Diet-induced thermogenesis and feed intake in poultry: broiler versus layer cockerels

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Research with adult mammals has shown that the diet-induced thermogenesis (DIT) related to the oxidation of macronutrients has a negative feedback on feed intake (FI), depending on the nutrient considered: proteins are combusted first, then carbohydrates and finally fat, corresponding to their satiating ability. However, previous studies revealed no significant differences in DIT between broilers reared on isocaloric low protein-high fat or high protein-low fat diets. The link between DIT and FI might be less distinct in broilers, which are characterized by a voracious appetite compared to layer strains. This study aimed to investigate the role of DIT in the regulation of FI in broiler and layer chickens. Also, the strain effect on plasma metabolite and hormone levels was studied.

Day-old male broiler (Ross) and layer (ISA Brown) chicks were reared under standard conditions on a commercial broiler diet. From 22 days of age, twice per week, 3 broilers and 6 layers were placed in six open circuit respiratory chambers. After adaptation, the animals were fasted for one day, and fasting heat production (HP) was measured by indirect calorimetry. During the subsequent 7 hour refeeding period, FI as well as DIT was measured. Blood samples were taken after fasting and refeeding.

During fasting and refeeding, the cockerels had a significantly higher HP per metabolic body weight (kg^{0.75}, MBW) than the broilers. This suggests that the broiler chickens use a greater proportion of the metabolisable energy intake for growth. The DIT per MBW and per FI was on average 320 % higher for the cockerels than for the broilers. However, FI per MBW was significantly higher in the cockerels. Thus, no feedback effect of DIT on FI per MBW was observed and the model formulated for adult mammals, relating DIT to FI could not be corroborated.

The level of 3,5,3’-triiodothyronine in the plasma of the cockerels was elevated compared to the broilers, which was statistically verifiable after fasting, confirming the higher HP in the layer cockerels. Circulating uric acid, glucose, triglyceride and free fatty acid levels were significantly elevated in the layer cockerels. As the diet was formulated according to the requirements of broilers, these higher metabolite levels of the layer cockerels might reflect a relative oversupply of dietary nutrients.

**Keywords:** feed intake regulation; diet-induced thermogenesis; broiler chickens; layer chickens

**Introduction**

The regulation of voluntary feed intake is a very complex and multifactorial mechanism, with numerous levels of control. Several models have been proposed in an attempt to comprehend the mechanisms that match energy and nutrient balance with feed intake and energy expenditure to maintain body homeostasis in mammals. One of the models linking diet-induced thermogenesis to feed intake in adult mammals is the hierarchic oxidation/storage model (Stubbs and O’Reilly, 2000). The DIT related to the oxidation of macronutrients has a negative feedback effect on feed intake, depending on the macronutrient: proteins are combusted first, followed by carbohydrates and finally...
fat, corresponding to their ability to induce satiety. However, in broiler chickens, previous research using diets with isocaloric substitutions between fat and protein but with constant carbohydrate levels, revealed no statistically verifiable effects on diet-induced thermogenesis (DIT) or on feed intake (Swennen et al., 2004). When genetically lean and fat broiler chickens (Leclercq et al., 1980) were raised on similar isocaloric diets, again no significant effect of diet composition or genetic background on DIT could be observed (Swennen et al., 2006). Therefore, the macronutrient ratio in the diet might not influence DIT in growing broiler chickens in contrast to observations in adult mammals. A possible explanation could be that the impact of DIT on feed intake is less important as an appetite regulation mechanism in the broiler chicken, characterized by a voracious appetite (Dunnington and Siegel, 1996). Hence, it would be interesting to compare broiler chickens with poultry genotypes that have not been selected for growth, such as layer chickens, to investigate the mechanisms involved in feed intake regulation.

Important objectives of the present study were to investigate the role of diet-induced thermogenesis in the control and regulation of voluntary food intake in age-matched broiler and layer chickens. Furthermore, the effect of genetic background on endocrine functioning and key metabolites of the intermediary nutrient metabolism was studied.

**Materials and methods**

Fifty day-old male chicks of a broiler genotype (Ross) were obtained from a local hatchery (Avibel, Zoersel, Belgium). Fifty day-old male chicks of a medium weight, brown egg layer type strain (ISA Brown) were purchased on the same day from another hatchery (VEPYMO, Poppel, Belgium). The chicks were divided over two floor pens (each genotype in a separate pen) in an environmentally controlled poultry house with wood shavings as litter. The temperature was set at day-old at 35 °C and was gradually decreased with 1 °C every 1 to 2 or 4 to 5 days, reaching a final or end temperature at 30 days of age of 19 °C or 24 °C for the broiler chickens and the layer cockerels, respectively. The chickens received a commercial broiler starter (until 21 days) and finisher (from 22 days) diet *ad libitum* (diet composition: Buyse et al., 2001). A representative number of chickens per genotype was weighed on a weekly basis. From 22 days of age, and repeated two times per week for four consecutive weeks, each time with different animals, three broiler chickens and six (three pairs) cockerels were housed in one of six open circuit respiratory cells (Buyse et al., 1998). The animals had feed and water *ad libitum* at their disposal. The same environmental conditions were used as for their floor-reared counterparts. After a 24 h adaptation period, the animals were feed-deprived for 24 hours though with drinking water available. Then they were given a preweighed amount of feed during seven consecutive hours for measuring diet-induced thermogenesis (DIT) as well as feed intake. After the adaptation period, gas exchanges ($O_2$ and $CO_2$) were measured continuously during the 24 h feed-deprivation and the 7 h refeeding period. Heat production was calculated from these data according to the short formula of Romijn and Lokhorst (1961): Heat production (kJ/h) = 16.18 $O_2$ (l/h) + 5.02 $CO_2$ (l/h). The individual body weight of the chickens was recorded before and after feed deprivation and after the refeeding period, when feed intake was also determined. Blood samples were collected after feed deprivation and after refeeding from a wing vein using a heparinised syringe and were immediately put on crushed ice. Plasma glucose, triglycerides, free fatty acids and uric acid concentrations were measured spectrofotometrically with an automated apparatus (Monarch Chemistry System, Instrumentation Laboratories, B-1930, Zaventem, Belgium). Plasma 3,5,3'-triiodothyronine ($T_3$) and thyroxine ($T_4$) concentrations were measured using a specific radioimmunoassay (Darras et al., 1992). This research protocol was approved by the Ethical Commission for Experimental Use of Animals of the K.U.Leuven.

All results were analyzed by ANOVA with genotype as classification variable (SAS for Windows, version 8e, SAS Institute Inc., Cary, NC., 1998).
Results and discussion

The effect of the genetic background on the weekly body weight (BW) is presented in figure 1A. Already at hatch, the broiler chickens had a significantly higher body weight compared to the layer cockerels (P < 0.0001). The layer chickens had a significantly (P < 0.05) higher feed intake (FI) per MBW during the 7 h refeeding period in the respiratory cells compared to the broilers (Figure 1B). Therefore, the difference in feed intake as such can not be the only factor determining the divergence in body weight between both genotypes.

![Figure 1. A) Weekly body weight (g/bird) of broiler chickens (●) and cockerels of a layer strain (○) reared on a commercial broiler starter and finisher diet. Values are means ± SEM (hatch and week 1 until week 5: n = 20 per genotype; week 5 and 6: n = 10 per genotype). B) Feed intake during the 7 h refeeding period of broiler chickens and cockerels of a layer strain on a commercial finisher diet. Values are means ± SEM (n = 24 per genotype). A significant difference between genotypes is indicated by *P < 0.05, ***P < 0.0001.](image)

During feed deprivation, the layer cockerels had a significantly elevated heat production (HP) per MBW and per day compared to the broilers (P < 0.05) (figure 2A). This difference between both genotypes was even more pronounced during the 7 h refeeding period (P < 0.0001) (figure 2B). To assess the diet-induced thermogenesis, the difference between the average value for HP during the last 8 h of feed deprivation and the HP at every measuring point during the refeeding period was calculated. The DIT was then calculated as the area under the heat production curve during the refeeding period and was expressed as a fraction of the feed intake during that interval. The DIT per MBW, per 7 h and corrected for feed intake was significantly (P < 0.0001) higher for the layer cockerels than for the broilers. The average difference between the genotypes was 320 % (Figure 2C).

The metabolisable energy absorbed from the ingested feed is used for maintenance on one hand and for production on the other hand. The energy used for maintenance can be partitioned in the basal metabolism, the energy expended on physical activity and the diet-induced thermogenesis (DIT) for maintenance. During the feed deprivation period, the layer cockerels had an elevated HP compared to the broiler chickens, indicating a higher basal metabolism in the former group. Although physical activity was not assessed in this experiment, previous research has revealed that broilers spend more time resting than layers do, suggesting that the total energy expended on activity by broiler chickens was considerably less compared to that of chickens of a layer type (Masic et al., 1974; Hocking et al., 1997). And finally, the DIT per gram feed intake was higher in the layer cockerels, demonstrating a higher use of metabolisable energy for digestion compared to broiler chickens. Taken together, these data reveal that broiler chickens were more efficient in retaining metabolisable energy for productive purposes.

In previous studies, the hierarchic oxidation model as formulated by Stubbs and O’Reilly (2000) for adult mammals could not be corroborated nor refuted for growing broiler chickens (Swennen et al., 2004, 2006). It is possible that the dietary macronutrient ratio does not affect the DIT and possibly also satiety in broiler chickens to the same degree as observed in mammals. Thus, the mechanisms linking DIT to feed intake might be disturbed or less active in the broiler chicken. This could be a result of intensive selection for growth rate, which resulted in a voracious appetite (Denbow, 1994;
Dunnington and Siegel, 1996). Therefore, it could be inferred that chickens of a layer strain, and thus not selected for growth, might show a stronger relation between DIT and feed intake. However, DIT per gram feed intake as well as feed intake during the 7 h refeeding period were significantly higher in the layer cockerels compared to the broiler chickens. Therefore, there does not seem to be an effect of DIT on feed intake in either genotype.

The effects of refeeding after feed deprivation on plasma levels of metabolites and hormones have been discussed previously (Buyse et al., 2002; Swennen et al., 2005) and will not be repeated here. No interactions between nutritional state and genotype were observed for any of the parameters.

The genotype effects on circulating metabolites and hormones for each nutritional state are presented in table 1. Circulating free fatty acid and triglyceride levels were significantly higher in the plasma of the layer cockerels compared to the broiler chickens, independent of the nutritional state (P < 0.05 after 24 h feed deprivation; P < 0.0001 after 7 h refeeding). After 24 h of feed deprivation, plasma glucose and uric acid levels were somewhat elevated in the plasma of the cockerels compared to the broiler chickens, although not statistically verifiable. After the 7 h refeeding period, this effect of the genotype was much clearer for both metabolites (P < 0.05). As the diet used in this experiment was formulated according to the requirements of broiler chickens, the higher metabolite levels in the plasma of the layer compared to the broiler chickens might reflect a relative oversupply of dietary nutrients in the former group.

The levels of T3 in the plasma of the layer cockerels were augmented compared to the levels in the plasma of the broiler chickens, though this genotypic difference was statistically verifiable only in the feed-deprived state (P < 0.05). As the level of T3 in the plasma is positively correlated with heat production (Klandorf et al., 1981), this corroborates the elevated feed-deprived HP in the layer cockerels. However, after refeeding, the difference in T3 concentrations between the genotypes...
disappeared, although the HP remained higher in the layer chickens. It is possible that a larger proportion of the T₃ is taken up by the cells for binding to its nuclear receptor, thus increasing HP. Independent of the nutritional state of the animals, T₄ concentrations were significantly (P < 0.001) lower in the plasma of the cockerels when compared to the broilers. This inversely related pattern of T₃ and T₄ levels due to genotype points to the T₃-driven feedback on thyroid functioning and hence T₄ production (Decuypere and Kühn, 1988).

Table 1. The effect of genotype (broiler versus layer chicken) on circulating metabolite and hormone levels per nutritional state (24 h feed-deprived or 7 h refed).

<table>
<thead>
<tr>
<th>Metabolites</th>
<th>Broiler</th>
<th>Layer</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feed-deprived</td>
<td>Refed</td>
<td>Feed-deprived</td>
</tr>
<tr>
<td>Free fatty acids</td>
<td>0.59 ± 0.04</td>
<td>0.25 ± 0.01</td>
<td>0.84 ± 0.04</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>18.6 ± 1.2</td>
<td>76.2 ± 4.8</td>
<td>23.3 ± 1.1</td>
</tr>
<tr>
<td>Glucose</td>
<td>240 ± 3</td>
<td>308 ± 5</td>
<td>248 ± 2</td>
</tr>
<tr>
<td>Uric acid</td>
<td>4.3 ± 0.3</td>
<td>4.8 ± 0.2</td>
<td>4.8 ± 0.4</td>
</tr>
<tr>
<td>Hormones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T₃</td>
<td>0.62 ± 0.06</td>
<td>1.97 ± 0.08</td>
<td>0.80 ± 0.04</td>
</tr>
<tr>
<td>T₄</td>
<td>14.1 ± 0.7</td>
<td>5.4 ± 0.5</td>
<td>10.2 ± 0.7</td>
</tr>
</tbody>
</table>

In conclusion, broiler chickens were more efficient in retaining metabolisable energy for productive purposes compared to cockerels of a layer line. In spite of an elevated diet-induced thermogenesis, the layer chickens also had a higher feed intake during the 7 h refeeding period than the broiler chickens. Therefore, the model of Stubbs and O’Reilly (2000) could not be corroborated or in other words, diet-induced thermogenesis had no feedback effect on feed intake in these strains of chickens. The elevated levels of metabolites in the plasma of the layer chickens compared to the broiler chickens might reflect a relative oversupply of nutrients in the former group. The elevated circulating T₃ levels during feed deprivation in the layer chickens corroborated the increased heat production compared to the broilers.

References


nd Symposium on Energy Metabolism, pp 46-59, European Association for Animal Production, Lunteren, the Netherlands.