCH<sup>1</sup>, Zdeněk FAJT<sup>1</sup>, Jan KUTA<sup>2</sup>, Václav KOTRBÁČEK<sup>3</sup>, Roman KONEČNÝ<sup>4</sup>, Jan TRÁVNÍČEK<sup>4</sup>, Martin SVOBODA<sup>1</sup>

- 1 Clinic of Ruminant and Swine Diseases, Faculty of Veterinary Medicine, University of Veterinary and Pharmaceutical Sciences Brno, Czech Republic
- 2 Research Centre for Toxic Compounds in the Environment (RECETOX), Masaryk University – Faculty of Science Brno, Czech Republic
- 3 Department of Physiology, Faculty of Veterinary Medicine, University of Veterinary and Pharmaceutical Sciences, Czech Republic
- 4 Department of Veterinary Discipline and Quality of Products, Faculty of Agriculture, University of South Bohemia in České Budějovice, Czech Republic

Correspondence to: Assoc. Prof. Martin Svoboda, DVM., PhD.,  
Clinic of Ruminant and Swine Diseases, Faculty of Veterinary Medicine,  
University of Veterinary and Pharmaceutical Sciences Brno, Czech Republic,  
Palackého 1/3, 612 42, Brno Czech Republic.  
TEL: +420 541 562 433; E-MAIL: svobodama@vfu.cz

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## Abstract

**OBJECTIVES:** The aim of the study was to compare iodine utilization from different sources by sows and their progeny and the levels of T<sub>3</sub> and T<sub>4</sub> in their serum.

**DESIGN:** Pregnant Czech Large White × Landrace sows were fed with an experimental KPK diet (a diet for lactating sows) 14 days before parturition until weaning (at a piglet age of 28 days). In group A (n=50, 10 sows, 40 piglets) the feed was supplemented with KI (0.6 mg of iodine per kg of feed). Iodine enriched alga *Chlorella spp.* (0.6 mg of iodine per kg of feed) was used as a supplement in group B (n=50, 10 sows, 40 piglets). In group C (n=50, 10 sows, 40 piglets) the sows were injected i.m. with IFAE at a dose of 100 mg of iodine per sow. Iodine, T<sub>3</sub> and T<sub>4</sub> were measured in each group for comparison of iodine utilization.

**RESULTS:** The use of IFAE resulted in higher serum concentrations in sows compared to KI and alga. In contrast, iodine concentrations in milk and piglets were lower when IFAE were used. We found a wide variation in the concentrations of T<sub>3</sub> and T<sub>4</sub> in the serum of piglets in all groups.

**CONCLUSION:** Our results indicate a good utilization of iodized oil by sows. However, its transfer into milk is lower compared to the other iodine sources.

## Abbreviations:

EDDI - ethylenediamine dihydroiodide  
IFAE - iodized fatty acid esters  
i.m. - intramuscular  
KI - potassium iodide  
KIO<sub>3</sub> - potassium iodate  
KPK - diet for lactating sows

Lipiodol - speciality drug of iodized fatty acid esters  
MCP - monocalcium phosphate  
T<sub>3</sub> - triiodothyronine (active form)  
T<sub>4</sub> - tetraiodothyronine (thyroxine - prohormone)  
TMAH - tetramethylammonium hydroxide

## INTRODUCTION

Iodine is an essential element for pigs. It is involved in the synthesis of thyroid hormones. Its deficiency causes goiter and developmental disorders (Jelínek & Koudela 2003). Piglets born to iodine deficient sows is the category of pigs most seriously affected by iodine deficiency (Gürtler *et al.* 1982). It is manifested clinically by the delivery of weak hairless piglets generally carried over the full gestation time (Hart & Steenbock 1917).

The iodine content in feed is affected by its content in the soil (Anke *et al.* 1993). In the Czech Republic the iodine content in the soil is insufficient (Oliveriusová 1997). Therefore, iodine supplements must be added to the animals' diets. The iodine form most commonly used is inorganic KI (Herzig *et al.* 2000).

Also, organic iodine forms such as EDDI, iodine-rich seaweed (Kaufmann & Rambeck 1998) and iodine-enriched freshwater alga *Chlorella spp.* (Kotrbaček *et al.* 2004) have been used. Another possibility is the use of iodinated fatty acid esters (IFAE). They have been used successfully in the prophylaxis of human iodine deficiency including that of pregnant women (Chaouki & Benmiloud 1994; Delange 1996). The important advantage of these products is their prolonged efficacy after a single dose (Furnee *et al.* 1995; Herzig *et al.* 2001; Wolff & Chaikoff 1948).

The aim of the study was to evaluate the efficacy of a single i.m. application of iodised oil (Lipiodol) as a method of iodine supplementation in lactating sows and compare it with inorganic KI and iodine enriched *Chlorella spp.* supplementation. The efficacy was investigated according to the determination of iodine T<sub>3</sub> and T<sub>4</sub> concentrations in blood serum in different groups of animals.

## MATERIALS AND METHODS

### Experimental design

Altogether, 30 pregnant Czech Large White x Landrace sows and their litters (120 piglets) were used in our study. The sows were fed with an experimental KPK diet (a diet for lactating sows) 14 days before parturition until weaning (at a piglet age of 28 days). In group A (n=50, 10 sows, 40 piglets) the feed was supplemented with KI (0.6 mg of iodine per kg of feed). In group B (n=50, 10 sows, 40 piglets) the feed was supplemented with iodine enriched alga *Chlorella spp.* (0.6 mg of iodine per kg of feed). The sows in group C (n=50, 10 sows, 40 piglets) were given a single i.m. injection of iodine in the form of iodised fatty acid esters (IFAE – speciality drug Lipiodol) 14 days before parturition at a dose of 100 mg iodine per sow. The feed mixture of the sows in group C did not contain iodine supplement. The composition of the feed mixtures used for the sows is presented in Table 1. The content of iodine in the basal diet was 0.2 mg/kg. The piglets were weaned at the age of 28 days.

### Sampling

Blood samples from sows were taken 14 days before parturition, 10 days after parturition and before weaning (altogether, 30 samples from each group). The blood from the sows was taken from *vena jugularis* and passed into HEMOS tubes (GAMA České Budějovice). Blood from piglets was taken from *vena cava cranialis* 10 days after parturition and before weaning (altogether, 80 samples from each group). After sampling, the blood was coagulated in HEMOS tubes. Colostrum was taken on the second day after parturition. Milk was taken on the 10<sup>th</sup> day after parturition and at weaning.

Serum, colostrum and milk were then collected in sterile tubes and frozen for subsequent analyses.

### Iodine analysis

The solubilization of milk and blood serum samples was carried out by a modified method proposed by Niedobova *et al.* (2005). Before analysis, samples were thawed in a refrigerator (2–8 °C). One millilitre of milk or blood serum was mixed with five millilitres of 10% w/w tetramethylammonium hydroxide (TMAH) in sealable glass tubes.

The mixture was then heated at 90 °C for three hours. Cooled samples were diluted 10 times in deionized water before analysis. Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) (Agilent 7500ce, Agilent Technologies, Japan) was used for the determination of iodine concentrations in solution. Internal standard

**Tab. 1.** Percentage composition of the experimental KPK diet.

Ingredient	Percentage (%)
Selacid GREEN growth <sup>a</sup>	0.2
Wheat	28.7
Corn	19.8
Barley	25.0
Soya extract	19.0
Soya bean oil	1.5
Yeast Vitex Q	0.8
Calcite	1.7
Salt (NaCl)	0.5
MCP	0.8
Trace mineral and vitamin supplement <sup>b</sup>	2.0

<sup>a</sup>organic acids – formic acid, acetic acid, sorbic acid, propionic acid

<sup>b</sup>supplied per kilogram diet: 0.6 mg of Co, 10.0 mg of Cu, 90.0 mg of Fe, 0.6 mg of I (Group A in KI form, group B in enriched iodine alga *Chlorella spp.* form, group C without iodine supplement in experimental diet), 50.0 mg of Mn, 110.0 mg of Zn, 0.4 mg of Se, 3500 I.U. of vit. A, 2000 I.U. of vit. D<sub>3</sub>, 120.0 mg of vit. E, 2.0 mg of vit. K<sub>3</sub>, 2.4 mg of vit. B<sub>1</sub>, 6.0 mg of vit. B<sub>2</sub>, 3.6 of vit. B<sub>6</sub>, 40.0 µg of vit. B<sub>12</sub>, 20.0 mg of niacin, 20.0 mg of calcii pantothenas, 1.2 mg of biotin, 8.0 mg of folic acid, 300.0 mg of cholin chloride, 100.0 mg of betaine, 20.0 mg of vit. C, 2.5 mg of beta-karoten, 2.7 g of lysine, 0.5 g of DL-methionine, 0.9 g of L-threonine.

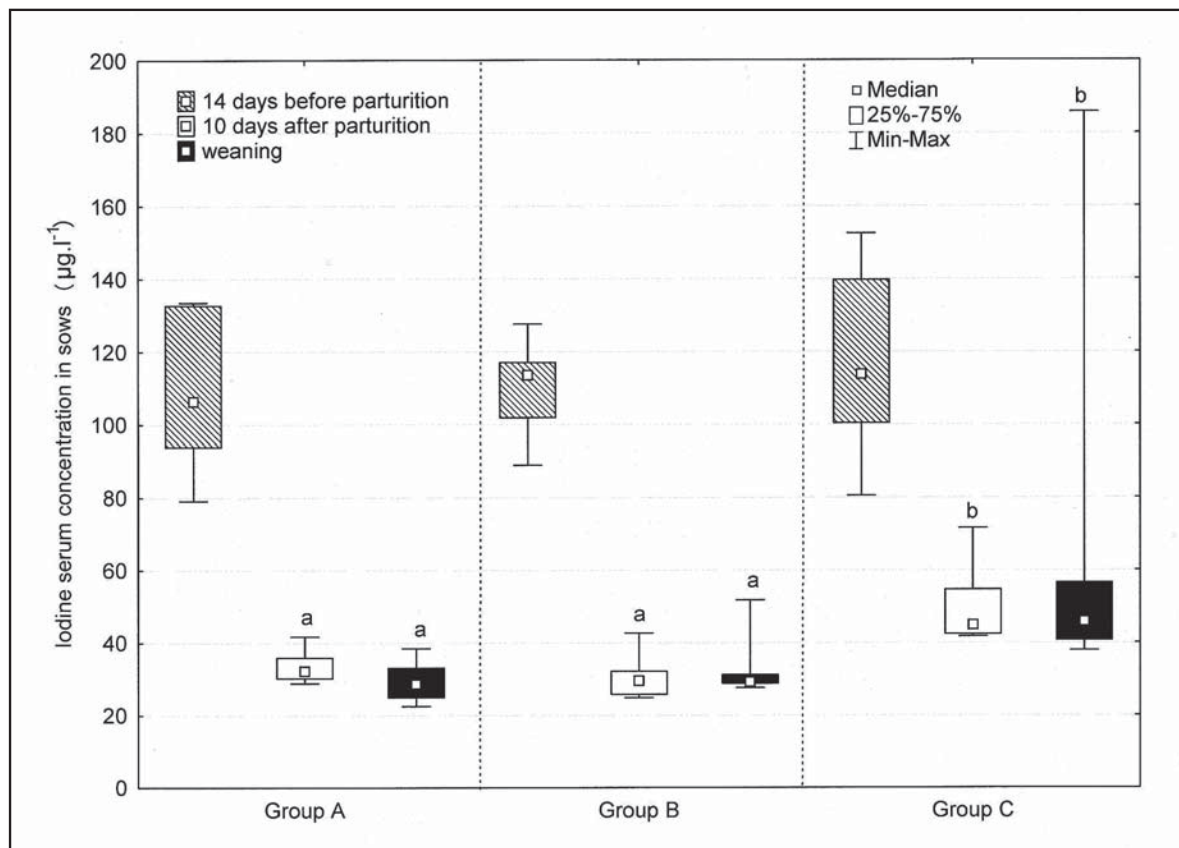


Fig. 1. Iodine serum concentrations in sows (Letters a, b express significant differences among groups at a level of significance of  $p < 0.05$ ).

Te<sup>127</sup> was used for the diminution of matrix effects and instrumental drift. The accuracy of the method was verified by analysis of several certified reference materials including non fat milk powder (NIST 1549) and blood serum (Seronorm Trace Element Serum L-1) (Niedobova *et al.* 2005).

#### T<sub>3</sub> and T<sub>4</sub> analysis

Before analysis, samples of blood serum were thawed in a refrigerator (2–8 °C). Radioimmunoassay (RIA) with TOTAL T<sub>3</sub>/T<sub>4</sub>/RIA KIT (Beckman Coulter) was used for the determination of T<sub>3</sub> and T<sub>4</sub> in serum.

Test samples, calibration samples and control samples were incubated together with I<sup>125</sup> in tubes with walls covered by monoclonal antibodies. After incubation the content of the tubes was aspirated and the binding activity was measured on a GAMA-COUNTER. Calibration curves were used to calculate the final concentration of T<sub>3</sub> or T<sub>4</sub> in the sample.

#### Statistical analysis

Statistical analysis of the data was performed using Statistica 8.0 for Windows (StatSoft CR). Analyzed indices were tested for normal distribution using the Kolmogorov-Smirnov test. The non-parametric Kruskal-Wallis test was used for iodine, T<sub>3</sub> and T<sub>4</sub> concentrations and  $p < 0.05$  was chosen as the level of significance.

## RESULTS

### Iodine serum concentrations in sows (Figure 1)

#### **14 days before parturition**

There were no differences among the experimental groups.

#### **10 days after parturition**

The intramuscular injection of IFAE (group C) resulted in higher iodine serum concentrations compared to *Chlorella spp.* (group B) and KI (group A) supplemented groups.

#### **Weaning**

The intramuscular injection of IFAE (group C) resulted in higher iodine serum concentrations compared to *Chlorella spp.* (group B) and KI (group A) supplemented groups.

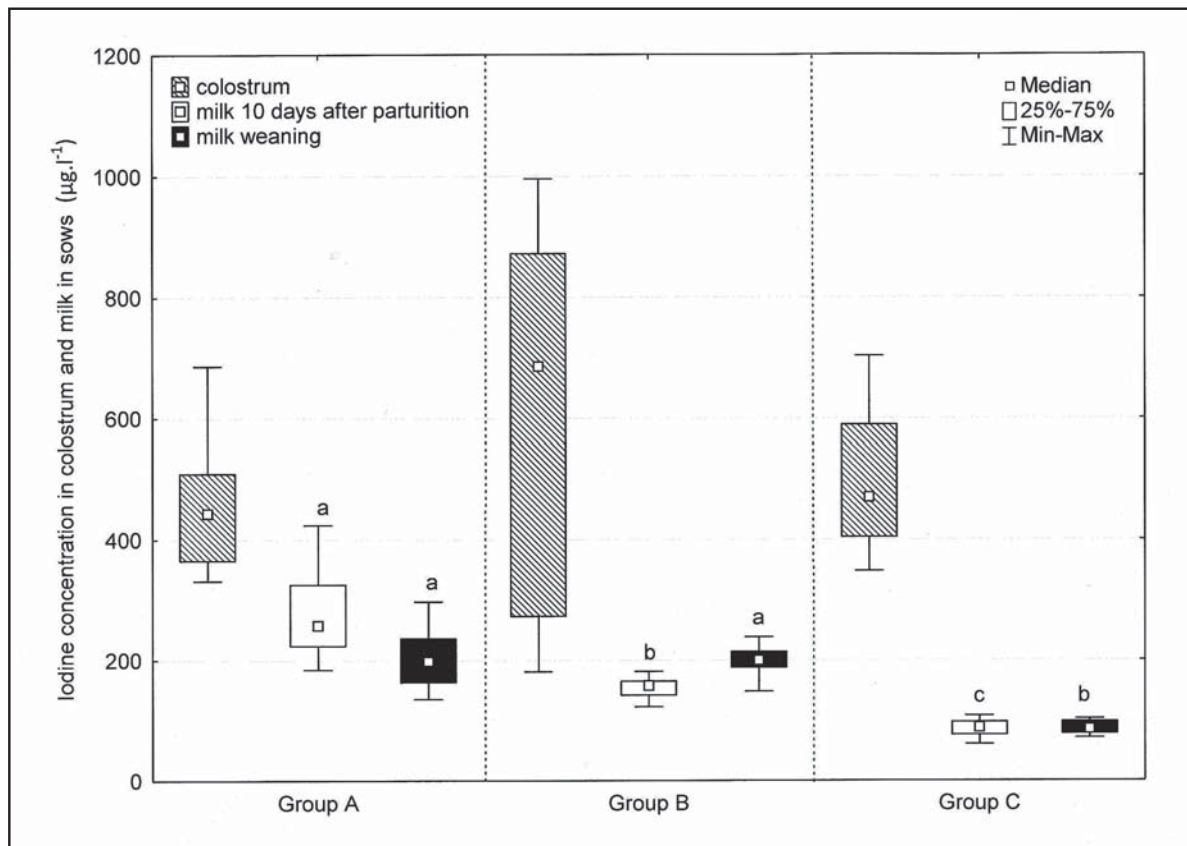
### Iodine colostrum and milk concentrations (Figure 2)

#### **Colostrum**

There were no differences among experimental groups.

#### **Milk 10 days after parturition and at weaning**

The iodine content of KI and *Chlorella spp.* supplemented groups was significantly higher than in the IFAE treated group.



**Fig. 2.** Iodine colostrum and milk concentrations in sows (Letters a, b, c express significant differences among groups at a level of significance of  $p < 0.05$ ).

### Iodine serum concentrations in piglets (Figure 3)

#### **10 day old piglets**

The iodine serum concentrations in piglets in the KI and *Chlorella spp.* supplemented groups were significantly higher than in the IFAE treated group.

#### **Weaned piglets**

The iodine serum concentrations in piglets in the KI-supplemented group were significantly higher than those in the *Chlorella spp.* supplemented group and the IFAE treated group.

### T<sub>3</sub> and T<sub>4</sub> serum concentrations in sows and piglets

#### **SOWS (Table 2)**

##### **T<sub>3</sub> serum concentrations**

##### *14 days before parturition*

There were no differences in the concentrations of T<sub>3</sub> among groups A, B and C.

##### *10 days after parturition*

There were differences in the concentrations of T<sub>3</sub> among groups A, B and C. Group B was significantly lower than groups A and C ( $p < 0.05$ ).

##### *Weaning*

There were no differences in the concentrations of T<sub>3</sub> among groups A, B and C.

##### **T<sub>4</sub> serum concentration**

##### *14 days before parturition*

There were no differences in the concentrations of T<sub>4</sub> among groups A, B or C.

##### *10 days after parturition*

There were differences among groups A, B and C. Group B was significantly lower than groups A and C ( $p < 0.05$ ).

##### *Weaning*

There are no differences in concentration of T<sub>3</sub> among groups A, B or C.

#### **PIGLETS (Table 3)**

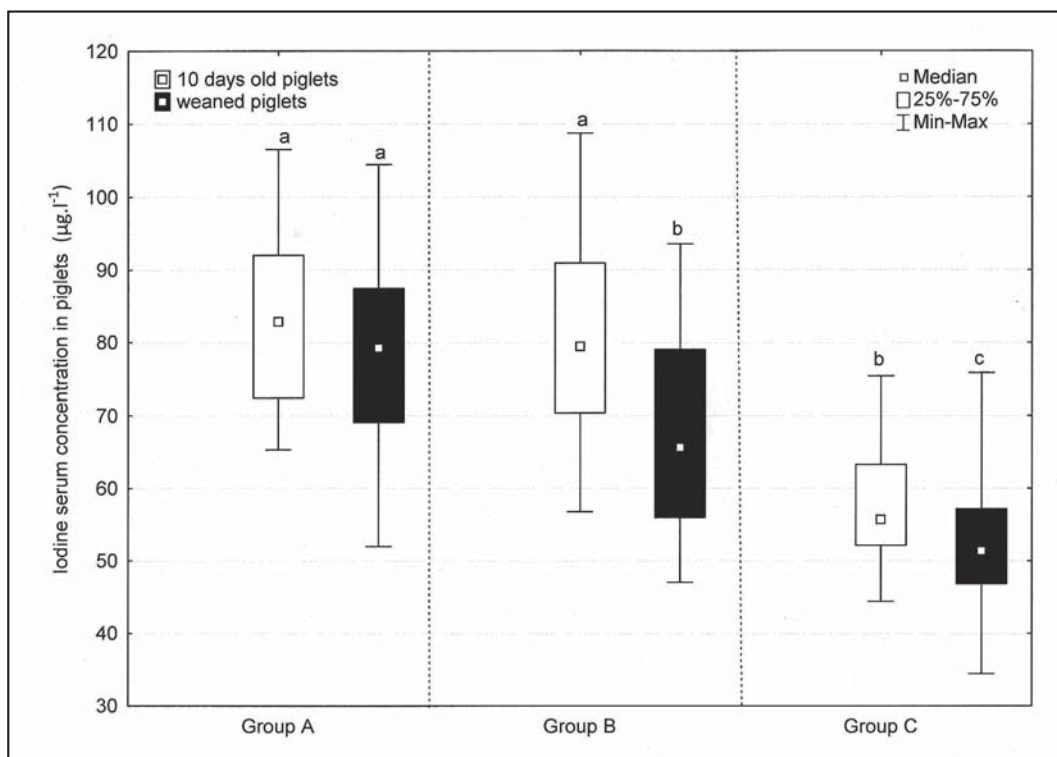
##### **T<sub>3</sub> serum concentration**

##### *10-day-old piglets*

There were differences among groups A, B and C. Group C was significantly lower than groups A and B ( $p < 0.05$ ).

##### *Weaned piglets*

There were differences among groups A, B and C. Group C was significantly higher than groups A and B ( $p < 0.05$ ).



**Fig. 3.** Iodine serum concentrations in piglets (Letters a, b, c express significant differences among groups at a level of significance of  $p < 0.05$ ).

**Tab. 2.** Comparison of  $T_3$  and  $T_4$  concentrations (nmol/l<sup>-1</sup>) in the serum of sows.

Thyroid hormones	Group A (n = 10)		Group B (n = 10)		Group C (n = 10)	
	Median	25 <sup>th</sup> /75 <sup>th</sup> perc	Median	25 <sup>th</sup> /75 <sup>th</sup> perc	Median	25 <sup>th</sup> /75 <sup>th</sup> perc
$T_3$ 14 days before parturition	1.71	1.51/2.13	1.83	1.52/2.22	1.48	1.32/1.78
$T_4$ 14 days before parturition	31.65	26.6/35.20	31.80	28.20/37.10	27.85	24.60/31.20
$T_3$ 10 days after parturition	1.47 <sup>a</sup>	1.33/1.97	0.98 <sup>b</sup>	0.75/1.03	1.80 <sup>a</sup>	1.70/1.90
$T_4$ 10 days after parturition	27.15 <sup>a</sup>	25.80/36.70	19.75 <sup>b</sup>	16.00/21.60	33.50 <sup>a</sup>	26.20/38.50
$T_3$ weaning	1.35	1.01/1.67	1.43	1.36/2.17	1.38	1.16/2.25
$T_4$ weaning	24.85	21.80/29.90	29.95	27.00/36.20	25.15	18.40/36.70

Letters a, b express significant differences among groups at a level of significance of  $p < 0.05$ .

#### $T_4$ serum concentration

##### 10 days old piglets

There were no differences in the concentrations of  $T_3$  among groups A, B or C.

##### Weaned piglets

There were differences among groups A, B and C. Group A was significantly higher than groups B and C ( $p < 0.05$ ).

#### Weight of piglets (Table 4)

##### 10 day-old-piglets

There were differences among groups A, B and C.

#### Weaned piglets

There were differences among groups A, B and C. Group A was significantly higher than group B and C.

## DISCUSSION

There is an increase in the need for iodine during pregnancy and lactation because of the transfer of iodine and  $T_4$  from the mother to the foetus and the loss of iodine in colostrum and milk during lactation (Delange 2004; Semba & Delange 1986).

According to the German Society of Nutrition Physiology (2006) the feed of breeding sows should be supplemented with 0.5–0.6 mg/kg of iodine in feed. This

recommendation is supported by Schöne *et al.* (2001), who found that 0.6 mg/kg of supplementary iodine in feed for lactating sows guarantee an almost balanced intake and replace the loss of iodine. Therefore, a supplement of 0.6 mg/kg of iodine (in the form of KI) was used for the sows in group A.

Lipiodol is the product of the addition of iodine to unsaturated fatty acids of poppy seed oil. The iodine is released continuously from the stored lipid over a long period of time. This ensures a long lasting effect (Prettel 1972; Elnagar *et al.* 1995). Lipiodol can be administered orally or parenterally. The effect of the intramuscular administration of iodised oil has been reported to last longer than that of oral treatment (Leverge *et al.* 2003). Therefore we decided for a single i.m. administration. Moreover the i.m. administration appears to avoid the extremely high early iodine levels seen after oral treatment (Wolff 2001). Furnee *et al.* (1995) found that dividing the dose does not enhance the efficiency of iodised oil based products. Therefore, the use of single administration was sufficient.

A large single dose of iodised oil was administered to the sows. A massive single dose of inorganic iodine (KI) or therapies with high iodine content (Czarnywojtek *et al.* 2009) have been associated with thyroid function abnormalities (Nauman & Wolff 1993). However, no iodine-induced abnormalities in thyroid function in sows have been conclusively demonstrated after the administration of Lipiodol. This was also confirmed in our study as no adverse effects on T<sub>3</sub> and T<sub>4</sub> levels were observed in our experiment.

Thyroid hormones play an important role in the thermoregulation of suckling piglets (Bate *et al.* 1993).

After exposure to cold, subsequent thermogenic activity is associated with catecholamine action potentiated by thyroid hormones (Slebozdinski 1979). It was difficult to draw conclusions from the obtained levels of thyroidal hormones in piglets. This was because we found a wide variation in the concentrations of thyroidal hormones in the serum of piglets in all groups. This is in agreement with Dvořák *et al.* (1986), who stated that such differences could be attributed not only to thyroid function, but also to possible genetically conditioned differences (Slebozdinski & Wallace 1979) and to differences in nutritional status (Dvořák *et al.* 1986). Also other factors such as selenium status may play an important role in thyroid hormone metabolism (Sewerynek *et al.* 2006).

Our results indicate good utilization of iodized oil by sows. However, its transfer into milk was lower compared to that in KI and iodine enriched alga supplemented groups. This could possibly be explained by the fact that Lipiodol is stored in the lipid tissues of sows and that a lower proportion is released into the milk. At a piglet age of 10 days, the highest iodine serum concentrations in sows were found in the group supplemented with KI. There was no difference in the serum iodine concentrations in sows among groups at weaning. This indicates that a single i.m. administration of Lipiodol can maintain appropriate iodine levels in sows for the whole suckling period. This is in agreement with studies conducted on other animal species (Azuolas & Caple 1984; Herzig *et al.* 2001).

Several authors supplemented animal feed with iodine-rich algae with variable results. He *et al.* (2002) improved iodine content in pork by supplementing the

**Tab. 3.** Statistical analysis and comparison of T<sub>3</sub> and T<sub>4</sub> concentrations (nmol/l<sup>-1</sup>) in the serum of piglets.

Thyroid hormones	Group A (n = 10)		Group B (n = 10)		Group C (n = 10)	
	Median	25 <sup>th</sup> /75 <sup>th</sup> perc	Median	25 <sup>th</sup> /75 <sup>th</sup> perc	Median	25 <sup>th</sup> /75 <sup>th</sup> perc
T <sub>3</sub> 10 days old piglets	2.31 <sup>a</sup>	1.98/2.51	2.45 <sup>a</sup>	2.05/2.92	1.61 <sup>b</sup>	1.44/1.91
T <sub>4</sub> 10 days old piglets	55.05	44.25/69.35	61.20	50.80/69.70	60.20	52.60/71.90
T <sub>3</sub> weaned piglets	1.47 <sup>a</sup>	1.14/1.68	1.30 <sup>a</sup>	0.89/1.70	1.76 <sup>b</sup>	1.60/2.30
T <sub>4</sub> weaned piglets	73.55 <sup>a</sup>	61.05/80.05	60.70 <sup>b</sup>	47.10/71.10	60.45 <sup>b</sup>	50.20/68.55

Letters a, b express significant differences among groups at a level of significance of  $p < 0.05$ .

**Tab. 4.** Statistical analysis and comparison of the weight (kg) of piglets.

Piglets	Group A (n = 40)		Group B (n = 40)		Group C (n = 40)	
	Median	25 <sup>th</sup> /75 <sup>th</sup> perc	Median	25 <sup>th</sup> /75 <sup>th</sup> perc	Median	25 <sup>th</sup> /75 <sup>th</sup> perc
10 days after parturition	3.50 <sup>a</sup>	3.15/4.25	4.28 <sup>b</sup>	3.59/4.54	4.55 <sup>c</sup>	4.26/4.87
Weaned piglets	8.15 <sup>a</sup>	7.00/9.05	7.20 <sup>b</sup>	6.30/7.88	7.00 <sup>b</sup>	6.40/7.60

Letters a, b, c express significant differences among groups at a level of significance of  $p < 0.05$ .

diet with alga *Laminaria digitata*. They found that the bioavailability of the algal iodine was higher than that of KI. The bioavailability of iodine from *Laminaria digitata* was superior to that of inorganic iodine also when used as a supplement for laying hens (Krbačová 2002). In contrast, the bioavailability of iodine from alga *Euchema spinosum* in laying hens was less compared to KIO<sub>3</sub> (Kaufmann & Rambeck 1998).

This indicates that the bioavailability of iodine differs among various algal iodine sources. This could probably be attributed to different iodine speciation profiles for algal species (Hou *et al.* 2000; Hou *et al.* 1997). Several speciation studies showed that up to 90% of *Laminaria* algae contains labile inorganic iodine (I and IO<sub>3</sub> form). The remainder consists of organic iodine in the form of iodo-amino acids (Hou *et al.* 1997). No speciation studies have yet been conducted with iodine-enriched *Chlorella spp.*

In our study we found comparable iodine concentrations in *Chlorella spp.* and KI-supplemented groups of sows. This indicates that the bioavailability of algal iodine was similar to that of the inorganic source. The effect of the feeding of iodine-enriched alga *Chlorella spp.* on the iodine content of sows' milk has been evaluated by Kotrbáček *et al.* (2004). However, it is difficult to compare our results with this study, because the Kotrbáček *et al.* (2004) evaluated the effects of adding algal iodine to feed that was already supplemented with KI. This means that a comparison between the same dose of algal iodine and the same dose of inorganic iodine was not carried out.

It can be concluded that a single i.m. administration of iodised oil at a dose of 100 mg I ensures an adequate iodine supply for sows throughout the whole suckling period. The iodine from iodine-enriched *Chlorella spp.* has a bioavailability comparable to that of inorganic KI. Thyroid hormones play an important role in thermoregulation of suckling piglets (Bate *et al.* 1993). After exposure to cold the subsequent thermogenic activity is associated with catecholamine action potentiated by thyroid hormones (Slebodziński 1979). Thyroid hormones also enhance the thermoregulation of piglets by stimulating adipocytes development (Ramsay *et al.* 1987). Therefore, an adequate iodine supply in milk for newborn piglets is essential.

No differences in the concentrations of thyroidal hormones in the serum of sows and piglets were found between group A and group B during any period of the trial. The development of T<sub>4</sub> levels in piglets were in agreement with observations made by Ślebodziński *et al.* (1981), i.e. there was a decrease in T<sub>4</sub> levels 5 days after parturition and then an increase at 14 days of piglet age. However, this is contradictory to Dvořák *et al.* (1986), who found a non-significant increase during the same period. These differences could be attributed not only to thyroid function, but also to possible genetically conditioned differences (Slebodziński & Wallace

1979) and to differences in nutritional status (Dvořák *et al.* 1986).

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