Growth, carcass composition and meat quality response to dietary concentrations in fast-, medium- and slow-growing commercial broilers

Maxime Quentin, Isabelle Bouvarel, Cécile Berri, Elisabeth Le Bihan-Duval, Elisabeth Baéza, Yves Jégo, Michel Picard

Anim. Res. 52 (2003) 65–77

DOI: 10.1051/animres:2003005

Original article

Growth, carcass composition and meat quality response to dietary concentrations in fast-, medium- and slow-growing commercial broilers

Maxime QUENTIN[a,b], Isabelle BOUVAREL[b], Cécile BERRI[a], Elisabeth LE BIHAN-DUVAL[a], Elisabeth BAÉZA[a], Yves JÉGO[c], Michel PICARD[a]*

[a]Institut National de la Recherche Agronomique, Station de Recherches Avicoles, 37380 Nouzilly, France
[b]Institut Technique de l'Aviculture, 28 rue du rocher, 75008 Paris, France
[c]Hubbard-ISA, Le Foeil, BP 169, 22800 Quintin, France

(Received 2 September 2002; accepted 16 January 2003)

Abstract — Growth, carcass composition and certain meat quality traits were studied in fast (F), medium (M) and slow (S) growing broilers fed with 3 regimes appropriate for each chicken type and differing on average by 418 kJ·kg^{-1} AMEn and 1% crude protein (P1 > P2 > P3). No significant interactions between chicken types and feed were measured before 3 weeks and after 6 weeks of age, indicating that the 3 genotypes had similar responses to the 3 diets during these periods. Before 3 weeks of age, body weight was 5% higher for P1 compared to P2 and P2 compared to P3 fed chickens for a comparable feed intake. After 6 weeks of age, a 10% reduction in feed intake occurred in P3 compared to P1 and P1 compared to P2 fed chickens for similar body weight gains. The differing responses after 6 weeks of age might be linked to high heat stress that occurred at 7 weeks of age. Between 3 and 6 weeks of age, interactions between chicken type and dietary concentration on feed intake, body weight gain characterised an "after 6 weeks of age" response for F-chickens whereas M- and S-chickens had a "before 3 weeks of age" response. These interactions might be explained by a higher sensitivity of fast-growing chickens to environmental conditions. For chickens slaughtered at market age (F = 6, M = 8 and S = 12 weeks of age), higher breast meat yield (*Pectoralis major* + *minor*) and lower abdominal fat content were observed in the F-chickens (17.2% and 2.64%, respectively) compared to the M- (15.7% and 2.86%, respectively) and S-chickens (14.4% and 3.44%, respectively; $P < 0.05$). Breast meat was more coloured in the S-chickens with lower L* and higher b* and a* 72 hours after slaughter than in the M- and F-chickens ($P < 0.05$). Dietary concentration had no significant effect on carcass composition, ultimate pH or drip loss of breast meat. Our results suggest that changes in dietary concentration alter growth performance but have little effect on carcass composition and meat quality traits.

meat chicken / growth / dietary concentration / meat quality

* Correspondence and reprints
Tel.: 33 (0)247427840; fax: 33 (0)247427778; e-mail: picard@tours.inra.fr

Résumé — Effet de la concentration de l'aliment sur la croissance, la composition de la carcasse et la qualité de la viande de poulets de chair à croissance rapide, moyenne ou lente. La croissance, la composition de la carcasse et quelques paramètres de qualité de la viande ont été étudiés chez des poulets à croissance rapide (F), moyenne (M) et lente (S) alimentés par 3 régimes de concentration énergétique et protéique croissante (+ 418 kJ·kg^{-1} EMAn et + 1 % de protéine brute, P1 > P2 > P3). Aucune interaction significative entre le génotype et l'aliment n'a été mesurée avant 3 semaines et après 6 semaines d'âge indiquant que les 3 types de poulets ont des réponses semblables aux 3 régimes. Avant 3 semaines d'âge, le poids vif est augmenté de 5 % avec P1 comparé à P2 et avec P2 comparé à P3 pour une consommation semblable des 3 aliments. Après 6 semaines d'âge, une réduction de 10 % de la consommation est observée entre les aliments P1 par rapport à P2 et P2 par rapport à P3 pour un gain de poids semblable avec les 3 aliments. Ces différentes réponses peuvent être liées aux fortes chaleurs survenues à 7 semaines d'âge et à la sensibilité des poulets à ce paramètre. Entre 3 et 6 semaines, les poulets F ont été plus sensibles aux conditions environnementales que les poulets M et S ; ce qui peut expliquer l'interaction significative entre le type de poulet et l'aliment pour les paramètres zootechniques. Cette interaction est due à une réponse à la concentration énergétique de l'aliment des poulets F du même type que celle observée après 6 semaines d'âge alors que les poulets M et S ont une réponse similaire à la période précédant 3 semaines d'âge. Pour des poulets abattus à l'âge commercial (F = 6, M = 8 et S = 12 semaines d'âge), un rendement en muscles pectoraux (*Pectoralis major + minor*) plus élevé et une teneur en gras abdominal plus faible des poulets F (17,2 %, 2,64 % respectivement) par rapport aux M (15,7 %, 2,86 % respectivement) et S (14,4 %, 3,44 % respectivement) sont observés ($P < 0,05$). Une couleur plus intense des viandes S par rapport aux viandes M et F se caractérise par un L* plus faible et des indices b* et a* plus élevés 72 heures après l'abattage ($P < 0,05$). La densité du régime n'a pas d'effets sur la composition de la carcasse tout comme sur le pH ultime et la perte en eau de la viande de poulet. Nos résultats suggèrent que malgré les effets de la concentration du régime sur la croissance des différents poulets de chair étudiés, la composition de la carcasse et la qualité de la viande sont peu affectés.

poulet de chair / croissance / concentration de l'aliment / qualité de viande

1. INTRODUCTION

Broilers reached 2 kg in 64 days in 1976 whereas today only 38 days are required to reach this body weight. Breast meat yield has also been increased whereas feed conversion ratio (FCR = feed per gain) has been improved regularly [19]. This rapid progress has resulted from extensive genetic selection combined with a better understanding of the broiler's nutritional and environmental requirements [21]. However at the same time, the broiler's sensitivity to heat stress, metabolic failure (sudden death or ascites) and leg problems have increased the mortality rate during the finishing period and the downgrading at the slaughterhouse [12].

New modes of production have been set up in France, to meet the consumer's demand for a better tasting meat obtained from slower growing "label" broilers raised to market weight at over 80 days. Little information is available regarding the nutritional requirements of medium and slow-growing broilers and some experiments have suggested that the crude protein requirement of slow-growing broilers is lower than that of fast-growing broilers [18]. Other reports have suggested that the lysine requirement expressed as a percentage of feed is the same whatever the growth rate [8, 9]. However, these experiments did not test the recent types of broiler, and the adjustment of the nutritional requirement to broiler genotypes remain rather empirical in practices today.

France produces three major types of meat chickens. A fast growing broiler corresponding to an international standard for breast meat production during the shortest period possible; a slow growing label-type

chicken which takes twice as long as the fast growing broiler to reach market weight; and a hybrid between the two exhibiting an intermediate growth rate. The two last types have progressively increased their market share, reaching 15% for the label and 20% for the intermediate hybrid in 2001 (Bouvarel, personal communication). There is a relative lack of data concerning the nutritional requirements of medium and slow-growing chickens. As a first step, it seems necessary to compare the chicken's responses to the range of dietary concentration available in practice. In the present experiment, the growth and some meat quality traits of the three major commercial broiler types were therefore compared, under the same conditions, while they received the three average dietary regimes appropriate to their respective rearing methods.

2. MATERIALS AND METHODS

2.1. Experimental design and housing

One day-old commercial male broiler chicks were obtained from the Hubbard-ISA hatchery. The three broiler types were comprised of 1128 fast-growing standard (F), 720 slow-growing label (S) and 720 medium-growing chickens (M), the latter being the crossbreed of F and S birds. S chicks were vaccinated against Marek disease just after hatching. They were weighed in groups of 100 individuals and randomly distributed in 18 floor pens (200 chicks F and 130 M and S per floor pen) to facilitate coccidiosis vaccination (Paracox8, Schering-plough©) at 5 days of age in an environmentally-controlled poultry shed. At 6 days of age the broilers were randomly redistributed in 72 floor pens of 3 m^2. The real bird densities at the start were 47 F per pen (15.7 chicken per m^2) and 30 M or 30 S per pen (10 chickens per m^2). F and M-chickens were reared until 8 weeks and S-chickens until 12 weeks of age.

Temperature was regulated by two lines of gas heaters (1 for 2 pens): 0–7 days at 32 °C, 8–14 days at 30 °C, 15–21 days at 28 °C and then progressively reduced to reach 20 °C at 28 days of age.

Lighting was on for 24 h a day for the first 3 days and then reduced to 14 h until 13 days of age in order to reduce F growth and limit leg problems and mortality after 6 weeks. An increase of 2 h light a week was then applied to reach 24 h per day at 41 days of age. Light intensity was 50 lux for the first 3 days, 20 lux until 15 days of age and then reduced to reach 2 lux after 21 days of age.

The three broiler types fed with the three feeding programmes were randomly distributed in 8 blocks in the poultry shed, each comprising the 9 treatments (9 treatments × 8 replicates = 72 floor pens of 30 or 47 chickens).

2.2. Diets

High (P1), medium (P2) and low (P3) dietary concentration feeding programmes were defined and formulated from an average of seven main French feed manufacturers practiced for the three types of broilers (Tab. I). P1 and P2 feeding programmes were composed of four diets. The first diet was only distributed during the first week, the second between 1 and 3 weeks of age and the third between 3 and 6 weeks of age. The last diet was distributed from 6 weeks until the end of the experiment (12 weeks). P3 was composed of 3 diets according to commercial label production. The first diet was distributed before 3 weeks of age, the second from 3 to 8 weeks of age and the last diet until the end of the experiment.

Feeds were prepared by the INRA Poultry Research Station (Nouzilly, France) a week before their use. The starter feeds (first week of age) were presented as mash and the other feeds were steam pelleted (diameter 2.5 mm).

Table I. Composition and nutrient content of the 3 experimental diets.

	P3			P2				P1			
Age (week)	0–3	3–8	8–12	0–1	1–3	3–6	6–12	0–1	1–3	3–6	6–12
Composition (%)											
Corn	31.15	19.00	33.20	33.50	35.50	30.00	65.62	33.48	41.59	42.62	57.60
Wheat	31.50	56.00	43.70	29.50	30.00	36.87		24.50	20.00	15.00	
Soybean meal, 48%	28.00	19.79	18.16	31.19	28.77	26.00	22.00	35.00	31.00	24.20	19.61
Soybean toasted	-	-	-	-	-	-	6.00			10.00	14.20
Wheat bran	4.00	-	-	-	-	-	-	-	-	-	-
Colza oil	1.00	1.00	1.00	1.20	1.50	3.00	2.45	2.50	3.20	4.30	4.65
Calcium carbonate	1.20	1.40	1.40	1.32	1.25	1.15	1.00	1.25	1.10	0.90	0.95
Dicalcium phosphate	1.87	1.47	1.35	1.95	1.70	1.70	1.75	2.00	1.90	1.80	1.75
L lysine HCl	0.10	0.19	0.06	0.15	0.10	0.09		0.09	0.10		0.06
DL methionine	0.18	0.15	0.13	0.19	0.18	0.19	0.18	0.18	0.17	0.18	0.18
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamins [A]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Trace minerals [B]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
TOTAL (%)	100	100	100	100	100	100	100	100	100	100	100
AMEn ($MJ \cdot kg^{-1}$)	11.72	11.92*	12.23*	11.93	12.15	12.30*	13.02*	12.14	12.56	12.77*	13.45*
Crude protein (%)	20.10	17.50	16.50	20.99	20.07	19.10	18.12	22.11	20.48	20.08	19.02
Lysine (%)	1.10	0.95	0.80	1.20	1.10	1.02	0.95	1.25	1.15	1.10	1.10
Methionine + cystine (%)	0.85	0.75	0.70	0.88	0.85	0.83	0.80	0.90	0.85	0.85	0.82
Ca (%)	1.03	0.99	0.95	1.10	1.00	0.96	0.91	1.10	1.00	0.90	0.90
Available P (%)	0.45	0.38	0.34	0.44	0.40	0.40	0.38	0.45	0.42	0.40	0.38

* measured values determined by an ad-libitum method on six adult roosters per diet.
P3: low dietary concentration, P2: medium dietary concentration, P1: high dietary concentration, AMEn: nitrogen-corrected apparent metabolisable energy.
[A] provides per kg of diet: viatmin A, 10 000 IU; Vitamin D, 2760 IU; vitamin E, 10 IU; menadione bisulfate, 2 mg; riboflavin, 6 mg; Ca pentothenate, 15 mg; niacin, 30 mg; folic acid, 1 mg; vitamin B_{12}, 10 µg; thiamine mononitrate, 2 mg; choline chloride, 200 mg.
[B] provides in $mg \cdot kg^{-1}$ of diets: Mn, 75; Zn, 60; Fe, 25; Cu, 3; I, 1; Se, 0.02.

2.3. Measures

2.3.1. Growth, feed intake and carcass composition

All chickens were individually weighed and food intake was measured per pen weekly.

The F-chickens were slaughtered at 6 weeks, the M at 8 weeks and the S at 12 weeks according to the commercial slaughter age. Twenty-four chickens per treatment for each slaughter (4 per pen) were sampled to match the average bodyweight and standard deviation of each treatment. The broilers were fasted for 8 hours before slaughter. Selected chickens were transported to the slaughterhouse two hours before slaughter. After scalding, automatic plucking and manual gut removal, the carcasses were chilled in a cold room for 24 h at 2 °C. The right and left *Pectoralis major* and *minor*, thigh + drumstick and abdominal fat were dissected and weighed according to the anatomical technique [17]. Carcass composition data were expressed in % of body weight previous to slaughter.

2.3.2. Meat quality

The ultimate pH was measured by inserting the pH electrode into the muscle 24 h after slaughter. Meat colour was measured 72 h after slaughter with a Hunterlab chromameter (Reston, VA20190) on the ventral side of the *Pectoralis major* by the CIE method (coordinate: L*, a*, b*) [5]. At 24 h post-mortem, the left *Pectoralis major* muscles were put in closed plastic bags and suspended by hooks. Drip loss was measured by the difference between the *Pectoralis major* weight at 24 h and 72 h after slaughter and expressed as the percentage of the 24 h weight.

2.4. Statistical analysis

Mortality rates were recorded per pen (number of dead). Chicken type and dietary concentration effect was tested with the Kruskal-Wallis non-parametric test. Average performances (weight, feed intake, gain, feed conversion ratio and AEG), composition and meat quality data per pen were analysed with a two way analysis of variance (chicken type × feed). The differences between the treatment means were tested for significance using the Student-Newmann-Keuls multiple comparison test ($P < 0.05$).

3. RESULTS

3.1. Environmental effects on mortality and growth

The total mortality of the F-chickens (9.1%) was significantly higher than the M- and S-chickens (2.9 and 3.3% respectively; $P < 0.001$) (Tab. II). Dietary treatments had no effect on mortality. A limited outbreak of necrotic enteritis in week 6 led to a drug treatment of all chickens for 5 days (Vetrimoxin; 1 g per 10 kg live weight). Several heat episodes were recorded during weeks 3, 6 and 7. Eight F-chickens per pen were removed at 3 weeks and only eight average weight F-chickens were kept per pen after the age of 7 weeks to limit the heat stress effects. Growth responses to heat stress were only observed in week 7 (Fig. 1). When comparing week 7 to week 6 of age, feed intake was reduced by 10% for the F-chickens whereas the feed intake of the M and S-chickens were little affected and body weight gain was reduced by 34%, 24% and 17% for F, M and S, respectively (Tab. II).

3.2. Growth responses of broilers to dietary concentration

At one day of age, the M-chicks were significantly lighter (34.3 g) than the S- (40.0 g) and F-chicks (43.7 g). There were no significant differences between dietary treatment (Tab. II). At slaughter, the S-chickens at 12 weeks (2923 g) were

Table II. Growth responses of fast growing (F), medium growing (M) and slow growing (S) chickens to high (P1), medium (P2) and low (P3) dietary concentrations. Effects on mean (± se) total mortality, body weight at slaughter and feed intake, body weight gain and feed conversion ratio during each dietary period.

Chicken		F			M			S				Statistics		
Feed		P1	P2	P3	P1	P2	P3	P1	P2	P3	SEM	Strain	Feed	S × F
Weight (g)	1 day	43.5	43.8	43.9	34.3	34.3	34.2	40.2	40.0	39.9	± 0.66	***	NS	NS
	Slaughter	2545 d	2566 d	2436 b	2681 c	2639 c	2536 d	2972 a	2937 a	2861 b	± 26.6	***	***	NS
Feed intake	0–1 week	93.8 b	97.4 a	95.1 a	68.2 d	69.9 c	71.2 c	62.4 e	64.9 e	66.1 d	± 2.6	***	**	NS
(g per chicken	1–3 weeks	894	891	900	556	557	557	416	426	426	± 56.5	***	NS	NS
per period)	3–6 weeks	3268 b	3553 a	3572 a	2264 d	2360 c	2316 c	1525 e	1451 f	1555 e	± 197	***	***	***
	6–8 weeks	2380 b	2544 b	2755 a	1957 d	2031 d	2130 c	1270 g	1315 f	1407 e	± 358	***	***	NS
	8–12 weeks							3231 c	3406 b	3628 a	± 128		***	
Gain	0–1 week	89.7 a	90.4 a	84.7 b	61.5 c	61.7 c	59.9 c	50.3 d	50.9 d	50.7 d	± 5.6	***	*	NS
(g per chicken	1–3 weeks	630 a	619 ab	602 b	379 c	368 d	357 e	271 f	261 g	254 g	± 34.3	***	***	NS
per period)	3–6 weeks	1782 a	1813 a	1705 b	1330 c	1293 d	1218 e	828 f	781 g	780 g	± 104	***	***	**
	6–8 weeks	997	952	959	877	882	866	570	577	553	± 189	***	NS	NS
	8–12 weeks							1212	1226	1183	± 68.3		NS	
Feed conversion ratio	0–1 week	1.04 f	1.08 e	1.12 d	1.11 de	1.13 d	1.19 c	1.24 b	1.28 a	1.3 a	± 0.09	***	***	NS
(g feed intake·g^{-1}	1–3 weeks	1.42 c	1.44 c	1.5 bc	1.47 bc	1.51 b	1.56 b	1.54 b	1.63 a	1.68 a	± 0.14	***	***	NS
gain)	3–6 weeks	1.83 d	1.96 b	2.1 a	1.7 e	1.83 d	1.9 c	1.84 d	1.86 d	1.99 b	± 0.12	***	***	**
	6–8 weeks	2.4 cd	2.7 b	2.88 a	2.23 d	2.3 cd	2.46 c	2.23 d	2.28 cd	2.54 c	± 0.44	***	***	NS
	8–12 weeks							2.67 c	2.78 b	3.07 a	± 0.10		***	
Mortality^{X} (%)		6.1 ± 1.7	7.4 ± 1.5	9.8 ± 3.5	2.1 ± 1.4	1.2 ± 1.2	4.6 ± 2.3	1.2 ± 0.6	2.5 ± 1.2	3.7 ± 2.0		***	NS	

a, b, c: different superscripts mean significant differences between values. ***: $P < 0.001$; **: $P < 0.01$; *: $P < 0.05$; NS: non-significant; mortality^{X}: differences between strains or feed were tested with the Kurskal-Wallis non-parametric test.

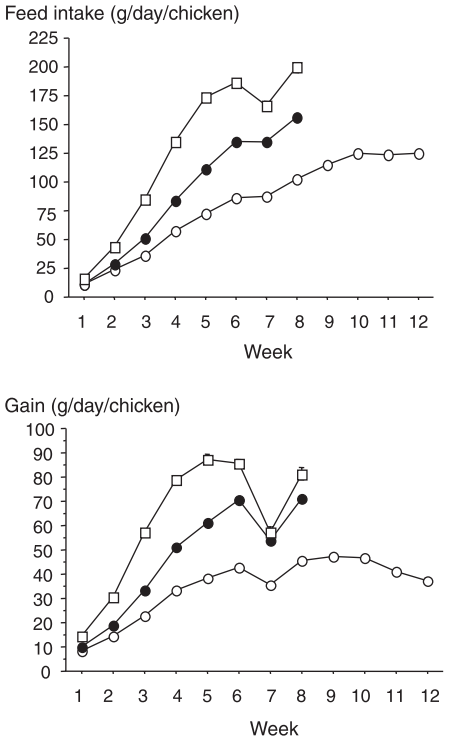

Figure 1. Feed intake (upper graph) and body weight gain (lower graph) of slow growing S- (–○–), medium growing M- (–●–) and fast growing F- (–□–) chickens until 8 weeks of age for M- and F-chickens and 12 weeks of age for S-chickens.

significantly heavier than the 8 week M- (2619 g) and 6 week F-chickens (2516 g). At this period, the body weights of the P3 fed chickens were 4.5% and 3.8% lighter than those fed the P1 and P2 diets, respectively ($P < 0.001$).

For all periods, feed intake (FI) and body weight gain differed in growth rates (F > M > S). A significant FI interaction between the chicken type and the diets during the 3–6 week period was observed (Tab. II, $P < 0.001$). It was mainly the consequence of a more pronounced reduction in FI with the P1 diet compared to the other two diets in the F- and M-chickens and to a lower intake of the P2 diet compared to the other two diets in the S-chickens. Before 3 weeks of age, FI did not differ significantly between the diets except during the first week when less P1 diet was consumed as compared to the other two. After 3 weeks of age, significantly greater quantities of low energy diets were consumed compared to the concentrated diets (P3 > P2 > P1) with the exception of the above described interaction.

A significant interaction between the chicken type and diets was measured for body weight gain for the 3–6 weeks period ($P < 0.001$). During this period, gain was higher with P1 and P2 than with the P3 diet for the F and S chickens and there was a P1 > P2 > P3 gain for the M chickens. Before 3 weeks of age, the concentrated diets significantly increased body weight gain compared to the diluted diets but after 6 weeks of age, the diets had no significant effect on body weight gain.

A significant interaction during the 3–6 weeks period between the chicken type and the diets was also observed for the feed conversion ratio (FCR). This interaction was due to the differences in FI and body weight gain that explained the significantly higher FCR with the P2 diet than with the P1 diet for the F- and M-chickens only. Before 3 weeks of age, FCR was significantly higher for S compared to M, and F was significantly lower than M. During the 6–8 weeks period, the F-chicken's FCR (2.66) was significantly higher than those of the M- and S-chickens (2.33 and 2.35, respectively). The concentrated diets significantly improved the FCR (P1 < P2 < P3) except for the interaction described above.

3.3. Available Energy for Growth (AEG)

An estimation of the available energy for growth (AEG) was calculated by the difference between energy intake (feed intake × feed AME) and the energy requirement for maintenance estimated by the equation of

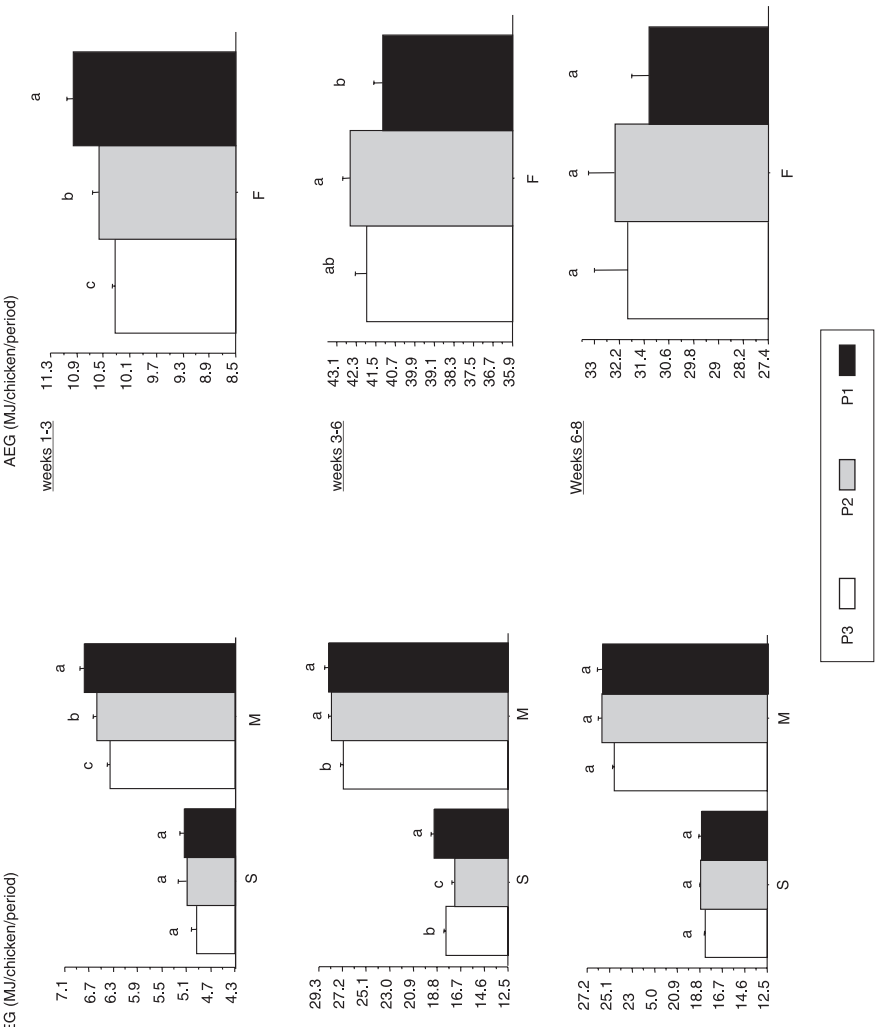

Figure 2. Response between high (P1), medium (P2) and low (P3) dietary concentration diets in the 3 types of chicken (F: fast-growing; M: medium growing and S: slow growing) for the available energy for growth (AEG ± se) during the 3 dietary periods.
[a,b,c]Different superscripts in the same type of chicken mean significant differences between the values at 5%.

Table III. The effects of strain: fast growing chickens (F) at 6 weeks of age, medium growing chickens (M) at 8 weeks of age and slow growing chickens (S) at 12 weeks of age, and the effects of high (P1), medium (P2) and low (P3) dietary concentrations on mean (± se) carcass composition, pH 24 hours after slaughter, drip loss and the 3 coordinates L*, a* and b* measured 3 days after slaughter.

	Chicken type			Dietary concentration			Statistics		
	F	M	S	P1	P2	P3	Strain	Feed	S × F
Carcass composition (% of body weight)									
Breast meat	17.2 ± 0.13 a	15.7 ± 0.12 b	14.4 ± 0.08 c	15.8 ± 0.27	15.8 ± 0.25	15.7 ± 0.25	***	NS	NS
Thigh +drumstick	24.2 ± 0.11 b	24.1± 0.1 b	24.6 ± 0.1 a	24.1 ± 0.11	24.4 ± 0.11	24.4 ± 0.12	***	NS	NS
Abdominal fat	2.64 ± 0.08 a	2.86 ± 0.07 a	3.44 ± 0.13 b	2.79 ± 0.1	3.04 ± 0.11	3.11± 0.14	***	NS	NS
Breast meat quality									
pH 24 h	6.01 ± 0.09 a	5.82 ± 0.01 b	5.59 ± 0.02 c	5.83 ± 0.04	5.82 ± 0.04	5.78 ± 0.04	***	NS	NS
Drip loss	1.03 ± 0.09	1.21 ± 0.08	1.2 ± 0.1	1.07 ± 0.08	1.15 ± 0.1	1.22 ± 0.09	NS	NS	NS
L*	54.5 ± 0.29 a	54.9 ± 0.31 a	53.5 ± 0.25 b	53.8 ± 0.2 y	54 ± 0.23 y	55.1 ± 0.38 x	***	**	NS
a*	–0.38 ± 0.13 b	–0.67 ± 0.07 c	0.28 ± 0.1 a	–0.18 ± 0.1 x	–0.05 ± 0.15 x	–0.53 ± 0.12 y	***	**	NS
b*	9.11 ± 0.18 a	6.89 ± 0.20 c	8.35 ± 0.19 b	8.34 ± 0.24 x	8.65 ± 0.26 x	7.37 ± 0.24 y	***	***	NS

a, b, c (for chicken type) or x, y (for dietary concentration): different superscripts mean significant differences between the values.
***: $P < 0.001$; **: $P < 0.01$; *: $P < 0.05$; NS: non-significant.

Leclercq and Saadoun [16]. Measured AMEn [4] were used to calculate AEG except for the 1–3 weeks period where calculated AME were used. An interaction between the chicken type and diets was measured for the 3–6 weeks period. AEG was significantly lower with the P1 diet compared to P2 and P3 for the F-chickens whereas the AEG on the P1 diet was significantly higher than P2 and P3 for the M- and S-chickens (Fig. 2). AEG for all periods corresponded to the growth rate of the chicken types (F > M > S). A significantly higher AEG was observed with a higher dietary concentration (P1 > P2 > P3) for the 1–3 weeks period but not during the 6–8 weeks period (P1 = P2 = P3).

3.4. Carcass composition and meat quality

No significant interactions between the chickens were measured and then only factorial averages are presented (Tab. III). Breast meat yield was significantly higher for F (17.2%) compared to the M (15.7%) and S-chickens (14.4%) ($P < 0.001$). Thigh + drumstick yield was significantly higher for the S- (24.6%) compared to the M- and F-chickens (24.1 and 24.2%, respectively). Abdominal fat content was significantly higher for the S- (3.44%) than for the M- and F-chickens (2.86 and 2.64%, respectively; $P < 0.01$). No significant dietary effect was observed on breast meat, tight + drumstick yield and abdominal fat.

The ultimate pH of breast meat from the S-chickens (5.59) was lower than those of the M- and F-chickens (5.82 and 6.01, respectively). Drip loss was not significantly different between the three types of chickens and the dietary treatments.

The lightness (L*) of the S-chicken breast meat was significantly lower than M and F at 72 h after slaughter ($P < 0.05$). Redness (a*) was higher for the S- than for the M- and F-chickens and yellowness (b*) was higher for the F- than for the M- and S-chickens.

4. DISCUSSION

When comparing young broilers (1–3 weeks) to older ones (6–8 weeks) two distinct types of response to dietary concentration were observed in the three genotypes. During the 1–3 weeks period, the F, M and S-chickens fed the P1 diet had higher body weight gain (5 and 7%) for the same

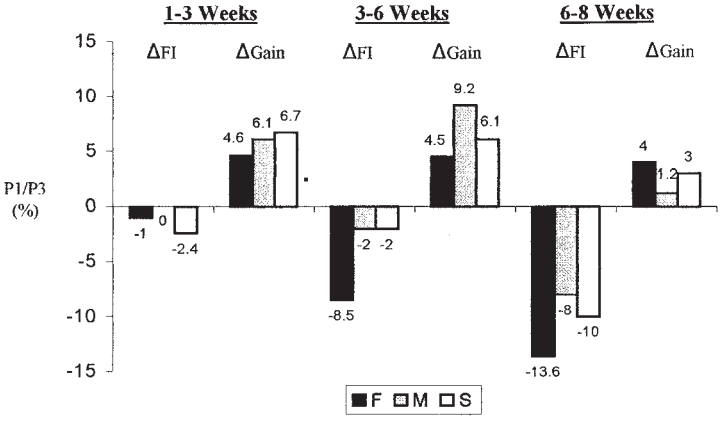

Figure 3. Relative variations (%) of average feed intake (ΔFI) and weight gain (ΔGain) between P1 (high concentration diets) and P3 (low concentration diets) fed to the F- (fast growing), M- (medium growing) and S- (slow growing) chickens.

feed intake compared to the P3 diets. During the 6 to 8 weeks period, the 3 types of chickens adjusted their feed intake to the diet to maintain approximately the same energy intake and body weight gain (Fig. 3). The 1980's chicken was believed to adjust its energy intake to its energy requirement (growth and maintenance) [10]. The energy intake adjustment to the diet concentration is the basis of feed intake prediction in several mathematical growth and requirement models [10, 15]. To compensate for the differences in live weight and maintenance energy requirements at the same age between broiler types, available energy for growth (AEG) was computed (Fig. 2). The results confirmed the two types of response observed on feed intake and body weight gain: overconsumption of concentrated compared to diluted diets before 3 weeks of age and the same energy intake after 6 weeks of age whatever the diet concentration.

Environmental conditions during the 1–3 and 6–8 weeks of age periods were different. The 6–8 weeks period was characterised by high heat stress that led all three types of chickens to reduce their feed intake to limit heat production in order to maintain their thermogenesis/thermolysis balance [7, 13]. The range of growth reduction observed during the hot period also depended on the type of chickens. From week 6 to week 7, the fast growing broilers showed a 10% reduction in feed intake and 30% reduction in weight gain while the slower growing chickens (S and M) reduced their feed intake by only 1% and their weight gain by 17%. These different capacities of adaptation might be related to the effects of selection on growth performance. Indeed, the increased metabolic activity in fast growing broilers may have increased their rate of heat production rather than their capacity to dissipate heat [20]. This imbalance between heat production and thermolysis might have increased the sensitivity of fast-growing chickens to their environment and reduced their adaptability to high temperature. High environmental temperatures that occurred during week 7 might also partly explain the difference in mortality rates between F and M or S chickens. Similarly, the consequence of necrotic enteritis was responsible for approximately a third of overall mortality and represented about half in the F-chickens. Our results indicated differences in sensitivity between F- and M- or S-chickens in disease and high temperature conditions.

The low number of significant interactions between chicken type and feed suggests that the three types of chickens responded similarly to the dietary concentration (Tab. II). The only different response between genotypes to dietary concentration was in FI, body weight gain and FCR during the 3–6 weeks period. If the P1 and P3 diets are only considered, feed intake adjustment can be questioned (Fig. 3). Between 3 to 6 weeks of age, the M- and S-chickens showed a response quite close to the previous period, whereas the F-chickens reduced their feed intake of the P1 diet compared to P3 intake but maintained a growth rate quite similar to the previous period. This might have been due to moderate heat conditions (25–26 °C) accentuated by the higher stocking density for F-chickens that would have limited performance in the F-chickens and not in the slower growing genotypes (stocking density at 5 weeks of age: F = 28 $kg \cdot m^{-2}$, M = 13.6 $kg \cdot m^{-2}$, S = 9.3 $kg \cdot m^{-2}$). Environmental parameters including necrotic enteritis or heat stress as well as bird densities and feed composition and form might have interacted with the three types of chickens and be responsible for a part of the measured interactions. This limited the interpretation of our results to the real conditions of the experiment. Nevertheless, the differential threshold of sensitivity between the three types of chickens requires further studies on the interactions between environmental (stocking density,

temperature, disease, etc.) and nutritional factors (energy concentration, amino acids, durability, etc.). Better understanding of such interactions might be used to adjust the models of diet composition to the current systems of production.

One of the aims of this experiment was to test the range of nutritional responses in broiler production. In terms of growth performance, more than 100 g higher body weight at slaughter and a 10% improvement in feed conversion ratio were measured with concentrated P1 diets compared to the diluted P3 diets for all three types of chickens. Surprisingly, carcass composition was not affected by the diet, suggesting that the 3 dietary concentrations were sufficient to reach the same breast and thigh + drumstick yields in our conditions. This result suggests that it is difficult to modify carcass composition without changes in body weight gain and feed conversion ratio in chickens [1, 11].

Meat quality varied between genotypes. A higher ultimate pH was observed in the F-chickens compared to slower-growing genotypes (Tab. III). Selection on body weight and breast meat yield might have caused a reduction in the breast muscle glycogen reserve that might explain the differences between the ultimate pH of F-, M- and S-chickens [3, 14]. Although it was not significant, there was also a tendency to higher drip loss in the S and M genotypes compared to the F genotype, which was consistent with the negative correlation between ultimate pH and drip loss often reported in chicken breast muscle [2, 14]. The breast meat of fast-growing birds was lighter (higher L*), confirming previous studies on lines selected for growth rate [3, 14]. Differences in breast meat lightness between genotypes could not be related to differences in ultimate pH since it is generally accepted that meat becomes lighter as the ultimate pH decreases [5]. The colour difference between chicken strains might be a consequence of their respective slaughter ages since the myoglobin content of broiler breast muscle increases between 9 and 12 weeks of age [22, 23].

One noticeable dietary effect was the reduction in redness and yellowness and the increase in lightness with the P3 diets. This can be explained by the differences in raw materials used for feed formulation. The P3 diet formulae contained more wheat than the other two diets which contained more corn. Corn contains carotenoid pigments known to modify the colour of meat [6]. It might be interesting to take into account the relationship between pigments in raw materials, feed formulation and meat colour to meet consumer preferences.

5. CONCLUSION

Despite the wide differences in growth performance between the three chicken types tested, the nutritional responses were essentially similar. Under non-limiting environmental conditions, the improvement of the feed conversion ratio in meat chickens fed with more concentrated diets was mainly due to a higher energy intake. Under limiting environmental conditions (i.e. high temperature, high stocking density or poor feed quality) or at an older age, chickens adjusted their energy intake to dietary concentration and had similar growth rates.

The sensitivity to non-limiting and limiting conditions might be different between genotypes, fast growing broilers being more sensitive than lower growing broilers. Body weight and/or the age of chickens might be crucial factors to determine the threshold between non-limiting and limiting environmental conditions. A better understanding of this threshold might help to develop new models for the different types of chicken growth.

Our results also showed that, despite the impact of dietary concentration on growth, carcass composition and certain meat quality parameters were not significantly

modified. Only meat colour was modified by diet composition, mainly due to its carotenoid contents. Taking into account the broad range of regimes and genotypes tested in the present experiment, our results suggest limited or no possibilities to changing the carcass composition of broiler chickens without significantly changing growth performance.

ACKNOWLEDGMENTS

This study was supported by OFIVAL and Hubbard ISA. The authors wish to thank the seven French feed manufacturers for their help in the formulation of the experimental diets, the technical staff of the experimental unit of the Poultry Research Station, particularly S. Nevoit for rearing animals, and the staff of the genetics and meat quality teams for their help at the slaughterhouse and for carcass dissections.

REFERENCES

[1] Acar N., Moran E.T., Bilgili S.F., Live performance and carcass yield of male broilers from two commercial strain crosses receiving rations containing lysine below and above the established requirement between six and 8 weeks of age, Poult. Sci. 70 (1991) 2315–2321.

[2] Barbut S., Problem of pale soft exudative meat in broiler chickens, Brit. Poult. Sci. 38 (1997) 355–358.

[3] Berri C., Wacrenier N., Millet N., Le Bihan-Duval E., Effect of selection for body composition on muscle and meat characteristics of broilers from experimental lines, Poult. Sci. 80 (2001) 833–838.

[4] Bourdillon A., Carré B., Conan L., Francesch M., Fuentes M., Huyghebaert G., Janssen W.M., Leclercq B., Lessire M., McNab J., et al., European reference method of in vivo determination of metabolisable energy in poultry: reproductibility, effect of age, comparison with predicted values, Brit. Poult. Sci. 31 (1990) 567–576.

[5] Fletcher D.L., Broiler breast meat color variation, pH and texture, Poult. Sci. 78 (1999) 1323–1327.

[6] Froning G.W., Color of poultry meat, Poult. Avian Biol. Rev. 6 (1995) 83–93.

[7] Geraert P.A., Métabolisme énergétique du poulet de chair en climat chaud, INRA Prod. Anim. 4 (1991) 256–267.

[8] Han Y., Baker D.H., Lysine requirements of fast- and slow-growing broiler chicks, Poult. Sci. 70 (1991) 2108–2114.

[9] Han Y., Baker D.H., Effects of sex, heat stress, body weight, and genetic strain on the dietary lysine requirement of broiler chicks, Poult. Sci. 72 (1993) 701–2708.

[10] Hurwitz S., Sklan D., Bartov I., New formal approach to the determination of energy and amino acid requirement of chickens, Poult. Sci. 57 (1978) 197–205.

[11] Hurwitz S., Sklan D., Talpaz H., Plavnik I., The effect of dietary protein level on the lysine and arginine requirements of growing chickens, Poult. Sci. 77 (1998) 689–696.

[12] Julian R.J., Rapid growth problems, ascites and skeletal deformities in broilers, Poult. Sci. 77 (1998) 1773–1780.

[13] Keshavarz K., Fuller H.L., The influence of widely fluctuating temperatures on heat production and energetic efficiency of broilers, Poult. Sci. 59 (1980) 2121–28.

[14] Le Bihan-Duval E., Millet N., Remignon H., Broiler meat quality: effect of selection for increased carcass quality and estimates of genetic parameters, Poult. Sci. 78 (1999) 822–826.

[15] Leclercq B., Beaumont C., Effects of genetic potential on the lysine requirement and economic results of simulated broiler flocks, Anim. Res. 50 (2001) 67–78.

[16] Leclercq B., Saadoun A., Selecting broiler for low or high abdominal weight: comparison of energy metabolism of the lean and fat lines, Poult. Sci. 61 (1982) 1799–1803.

[17] Marche G., La découpe anatomique et la dissection des volailles : le poulet, le canard, la dinde, SYSSAF-INRA, Nouzilly, France, 1985.

[18] Morris T.R., Njuru D.M., Protein requirement of fast- and slow growing chicks, Brit. Poult. Sci. 31 (1990) 803–809.

[19] Nicholson D., Research: is it the broiler industry's partner into the new millennium?, World's Poult. Sci. J. 54 (1998) 271–278.

[20] Padilha J.F.C., Influence de la chaleur sur le métabolisme énergétique et sa régulation chez les poulets en croissance, Thèse de doctorat, Université de Tours, France, 1995.

[21] Sauveur B., Stratégies pour de nouveaux progrès techniques et économiques en aviculture, INRA Prod. Anim. 4 (1991) 31–40.

[22] Touraille P.C., Kopp J., Valin C., Ricard F.H., Chicken meat quality. 1. Influence of age and growth rate and physico-chemical and sensory characteristics of the meat, Arch. Geflügelkd. 45 (1981) 69–76.

[23] Touraille P.C., Kopp J., Valin C., Ricard F.H., Chicken meat quality. 2. Change with age of some physico-chemical and sensory characteristics of the meat, Arch. Geflügelkd. 45 (1981) 97–104.