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Original article

Growth characteristics and lipid distribution in two lines of chicken selected for low or high abdominal fat

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Summary — Growth curves and lipid distribution have been compared in 2 lines of chickens divergently selected for high or low abdominal fat. With the Gompertz model it has been shown that lean chickens (LL) exhibit a slower growth rate from hatching to 63 days of age. The maximum growth rate is reached later than in fat chickens (FL). The mature weight of LL is superior to that of FL in both sexes. FL chicks are fattier at hatching due to the higher proportion of yolk in the eggs. This difference disappears at 7 days of age. At 15 days of age, significant differences were found for abdominal fat but not for other fat deposits. Thereafter, significant differences were found for both abdominal triglycerides and extra-abdominal triglycerides. Maximum divergence between lines happened at 63 days. This difference tended to diminish in females near sexual maturity. Difference in abdominal triglyceride content was always more pronounced than that in extra-abdominal triglycerides. These observations suggest that there is specific control of fat deposition in different adipose tissues.

chicken – obesity – growth – lipid

Résumé — Caractéristiques de la courbe de croissance et répartition des lipides de réserve chez deux lignées de poulets génétiquement maigre ou gras. *L'étude a porté sur des poulets mâles et femelles de 2 lignées sélectionnées pour un dépôt adipeux abdominal faible ou élevé. Les animaux ont été pesés aux âges de 0, 7, 15, 22, 28, 35, 42, 50, 63, 76, 97 et 112 jours. Les courbes de croissance ont été modélisées selon le modèle de Gompertz. Les courbes de croissance sont significativement différentes, les poulets maigres présentant une croissance moins rapide dans le jeune âge et un poids vif adulte plus élevé que celui des poulets gras. A l'éclosion, les poussins de la lignée grasse sont plus gras que ceux de la lignée maigre; cette différence disparaît à l'âge de 7 jours puis réapparaît, s'amplifie jusqu'à l'âge de 63 jours et se maintient constante au-delà. La différence entre lignées pour le dépôt gras abdominal apparaît plus tôt que celle correspondant aux autres tissus adipeux; elle est en outre toujours plus prononcée. La divergence entre lignées est maximum à 63 jours et ne s'amplifie plus ensuite. Elle tend à diminuer à l'approche de la maturité sexuelle, surtout chez les femelles. Etant donné le contrôle polygénique de l'engraissement, on peut penser que certains gènes contrôlent les mécanismes généraux de l'engraissement (lipogenèse hépatique) et que d'autres exercent leur contrôle au niveau des différents dépôts adipeux (aptitude à la captation des triglycérides ou lipolyse).*

poulet – obésité – croissance – lipides

Introduction

Two lines of chickens were created by divergent selection using proportion of abdominal fat in live weight of 9-wk-old males as the criterion. Details about this experimental selection have been published (Leclercq *et al.*, 1980; Leclercq, 1988). This selection programme was conducted so that the live weights of birds were similar at 9 wk of age. Both lines were compared at the F4 generation for their lipid content according to age (Simon and Leclercq, 1982). The present experiment was undertaken in order to observe any change in the distribution of lipids since the selection programme was continued from F4 to F7. Moreover, lipid composition was determined so that reserve lipids (triglycerides) could be distinguished from structural lipids (phospholipids and cholesterol). Finally, since it seemed that growth curves were different, both lines were also compared from this point of view.

Materials and Methods

Three hundred chicks from both lines were placed in a floor pen (45 m^2) at hatching. They came from F10. The history of these lines has been extensively described (Leclercq, 1988). Briefly, birds came from 6 different origins in order to collect as many genes as possible. These breeders gave birth to F0. Four males per dam were slaughtered at 63 days of age and their abdominal fat pads were weighed. Families were classified as fat (FL) or lean (LL) families according to the deviation from the linear regression between the proportion of abdominal fat and live weight. We took care to put birds of the 6 origins into both lines. Fourteen to 15 sires were kept per line from F0 to F7. They were crossed with 5 or 6 dams. Successive generations were weighed at 9 wk of age. At each generation 4 sons per dam were slaughtered and their abdominal fat was weighed. Within each line the best families (about one-third of total families) were kept to produce the following generation. We took care not to cross full-sibs or half-sibs. The selection programme was conducted during 7 successive generations and then stopped. At that time a representative sample of birds were kept as breeders for subsequent generations, namely one son per sire and one daughter per dam. Each son succeeded its father. Daughters were randomly distributed in other pens, without crossing full-sibs or half-sibs. At each generation (F8, F9, and F10) a representative sample of male chickens was raised to 9 wk of age and slaughtered. Abdominal fat was measured. Thus we were able to observe that the difference between lines remained constant between F7 and F10; thus, F10 can be considered as similar to F7 (last generation of selection). The chickens were fed from hatching to 3 wk on a starter diet containing 3,040 kcal of metabolisable energy (AMEn) and 221 g crude protein per kg. From 3 to 9 wk of age, they were given a diet containing 2,980 kcal AMEn and 190 g crude protein per kg. Both these diets were given as pellets. From 63 to 112 d of age birds were fed on a mash-diet containing 2,890 kcal AMEn and 147 g crude protein per kg.

Birds were weighed at 0, 7, 15, 22, 28, 35, 42, 50, 63, 76, 97, and 112 d of age after 18 h of fasting. Samples of 8 males and 8 females per line were collected at 0, 7, 15, 28, 63, and 97 days of age. They were killed by an intracardiac injection of Nembutal. At hatching the residual yolk sac was removed. The abdominal fat was dissected and weighed at 15, 28, 63, and 97 days of age and kept for analysis. The birds were then frozen and kept until analysis. Mixed abdominal fat was measured for lipid content which was assumed to be composed only of triglycerides. The remaining carcass (without abdominal fat) was finely minced and freeze-dried. Lipids were measured after extraction by chloroform-methanol (2-1). Phospholipid proportion was determined by measuring the phosphorus content of lipids (BIPEA, 1976) using the mean content of 40 mg phosphorus per g phospholipids (Daggy *et al.*, 1987). Phospholipid plus cholesterol proportion was estimated by multiplying the phospholipid content by 1.06 (Ricard and Leclercq, 1984). The difference between total lipid and phospholipid plus cholesterol was assumed to be triglyceride, *i.e.* reserve lipids.

Growth curves were modelled by means of the Gompertz model as described by France and Thornley (1984); calculations were done with the HAUS 59 programme (Bachacou *et al.*, 1981). The Gompertz model was chosen as it gave the best coefficient of determination when compared to the logistic and Chanter models. In the classical model of Gompertz it is assumed that : (1) The substrate is non-limiting; (2) The growth rate is proportional to weight with a constant of proportionality k; (3) The effectiveness of growth decays with time according to an exponential decay whose constant is k_2. Consequently, growth rate is given by equation :

$$dW/dt = k * W, \text{ and : } k = k_1 \exp(-k_2 t),$$

where W is live weight; t is time.

By integrating these equations and assuming that $W = Wo$ when $t = 0$, we may write :

$$W = Wo * \exp(k_1(1 - \exp(-k_2 t))/k_2).$$

The point of inflexion occurs at time t_{max}, when growth rate is maximum, with t_{max} =

$$(\log (k_1/k_2)) / k_1$$

The mature weight W_{max} may be estimated by the equation :

$$W_{max} = Wo * \exp(k1/k2)$$

When correlations were significant between live weight and any body component, comparison between lines was performed by analysis of covariance. Otherwise a t-test was performed to compare genotypes.

Results

Live weights of both lines and both sexes are given in Table I. Fat chickens (FL) were heavier than lean chickens (LL) from 15 to 97 d of age for males and from 7 to 63 d of age for females. Results of fitting growth curves according to the Gompertz model are provided by Table II. Both constants were significantly different between lines for both sexes. Estimated maximum live weights (W_{max}) of LL males and females were greater than those of FL chickens. Conversely, age at maximum growth rate (t_{max}) of LL was greater than that of FL chickens.

Absolute values of abdominal fat, live weights, and their linear regression are given in Table III. Significant differences between lines were found at all ages. These were tested by analysis of covariance except for 15-d-old males for which correlation was not significant in FL chickens. However, a t-test showed a significant effect of line in that case (t = 4.2). Similar data about total lipids are provided in Table IV. In some situations correlations between total lipids and live weights were not significant; analysis of variance (t-test) was then used instead of analysis of covariance to compare lines. At hatching, FL chicks were fatter than LL ones; this was true for males (t = 2.85) and mixed sexes (t = 2.55). This difference disappeared at 7 and 15 d of age. It again appeared and became significant at 28 days of age and thereafter. Total triglycerides and their linear regression with live weight are given in Table V. Results are similar to those of total lipids. Extra-abdominal triglycerides and their regression on live weight are presented in Table VI. No differences could be observed at 15 d of age. However, at 28 d of age and thereafter significant differences were found between lines in both sexes. Last, linear regressions between abdominal triglycerides and extra-abdominal triglycerides are given in Table VII. Significant correlations were found at most ages, except in FL males at 15 and 28 days of age and in LL females at 15 days of age, probably because of the low number of birds (8 per line per sex).

Table I. Live weight (g) of chickens of fat and lean lines according to sex and age.

	Lean line		Fat line		Significance between lines	
	Males	Females	Males	Females	Males	Females
0	34.1	32.6	33.2	31.2		
7	87 (12)	83 (9)	91 (9)	90 (9)	N.S.	$P < 0.01$
15	179 (28)	168 (24)	192 (22)	184 (21)	$P < 0.01$	$P < 0.01$
22	300 (50)	269 (47)	320 (50)	305 (43)	$P < 0.05$	$P < 0.01$
28	454 (78)	400 (69)	487 (93)	452 (85)	$P < 0.05$	$P < 0.01$
35	673 (116)	583 (103)	730 (165)	669 (114)	$P < 0.05$	$P < 0.01$
42	881 (139)	756 (121)	964 (165)	859 (138)	$P < 0.01$	$P < 0.01$
50	1 171 (177)	1 019 (149)	1 319 (199)	1 144 (165)	$P < 0.01$	$P < 0.01$
63	1 818 (218)	1 498 (165)	1 916 (241)	1 577 (196)	$P < 0.05$	$P < 0.05$
76	2 186 (247)	1 831 (225)	2 338 (257)	1 882 (277)	$P < 0.01$	N.S.
97	2 885 (348)	2 319 (255)	3 025 (358)	2 275 (284)	$P < 0.05$	N.S.
112	3 290 (407)	2 584 (289)	3 319 (418)	2 453 (355)	N.S.	$P < 0.05$

Standard deviations are given between parentheses.

Table II. Coefficients of equations describing growth curves according to the Gompertz model*.

	Lean line		Fat line		Significance between lines	
	Males	Females	Males	Females	Males	Females
R^2	0.9991	0.9995	0.9997	0.9997		
k_1 **	0.1253 (0.1222-0.1284)	0.1215 (0.1195-0.1236)	0.1345 (0.1327-0.1364)	0.1363 (0.1346-0.1381)	$P < 0.05$	$P < 0.05$
k_2 **	0.0267 (0.0258-0.0276)	0.0275 (0.0268-0.0282)	0.0286 (0.0282-0.0292)	0.0315 (0.0310-0.0321)	$P < 0.05$	$P < 0.05$
W_{max} (g)	4 148	3 203	4 079	2 801		
t_{max} (d)	57.8	54.3	54.1	46.4		

* $W = Wo \exp((k_1/k_2)(1 - \exp(-k_2 t)))$.
Where Wo is live weight at hatching, t age (in days), W live weight at age t.
** Interval of confidence at 5 % level is given between parentheses.

Table III. Linear regressions between abdominal fat and live weight in lean (LL) and fat (FL) lines of chicken.

Age (d)		Abdominal fat (g)	Live weight (g)	*b*	*a*	Analysis of covariance	
						Non parallelism *F*	Line *F*
15	Males						
	LL	0.57	156.9	0.0085	− 0.76		
	FL	1.41	181.7				
	Females						
	LL	0.51	155.2	0.0092	− 0.91	2.06	28.1
	FL	1.49	164.8	0.0242	− 2.50		**
28	Males						
	LL	3.10	468.6	0.0169	− 4.81	2.29	34.3
	FL	10.46	498.7	0.0377	− 8.36		**
	Females						
	LL	3.25	423.8	0.0175	− 4.18	1.1	53.9
	FL	11.00	447.1	0.0517	− 12:1		**
63	Males						
	LL	24.9	2 000	0.0533	− 81.8	2.94	253.6
	FL	87.4	2 045	0.0832	− 82.7		**
	Females						
	LL	38.1	1 674	0.0738	− 85.5	0.01	42.5
	FL	83.3	1 667	0.0679	− 29.9		**
97	Males						
	LL	45.0	2 921	0.0529	− 109.4	1.28	48.4
	FL	158.5	2 994	0.1073	− 163.0		**
	Females						
	LL	71.2	2 418	0.1063	− 185.8	1.00	52.2
	FL	166.0	2 451	0.1620	− 230.9		**

Abdominal fat : $a + b \cdot$ live weight.

Table IV. Linear regressions between total lipids and live weight in lean (LL) and fat (FL) lines of chicken.

Age (d)		Lipids (g)	Live weight (g)	*b*	*a*	Analysis of covariance	
						Non parallelism *F*	Line *F*
0	Males						
	LL	1.53	34.1				
	FL	1.76	33.2				
	Females						
	LL	1.53	32.6				
	FL	1.60	31.9				
7	Males						
	LL	8.14	85.9	0.157	− 5.35		
	FL	7.46	80.2				
	Females						
	LL	8.37	90.0	0.140	− 4.18	0.02	0.01
	FL	7.59	84.9	0.149	− 5.06		
15	Males						
	LL	12.14	156.9	0.087	− 1.53	0.6	0.01
	FL	14.48	181.7	0.110	− 5.56		
	Females						
	LL	11.21	155.2				
	FL	13.83	164.8	0.217	− 21.9		
28	Males						
	LL	35.17	468.6	0.144	− 32.2	0.12	19.9
	FL	57.44	498.7	0.162	− 23.5		**
	Females						
	LL	34.78	423.8	0.109	− 11.2	2.56	19.4
	FL	56.71	447.1	0.273	− 65.5		**
63	Males						
	LL	215.4	2 000	0.242	− 268.5	3.12	81.0
	FL	385.2	2 045	0.384	− 399.1		**
	Females						
	LL	240.5	1 674	0.255	− 186.5	0.01	33.7
	FL	337.5	1 669	0.256	− 89.8		**
97	Males						
	LL	369.9	2 921	0.254	− 377.0	0.63	45.4
	FL	644.8	2 994	0.351	− 406.2		**
	Females						
	LL	440.3	2 418	0.401	− 529.9	0.02	22.6
	FL	607.7	2 451	0.403	− 380.8		**

Total lipids : $a + b \cdot$ live weight.

Table V. Linear regressions between total triglycerides and live weight in lean (LL) and fat (FL) lines of chicken.

Age (d)		Triglycerides (g)	Live weight (g)	*b*	*a*	Analysis of covariance	
						Non parallelism *F*	Line *F*
0	Males						
	LL	1.27	34.1				
	FL	1.46	33.2				
	Females						
	LL	1.22	32.6				
	FL	1.33	31.9				
7	Males						
	LL	7.12	85.9	0.144	− 5.28		
	FL	6.51	80.2				
	Females						
	LL	7.31	90.0	0.128	− 4.23		
	FL	5.51	84.9				
15	Males						
	LL	11.13	156.9	0.090	− 2.94	1.88	0.04
	FL	13.47	181.7	0.122	− 8.75		
	Females						
	LL	10.12	155.2				
	FL	12.57	164.8	0.209	− 21.9		
28	Males						
	LL	31.96	468.6	0.139	− 33.2	0.23	22.1
	FL	54.61	498.7	0.164	− 26.9		**
	Females						
	LL	32.20	423.8	0.103	− 11.5	15.4	
	FL	53.58	447.1	0.267	− 65.8		
63	Males						
	LL	204.3	2 000	0.237	− 269.3	3.30	81.7
	FL	374.3	2 045	0.382	− 406.6		**
	Females						
	LL	231.5	1 674	0.253	− 191.3	0.01	32.9
	FL	328.4	1 667	0.253	− 92.0		**
97	Males						
	LL	349.8	2 921	0.247	− 372.6	0.68	45.7
	FL	630.9	2 994	0.348	− 410.7		**
	Females						
	LL	428.0	2 418	0.398	− 534.9	0.01	22.8
	FL	596.1	2 451	0.399	− 381.1		**

Triglycerides : $a + b \cdot$ live weight.

Table VI. Linear regressions between extra-abdominal triglycerides and live weight in lean (LL) and fat (FL) lines of chicken.

Age (d)		Extra-abdominal triglycerides (g)	Live weight (g)	*b*	*a*	Analysis of covariance	
						Non parallelism *F*	Line *F*
15	Males						
	LL	10.85	156.9	0.085	− 2.50	1.49	0.48
	FL	12.76	181.7	0.114	− 7.93		
	Females						
	LL	10.12	155.2				
	FL	12.57	164.8	0.209	− 21.9		
28	Males						
	LL	30.00	468.6	0.128	− 30.1	0.01	11.0
	FL	45.93	498.7	0.132	− 20.0		**
	Females						
	LL	30.13	423.8	0.092	− 8.84	0.8	10.0
	FL	44.45	447.1	0.224	− 55.7		**
63	Males						
	LL	185.9	2 000	0.197	− 208.8	2.19	44.4
	FL	291.0	2 045	0.297	− 316.3		**
	Females						
	LL	203.3	1 674	0.198	− 128.1	0.01	15.0
	FL	252.9	1 667	0.195	− 72.5		**
97	Males						
	LL	307.9	2 921	0.198	− 270.7	0.29	31.1
	FL	483.5	2 994	0.248	− 259.2		**
	Females						
	LL	361.7	2 418	0.299	− 362.1		
	FL	441.7	2 451				

Extra-abdominal triglycerides : $a + b \cdot$ live weight.

Table VII. Linear regressions between extra-abdominal triglycerides and abdominal fat triglycerides in lean (LL) and fat (FL) lines of chicken.

Age (d)		Extra-abdominal triglycerides (g)	Abdominal triglycerides (g)	*b*	*a*	Analysis of covariance	
						Non-parallelism *F*	Line *F*
15	Males						
	LL	10.85	0.28	12.65	7.27		
	FL	12.76	0.71				
	Females						
	LL	9.86	0.26				
	FL	11.83	0.74	7.68	6.11		
28	Males						
	LL	30.00	1.98	9.79	10.57		
	FL	45.93	8.69				
	Females						
	LL	30.13	2.07	5.70	18.35	0.16	12.6
	FL	44.45	9.13	4.65	2.02		**
63	Males						
	LL	185.9	18.4	4.08	110.7	0.33	29.0
	FL	291.0	83.3	3.51	− 1.85		**
	Females						
	LL	203.3	28.2	2.64	128.9	0.64	4.65
	FL	252.9	75.6	1.82	115.5		
97	Males						
	LL	307.9	41.8	3.30	170.0	1.51	0.33
	FL	483.5	147.4	1.76	223.9		
	Females						
	LL	361.7	66.3	2.38	203.9	1.20	3.69
	FL	441.7	154.3	1.53	205.0		

Extra-abdominal triglycerides : $a + b \cdot$ abdominal triglycerides.

Last, as shown in Fig. 1, there was a larger proportion of abdominal triglycerides as birds aged. However, LL chickens always exhibited a lower percentage of abdominal triglycerides in total triglycerides. Differences between lines became less pronounced as birds approached sexual maturity.

Since lipid measurements were performed only on samples of 8 birds, parameters of fattening have been adjusted for the total population by means of regression. Results are presented in Table VIII.

Discussion

Both lines exhibited, in this experiment, a slightly lower growth rate than in other experiments, due to frequent weighing of birds. However, our observations provide significant conclusions about differences in growth curve and lipid distribution.

Our lean chickens exhibited a slower growth rate during the exponential first phase of growth. The maximum growth rate happened 3-6 d later than that of FL chickens. By contrast, during the second phase of growth LL slowed down their growth rate later and reached a heavier mature weight than FL chickens. This last observation confirms many of our previous observations during the adult period (Leclercq, 1988). The correlation we observed between growth curve and fattening is close to that of Ricard (1978), who found that selecting chickens either for low immature weight (6 wk of age) and high mature weight (16 wk of age) or for high immature weight and low mature weight led,

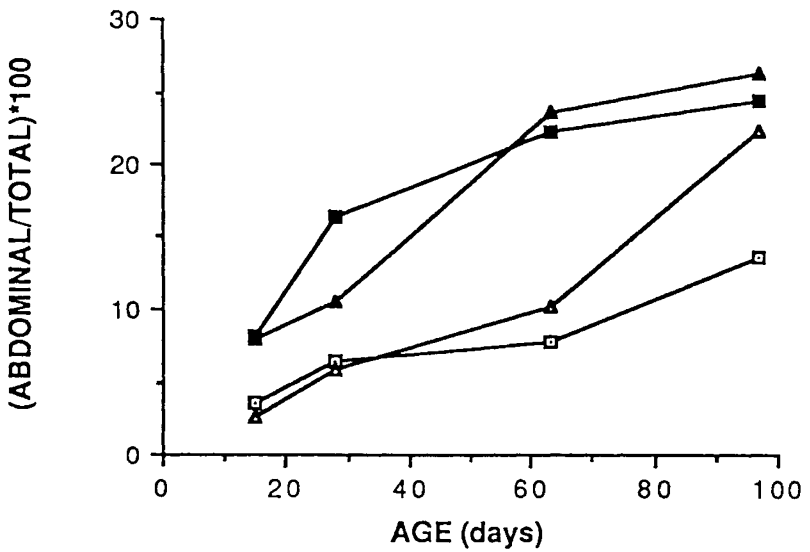

Fig. 1. Abdominal fat triglycerides as proportion of total triglycerides according to age, line, and sex. □ LL males; △ LL females; ■ FL males; ▲ FL females.

Table VIII. Adjusted values of fatness of both lines.

Age (d)		LL		FL	
		Males	Females	Males	Females
0	Live weight (g)	34.1	32.6	33.2	31.9
	Total lipids (g/kg)	45.0	53.3	47.5	50.1
	Total triglycerides (g/kg)	37.2	37.8	44.1	41.7
7	Live weight (g)	87	83	91	70
	Total lipids (g/kg)	94.4	93.2	92.3	88.7
	Total triglycerides (g/kg)	82.5	80.6	81.3	76.9
15	Live weight (g)	179	168	192	184
	Total lipids (g/kg)	78.5	72.3	81.0	82.9
	Total triglycerides (g/kg)	73.6	65.2	76.4	76.3
	Extra-abdominal triglycerides (g/kg)	71.0	63.5	72.7	70.8
	Abdominal fat (g/kg)	4.3	3.8	7.7	10.6
28	Live weight (g)	454	400	487	452
	Total lipids (g/kg)	73.1	81.0	113.7	128.1
	Total triglycerides (g/kg)	65.9	74.2	108.8	112.7
	Extra-abdominal triglycerides (g/kg)	61.7	69.9	90.9	100.8
	Abdominal fat (g/kg)	6.3	7.1	20.5	24.9
63	Live weight (g)	1 818	1 498	1 916	1 577
	Total lipids (g/kg)	94.3	130.5	175.7	199.1
	Total triglycerides (g/kg)	88.9	125.3	169.8	194.7
	Extra-abdominal triglycerides (g/kg)	82.1	112.5	131.9	149.0
	Abdominal fat (g/kg)	8.3	16.7	40.0	48.9
97	Live weight (g)	3 290	2 584	3 319	2 453
	Total lipids (g/kg)	139.4	195.9	228.6	247.8
	Total triglycerides (g/kg)	133.7	191.0	224.3	243.6
	Extra-abdominal triglycerides (g/kg)	115.7	148.5	169.9	179.7
	Abdominal fat (g/kg)	19.6	34.4	58.2	67.9

respectively, to lean and fat lines of chickens. So there seems to be a correlation between the shape of the growth curve and the propensity to become fat. The mechanism involved has to be found.

FL chicks were fatter at hatching than LL ones due to the higher proportion of yolk in FL eggs (Leclercq *et al.*, 1985). Difference in proportion of abdominal fat appeared after 15 d of age when no difference could be observed for the proportion of other adipose deposits. Divergence between lines for abdominal fat proportion increased in both sexes until 63 d of age, then the difference remained constant. At all ages genetic difference for abdominal fat proportion was more pronounced than for extra-abdominal adipose tissues. Compared to results from F4 (Simon and Leclercq, 1982), the present results show a more pronounced difference between lines for the abdominal fat proportion; this is obviously due to continuing the selection programme. It was also accompanied by a larger difference of total lipid concentration in live weight. However, divergence for total lipid progressed less rapidly than divergence for abdominal fat, indicating a specific effect of the selection programme on lipid distribution.

These last observations suggest that besides general control of fattening, there must be some local control on specific tissues. Indeed, significant differences were observed in these lines, for example, for liver lipogenesis (Saadoun and Leclercq, 1987) or for

some hormones implicated in the control of lipid metabolism like insulin or thyroid hormones (Simon and Leclercq, 1982; Saadoun *et al.*, 1988). These phenomena may explain why FL chickens exhibit higher body lipid concentration than LL ones. However, distribution of reserve lipid within different adipose tissues requires some local control. We have recently shown that in FL chickens, *in vitro* sensitivity to lipolytic activity of glucagon is lower in abdominal fat adipocytes as compared to subcutaneous adipocytes, while similar sensitivity was observed in subcutaneous adipocytes of both lines (Leclercq *et al.*, 1988), suggesting that in FL chickens higher abdominal fat proportion is partly due to a reduced lipolysis of this adipose tissue. Other local mechanisms might be present, such as a capability for hyperphasia (Hermier *et al.*, unpublished observations), but they are to be further investigated. Moreover, in addition to these phenomena implicated in the control of fattening of the immature bird, the new hormonal status of sexually maturing birds may modify differences observed during the immature period. Such controls have to be elucidated.

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