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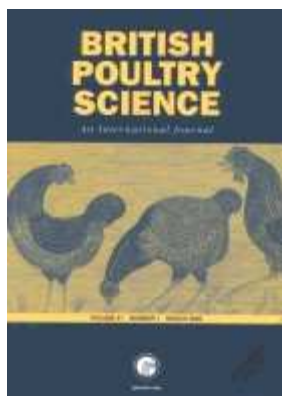
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Divergent selection for shape of growth curve in Japanese quail.

4. Carcass composition and thyroid hormones

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Divergent selection for shape of growth curve in Japanese quail. 4. Carcass composition and thyroid hormones

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RUNNING TITLE: GROWTH CURVE AND CARCASS COMPOSITION

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3 **Abstract** 1. Changes in the relative weights of carcass, abdominal fat, breast and leg muscles,
4 and plasma thyroid hormone concentrations occurring during the first 6 weeks of postnatal
5 growth were analysed in males of HG and LG lines divergently selected for high and low
6 relative body weight (BW) gain between 11 and 28 d of age, respectively, and constant adult
7 BW.
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15 2. The second week of postnatal life was a critical age at which the HG males exhibited a
16 relatively faster growth in comparison than their LG counterparts and permanently exceeded
17 LG males in the percentage by weight of carcass, breast and leg muscle. A higher production
18 of muscle tissues was associated with lower accumulation of abdominal fat before sexual
19 maturity.
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27 3. In general, the plasma T_3 level of HG quail exceeded that of LG quail. Nevertheless,
28 significant differences were found only at 14, 21 and 28 d of age, *i.e.* in the period during
29 which the highest inter-line differences in relative growth rate were noted. Also the T_3/T_4
30 ratio followed a similar trend while plasma T_4 level showed no clear and consistent inter-line
31 differences.
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39 4. The results suggest that the selection for the shape of the growth curve, like the selection
40 for body fat, modifies the carcass quality owing to shortening/prolongation of acceleration
41 growth phase. Individuals with a short acceleration phase of the growth curve are
42 characterised by low carcass quality during the fattening period.
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48 INTRODUCTION

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50 Lean and fat broiler chicken lines established by several research teams (Leclercq *et al.*, 1980;
51 Whitehead and Griffin, 1984; Sørensen, 1984; Cahaner *et al.*, 1986; Leenstra and Pit, 1987)
52 were subsequently studied in order to understand the physiological pathway leading to the
53 excessive fatness (Buyse *et al.*, 1999) that represented a negative correlated response
54 accompanying long-term selection for a high juvenile growth rate in broiler parent flocks
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3 (McCarthy and Siegel, 1983). Although these experimental lines differed in origin and
4
5 selection strategy used for their formation, comparative analyses revealed that all lean broiler
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7 chickens had a better food and protein conversion efficiency, higher susceptibility to
8
9 suboptimal dietary protein level, and usually a higher breast weight percentage than their fat
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11 counterparts. With respect to energy metabolism, the most striking differences between lean
12
13 and fat broilers were observed in the differential partition of the retained energy between
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15 muscle and adipose tissues. In terms of the selection criteria, considerable differences were
16
17 found only in endocrine parameters. Whereas the indirect selection for leanness (for low
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19 conversion ratio) enhanced the pulsative growth hormone release, direct selection for fat
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21 content (for abdominal fat or plasma level of very low density lipoproteins - VLDL) had a
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23 significant effect on the thyrotrophic axis (Buyse *et al.*, 1999).
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30 These observations on fat and lean selection lines provided more insight into the
31
32 physiology of excessive fatness and extended a practical tool for poultry breeders. In addition,
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34 correlated responses in the growth of lean and fat chickens (Leenstra and Pit, 1987; Leclercq
35
36 *et al.*, 1989) implied that genetical changes in the growth pattern could be the primary
37
38 mechanism causing the relatively high fat content of broilers selected solely for BW.
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40 Nevertheless, the direct relationship between the genetical manipulation of the growth curve
41
42 and the increase of body fat content has not been unambiguously clarified. One could ask why
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44 the same selection strategy initially increased the growth potential (quantitative change of
45
46 body mass), while subsequently it modified the carcass composition in favour of fat
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48 (qualitative change of body mass).
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54 Our previous study on quail lines selected for high (HG) and low (LG) relative BW
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56 gain during early age (Hyánková and Novotná, 2007) suggested that this qualitative change
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58 could be induced by an extreme shortening of the acceleration phase of the growth curve due
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60 to the gradual decrease of selection age during long-term selection for BW. To support this

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3 assumption, we carried out several comparative studies using the same quail lines, with
4 special reference to the traits exhibiting significant differences between the lean and fat
5 chicken lines directly selected for body fat (Buyse *et al.*, 1999). The goal of the present study
6 was to analyse the differences between the HG and LG lines in (a) carcass composition in
7 terms of body parts and (b) plasma thyroid hormone, 3, 3',5 triiodothyronine (T₃) and
8 thyroxine (T₄), levels.
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17 18 MATERIALS AND METHODS 19

20 21 **Quail, housing and management** 22

23 The HG and LG lines were selected for high and low relative BW gain between 11 and 28 d
24 of age ($RG_{11-28} = (BW_{28} - BW_{11}) / BW_{28}$), respectively, to modify the slope of the linear part
25 of the growth curve. In a second selection step, BW at 49 d of age (90 – 95 % of adult BW)
26 was kept similar for both lines, approximately at the level of the control C line. Details
27 concerning the selection process and husbandry of the lines have been reported previously
28 (Hyánková *et al.*, 2001).
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38 In the present study, the quail were the progeny of generation 18 obtained from a
39 single hatch. One-d-old quail were placed into plastic boxes. At 14 d of age, they were
40 transferred into a rearing room with a grating floor, where the lines were kept separately (1
41 pen/line) for one week and then they were intermingled. Stocking density, temperature and
42 light regimes, as well as the composition of diets were the same as during the selection phase
43 (Hyánková *et al.*, 2001).
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53 **Growth pattern and carcass composition** 54

55 All males of both lines were weighed weekly from hatching to 70 d of age. Twenty males
56 per line were sacrificed by cervical dislocation at each week between 7 and 42 d of age.
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3 Subsequently, their defeathered and eviscerated carcasses, breast and leg muscles, abdominal
4 fat depots, and testes were weighed.
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7 **Plasma thyroid hormone concentrations**

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10 Plasma thyroxine (T₄) and 3, 3',5 triiodothyronine (T₃) concentrations were determined in the
11 same age categories as carcass composition (10 males per line and age). Blood samples
12 obtained from cervical arteries before killing the birds were collected in heparinised tubes and
13 immediately centrifuged. The plasma was stored at -20°C until T₃ and T₄ were assayed by
14 radioimmunoassay (RIA) as previously described (Beck *et al.*, 2006). All samples were
15 analysed in a single assay. The T₃ RIA had a detection limit of 2 fmol and an intra-assay
16 variability of 2.2%. The T₄ RIA had a detection limit of 5 fmol and an intra-assay variability
17 of 2.8%. Increasing amounts of T₃ or T₄ added to quail plasma were accurately detected,
18 confirming there was a good parallelism with the standard curve.
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31 **Statistical analysis**

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33 The data were analysed using the general linear model procedure of the Statistical Analysis
34 System (SAS Institute Inc., 1989) according to the model :

$$35 y_{ij} = \mu + g_i + e_{ij}$$

36
37 where y_{ij} is the value of j th individual belonging to i th line, μ is the general mean, g_i is the
38 effect of i th line, e_{ij} is residual effect. Unless otherwise stated, all statements of significance
39 were based on testing at the $P < 0.05$ level.
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50 **RESULTS**

51 **Postnatal growth pattern**

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53 The growth pattern of the HG and LG lines was considerably different as a consequence of
54 selection (Figure 1a). HG males exhibited lower body weight (BW) than LG males until 21 d
55 of age. Around 24 d of age, the growth curves of the two lines crossed one another, and from
56 28 d of age, the HG line demonstrated continuously higher BW than the LG one. Differences
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3 between the lines resulted from a different growth rate of the lines during two postnatal
4 periods (Figure 1b). Whereas LG males grew relatively faster than HG males up to 7 d of age,
5
6 the opposite was true from 7 to 35 d of age.
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Figure 1 & Table 1 near here

9 10 **Carcase composition**

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12 Differences between HG and LG quail in absolute weights of carcass, breast and leg muscles
13 were dependent on BW achieved at given age (Table 1). A higher BW of LG vs HG males
14
15 between 7 and 21 d of age was associated with higher weight of all analysed body parts in LG
16
17 than HG males. From 28 d of age, the situation changed in favour of HG males.
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22 In contrast to absolute weights, the relative weights of carcass, breast and leg muscles
23 (percentage of BW) were independent of BW achieved at given age (Table 2, Figure 1a).
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25 Except for the first week of life, when LG quail had a higher percentage of all analysed body
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27 parts than HG quail, the percentage of carcass, breast and leg muscles in HG quail exceeded
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29 that observed in LG quail (Table 2, Figure 1b,c). This corresponded with actual growth rate of
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31 the lines – the higher relative growth rate was achieved at given age, the higher proportional
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33 weights of carcass, breast and leg muscles were noted. In addition, a lower percentage of
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35 abdominal fat in HG vs LG quail at 14 and 21 d of age suggested that a relatively higher
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37 production of muscle tissues was simultaneously associated with a lower accumulation of
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39 body fat. The difference in abdominal fat disappeared at 28 d of age, when the growth of
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41 testes in both lines indicated sexual maturation.
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Figure 2 & Table 2 near here

47 48 **Plasma thyroid hormone concentrations**

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50 Plasma T₄ level showed no consistent line- or age-related pattern during the analysed growth
51
52 period (Figure 2a). In contrast, plasma T₃ level decreased with age in both lines with
53
54 generally higher values in HG than in LG quail (Figure 2b) although the differences between
55
56 lines were statistically significant only at 14, 21 and 28 d of age, i.e. during the age-period of
57
58 maximum HG and LG differences in relative growth rate (Figure 2b and 1c).
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3 Also the plasma T_3/T_4 ratio decreased with increasing age and exhibited considerable
4 differences between lines with HG quail tending to higher values than LG quail (Figure 2c).
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7 8 DISCUSSION

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10 Correlated responses accompanying the selection processes of quail and chickens may be
11 compared providing that inter-species differences in physiological age are respected. Reports
12 describing the growth curve with a mathematical function suggest that the inflection point of
13 the growth curve, *i.e.* the end of acceleration phase and the onset of retardation phase, varies
14 in the meat-type chickens between 6 and 9 weeks of age depending on selection traits used for
15 their formation (Leclercq *et al.*, 1989; Knížetová *et al.*, 1991; 1995; Mignon-Grasteau *et al.*,
16 2000). In contrast, in the meat-type quail this was usually observed between 2 and 3 weeks of
17 age (Marks 1978; Anthony *et al.*, 1991; Hyánková *et al.*, 1998; 2001; 2002). Hence, in the
18 present study the experimental period covered both acceleration and retardation growth
19 phases until the onset of sexual maturity, while a comparative study of lean and fat chickens
20 at 4 and 7 weeks of age (Buyse *et al.*, 1999) was limited only to the second half of the
21 acceleration phase and the early part of the retardation phase.
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38 **Carcase composition**

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40 Differences in the proportion of body parts between the HG and LG lines during the
41 acceleration growth phase demonstrated that correlated responses in quail fully corresponded
42 to those in chickens. HG males, similarly to lean chickens (Buyse *et al.*, 1999), exhibited
43 significantly higher percentage of the breast muscles and lower percentage of the abdominal
44 fat in comparison with their counterparts. In addition, the HG line showed a higher percentage
45 of the carcass and leg muscles than the LG one.
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56 HG vs LG differences in the proportion of leg and breast muscles persisted also during
57 the retardation growth phase. In contrast, differences in abdominal fat disappeared during the
58 sexual maturation. Our preliminary results of chemical carcass analysis suggested that the
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3 total lipids followed the same trend as abdominal fat (Hyánková *et al.*, 2003). These data
4
5 correspond with findings in chicken lines divergently selected for abdominal fat. According
6
7 to Leclercq *et al.* (1989), significant inter-line differences for both abdominal and extra-
8
9 abdominal triglycerides were observed after 15 d of age, maximum divergence between lines
10
11 occurred at 63 d of age, and subsequently these differences tended to diminish near sexual
12
13 maturity. A similar disappearance of inter-line differences in fatness was reported also in the
14
15 chicken lines divergently selected for VLDL (Whitehead *et al.*, 1990). However, in both cases
16
17 this phenomenon was observed only in females. The obvious discrepancy between the
18
19 findings in chickens and quail could be associated with inter-species differences in sexual
20
21 dimorphism. While in quail the males represent the sex with lower growth potential (Marks,
22
23 1990; Hyánková *et al.*, 1998; 2001) and higher fatness (Sadjadi and Becker, 1980; Marks
24
25 1990), the opposite is true in chickens (Gyles *et al.*, 1982; Becker and Mirosh, 1984).
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31 **Thyroid hormones**

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33 Analogously to carcass composition, the differences in the plasma level of thyroid hormones
34
35 between HG and LG quail also corresponded with the findings in chickens directly selected
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37 for body fat. Higher plasma T₃ level and a higher T₃/T₄ ratio during the growth period were
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39 detected in the HG relative to LG line as well as in lean chicken lines compared to fat ones
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41 (Leclercq *et al.*, 1988; Mitchell, 1988; Buyse *et al.*, 1999).
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46 In agreement with results in chickens (Bobek *et al.*, 1977; Buyse *et al.*, 1991; 1999;
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48 Decuypere *et al.*, 1993), both HG and LG quail showed age-dependent decrease of plasma T₃
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50 concentration that corresponded with the decrease in their relative growth rate. Moreover, age
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52 trend of T₃/T₄ ratio (relative T₃ concentration) implied that the developmental rate could
53
54 determine differences between HG and LG quail. In comparison with LG quail, HG quail
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56 showed constant T₃/T₄ ratio one week later, *i.e.* after the third week of age. In both lines this
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58 agreed with a higher abdominal fat cummulation as well as with the onset of the retardation
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3 growth phase (14.1 and 18.9 d of age in LG and HG males, respectively; Hyánková *et al.*,
4
5 2001). In general, the relatively higher T₃ concentrations and lower proportion of the body fat
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7 in HG quail (or lean chicken) vs LG quail (or fat chicken) of the same age simply reflect
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9 developmental delay of HG quail (lean chicken) in comparison with its fat counterpart.
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11

12 **Correlated responses in term of growth pattern and development**

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15 Our previous studies documented that developmental divergency between HG and LG quail
16
17 appeared already during embryogenesis and persisted postnatally until the onset of sexual
18
19 maturity (Hyánková *et al.* 2001; 2004; Hyánková and Novotná, 2007). During postnatal
20
21 growth, the developmental retardation of the HG vs LG line was characterised by (1) lower
22
23 food intake and growth rate immediately after hatching, (2) better food efficiency during a 5-
24
25 week-fattening period, (3) longer acceleration phase of the growth curve and (4) higher adult
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27 BW (Hyánková *et al.*, 2001; 2004). Similar differences in the food intake, food conversion
28
29 and growth pattern were described between lean and fat chicken lines (Leclercq *et al.*, 1989;
30
31 Buyse *et al.*, 1999). Using a Gompertz growth function, Leclercq *et al.* (1989) demonstrated
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33 that the line selected for low abdominal fat exhibited a slower early growth rate, a more
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35 advanced age at the inflection point of the growth curve and a higher adult BW than the fat
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37 line.
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44 In conclusion, our results demonstrated that direct selection for the shape of the
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46 growth curve induced the same correlated responses in the plasma thyroid hormone levels and
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48 carcass composition as did the direct selection for body fat. In addition, the changes in the
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50 growth pattern accompanying the direct selection for abdominal fat were analogous to those
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52 arising from selection for the shape of the growth curve. Hence, the modification of the shape
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54 of the growth curve could represent the primary mechanism leading to excessive fatness in
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56 broiler chickens long-term selected only for a high BW.
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Developmentally delayed HG genotypes characterised by a relatively better carcass composition and food conversion exhibited a higher BW than developmentally accelerated LG genotypes in more advanced age categories. In contrast, LG genotypes reached a higher BW than HG ones at a younger age. Thus, the sole selection for high BW is not unambiguously associated with improvement of meat efficiency. Gradual shifting of this selection towards younger ages could represent in the past a key factor modifying the genotype of commercial chicken populations in favour of developmentally accelerated fat individuals. Therefore, the modern breeder strategies involve an additional selection, e.g. for low food conversion ratio, that decelerates the developmental events during acceleration growth phase and compensate thus the negative effects of sole selection for high BW.

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FIGURE LEGENDS

Figure 1. *Growth characteristics of the HG and LG lines selected for high and low relative BW gain between 11 and 28 d of age, respectively: (a) Postnatal growth curves, (b) Relative differences in BW (LG = 100%), (c) Relative growth rate. The data were obtained from 20 males per line. S.D. = standard deviation.*

Figure 2. *Plasma thyroid hormone concentrations of the HG and LG lines selected for high and low relative BW gain between 11 and 28 d of age, respectively: (a) thyroxine (T_4), (b) 3,3', 5 - triiodothyronine (T_3), (c) T_3/T_4 ratio. The data were obtained from 10 males per line. S.E. = standard error, * $P < 0.05$.*

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Table 1. Absolute weights of body parts (mean \pm standard error)

Age (d)	Line	Weight (g)					
		Body	Carcase	Breast muscles	Leg muscles	Abdominal fat	Testes
7	HG	29.9 \pm 0.56*	15.2 \pm 0.40*	2.9 \pm 0.09*	3.1 \pm 0.09*	nm	nm
	LG	42.2 \pm 0.61	23.8 \pm 0.49	5.3 \pm 0.20	4.9 \pm 0.11	nm	nm
14	HG	76.5 \pm 1.12*	47.9 \pm 0.73*	13.7 \pm 0.25*	9.1 \pm 0.20*	0.02 \pm 0.008*	nm
	LG	92.4 \pm 1.09	57.2 \pm 0.86	15.9 \pm 0.25	10.5 \pm 0.23	0.12 \pm 0.016	nm
21	HG	126.4 \pm 1.10*	81.4 \pm 0.78*	24.8 \pm 0.41	15.7 \pm 0.23	0.14 \pm 0.012*	0.10 \pm 0.015*
	LG	133.1 \pm 1.36	85.1 \pm 0.93	25.5 \pm 0.35	15.9 \pm 0.24	0.28 \pm 0.026	0.18 \pm 0.026
28	HG	173.9 \pm 1.92*	117.9 \pm 1.34*	38.3 \pm 0.48*	23.9 \pm 0.37*	0.71 \pm 0.067	0.80 \pm 0.079
	LG	159.2 \pm 2.03	106.5 \pm 1.51	32.8 \pm 0.59	21.2 \pm 0.34	0.65 \pm 0.080	1.07 \pm 0.156
35	HG	195.2 \pm 1.98*	139.5 \pm 2.26*	42.9 \pm 0.84*	26.6 \pm 0.42*	2.33 \pm 0.195	3.07 \pm 0.244
	LG	181.1 \pm 2.75	123.5 \pm 1.73	36.6 \pm 0.68	23.7 \pm 0.41	2.20 \pm 0.245	3.09 \pm 0.357
42	HG	206.1 \pm 2.87*	139.6 \pm 2.36*	41.9 \pm 0.86*	28.4 \pm 0.55*	2.53 \pm 0.217	5.86 \pm 0.345
	LG	189.0 \pm 3.24	124.4 \pm 2.36	35.6 \pm 0.77	25.5 \pm 0.63	2.17 \pm 0.209	5.93 \pm 0.311

* - significant difference between the lines ($P < 0.05$); nm = non-measurable (weight < 0.01 g); the data were obtained from 20 males per line and age.

Table 2. *Relative weights of body parts (mean ± standard error)*

Age (d)	Line	Proportion of body weight (%)				
		Carcase	Breast muscles	Leg muscles	Abdominal fat	Testes
7	HG	50.8 ± 0.50*	9.7 ± 0.20*	10.2 ± 0.22*	-	-
	LG	56.3 ± 0.61	12.6 ± 0.38	11.0 ± 0.17	-	-
14	HG	62.5 ± 0.27	18.0 ± 0.20*	11.9 ± 0.15*	0.03 ± 0.010*	-
	LG	61.8 ± 0.33	17.2 ± 0.19	11.4 ± 0.18	0.13 ± 0.024	-
21	HG	64.4 ± 0.32	19.6 ± 0.27	12.4 ± 0.13*	0.11 ± 0.015*	0.08 ± 0.017*
	LG	63.9 ± 0.25	19.1 ± 0.23	12.0 ± 0.13	0.21 ± 0.026	0.13 ± 0.026
28	HG	67.7 ± 0.20*	22.0 ± 0.14*	13.8 ± 0.14*	0.41 ± 0.052	0.46 ± 0.065*
	LG	66.9 ± 0.29	20.6 ± 0.31	13.3 ± 0.13	0.40 ± 0.064	0.67 ± 0.068
35	HG	71.4 ± 0.77*	22.0 ± 0.44*	13.7 ± 0.21*	1.18 ± 0.131	1.57 ± 0.166
	LG	68.1 ± 0.40	20.2 ± 0.35	13.1 ± 0.20	1.15 ± 0.167	1.64 ± 0.265
42	HG	67.7 ± 0.32*	20.3 ± 0.32*	13.8 ± 0.18	1.22 ± 0.146	2.85 ± 0.243
	LG	65.8 ± 0.33	18.8 ± 0.33	13.5 ± 0.20	1.13 ± 0.136	2.98 ± 0.307

* - significant difference between the lines ($P < 0.05$); the data were obtained from 20 males per line and age.

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