

Effect of dietary protein on the allometric relationships between some carcass portions and body protein in three broiler strains

R. Danisman & R.M. Gous[#]

Animal and Poultry Science, University of KwaZulu-Natal, Pietermaritzburg 3209, South Africa

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Abstract

This paper reports the allometric relationships between some of the physical parts and body protein weight of three commercial broiler strains reared, sexes separate, on four dietary protein levels to six weeks of age. Birds were sampled at day old and then weekly from each of the treatments to determine the weights of the physical parts and the chemical composition of each of 582 birds. Allometric regressions were compared between strains, sexes and dietary protein levels using linear regression with groups. Whereas these regressions were similar over strains and sexes, some interactions were evident between factors, and differences occurred when broilers were fed differing dietary protein levels. These differences may be explained on the basis that lipid is deposited to different extents in each of the parts in response to dietary protein, although this was not tested. The allometric regressions presented are an attempt to provide information that would enable the prediction of the weights of breast meat, thigh, drum and wing at different stages of growth of broilers whose genotype and feed composition are adequately described.

Keywords: Breast meat, thigh, drum, wing, carcass yield, simulation modelling

[#] Corresponding author: gous@ukzn.ac.za

Introduction

The increasing consumer demand for breast meat has resulted in a search for ways of producing chickens that yield greater amounts of this desirable body component, the two most important approaches being through genetic selection and nutrition. Broilers have been subjected to selection for many decades, and geneticists have in that time considerably improved traits such as body weight gain, feed conversion efficiency and carcass characteristics (Havenstein *et al.*, 2003; McKay, 2008). Many reports claim that improvements have been made in the yield of parts (breast meat in particular) of broilers, with resultant 'high yield' strains having been developed by some breeding companies (Cobb, 2007; Aviagen, 2009). Similarly, there are numerous claims that breast meat yield can be improved by altering dietary nutrient specifications: examples are the comprehensive dataset published by Hakansson *et al.* (1978) and the effects of dietary protein content on breast meat yield (Kemp *et al.*, 2005). These improvements raise a general problem in growth analysis, which is to be able to predict the effects of genotype, feed and environment on the growth of protein and lipid in breast meat and other body components.

Such predictions may be accomplished directly, using a growth function specific to each component, or indirectly, by predicting the growth of the component as a proportion of body protein growth. Potential protein growth rates have been described for various genotypes (Hancock *et al.*, 1995; Gous *et al.*, 1996) using a Gompertz growth function (Gous *et al.*, 1999) and simulation models already exist for predicting the actual growth of body protein as influenced by genotype, feed and environment (Emmans, 1981; EFG Software, 2007). Such models may therefore be used to predict the growth of any scaled component of the body, as any components that share the same rate of maturing can be scaled allometrically (Emmans, 1987; 1988). What is needed for each genotype is a description of the potential rates of growth of body protein and of the different components of the body so that the allometric relationships between the important components of the body and body protein can be determined. Differences in the allometric relationships

between genotypes, or those brought about through nutritional or environmental manipulation would enable these effects to be modelled.

The proportions of the body change in a regular fashion throughout growth, and such non-isometric scaling is called allometry. Many morphological and physiological variables are scaled, relative to body size, according to allometric equations of the general form $y = ax^b$. In a simple proportionality the slope (b) will be 1.0, as with the weight of blood in relation to body mass, or the amount of ash relative to the weight of body protein (Schmidt-Nielsen, 1984; Emmans, 1987). If the dependent variable increases at a slower rate than would be indicated by simple proportionality the regression line would have a slope less than 1.0, such as with metabolic rate (0.75 of body weight) and body water (0.9 of body protein weight). Body lipid content would generally increase at a faster rate than body protein content, and hence the slope would be greater than 1.0. Where the quantities do not change with body size, such as the haemoglobin concentration in the blood, the slope is zero. Some functions even decrease with body size: the slope for heart rate vs. body size, for example, is -0.25. Knowledge of these relationships would be invaluable for predicting the weights of the commercially important physical components of a broiler, as it means that only the weight of body protein needs to be predicted, after which the weights of all the remaining chemical and physical components of the body can be calculated using the appropriate allometric coefficients. However, no such relationships for broilers have been published in the scientific literature nor is it possible to determine such relationships accurately using the data that have been published.

Where mean weights have been published of the physical components of broilers resulting from changes in genotype, feed quality or the environment, a rough estimate of the allometric relationships with body weight can be obtained, but this is inaccurate for two reasons: firstly, because of variation between individuals on the same treatment the regressions would be more accurate if the individual results were used instead of treatment means; and secondly, because the treatments applied often influence the amount of lipid in the body, it is more accurate to regress component weights against body protein weight rather than on body weight thereby eliminating the confounding effect of body lipid content. This implies that the body protein content should be measured of each bird sampled for the measurement of body component weights.

In the trial reported here, the weights of various parts of the body were measured at different stages of growth after which all components of each bird were minced together in order to determine the chemical composition of each bird. With the information about the weights of the components and of the protein content of each bird it was possible to determine the allometric relationships between the components and body protein, and to compare these between genotypes and feed protein levels. Apart from similar exercises having been conducted previously in our laboratory (Lindsay, 1992; Gous *et al.*, 1996) no other such data exist for comparison.

This study was designed to examine the relationships between some important components of the body and body protein among three broiler genotypes and two sexes fed four protein levels over a period of six weeks to ascertain whether differences in these allometric relationships exist.

Materials and Methods

Day-old sexed broiler chickens of three strains available in South Africa, namely, Ross 788, Ross 308 and Cobb 500, were used in the trial. A total of 48 pens was used with 70 chickens being placed initially per pen and with males and females being reared separately, i.e. eight pens of males and eight of females of each of three strains were used in the trial. The trial was terminated when the birds were 42 d of age.

Two basal starter and finisher feeds, one high and the other low in protein were formulated (Table 1) to contain equal contents of apparent metabolisable energy (AME) and major minerals, using a well balanced amino acid mixture derived from the EFG Broiler Growth Model (EFG Software, 2007). These two feeds were blended to produce two intermediate levels of protein (Table 2). The basal feeds were sampled after mixing and these were analysed for AME using the method of Fisher & McNab (1987) and digestible amino acid contents using a Waters amino acid analyser (AOAC, 2003). The starter feeds were fed to three weeks of age and the finisher feeds were used thereafter. Feed and water were offered *ad libitum* throughout the trial.

A representative sample (0.5) of birds in each pen was weighed at weekly intervals up to 42 d. Feed allocated to each pen was weighed and transferred to the feeding troughs when necessary. At the end of each week feed remaining in the troughs and in the bag was weighed, to determine the amount of feed consumed during the week.

At day old, six birds were sampled from each strain x sex, the weights of the parts were dissected and measured then replaced before each chick from each strain and sex was minced and subjected to chemical analysis. Two birds were removed from each pen for carcass analysis each week up to the 6th week, resulting in a total of 6 (initial) + 96 x 6 = 582 birds being used for carcass analysis. The weight of each bird was recorded after killing (without loss of blood), plucked weight was recorded (feather weight calculated by difference), and then the breast, without skin or bone, breast skin, breast bone, thighs, drums, wings, intestine, liver, and remainder were dissected and weighed. All the body parts, except for feathers, from each bird were placed together in a separate plastic bag, clearly marked with the identity of the bird, and stored in a freezer until mincing took place. Each chicken was minced separately and sampled for chemical analysis which included water, protein (as N using the Dumas method on a LECO N analyser, AOAC, 2003), ash (AOAC, 2003), and gross energy (GE) using a bomb calorimeter. Lipid (L) content was calculated from GE using the equation $L = -0.8756 + 0.04754 * GE$ (University of KwaZulu-Natal, unpublished).

Table 1 Ingredient and nutrient composition (g/kg) of the low (LP) and high protein (HP) basal starter and finisher feeds used

Ingredient	Starter		Finisher	
	LP	HP	LP	HP
Maize	532	405	630	485
Soybean full fat	266	470	265	381
Soybean 480 g CP/kg	127			
Sunflower 370 g CP/kg		334		228
Fish meal 650 g CP/kg		555		
Limestone	169	124	176	169
L-lysine HCl	0.1	0.5	0.5	0.9
DL methionine	1.7	3.4	1.3	2.7
L-threonine		0.6		0.4
Vit+min premix	2.5	2.5	2.5	2.5
Choline chloride 60	0.7		7.6	12.9
Salt	3	2	14	
Monocalcium phosphate	16.6	11.6	16.8	16.6
Sodium bicarbonate	3	2.5	6.7	8.4
Oil - Soya	30		50	50
Chemical composition - determined				
AME (MJ/kg)	13.2	13.3	13.4	13.6
Crude protein	207	261	153	194
Lysine ¹	10.2	14	7.4	10.1
Methionine ¹	4.5	7.2	3.5	5.3
Methionine & cysteine ¹	7.4	10.3	5.8	7.9
Threonine ¹	6.8	9.2	5	6.7

¹Digestible amino acid content.

The weight and natural log (*ln*) of each chemical component of the body was calculated, from which the allometric relationships between the components (Y) and body protein weight (X) were determined using the

equation $\ln Y = \ln a + b \ln X$. The exponent b represents the slope of the linear regression obtained in a logarithmic plot.

A factorial design was used, with three protein levels, four strains and two sexes. Two replications of each treatment combination were used. Data were subjected to statistical analysis using analysis of variance for calculation of treatment means only, and simple linear regression of the form $\ln Y = a + b \ln X$ using natural logarithms (\ln) of both the component (Y) and body protein (X) weights to determine the allometric coefficients. The groups procedure of Genstat (2002) was applied to determine differences between constant terms (a) and slopes (b) of the regressions. Main effects and two- and three-way interactions between factors were compared in this way.

Table 2 Feed protein treatment, blending proportions, and protein content (g/kg) of starter and grower feeds

Treatment	HP	LP	Protein in Starter	Protein in Grower
1	100	0	261	194
2	67	33	243	181
3	33	67	225	167
4	0	100	207	153

HP- high protein; LP - low protein.

Results

Table 3 Mean body weight (g) and feed conversion efficiency (g gain/kg feed) of males (M) and females (F) of three strains of broiler fed four levels of balanced protein to six weeks of age, and mean body lipid content (g/kg) of broilers sampled for carcass analysis at the end of the trial

Sex	High Protein		Protein 2		Protein 3		Low Protein	
	F	M	F	M	F	M	F	M
Body weight at six weeks								
Ross 308	2400	2847	2465	2876	2425	2826	2296	2636
Ross 788	2387	2792	2427	2849	2401	2739	2319	2533
Cobb	2508	2866	2506	3031	2486	2902	2366	2614
Main effect	2633		2692		2630		2461	
RMS ¹	2792							
Feed conversion efficiency								
Ross 308	572	602	563	578	553	581	550	542
Ross 788	585	585	568	577	565	588	557	553
Cobb	620	633	603	652	602	625	581	585
Main effect	600		590		586		561	
RMS	197							
Body lipid content at six weeks								
Ross 308	126	47	148	86	196	109	151	151
Ross 788	144	76	158	100	192	125	188	136
Cobb	133	89	162	96	157	107	138	158
Main effect	103		125		148		154	
RMS	80.8							

¹ Residual mean square.

The objective of the trial was not to determine the extent to which broiler genotypes differed, or the extent to which dietary protein content would alter growth rate and feed conversion efficiency, but rather to produce a wide range of body weights and carcass compositions throughout the growing period such that the allometric relationships between the physical parts of broilers and their body protein contents could be determined. Therefore, although the body weights and food intakes of broilers on each of the treatments were recorded each week, only the mean final body weight and feed conversion efficiency (FCE) for each strain, sex and balanced protein level are presented here (Table 3) to indicate the extent to which these varied between birds on the various treatments. In all cases, males were heavier than females, and dietary protein content influenced growth rate, with the highest body weight being recorded on the second-highest feed protein level. Food intake was maximised on the second-highest feed protein level, declining at higher and lower levels, whereas FCE decreased linearly with dietary protein content, the highest (600 g gain/kg food) being on the highest protein feed.

Also presented in Table 3 are the mean body lipid contents of the broilers sampled for carcass analysis at 42 d of age. Females had higher ($P < 0.001$) lipid contents than males (158 vs. 107 g/kg) and there was a

Table 4 Mean breast meat weights, at weekly intervals, of males and females of three strains of broiler fed one of four dietary protein levels

Genotype	Dietary protein	Age, weeks					
		1	2	3	4	5	6
Females							
Cobb	High	15	59	126	233	268	398
	2	16	54	141	167	317	385
	3	16	52	121	211	226	391
	Low	12	45	108	203	224	312
Ross 308	High	14	49	116	192	290	337
	2	13	49	112	202	231	360
	3	13	44	103	191	264	328
	Low	9	33	100	169	223	283
Ross 788	High	13	49	128	183	252	294
	2	14	50	97	177	263	354
	3	10	47	93	187	197	361
	Low	10	41	97	154	179	308
Males							
Cobb	High	15	65	155	250	283	436
	2	16	51	157	233	342	430
	3	12	58	144	227	306	474
	Low	11	49	124	202	288	309
Ross 308	High	15	57	118	215	288	371
	2	15	51	126	168	294	433
	3	12	47	93	193	261	413
	Low	8	36	96	155	197	286
Ross 788	High	13	54	125	216	264	405
	2	14	49	123	182	335	450
	3	11	42	103	198	254	385
	Low	11	32	112	147	194	286
	RMS	3.1	50	309	879	2539	4088

linear increase in lipid content as dietary protein content declined. The mean values presented here demonstrate that the factors used, namely, strain, sex and feed protein content, produced differences in the body weights and feed efficiencies of the broilers, and because feed efficiencies differed, so too did the body composition of birds on the different protein treatments.

Of the components of the body that were measured, only the weights of breast meat, thigh, drum and wing are given in the tables below. The mean weights of the remaining five components measured, namely, breast skin and bone, liver, gut and the remainder of the carcass are not presented in this paper, nor are the results of the chemical analyses of the carcasses other than the lipid content at six weeks. The entire dataset is available from the corresponding author on request.

Table 5 Main effects of strain, sex and feed protein content on the allometric coefficients (constant term and regression coefficient \pm standard error) relating the weights of breast meat, thigh, drum and wing to body protein weight, with goodness of fit (R^2). Where no differences exist between levels of a factor only one value is given for the constant term and/or regression coefficient

Strain	Constant term			Regression Coefficient			R^2
	Ross 308	Cobb	Ross 788	Ross 308	Cobb	Ross 788	
Breast meat		-2.379 \pm 0.056			1.409 \pm 0.011		96.2
Thigh	-0.563	-0.611 \pm 0.021	-0.563		1.036 \pm 0.004		99.1
Drum	-0.623	-0.664 \pm 0.018	-0.623		1.015 \pm 0.04		99.3
Wing		-1.130 \pm 0.047	-0.946		1.068 \pm 0.009	1.040	98.5

Sex	Constant term		Regression coefficient		R^2
	F	M	F	M	
Breast meat		-2.379 \pm 0.056		1.409 \pm 0.011	96.2
Thigh		-0.585 \pm 0.020		1.036 \pm 0.004	99.1
Drum		-0.649 \pm 0.018	-0.621	1.015 \pm 0.004	99.3
Wing		-1.047 \pm 0.027		1.055 \pm 0.005	98.5

Feed protein	Constant Term				Regression Coefficient				R^2
	260	240	223	207	260	240	223	207	
Breast meat	-1.214	-1.261 \pm 0.055	-1.317	-1.536	1.191	1.200 \pm 0.011	1.205	1.237	98.9
Thigh	-0.490	-0.490 \pm 0.047	-0.490	-0.628	1.010	1.010 \pm 0.009	1.010	1.056	98.9
Drum	-0.659	-0.702 \pm 0.022	-0.702	-1.352		1.025 \pm 0.004			99.1
Wing	-0.728	-0.728 \pm 0.025	-0.728	-0.684		0.993 \pm 0.005			98.8

The mean breast meat weights, at weekly intervals, of males and females of three strains of broiler fed four dietary protein levels are given in Table 4. The weights refer to the entire breast meat and exclude skin and bone. Over all ages the weights were heavier in males than in females (390 vs. 343 g at 42 d), heavier in the Cobb strain than in Ross 308 or 788 (392, 351 and 355 g, respectively at 42 d), and dietary protein content resulted in a curvilinear response, with the highest weight of breast meat on protein level 2 (374, 402, 392 and 297 g, respectively at 42 d).

Data for breast meat and body protein weight from each bird sampled were used to calculate allometric equations for each strain, sex and feed protein level, which were compared using simple linear regression with groups in Genstat, the respective coefficients for the main effects of the three factors being presented in Table 5. Where no differences were apparent in either the constant term or regression coefficient the common value is presented, as with those between strains and sexes, where only one constant term (-2.379) and regression coefficient (1.409) is necessary to describe breast meat weight in terms of body protein content in all three strains and both sexes. The only differences in allometric coefficients between factors for breast meat were those brought about by feeding different levels of dietary protein, which resulted in linear trends in both constant terms (decreasing from -1.214 on the highest protein level to -1.536 on the lowest) and regression coefficients, which increased from 1.191 to 1.237.

Significant two-way interactions in the allometric coefficients for breast meat yield occurred between strain and sex (Table 6) with Ross 308 and 788 males differing from Cobb males and all females. The constant term for Ross males was between 0.182 ± 0.090 (Ross 788) and 0.196 ± 0.090 (Ross 308) higher, and the regression coefficient 0.054 and 0.058 ± 0.018 lower than for the Cobb males, indicating that the Ross strain had higher breast meat weights in the early stages of growth but with the Cobb strain overtaking this advantage at some stage before the end of the growing period. Interactions also occurred between strain and feed (Table 7) where the Ross 308 strain on protein level 4, for example, had a lower constant term (-0.421 ± 0.124) and a higher regression coefficient (0.054 ± 0.025) than the Cobb strain on the highest protein level, and between feed protein level and sex (Table 8). An example of the latter interaction is that between males and females on the highest protein level, where females had a lower constant term (-0.268 ± 0.108) and a higher regression coefficient (0.062 ± 0.021). The three way interactions between strain, sex and dietary protein levels are given in Table 9. No significant trends were evident but Ross 308 appeared to differ more than the Ross 788 from the Cobb strain.

Table 6 Parameter estimates for the two-way interactions between strain and sex over all protein levels in breast meat and drum weight

Parameter	estimate	SE	t(549)	t pr.
Breast meat				
Constant ¹	-1.428	0.066	-21.6	<0.001
ln_BP ²	1.236	0.013	94.4	<0.001
R308 M ³	0.196	0.090	2.18	0.03
R788M ⁴	0.182	0.090	2.01	0.044
ln_BP. 308M	-0.058	0.018	-3.25	0.001
ln_BP. 788M	-0.054	0.018	-3	0.003
Drum				
Constant	-0.588	0.041	-14.4	<0.001
ln_BP	1.00	0.008	119	<0.001
308F ⁵	-0.174	0.058	-3.31	0.003
ln_BP. 308F	0.040	0.012	2.61	<0.001

¹ Constant term with reference level being Cobb male.

² Regression coefficient with reference level being Cobb Male.

³ Ross 308 male; ⁴ Ross 788 male; ⁵ Ross 308 female.

The mean thigh weights of broilers on the various treatments, at weekly intervals, are given in Table 10. The weight referred to here includes bone and skin and is the mean of the two thighs from each bird. At six weeks the mean thigh weights of the three strains over all protein levels were similar (285, 282 and 280 g for Cobb, Ross 308 and 788, respectively), whereas the mean weight of male thighs (303 g) was 42 g heavier than those of females. A curvilinear response in thigh weight to dietary protein level was evident, with mean weights at six weeks of 270, 290, 300 and 270 g, respectively. The main effect of strain on the allometric relationship between thigh weight and body protein weight (Table 5) resulted in significant differences in constant terms between the Cobb strain vs. the two Ross strains but all having the same regression coefficient, i.e. the rate at which thigh weight increased with body protein content was the same in all strains, but the initial weight of the Cobb was higher, and this difference therefore was maintained throughout the growing period. Both the constant term and regression coefficient were the same for both sexes, but the constant term, whilst the same for the three highest protein levels, was significantly lower for the lowest protein level whilst the regression coefficient for this treatment was steeper than for the other protein levels.

There were no two-way interactions between strain and sex in the case of thigh weight, but feed protein level interacted with both strain (Table 7) and sex (Table 8). The interaction with strain occurred in one case only, with the regression coefficient for the Ross 788 fed the lowest feed protein level being 0.064 ± 0.022 higher than all other combinations of strain and feed protein content. The interaction with sex was brought about also at the lowest feed protein content, with a higher regression coefficient being exhibited by females (0.049 ± 0.018), and males (0.044 ± 0.018) on protein level 4. No three-way interactions were evident for thigh weight.

Table 7 Parameters for the significant two-way interactions between strain and feed protein level over both sexes in breast meat, thigh and drum weight

Parameter	estimate	SE	t(537)	t pr.
Breast meat				
Constant ¹	-1.341	0.091	-14.7	<0.001
ln_BP ¹	1.225	0.018	68.1	<0.001
R308 P4 ²	-0.421	0.124	-3.41	<0.001
ln_BP. R308 P1	-0.056	0.025	-2.25	0.025
ln_BP. R308 P2	-0.061	0.025	-2.46	0.014
ln_BP. R308 P4	0.054	0.025	2.17	0.031
Thigh				
Constant	-0.560	0.082	-6.84	<0.001
ln_BP	1.018	0.016	63.3	<0.001
ln_BP. R788 P4	0.064	0.022	2.85	0.005
Drum				
Constant	-0.604	0.075	-8.07	<0.001
ln_BP	1.000	0.015	67.9	<0.001
R308 P1	-0.237	0.104	-2.29	0.023
ln_BP. R308 P1	0.054	0.020	2.62	0.009
ln_BP. R308 P4	0.044	0.020	2.20	0.029
ln_BP. R788 P4	0.047	0.020	2.31	0.021

¹ Reference level is Cobb on Protein level 1.

² Ross 308 on Protein level 4.

³ Ross 788 on Protein level 1.

Table 8 Parameters for the significant two-way interactions between feed protein level and sex over all strains in breast meat and thigh weight

Parameter	estimate	SE	t(545)	t pr.
Breast meat				
Constant ¹	-1.097	0.074	-14.8	<.001
ln_BP ¹	1.164	0.015	80.5	<.001
P1F ²	-0.268	0.108	-2.49	0.013
P3F	-0.295	0.106	-2.79	0.005
P4F	-0.470	0.104	-4.5	<.001
P4M ³	-0.408	0.104	-3.92	<.001
ln_BP. P1F	0.062	0.021	2.93	0.004
ln_BP. P3F	0.061	0.021	2.89	0.004
ln_BP. P4F	0.086	0.021	4.12	<.001
ln_BP. P4M	0.062	0.021	2.96	0.003
Thigh				
Constant	-0.484	0.065	-7.43	<.001
ln_BP	1.010	0.013	79.6	<.001
ln_BP. P4F	0.049	0.018	2.68	0.008
ln_BP. P4M	0.044	0.018	2.42	0.016

¹ Reference level is Male on Protein level 1.

² Protein level 1, Female; ³ Protein level 4, Male.

Table 9 Parameters for the significant three-way interactions between strain, sex and feed protein level in breast meat and thigh weight

Parameter	estimate	SE	t(513)	t pr.
Breast meat				
Constant ¹	-1.376	0.127	-10.84	<.001
ln_BP ¹	1.230	0.025	49.51	<.001
R308 F P4 ²	-0.422	0.172	-2.45	0.015
R308 M P1 ³	0.414	0.175	2.37	0.018
R308 M P2	0.429	0.171	2.51	0.012
R308 M P4	-0.353	0.17	-2.07	0.039
R788M P1 ⁴	0.373	0.172	2.17	0.031
ln_BP. R308 M P1	-0.100	0.034	-2.93	0.004
ln_BP. R308 M P2	-0.097	0.034	-2.89	0.004
ln_BP. R788M P1	-0.089	0.034	-2.66	0.008

¹ Reference level is Cobb Male on Protein level 1.

²Ross 308, Female, Protein level 4; ³Ross 308, Male, Protein level 1;

⁴Ross 788, Male, Protein level 1.

The mean weights of the drum of broilers on the various treatments, at weekly intervals, are given in Table 11. These weights include bone and skin and represent the mean weights of the two drums from each bird. At six weeks the mean drum weight of the Cobb strain, over all protein levels, was lighter (230 g) than that of the Ross strains, which were both 240 g. Mean weight of male drums (129 g) was 22 g heavier than that of females. A curvilinear response in drum weight to dietary protein level was evident, with mean weights at six weeks of 233, 247, 247 and 220 g, respectively.

Table 10 Mean thigh weight (g), at weekly intervals, of males and females of three strains of broiler fed one of four dietary protein levels. Thigh weight includes bone and skin and is the mean of the two thighs from each bird

Genotype	Dietary protein content	Age, weeks					
		1	2	3	4	5	6
Females							
Cobb	High	16	49	105	151	170	265
	2	19	55	103	118	229	270
	3	18	46	103	145	153	266
Ross 308	Low	16	48	101	153	180	260
	High	19	46	98	151	206	236
	2	16	48	103	158	194	258
Ross 788	3	16	45	95	157	207	277
	Low	15	41	94	156	200	260
	High	17	46	100	146	193	207
Ross 788	2	15	45	97	132	193	281
	3	14	40	73	152	169	285
	Low	13	46	90	151	177	272
Males							
Cobb	High	18	58	110	165	200	287
	2	21	49	117	164	233	300
	3	15	52	110	169	229	351
Ross 308	Low	15	46	111	163	229	282
	High	19	52	106	179	233	307
	2	18	49	100	146	225	319
Ross 788	3	16	45	92	157	259	318
	Low	15	44	99	149	206	264
	High	14	50	108	150	229	318
Ross 788	2	16	48	113	152	255	309
	3	14	41	97	155	219	306
	Low	15	38	99	151	215	278

Two-way interactions were evident between strain and sex (Table 6) and between strain and feed protein level (Table 7), but not between sex and feed protein level. Females of the Ross 308 strain differed from all other strains and sexes by having a lower constant term (-0.174 ± 0.058) and a higher regression coefficient (0.040 ± 0.012) than the other combinations. This strain also responded differently to the highest and lowest feed protein levels, in the first case showing the same trend as the Ross 308 females (lower constant term and higher regression coefficient), and, in the latter case, together with the Ross 788 strain, showing a higher regression coefficient on the lowest dietary protein level. There were no three-way interactions in drum weight between factors.

The mean weights of the wing of broilers on the various treatments, at weekly intervals, are given in Table 12. These weights include bone and skin and represent the mean weights of the two wings from each bird. Male wings were heavier than those of females at six weeks (201 vs. 174 g) and those of all three strains were similar (185, 185 and 193 g for Cobb, Ross 308 and 788, respectively). Weights were curvilinearly related to dietary protein level (186, 194, 195 and 175 g, respectively). There were no two- or three-way interactions between factors in the case of mean wing weight.

Discussion

The three strains, two sexes and four dietary protein levels used in the trial had the desired effect of producing a wide range of rates of growth of the body and of the weights of the physical and chemical components of the birds sampled. The body weights achieved exceeded the breed standards for the three strains used. In addition, because a large number of birds ($n = 582$) was sampled throughout the growing period, the resultant allometric equations derived for each treatment combination are likely to be accurate

representations of the effects of the various treatments imposed. The objective was to derive and then compare these allometric equations between the weights of the various physical parts and body protein, and this was accomplished using simple linear regression with groups; the groups in this case being the factors

Table 11 Mean drum weights (g), at weekly intervals, of males and females of three strains of broiler fed one of four dietary protein levels. These weights include the bone and skin and are the mean of the two drums from each bird

Genotype	Dietary protein content	Age, weeks					
		1	2	3	4	5	6
Females							
Cobb	High	15	44	82	132	150	226
	2	16	45	85	106	166	226
	3	16	42	79	120	140	216
	Low	14	39	80	134	158	194
Ross 308	High	13	40	83	132	182	206
	2	13	41	82	126	170	234
	3	14	40	80	130	174	220
	Low	12	33	78	132	156	208
Ross 788	High	14	40	87	124	176	192
	2	13	43	74	124	166	214
	3	12	36	62	130	144	224
	Low	12	36	74	114	134	218
Males							
Cobb	High	15	51	92	150	176	238
	2	16	42	98	144	200	240
	3	13	48	100	148	188	274
	Low	14	39	86	140	188	224
Ross 308	High	14	44	94	150	218	264
	2	15	43	94	138	206	276
	3	13	40	76	140	204	276
	Low	12	37	84	126	166	234
Ross 788	High	13	45	100	150	196	272
	2	15	40	92	134	232	290
	3	13	38	82	138	184	274
	Low	14	32	88	128	180	236

strain, sex and feed protein level. Because the constant terms and slopes of the regressions were being compared, and not the mean values at different stages of growth, it is not appropriate to use an analysis of variance or t- tests to compare these relationships (Morris, 1983; Gous, 2010).

A number of interesting effects were noted in the relationship between breast meat and body protein content. In spite of differences in growth rates and carcass composition between the strains and sexes used in the trial, breast meat weight was unaffected by these factors when expressed as a proportion of the body protein content of the broiler. However, differences in the constant term and regression coefficient describing this relationship were brought about by rearing the birds on different levels of dietary protein, with the constant terms decreasing and the slopes increasing as feed protein content decreased. One possible explanation for this effect would be that increasing amounts of lipid are deposited in the breast muscle as feed protein content is reduced resulting in increasing breast weights at a given body protein weight. It is

known that body lipid deposition increases as feed protein content declines (Gous *et al.*, 1990) and this is

Table 12 Mean wing weights (g), at weekly intervals, of males and females of three strains of broiler fed one of four dietary protein levels. These weights include the bone and skin and are the mean of the two wings from each bird

		Dietary protein content	Age, weeks				
			1	2	3	4	5
Females							
Cobb	High	12	38	76	108	118	186
	2	14	40	74	86	130	170
	3	12	38	72	102	116	170
	Low	10	36	70	102	126	160
Ross 308	High	12	38	76	104	148	158
	2	12	36	72	110	134	184
	3	12	34	68	114	144	178
	Low	12	30	66	110	126	160
Ross 788	High	12	36	74	108	132	156
	2	12	38	74	104	130	196
	3	12	34	58	108	132	186
	Low	10	34	64	108	110	184
Males							
Cobb	High	12	46	84	112	138	198
	2	14	38	82	118	156	198
	3	10	40	82	120	152	218
	Low	12	36	80	118	164	176
Ross 308	High	12	38	80	120	162	202
	2	12	36	72	106	152	210
	3	10	34	66	110	164	208
	Low	10	32	68	94	134	182
Ross 788	High	10	40	80	126	148	218
	2	12	36	82	114	178	204
	3	10	32	72	106	144	208
	Low	10	30	68	96	136	190

evident also from the results of this trial (Table 3), where maximum rates of body growth were achieved on feeds intermediate in protein content. Such differences in lipid deposition would help to explain the two- and three-way interactions evident between factors, as the different strains and sexes deposited body lipid at different rates on the various dietary protein levels. If the skin and bone had been added to the portion of breast measured, the amount of lipid incorporated into the portion, and hence the effect of dietary protein content, would have been greater. But as the lipid content of the breast meat was not determined in this trial it is not possible to state to what extent differences in lipid deposition occurred in this muscle between treatments, and this information would clearly be useful in explaining the change in this allometric relationship with feed protein content.

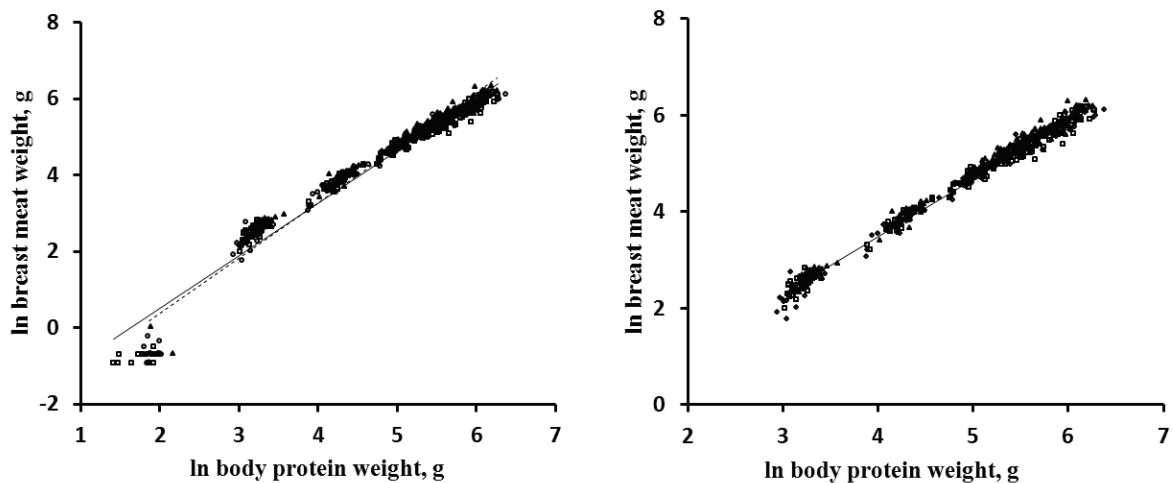


Figure 1 Allometric relationship between breast meat and body protein weight. Both graphs illustrate effect of three strains: Cobb, ... Δ ; Ross 308, - - - \circ ; Ross 788, ___ \square . Right hand graph illustrates relationship when excluding relationships at day-old.

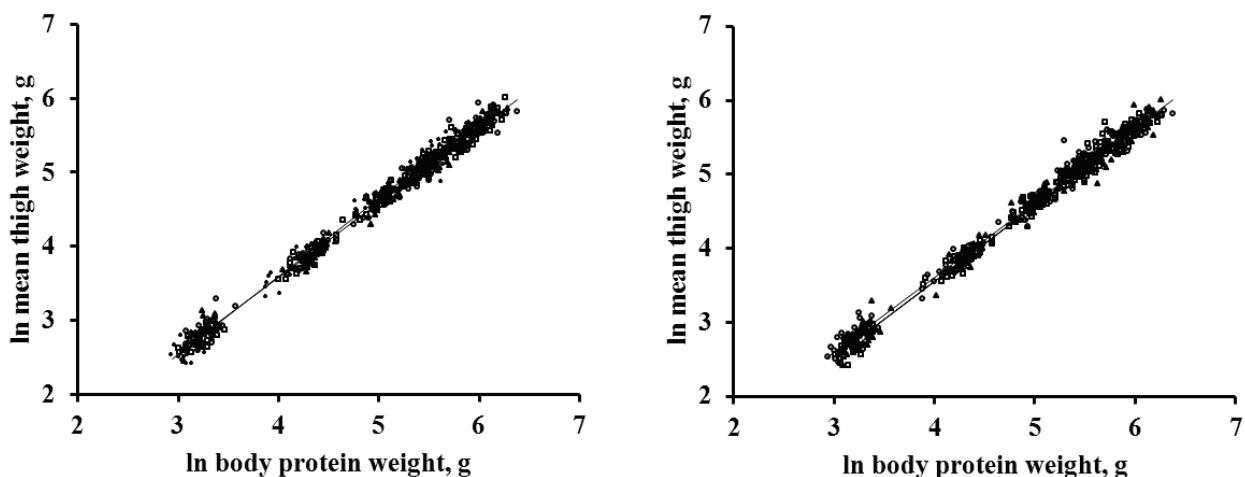


Figure 2 Allometric relationship between mean thigh weight and body protein weight. Left hand graph illustrates effect of three strains: Cobb, ... Δ ; Ross 308, - - - \circ ; Ross 788, ___ \square . Right hand graph illustrates effect of four levels of balanced protein: P1 ___ Δ ; P2.... \circ ; P3 ---- \square ; P4 -.-.- +.

The relationships between \ln breast meat and \ln body protein weight and between \ln thigh weight and \ln body protein weight are illustrated in Figures 1 and 2 for the three strains and the four feed protein levels. It is evident in Figure 1 that the weights of breast meat at day old did not conform to the allometric relationship developed during the remaining six week growing period: all day old weights fell below the regression line, suggesting that nutrients had been depleted from this tissue prior to, or immediately after hatching. Only the breast meat was affected in this way as no other tissues measured in this trial fell below the fitted allometric regression at day old. There is evidence in the literature that breast tissue is used to supply nutrients to the body when these are needed and when they are not supplied by the feed (Halevy *et al.*, 2006; Noy & Sklan, 1998). Although early and *in ovo* feeding have been shown to increase breast muscle weight (Uni & Ferket, 2004; Noy & Sklan, 1997; 1998), the weights reported on those held and early-fed treatments have not been accompanied by body protein weights, so it is not possible to determine whether such treatments increased the breast meat weight specifically at an equivalent body protein weight, or whether the weights of all components were similarly increased.

The relationships between the thigh and drum and body protein weight were marginally affected by strain and sex but more so by the feed protein content, again suggesting that these differences may be the result of increasing amounts of lipid being deposited in these components as feed protein content is reduced. Ideally, the weight of protein in the various parts should be measured, to be regressed against body protein weight, rather than including the lipid content of these parts in deriving allometric equations, for the same reason as was given for using body protein content as the independent variable rather than body weight. But it would then be necessary to determine the amount of lipid that is deposited in each of the body parts depending on the feed protein content, and this would have to be added to the weight of protein (and bone where appropriate) to predict the weight of each component. If the amount of lipid deposited in each part, on feeds differing in protein content, could be predicted, the weights of the parts could be adjusted by this amount to improve the accuracy of prediction, without having to define a different allometric equation for each level of dietary protein fed to broilers.

The allometric regressions presented here are the first such regressions to be published in the scientific literature. No previous relationships have regressed weights of different body components against body protein weight, thereby ignoring the variable amounts of body lipid that are deposited in broilers dependent on the genotype and feed protein content. The regressions presented here suffer also from the confounding effects of body lipid, which in this case are at the level of the body components and not the entire body. Although the equations presented here are more useful in predicting the weights of the physical parts of a broiler than any previous attempts, such predictions would be improved if the amount of lipid that is deposited in each component in relation to the feed protein content were known, or could be predicted. Apart from addressing a general problem of using body protein as a predictor of component weights whilst avoiding the problem of fatness, such information would be valuable to simulation modellers attempting to predict the weights of these important components of the body.

Conclusions

The research reported here suggests that, aside from the variable amounts of lipid that are deposited in the various body components resulting from differences in dietary protein content, the weights of these components may be accurately estimated from the body protein content of the broiler. It appears that day-old breast meat weight is influenced by the nutritional status of the embryo but that no other components measured in this trial are thus affected. To improve the accuracy of prediction of component weights as influenced by strain, sex and dietary protein content the minimum and maximum amounts of lipid that can be deposited in these components by different broiler strains should be measured.

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