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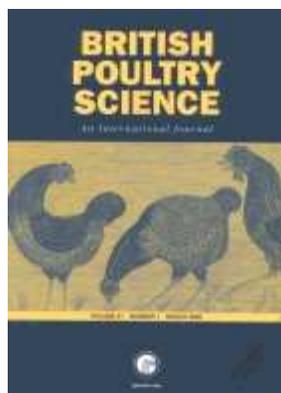
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The effect of various iodine supplementations and two different iodine sources on performance and iodine concentrations in different tissues of broilers

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4 **The effect of various iodine supplementations and two different sources on performance**
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6 **and iodine concentrations in different tissues of broilers**
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30 **Running title: Iodine supplementation in broilers**
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1 **Abstract** 1. The objective of this study was to determine the influence of iodine (I)
2 supplementation of feed, within the range of the European guidelines, on the performance of
3 broiler chickens and I transfer into different organs and tissues, especially meat. The main
4 emphasis was to assess whether broiler meat could be enriched and used as an I source in
5 human nutrition.
6 2. Two experiments were performed, one with KI and the other with $\text{Ca}(\text{IO}_3)_2$. For each
7 experiment, 288 d-old broiler chicks were divided into 4 groups (72 birds/group) and fed on
8 diets with supplementations between 0 and 5 mg I/kg feed. The birds were reared to 35 d of
9 age under standard conditions. Six birds per group were slaughtered at 35 d and samples of
10 blood, thyroid gland, liver, pectoral and thigh meat taken.
11 3. Iodine treatment did not significantly affect the growth and slaughter performance of the
12 broiler chickens. In all investigated parameters, I concentrations increased significantly with
13 increasing I intake of the animals. The lowest I concentrations were measured in the meat, but
14 they were considerably higher in blood serum, liver and thyroid gland. Since the I content of
15 meat was still low in the highest supplemented group (highest median concentration:
16 67.8 μg I/kg thigh meat), there is no evidence that this could substantially improve I supply in
17 human nutrition.

18 INTRODUCTION

19 Iodine (I) deficiency is still a widely prevalent problem in human nutrition around the world,
20 approximately 57 % of the European population and 35 % of the world's population having
21 insufficient iodine intake (urinary iodine < 100 $\mu\text{g}/\text{l}$; de Benoist *et al.*, 2004). I is an essential
22 trace element for humans and animals, being required for the synthesis of the thyroid
23 hormones triiodothyronine (T_3) and tetraiodothyronine (T_4). The appropriate I provision is
24 important for a normal thyroid function and the associated physiological mechanisms. For an
25 adult person, the D-A-CH (German-, Austrian- and Swiss Nutrition Society) recommends a

1
2
3 26 daily intake of 180-200 µg I and a 'Tolerable Upper Intake Level' (UL) of 500 µg I/d (D-A-
4
5 27 CH, 2008). I is assigned to the 'high risk category' and also to 'supply category 1'. This means
6
7
8 28 there is only a narrow range between recommended daily intake and UL ($\approx 1:3$) (Gaßmann,
9
10 29 2006). Due to adverse health effects, deficiency as well as excessive intake should be avoided.
11
12 30 A lack in I supply impairs thyroid hormone synthesis, which results in hypothyroidism and
13
14
15 31 leads to various developmental and functional disorders, summarised as 'Iodine Deficiency
16
17 32 Disorders' (IDD) (Hetzl, 1983; de Benoist *et al.*, 2004). IDD can affect the organism in all
18
19 33 stages of life: foetus (*e.g.*, abortions, endemic cretinism), neonate (*e.g.*, endemic mental
20
21 34 retardation), child and adolescent (*e.g.*, goitre, retarded physical development) and adult (*e.g.*,
22
23 35 hypothyroidism, spontaneous hyperthyroidism in the elderly) (Hetzl, 1983; Stanbury *et al.*,
24
25 36 1998; Laurberg *et al.*, 2000).

26
27
28
29 37 To counteract I deficiency, salt iodination was implemented, but this did not solve the
30
31 38 problem to a satisfactory extent, so further I sources were sought. Products of animal origin,
32
33 39 such as milk or eggs, can, for example, be enriched by feed iodination. Feed iodination is
34
35 40 limited by EU regulations to avoid I excess, the maximum allowance of feed iodination for
36
37 41 broiler chickens being 10 ppm (EU Commission, 2005). Due to high carry-over into milk and
38
39 42 eggs, the UL for laying hens and dairy cows was reduced from 10 ppm to 5 ppm (EU
40
41 43 Commission, 2005). The I requirements of animals depend on species, age and physiological
42
43 44 stage. The maximum allowance for broiler feed of 10 mg I/kg compares with a requirement of
44
45 45 0.35 mg I/kg feed for broilers (NRC, 1994). Thus health and performance of the animals have
46
47 46 to be considered at the intention of feed iodination and possible elevation of the legal feed
48
49 47 UL.

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53 48 The present study encompassed two feeding experiments with broilers. A range of I
54
55 49 supplementations and two different I sources were tested to investigate the influence on I
56
57 50 concentrations of different tissues and the impact on growth and slaughter performance.
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3 51 Specifications for the I content of poultry meat are absent from the nutrition table of Souci *et*
4
5 52 *al.* (2008); this shows the necessity of determining these data. The motivation for this study
6
7
8 53 was a document of the European Food Safety Authority (2005) (EFSA) about the use of I in
9
10 54 feeding stuffs, which concluded that more dose-response studies were necessary to assess the
11
12 55 resulting I content in food of animal origin. The experiments were conducted to investigate
13
14 56 the impact of broiler feed iodination on the I concentrations of tissues, organs and blood
15
16 57 serum. The main interest of the study was to determine to what extent chicken meat can be
17
18 58 enriched with I when broilers ingest feed supplied with I according to EU guidelines. As
19
20 59 different I sources are permitted as feed additives in the EU (EU Commission, 2005), two of
21
22 60 them were tested – potassium iodide (KI) and calcium iodate ($\text{Ca}(\text{IO}_3)_2$). Growth and
23
24 61 slaughter performance were determined in these feeding experiments to evaluate the tolerance
25
26 62 of the broilers towards different I concentrations.
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31

32 MATERIALS AND METHODS

33 **Animals, diets and sampling**

34
35
36 64 Two experimental approaches were conducted to test the two different I sources – iodide (KI)
37
38 65 and iodate ($\text{Ca}(\text{IO}_3)_2$). Both experiments were conducted at the same experimental station
39
40 66 (Friedrich-Loeffler-Institute, Institute of Animal Welfare and Animal Husbandry, Celle,
41
42 67 Germany) under identical experimental conditions. The experimental approach testing KI was
43
44 68 conducted in April/May 2007; the approach testing $\text{Ca}(\text{IO}_3)_2$ was carried out in March/April
45
46 69 2008.
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Table 1 near here

53 71 Each of the two experimental trials was performed as follows. Ten Ross 308 broiler
54
55 72 breeder hatching eggs which had been produced under standard management conditions were
56
57 73 used to determine the initial I concentration. On the day of hatch, 288 male chicks were
58
59 74 divided into 4 groups (72 per group) and a further 10 chicks killed for I determination. The

1
2
3 75 birds of each group were allocated to 6 cages (1.28 x 0.82 m) with 12 birds (11.4 chickens/m²)
4
5 76 per cage and reared to 35 d under standard management conditions. Feed and water were
6
7
8 77 provided *ad libitum*. The feed composition is detailed in Table 1. Feed intake (FI) was
9
10 78 recorded by cage weekly and body weight (BW) measured on a cage basis at 7 d and
11
12 79 individually at 14, 21 and 35 d, and the data used to calculate the feed conversion ratio (FCR).
13
14

15 80 KI and Ca(IO₃)₂ were tested as different I sources in a range of concentrations (0
16
17 81 (control), 1, 2.5 and 5 mg I/kg feed). The feed for both experiments was mixed at the same
18
19 82 time. An I-free mineral premix was used for the composition of the feed mixtures. Pre-
20
21 83 mixtures were produced to achieve a homologous dispersion of I in the feed. In a first step,
22
23 84 the calculated I amounts were applied to 70 g ground wheat, then 70 g were mixed into 2 kg
24
25 85 ground wheat, and finally this pre-mixture was mixed into the 300-kg feed mixture. The
26
27 86 control group were given the same basic diet as the test groups but without additional I; these
28
29 87 birds only received naturally occurring I from the feed ingredients. Only I concentrations of
30
31 88 up to 5 mg I/kg were tested, despite 10 mg I/kg being allowed for growing birds, because
32
33 89 other experiments conducted with laying hens used 5 mg I/kg.
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38 90 On d 35, one bird from each cage with a BW close to the mean of the respective cage-
39
40 91 group was slaughtered by electrical stunning and severance of the carotid artery and jugular
41
42 92 vein according to welfare regulations (EU Commission, 2008). The blood was collected into
43
44 93 test tubes [10 ml, SARSTEDT, No./REF 26.323] containing a clot activator to retrieve blood
45
46 94 serum. Afterwards, samples were taken from the thyroid gland, liver, pectoral and thigh meat
47
48 95 of the carcass for weighing and I determination. Heart, liver, ventriculus (gizzard), spleen,
49
50 96 breast skin, breast meat, thigh, abdominal fat and empty body (empty carcass, without head,
51
52 97 innards and tibiotarsi) were weighed to determine the carcass composition of the birds.
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57 98 **Analysis of feed composition**

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3 99 Feed analyses were performed of the feed mixtures from each experimental group. Dry
4
5 100 matter, crude fibre, crude ash, crude protein (CP), crude fat (EE), starch (ST), sucrose (S),
6
7
8 101 NDF, ADF and Ca were analysed according to the guidelines of “Verband Deutscher
9
10 102 Landwirtschaftlicher Untersuchungs- und Forschungsanstalten“ (VDLUFA, 1976).

103 **I analyses**

104 The I contents were measured using Inductively Coupled Plasma-Mass Spectrometry (ICP-
15
16 105 MS) [Agilent 7500C]. The measuring solutions were prepared in an alkaline medium in order
17
18 106 to avoid vaporisation of I (Wagner, 2007). Feed samples (5 g) were boiled for 30 min with
19
20 107 ammonia solution (0.59 mol/l). After cooling, samples were filled with ammonia solution up
21
22 108 to 1000 ml, and then filtered with a fluted filter. Prior to use, filters were flooded twice with
23
24 109 boiling distilled deionised water and then dried in an oven to remove possible I and avoid
25
26 110 contamination. After filtration with a syringe filter (Minisart 0.45µm), 10 ml of the filtrate
27
28 111 were taken for measurements. Blood serum was diluted 1:10 with 0.11 mol/l
29
30 112 Tetramethylammonium hydroxide solution [TMAH, Alfa Aesar GmbH & Co KG Karlsruhe,
31
32 113 25 % w/w aq.soln., Electronic Grade, 99.9 %] before measuring. Meat, liver, 1-d-old chicks
33
34 114 and egg samples were each homogenised with a mixer [ESGE-ZauberStab®] prior to
35
36 115 digestion, with the exception of the thyroid gland, which was taken in whole due to its small
37
38 116 size. Therefore, the thyroid weight was included into the calculation for its I concentration.
39
40 117 After mechanical homogenisation, meat, liver, eggs and 1-d-old chicks were digested
41
42 118 chemically with TMAH (Fecher *et al.*, 1998) and a 1-g sample heated for 3 h at 90°C in a gas-
43
44 119 tight Erlenmeyer flask, with 5 ml distilled deionised water and 1 ml TMAH. After cooling,
45
46 120 the solution was filled up to 25 ml with distilled deionised water. 10 ml of the solution were
47
48 121 taken for measurement using ICP-MS, 0.5 ml tellurium oxide solution [100 µg/l; tellurium
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53 122 (IV) oxide, Alfa Aesar GmbH & Co KG Karlsruhe, 99.9 %] as the internal standard. The
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3 123 masses of 127 for I and 125 for Te were used. During calculation of I concentrations, the
4
5 124 standard addition method was applied during calibration.
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9 125 **Statistical analyses and calculations**

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11 126 The carryover was calculated as the percentage of I content of the sample from the total
12
13 127 amount of I which was ingested during the whole experiment (35 d). Nitrogen-corrected
14
15 128 apparent metabolisable energy, was calculated with the energy estimation formula:
16
17 129 $AME_N [MJ/kg] = (15.51 \text{ g CP/kg} + 34.31 \text{ g EE/kg} + 16.69 \text{ g ST/kg} + 13.01 \text{ g S/kg})/1000$
18
19 130 (WPSA, 1984 in GfE, 1999).
20
21
22

23
24 131 The statistical analyses were carried out with SAS 9.1 (© by SAS Institute Inc., Cary,
25
26 132 NC, USA) and STATISTICA 8.0 (StatSoft, Inc. 2007). Differences were recognised as
27
28 133 significant at $P < 0.05$. Since the two experiments were carried out at two different points in
29
30 134 time, the effects of iodate and iodide were not compared with each other. Outliers were
31
32 135 detected with the ROBUSTREG procedure and then excluded from subsequent analysis.
33
34 136 Afterwards, data were tested for normality with the procedure UNIVARIATE, using the
35
36 137 Kolmogorov-Smirnov test ($P = 0.01$). Performance and slaughter data were normally
37
38 138 distributed and thus analysed parametrically with the Tukey test using the GLM procedure.
39
40 139 The data of I concentrations showed significant differences from the normal distribution.
41
42 140 These not normally distributed data were analysed non-parametrically with the Kruskal-
43
44 141 Wallis test using STATISTICA.
45
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48

49 142 **RESULTS**

50 143 **Feed I concentrations**

51
52 144 The naturally occurring I concentration of the feed mixtures was 0.5 mg I/kg in the control
53
54 145 diet of both experiments. The I concentrations of the groups supplemented with 1, 2.5 and
55
56 146 5 mg I/kg approximated to the desired concentrations of 0.6, 2.4 and 5.5 mg I/kg respectively
57
58
59 147 in KI groups and 0.9, 2.7 and 4.7 mg I/kg in $Ca(IO_3)_2$ groups.
60

148 **Rearing performance**

149 The I supplementation had no significant effect on FI and BW gain (BWG) (Tables 2 and 3).

150 The mean FI of all groups and total experimental period was 98.2 ± 3.3 g/d in KI groups and
151 97.2 ± 3.6 g/d in $\text{Ca}(\text{IO}_3)_2$ groups. The mean BWG was 65.1 ± 2.2 g/d in KI groups and
152 67.3 ± 2.4 g/d in $\text{Ca}(\text{IO}_3)_2$ groups.

153 The FCR of KI-birds was significantly improved between 21 and 35 d, where the
154 5 mg I/kg supplemented group had a significantly superior FCR to the control group
155 (1.61 kg/kg vs. 1.68 kg/kg). There was no significant effect on FCR during the other phases
156 (Table 2). When testing FCR through to 35 d, the FCR of the 5 mg I/kg (1.49 kg/kg) was also
157 significantly higher than in the control (1.53 kg/kg; $P = 0.0071$). In the $\text{Ca}(\text{IO}_3)_2$ broilers no
158 significant differences were found between the different groups, the average FCR of all
159 $\text{Ca}(\text{IO}_3)_2$ groups was 1.45 ± 0.04 kg/kg. In contrast to KI groups the highest supplemented
160 group had in tendency a lower FCR than the control group. The significant positive effect in
161 FCR, found in the 5 mg I/kg KI group was caused by negligibly low standard deviation and
162 was not considered to have biological relevance.

Tables 2, 3, 4 & 5 near here

163 **Slaughtering performance**

164 The data retrieved at slaughtering are listed in Tables 4 and 5. The final BW was not
165 significantly affected by the various I concentrations, neither with KI supplementation
166 (2230 ± 87 g) nor with $\text{Ca}(\text{IO}_3)_2$ supplementation (2303 ± 58 g) birds.

167 No significant differences were found in the mass of the different organs and fractions
168 or in their proportions of final BW as influenced by I supplementation. Considering the
169 masses of samples gained from KI- and $\text{Ca}(\text{IO}_3)_2$ -supplemented birds, the mean weight of
170 pectoral meat was 340.1 g and 371.1 g, of breast skin 26.2 g and 29.7 g and thigh mass with
171 bone and skin 440.5 g and 472.0 g respectively. In the other fractions and organs, mean
172 weights were: heart 10.6 g and 11.5 g, liver 47.0 g and 44.9 g, spleen 1.93 g and 2.19 g,

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2
3 173 ventriculus 24.7 g and 27.7 g and abdominal fat pad 33.5 g and 30.0 g respectively for KI and
4
5 174 $\text{Ca}(\text{IO}_3)_2$ supplementation. The thyroid gland had a mean weight of 0.15 ± 0.04 g in KI and
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7
8 175 0.19 ± 0.08 g in $\text{Ca}(\text{IO}_3)_2$ broilers.
9

10 11 176 **I concentrations**

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13
14 177 The hatching eggs ($n = 10$) had I concentrations of 687 ± 170 $\mu\text{g I/kg}$ in the KI experiment and
15
16 178 484 ± 82 $\mu\text{g I/kg}$ in the $\text{Ca}(\text{IO}_3)_2$ experiment. The 1-d-old chicks had concentrations of
17
18 179 749 ± 107 $\mu\text{g I/kg}$ in the KI experiment and 565 ± 148 $\mu\text{g I/kg}$ in the $\text{Ca}(\text{IO}_3)_2$ experiment. I
19
20 180 content was less than 1 % of the final I concentration found in the slaughtered birds at the end
21
22 181 of the experiment, and so the initial I content was ignored in carry-over calculations.
23
24

25
26 182 Increasing I supplementation significantly raised the I concentration in all investigated
27
28 183 tissues and blood serum of the birds (Tables 6 and 7). The order of I concentrations in the
29
30 184 different investigated samples was meat < liver < serum < thyroid gland. Tables 6 & 7 near here
31
32

33 185 I concentration of the thyroid was independent of feed I supplementation, the highest
34
35 186 of the various samples, and increased significantly with rising feed I concentration. In KI
36
37 187 groups, it ranged from 2317 to 5053 $\mu\text{g I/g}$ and in $\text{Ca}(\text{IO}_3)_2$ groups from 2323 to 3652 $\mu\text{g I/g}$.
38
39 188 Calculated on the weight of the thyroid gland, the I content of one thyroid gland of the highest
40
41 189 KI supplemented group had a mean I content of 825 ± 373 μg and in the highest $\text{Ca}(\text{IO}_3)_2$
42
43 190 groups the I content of one thyroid gland was 601 ± 197 μg . The carry over of I into the
44
45 191 thyroid was higher than the other samples. Regarding both I sources, the carry-over decreased
46
47 192 with increasing feed I concentration, the median amount in the control group of KI birds was
48
49 193 18.0 % and 21.8 % in $\text{Ca}(\text{IO}_3)_2$ birds. In the highest KI group, the median carry over into the
50
51 194 thyroid was 4.2 % and, in the highest $\text{Ca}(\text{IO}_3)_2$ group, 3.5 %.
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56 195 In comparison with liver and meat samples, the I concentration of blood serum was
57
58 196 relatively high. The I concentration in the control groups was 29 $\mu\text{g I/l}$ (KI groups) and
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2
3 197 28 µg I/l (Ca(IO₃)₂ groups) and increased to 382 µg I/l (KI groups) and 350 µg I/l (Ca(IO₃)₂)
4
5 198 groups) in the highest supplemented groups.

6
7
8 199 The results show that the I concentration of liver was at a higher level than meat and
9
10 200 also increased significantly with increasing feed I concentrations. I concentrations of liver
11
12 201 ranged from 22.4 to 173.4 µg I/kg in KI groups and from 28.1 to 181.3 µg I/kg in Ca(IO₃)₂
13
14 202 groups.

15
16
17 203 The transfer into the meat (pectoral) was below 0.17 ± 0.04 %. Hence the total I
18
19 204 content of meat was low compared with the other tissues investigated. The I concentrations of
20
21 205 pectoral and thigh meat were similar and increased significantly with increasing I content of
22
23 206 the feed. In KI groups, the I concentrations of pectoral meat ranged from 5.8 µg I/kg for the
24
25 207 control to 58.0 µg I/kg for the highest group and from 5.9 µg I/kg to 63.1 µg I/kg respectively
26
27 208 in thigh meat. Breast meat of Ca(IO₃)₂ groups contained between 7.0 µg I/kg in the control
28
29 209 and 52.1 µg I/kg in the highest supplemented group, and correspondingly 12.2 µg I/kg to
30
31 210 67.8 µg I/kg in thigh meat.

32 33 34 35 36 211 DISCUSSION

37 212 **Feed I concentrations**

38
39
40 213 The control feed met the I requirements of the broiler chickens (NRC, 1994). Since an I-free
41
42 214 premix was used this relatively high naturally occurring concentration must have been due to
43
44 215 feed ingredients.

45 46 47 216 **Growing performance**

48
49 217 The results regarding growing performance agree with previously published studies, which
50
51 218 found no significant impact on FI, BWG or FCR when similar feed I concentrations were
52
53 219 supplied (Perry *et al.*, 1989; Kaufmann and Rambeck, 1998; Maroufyan and Kermanshahi,
54
55 220 2006). These results show that the I concentrations used in the current study met the
56
57 221 requirements and did not exceed a critical level for the broilers.
58
59
60

222

223 **Slaughtering performance**

224 The results of the slaughtering performance are in accordance with previous studies, which
225 investigated the impacts of I supply at concentrations up to 10 mg I/kg and found no
226 significant effect (Kaufmann and Rambeck, 1998; Maroufyan and Kermanshahi, 2006). The
227 effect on thyroid weight observed in present study confirms the results of Travnicek *et al.*
228 (1999) who investigated the influence of dietary I concentrations between 0.3 (control) and
229 15 mg I/kg on histometric parameters and thyroid gland weight in layers over a 74-d period.
230 They found a decrease in the height of follicular cell-thyreocytes with increasing feed I
231 content, but no significant impact on thyroid weight. The present experiment showed that I
232 applications at moderate amounts below EU-regulations did not significantly affect the weight
233 of the thyroid gland. Further studies of the impact of I on thyroid glands of growing chickens,
234 histological investigations should be carried out to identify possible hyperplasia or
235 hypertrophy of the thyroidal follicle cells.

236 **I concentrations**

237 According to previous studies on egg I contents, the I content of the hatching eggs
238 corresponded with concentrations of eggs from laying hens provided with I concentrations of
239 approximately 1.6 mg I/kg (Roettger *et al.*, 2008).

240 The relatively high I concentrations in the blood serum can be explained by the intense
241 absorption of iodide in the small intestines, which occurs after ingestion and the reduction of
242 free I and iodate into iodide (Lewis, 2004). Subsequently, iodide enters the extracellular fluid
243 which includes blood plasma and interstitial fluid.

244 From the extracellular compartment, the sodium/iodide-symporter (NIS) actively
245 transports I into the thyroid gland. The concentration gradient between plasma and thyroid
246 can be 1 to 100 or more. The high I concentration measured in thyroid samples is enabled by
247 the active NIS-transport and is necessary for the thyroid function as an I reservoir and

1
2
3 248 endocrine gland for the synthesis of thyroid hormones. The lower carry-over in high
4
5 249 supplemented groups is caused by saturation, which occurs above a certain point of provision.
6
7
8 250 There are no data for I concentration in practical broiler diets. Grünewald *et al.* (2006)
9
10 251 investigated the actual I concentration of laying hen feed, which meets a mean I concentration
11
12 252 of 1.09 mg/kg (min/max: 0.5/ .16 mg I/kg); this corresponds with the I content supplied in
13
14
15 253 group 2 (1 mg I/kg) of the present study. Based on the data from this study, and at typical
16
17 254 dietary I inclusions, the I content of a thyroid gland would amount to $492 \pm 127 \mu\text{g}$ with KI
18
19 255 supplementation and $562 \pm 395 \mu\text{g}$ with $\text{Ca}(\text{IO}_3)_2$ supplementation. This exceeds the
20
21
22 256 recommended 200-mg daily I intake and agrees with the UL for an adult human suggested by
23
24 257 the D-A-CH. However, the risk for an oversupply through a consumption of the thyroid gland
25
26
27 258 remains minimal, because the thyroid is usually removed with oesophagus and trachea during
28
29 259 processing.

30
31 260 Thyroid hormones and I enter the liver *via* the *venae portae*. The liver is an important
32
33 261 location for deiodination of T_4 . If the outer ring is deiodinated, T_3 is generated, and
34
35 262 deiodination of the inner ring rT_3 is produced (Visser *et al.*, 1988). Because of this, a greater
36
37 263 accumulation of I was assumed for that tissue compared with meat. Groppe *et al.* (1991) and
38
39 264 Kaufmann and Rambeck (1998) investigated the influence of KI and KIO_3 supplementation
40
41 265 on the I content in tissues of male broiler chickens. In liver samples of the 1 mg I/kg
42
43 266 supplemented group they found $71.0 \mu\text{g I/kg}$ dry matter, assuming a 70.3 % water content for
44
45 267 the liver (Souci *et al.*, 2008), which amounts to $21.1 \mu\text{g I/kg}$ fresh matter. In the 0.9 mg I/kg
46
47 268 supplemented $\text{Ca}(\text{IO}_3)_2$ group of the present study, approximately double this concentration
48
49 269 ($44.1 \mu\text{g I/kg}$) was measured. Furthermore, in 10 mg I/kg-groups, Souci *et al.* found the same
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51 270 or only the 1.5 fold amount of the concentration found in this study at 5 mg supplementation,
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53 271 but this difference partly lay within the range of standard deviation. However, Stibilj and
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55 272 Holcman (2002) detected $31.7 \mu\text{g I/kg}$ with a supplementation of 0.66 mg I/kg in laying-hen

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3 273 feed. This agrees well with the data gained in this study; in comparable groups, KI birds
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5 274 showed 31.0 and $\text{Ca}(\text{IO}_3)_2$ birds 28.1 $\mu\text{g I/kg}$.

7
8 275 There are very few studies on the I concentration of fowl meat, in response to
9
10 276 moderate I supplementation. In studies of I concentration in the tissues of male broiler
11
12 277 chickens, Groppe *et al.* (1991) and Kaufmann and Rambeck (1998) found 73 $\mu\text{g I/kg}$ dry
13
14 278 matter in breast meat in response to a dietary I concentration of 1 mg I/kg. Converted to fresh
15
16 279 matter and assuming 70 % as water content of the meat (Souci *et al.*, 2008), this would be
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18 280 22 $\mu\text{g I/kg}$ fresh matter, which is in good agreement with the 22.9 $\mu\text{g I/kg}$ found in thigh meat
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20 281 of the 1 mg I/kg $\text{Ca}(\text{IO}_3)_2$ group of the present study. The I concentration of meat found in a
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22 282 group given a 10 mg I/kg-feed (115 $\mu\text{g I/kg}$ meat) was approximately double that found in the
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24 283 present study in the 5 mg I/kg supplemented groups (50 to 60 $\mu\text{g I/kg}$). At an I dosage of
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26 284 0.66 mg I/kg in laying-hen feed, Stibilj and Holcman (2002) reported an I content of
27
28 285 6.8 \pm 1.2 $\mu\text{g/kg}$ in muscle tissue. At comparable feed I concentrations, similar meat I
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30 286 concentrations were found in the present study (Tables 6 and 7).

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32 287 In studies investigating the influence of I supplementation on meat I concentration of
33
34 288 other livestock, it was concluded that the impact was rather minor. Franke *et al.* (2008) and
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36 289 Schöne *et al.* (2006) investigated the carry-over of I in pigs; Meyer *et al.* (2008) studied this
37
38 290 issue on fattening bulls. At I supplementations between 0.17 and 4.38 mg I/kg feed, Franke *et*
39
40 291 *al.* (2008) measured between 3.9 and 17.1 $\mu\text{g I/kg}$ in the muscle/fat fraction, Schöne *et al.*
41
42 292 (2006) detected up to 14.6 $\mu\text{g I/kg}$ meat at a supplementation of 3 mg I/kg feed and Meyer *et*
43
44 293 *al.* (2008) found a significant influence of feed I concentration on meat I concentration, but
45
46 294 these were still at a rather low level: 0.79 to 8.31 mg I/kg feed produced 16 to 147 $\mu\text{g I/kg}$ in
47
48 295 muscle.

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50 296 The German annual per capita consumption of chicken meat in 2007 was 18 kg
51
52 297 (Damme and Möbius, 2009). At the usual feed I dosages of 1 mg I/kg (Grünwald *et al.*,

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3 298 2006) and a median measured I concentration of 10.6 $\mu\text{g I/kg}$ in broiler meat (thigh and
4
5 299 pectoral), this meat would contribute with 0.5 $\mu\text{g I/d}$ to the daily I uptake in consumers. If the
6
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8 300 feed was enriched with 5 mg I/kg (median concentration of pectoral and thigh meat:
9
10 301 60.2 $\mu\text{g I/kg}$), the daily contribution would amount to 3.0 $\mu\text{g I/d}$. In comparison with the
11
12 302 recommended daily I intake of 200 μg for adults, it becomes obvious that meat of broiler
13
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15 303 chickens fed on EU guidelines is not a considerable I source. However, the European
16
17 304 guidelines should not be elevated above 10 mg I/kg feed, because the meat I concentration
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19 305 will not be remarkably elevated therewith, but high I doses could have possible adverse
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21 306 effects on broiler health and performance. A reduction of feed UL is not recommended as
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23
24 307 well because, at current levels, there is no risk for consumers due to the low carry-over into
25
26 308 the broiler meat, and furthermore the UL for feed iodisation is not exhausted in practice
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29 309 (Grünewald *et al.*, 2006). It can be positively reviewed that the consumption of chicken meat
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31 310 would not hold the risk for an over-dosage, if thyroid tissue is excluded from comestible
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34 311 production.

35
36 312 **Conclusion.** The study showed that neither of the two I sources at the applied concentrations
37
38 313 had a significant impact on growing and slaughtering performance. The investigations show
39
40 314 that the carry-over and accumulation into meat is marginal; thus, the contribution to the I
41
42 315 supply of consumers is considered as minor. The thyroid gland should be removed at
43
44 316 slaughtering to prevent over-consumption. However, the European guidelines on UL for
45
46 317 broiler feed should be retained because feed I concentration does not greatly influence the
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48 318 carryover into meat. An elevation could lead to possible adverse effects on health and
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50 319 performance of the birds, but a reduction is also not necessary because in practice the UL for
51
52 320 feed iodisation is not exhausted.

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57 321 Detailed studies concerning I metabolism and I distribution in different tissues in
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59 322 chicken are still lacking. Therefore more holistic studies with regard to carry-over into eggs,

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3 323 together with meat, blood serum, organs (especially thyroid gland) and the loss *via*
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5 324 excrements, as well as studies on long term effects of I supply, are necessary.

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407 **Table 1.** *Composition of the diets for KI and Ca(IO₃)₂ supplemented groups, without I*
 408 *supplementations*

Composition of the feed mixture (g/kg)		
Wheat		200.0
Maize		336.0
Soybean oil		42.9
Soybean meal		196.7
Dicalcium phosphate		22.0
Calcium carbonate		4.6
Salt		3.2
DL-Methionine		2.9
L-Lysine-HCl		1.7
Soy beans		180.0
Mineral/vitamin premix ¹		10.0
<i>Analysed and calculated composition (g/kg)</i>	<i>KI</i>	<i>Ca(IO₃)₂</i>
Dry matter	902.4	893.6
Crude protein (CP)	196.6	190.3
Crude fat (EE)	95.0	102.7
Starch (ST)	364.3	352.2
Sugar (S)	47.8	38.7
Lysine ²	12.5	12.5
Methionine + cysteine ²	9.6	9.6
Methionine ²	6.0	6.0
Metabolisable Energy (MJ/kg) ³	13.01	12.86

409 ¹Content per kg premix: 360 mg vitamin A, 75 mg cholecalciferol, 3000 mg 2-
 410 *ambo*- α -tocopherol, 200 mg thiamin, 480 mg riboflavin, 360 mg pyridoxine,
 411 1.5 mg cyanocobalamin, 300 mg menadione, 2700 mg nicotinic acid, 900 mg Ca-
 412 pantothenic acid, 90 mg folic acid, 5 mg biotin, 80000 mg choline chloride,
 413 5000 mg Fe, 1500 mg Cu, 12000 mg Mn, 8000 mg Zn, 40 mg Se, 55 mg Co.

414 ²Calculated from amino acid contents of feeds.

415 ³Calculated *via* the energy estimation formula, of the WPSA (1984).
 416

417 **Table 2.** Mean \pm SD feed intake (FI), body weight gain (BWG) and feed conversion
 418 ratio (FCR) of broilers fed diets supplemented with KI to give I concentrations of 0, 1, 2.5 or 5
 419 mg/kg ($n = 6$)

Iodine supplementation (mg I/kg feed)	FI (g/d)	BWG (g/d)	FCR (kg/kg)
0 – 14 d			
0	39.3 \pm 1.5	30.9 \pm 1.7	1.25 \pm 0.02
1.0	37.8 \pm 1.2	30.4 \pm 1.6	1.24 \pm 0.03
2.5	39.3 \pm 0.5	31.2 \pm 0.7	1.26 \pm 0.02
5.0	38.1 \pm 1.2	30.5 \pm 1.6	1.25 \pm 0.03
14 – 21 d			
0	99.0 \pm 3.6	72.0 \pm 2.2	1.37 \pm 0.04
1.0	97.5 \pm 3.0	71.7 \pm 2.1	1.36 \pm 0.01
2.5	101.0 \pm 2.8	72.9 \pm 3.0	1.39 \pm 0.06
5.0	97.9 \pm 2.9	71.2 \pm 2.2	1.38 \pm 0.01
21 – 35 d			
0	156.9 \pm 5.6	93.3 \pm 3.9	1.68 ^a \pm 0.03
1.0	154.9 \pm 5.6	94.3 \pm 4.6	1.64 ^{ab} \pm 0.04
2.5	160.5 \pm 7.4	98.8 \pm 5.2	1.63 ^{ab} \pm 0.04
5.0	157.4 \pm 6.0	97.7 \pm 3.2	1.61 ^b \pm 0.05
0 – 35 d			
0	98.3 \pm 3.4	64.1 \pm 2.3	1.53 ^a \pm 0.02
1.0	96.5 \pm 2.6	64.2 \pm 2.1	1.50 ^{ab} \pm 0.01
2.5	100.1 \pm 3.5	66.6 \pm 2.3	1.50 ^{ab} \pm 0.02
5.0	97.7 \pm 3.2	65.5 \pm 1.7	1.49 ^b \pm 0.02

420 ^{a,b}Within a column and time period, means without a common superscript are significantly
 421 different at $P < 0.05$.
 422

Table 3. Mean \pm SD feed intake (FI), body weight gain (BWG) and feed conversion ratio (FCR) of broilers fed diets supplemented with $\text{Ca}(\text{IO}_3)_2$ to give I concentrations of 0, 1, 2.5 or 5 mg/kg ($n=6$)

Iodine supplementation (mg I/kg feed)	FI (g/d)	BWG (g/d)	FCR (kg/kg)
0 – 14 d			
0	36.9 \pm 1.0	29.8 \pm 0.9	1.24 \pm 0.01
1.0	36.9 \pm 1.5	30.0 \pm 1.5	1.23 \pm 0.03
2.5	37.2 \pm 1.7	30.3 \pm 1.5	1.23 \pm 0.02
5.0	36.9 \pm 0.8	30.1 \pm 0.7	1.23 \pm 0.01
14 – 21 d			
0	94.2 \pm 4.0	70.6 \pm 3.2	1.33 \pm 0.04
1.0	95.4 \pm 4.3	70.2 \pm 3.7	1.36 \pm 0.02
2.5	94.4 \pm 5.0	69.7 \pm 4.0	1.35 \pm 0.03
5.0	93.6 \pm 2.1	67.9 \pm 2.3	1.38 \pm 0.02
21 – 35 d			
0	163.6 \pm 6.2	107.2 \pm 4.0	1.53 \pm 0.04
1.0	159.6 \pm 7.3	102.8 \pm 5.6	1.55 \pm 0.06
2.5	160.0 \pm 5.5	102.7 \pm 2.8	1.56 \pm 0.05
5.0	158.0 \pm 5.9	100.6 \pm 5.2	1.57 \pm 0.04
0 – 35 d			
0	98.1 \pm 4.7	68.9 \pm 1.9	1.42 \pm 0.04
1.0	97.3 \pm 3.8	67.2 \pm 2.9	1.45 \pm 0.04
2.5	97.4 \pm 3.6	67.1 \pm 2.0	1.45 \pm 0.03
5.0	95.9 \pm 2.8	65.8 \pm 2.1	1.46 \pm 0.02

426

427 **Table 4.** Mean \pm SD organ and fraction weights of broilers fed diets supplemented with KI to
 428 give I concentrations of 0, 1, 2.5 or 5 mg/kg (n = 6)

	Iodine supplementation (mg/kg)			
	0	1.0	2.5	5.0
Final body weight (g)	2211.2 \pm 120.4	2184.7 \pm 53.4	2226.8 \pm 49.2	2296.0 \pm 82.3
Pectoral meat (g)	349.5 \pm 40.6	323.0 \pm 16.2	341.8 \pm 30.1	347.1 \pm 13.6
Breast skin (g)	28.5 \pm 6.4	25.4 \pm 3.3	25.7 \pm 3.7	25.1 \pm 3.8
Thigh (g)	437.9 \pm 18.7	439.1 \pm 11.8	439.9 \pm 33.9	445.6 \pm 13.6
Heart (g)	11.1 \pm 2.3	11.0 \pm 1.3	9.6 \pm 0.3	10.8 \pm 1.4
Liver (g)	46.7 \pm 3.7	44.4 \pm 2.6	47.2 \pm 1.2	49.5 \pm 4.5
Spleen (g)	1.95 \pm 0.48	1.74 \pm 0.11	1.95 \pm 0.32	2.07 \pm 0.33
Ventriculus (g)	28.8 \pm 7.2	24.2 \pm 4.2	22.2 \pm 4.7	23.7 \pm 4.5
Abdominal fat pad (g)	27.0 \pm 11.3	32.9 \pm 6.9	34.3 \pm 6.9	38.7 \pm 6.2
Thyroid gland (g)	0.14 \pm 0.03	0.15 \pm 0.03	0.17 \pm 0.06	0.16 \pm 0.05

429 **Table 5.** Mean \pm SD organ and fraction weights of broilers fed diets supplemented with
 430 $Ca(IO_3)_2$ to give I concentrations of 0, 1, 2.5 or 5 mg/kg ($n = 6$)

	Iodine supplementation (mg/kg)			
	0	1.0	2.5	5.0
Final body weight (g)	2285.8 \pm 39.8	2340.5 \pm 82.8	2302.5 \pm 55.8	2284.3 \pm 37.7
Pectoral meat (g)	348.5 \pm 34.2	377.6 \pm 44.6	383.6 \pm 45.5	374.9 \pm 34.4
Breast skin (g)	27.9 \pm 2.9	29.2 \pm 8.3	31.8 \pm 5.7	30.2 \pm 5.4
Thigh (g)	471.2 \pm 12.8	469.7 \pm 27.8	472.4 \pm 17.0	474.5 \pm 28.3
Heart (g)	12.4 \pm 1.3	11.4 \pm 1.4	10.81.3 \pm	11.4 \pm 1.5
Liver (g)	44.7 \pm 2.4	45.3 \pm 3.9	44.2 \pm 3.5	45.5 \pm 2.7
Spleen (g)	2.08 \pm 0.17	2.40 \pm 0.49	2.03 \pm 0.34	2.20 \pm 0.30
Ventriculus (g)	25.0 \pm 3.7	30.2 \pm 6.0	28.2 \pm 6.6	27.5 \pm 4.3
Abdominal fat pad (g)	32.4 \pm 8.8	27.3 \pm 4.5	32.3 \pm 6.4	28.1 \pm 5.1
Thyroid gland (g)	0.23 \pm 0.13	0.17 \pm 0.04	0.18 \pm 0.07	0.17 \pm 0.04

431 **Table 6.** *I* concentration of samples collected from broilers fed diets supplemented with KI to
 432 give *I* concentrations of 0, 1, 2.5 or 5 mg/kg (median, Q25, Q75; n=6)

		Iodine supplementation (mg/kg)											
		0			1.0			2.5			5.0		
Pectoral meat	(µg/kg)	5.8 ^c	5.0	7.0	10.3 ^{bc}	9.1	10.4	39.3 ^{ab}	37.1	42.9	58.0 ^a	52.3	59.5
Thigh meat	(µg/kg)	5.9 ^b	5.5	7.3	6.9 ^b	6.1	9.4	38.6 ^{ab}	32.3	44.8	63.1 ^a	58.2	66.1
Liver	(µg/kg)	22.4 ^c	20.0	24.7	31.0 ^{bc}	27.2	35.4	103.6 ^{ab}	97.8	131.9	173.4 ^a	163.8	197.1
Blood serum	(µg/l)	29.1 ^c	27.2	30.3	50.0 ^{bc}	41.9	68.5	226.4 ^{ab}	221.5	305.6	382.4 ^a	366.3	430.8
Thyroid gland	(µg/g)	2317 ^b	1991	2385	3315 ^{ab}	3071	3448	4599 ^a	4304	4812	5053 ^a	4446	5899

433 ^{a,b,c} Within a row, means without a common superscript are significantly different at $P < 0.05$.

434 **Table 7.** *I concentration of samples collected from broilers fed diets supplemented with*
 435 *Ca(IO₃)₂ to give I concentrations of 0, 1, 2.5 or 5 mg/kg (median, Q25, Q75; n=6)*

		Iodine supplementation (mg/kg)											
		0			1.0			2.5			5.0		
Pectoral	(µg/kg)	7.0 ^c	6.3	8.7	11.5 ^{bc}	10.6	12.7	27.9 ^{ab}	25.1	30.8	52.1 ^a	48.5	54.9
meat													
Thigh	(µg/kg)	12.2 ^b	11.3	16.7	22.9 ^b	12.8	28.8	37.7 ^{ab}	35.6	41.1	67.8 ^a	62.9	78.4
meat													
Liver	(µg/kg)	28.1 ^c	27.5	32.1	44.1 ^{bc}	41.9	47.6	104.5 ^{ab}	97.7	112.0	181.3 ^a	175.0	198.7
Blood	(µg/l)	28.2 ^c	23.8	34.1	50.5 ^{bc}	48.0	68.9	179.4 ^{ab}	172.9	198.9	349.9 ^a	318.5	386.5
serum													
Thyroid	(µg/g)	2323 ^b	1927	2723	3170 ^{ab}	2960	3517	3117 ^{ab}	2740	4206	3652 ^a	3154	3840
gland													

436 ^{a,b,c} Within a row, means without a common superscript are significantly different at $P < 0.05$.