Relative Size of the Hind Limb and Wing Part, and the Muscle Distribution in Chicks and Broilers Produced Under Different Nutritional Regimes

Das, Chamali
Laboratory of Functional Anatomy, Division of Animal Science, Department of Animal and Marine Bioresource Sciences, Graduate School of Bioresouce and Bioenvironmental sciences, Kyushu University

Roy, Bimol Chandra
Scientific Officer, Bangladesh Livestock Research Institute

Oshima, Ichiro
Assistant Professor, Department of Health and Nutrition, Niigata University of Health and Welfare

Miyachi, Hideyuki
Yokoo & Co, Ltd,

他

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Relative Size of the Hind Limb and Wing Part, and the Muscle Distribution in Chicks and Broilers Produced Under Different Nutritional Regimes

Chamali DAS[1], Bimol Chandra ROY[2], Ichiro OSHIMA[3], Hideyuki MIYACHI[4], Shotaro NISHIMURA*, Hisao IWAMOTO and Shoji TABATA

Laboratory of Functional Anatomy, Division of Animal science, Department of Animal and Marine Bioresource Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan

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1. The purpose of the present study was to develop a feeding method for producing an increased size of the hind limb part of chickens, of a darker colour, using different nutritional regimes. In experiment 1, chicks were reared with 4 feeds of different nutritional levels up to post–hatching 21 days.
2. Carcass weight differed by 2.4 times between the largest and the smallest group effects. In the smallest chicks the percentages of the hind limb relative to the wing for both the total weight and muscle weight were 93%, much larger than the 82–86% and 77–83%, respectively, in the other chick groups. A greater depression of the wing development was observed in the smallest chicks.
3. In experiment 2, broilers were reared under different nutritional regimes during the early period of 0 to 21 days of age, and then the later period of 22 to 80 days of age. The largest carcass weight was observed in the conventionally fed broilers, followed by the broilers with a compensatory growth in the later period, and the smallest weight was shown by the broilers with the growth limitation in the later period.
4. The smallest broilers exhibited larger values (88–90% for the total weight, 84–86% for the muscle weight) in the percentages of the hind limb relative to the wing compared with the other bird groups (80–81% for the total weight, 74–78% for the muscle weight).
5. In experiment 3, the broilers of the smallest carcass weight were fattened for a further 15 days to attain enough body size. By 95 days of age, the percentage of the hind limb relative to the wing was maintained at 89–90% for the total weight and 86% for the muscle weight.
6. These results suggest that the percentage of the hind limb relative to the wing could be increased by restricting broiler growth during the later growth stages, while the large relative weight of the hind limb resulting from severe disturbance of early growth had completely disappeared after a compensatory growth during the later stages.

INTRODUCTION

The skeletal muscles that make up the breast meat of chicken, especially the large muscles such as the *pectoralis* and *supracoracoideus*, are composed mainly of white (type IIB) myofibres, while those in the thigh are made up of a range of myofibre types (type I, ⅡA, and ⅡB) in the various individual muscles (Suzuki, 1978; Suzuki *et al*., 1985; Iwamoto *et al*., 1998). A rapid growth rate of muscle tissue arises from extensive development of existing myofibres (Mizuno and Hikami, 1971; Iwamoto *et al*., 1993; Ono *et al*., 1993); the white myofibres of the *pectoralis* muscle respond markedly to the nutritional level of the feed (Henkel, 1991; Tesseraud *et al*., 1996; Velotto and Crasto, 2004; Roy *et al*., 2006). Generally, in broilers the *iliotibialis lateralis*, a thigh muscle, also contains a high proportion of white myofibres ensuring its rapid growth in birds on a high nutritional plane (Iwamoto *et al*., 1997, 1998).

During the first two weeks of post–hatching growth, the total wing muscle has been shown to increase in volume by 11.0–fold, and growth in the shoulder girdle muscle increases particularly markedly (15.6–fold) (Iwamoto *et al*., 1975). On the other hand, the volume of the hind limb muscle increases only 3.4–fold and the volume of the cervicodorsal muscle 2.9–fold over the same growth stage. In the *pectoralis* and *supracoracoideus* muscles of the shoulder girdle component of wing muscle, the myofibres are very fine (5 μm) at hatching time, and increase in diameter three–fold during this early growth period (Ono *et al*., 1989). These findings suggest that in this early period, restriction of body growth could negatively affect muscle growth, especially wing muscle growth, and thus change the relative size of the hind limb to the wing muscle.

Since a relatively constant growth rate is observed across individual muscles of both the hind limb and the wing parts between 2 and 15 weeks of age (Iwamoto *et al*., 1975, 1993), we hypothesised that the larger relative weight of the hind limb muscle would be maintained throughout the compensatory growth phase. However, a high plane of nutrition promotes more muscle development in the wing (forelimb) than in the hind limb of

[1] Laboratory of Functional Anatomy, Division of Animal Science, Department of Animal and Marine Bioresource Sciences, Graduate School of Bioresouce and Bioenvironmental sciences, Kyushu University, Fukuoka 812–8581, Japan
[2] Scientific Officer, Bangladesh Livestock Research Institute, Savar, Dhaka 1341, Bangladesh
[3] Assistant Professor, Department of Health and Nutrition, Niigata University of Health and Welfare 1398, Shimami–cho, Niigata–shi, 950–3198 Japan
[4] Yokoo & Co, Ltd, Tosu–shi, 841–8602, Japan
* Corresponding author (E–mail: shotaro@agr.kyushu–u.ac.jp)

broilers (Roy *et al.*, 2007), and conversely, limitation of body growth induced by feeding on a low nutritional plane reduces growth of the wing muscle (Gordon and Charles, 2002).

The breast is typically the most worthwhile part of the chicken carcass in many countries, and it is important in obtaining the greatest carcass yield, although in many other countries the thighs are of equal or even more value and preference than the breast (Khosravinia *et al.*, 2006). In Japan, because the traditional method of cooking chicken involves boiling with vegetables, dark meat with its tougher and tastier quality is preferred (Nakamura *et al.*, 1975; Iwamoto *et al.*, 1997, 1998; Nakamura *et al.*, 2003). Feeding regimes which increase the relative amount of hind limb meat in chickens would be commercially desirable. In the present study, we investigated feeding methods for increasing the relative size of the hind limb part of broilers through nutritional manipulation.

MATERIALS AND METHODS

Animals

Red Cornish × New Hampshire (Shaver, Fort Médoc, France) one–day–old chicks in each experiment were randomly allocated to different floor pens (25 chicks/pen, 1.8 m×1.8 m) in an experimental facility using litter on a concrete floor. Feed and water were provided ad libitum with two tube feeders and one drinker in each pen.

Experiment 1: The chicks were divided into four groups which were reared with either broiler finisher (BF, metabolizable energy 13.47 MJ/kg, crude protein 180 g/kg), layer starter (LS, ME 12.34 MJ/kg, CP 210 g/kg), layer grower (LG, ME 11.92 MJ/kg, CP 170 g/kg), or pre–layer (PL, 11.72 MJ/kg, CP 140 g/kg) complete feeds (Marubeni Nisshin Feed Co. Ltd., Tokyo, Japan) up to the post–hatching 21 days. These chick groups were termed BF–21d, LS–21d, LG–21d, and PL–21d, respectively.

Experiment 2: Normal feeding broilers were reared with broiler starter (BS, ME 13.18 MJ/kg, CP 205 g/kg) complete feed up to the post–hatching 21 days, and then BF feed up to 80 days (BSBF–80d group). Other groups of chicks were limited in their growth by rearing with either LG or PL feeds up to 21 days, and then their growth was enhanced with BF feed up to 80 days (LGBF–80d and PLBF–80d groups, respectively). The next group of chicks was ensured normal growth by rearing with BS feed up to 21 days of age, followed by limitation of the growth with PL feed up to 80 days (BSPL–80d group). A final group was grown slowly by feeding LG feed throughout the post–hatching 80 days (LGLG–80d group).

Experiment 3: As the BSPL–80d and LGLG–80d groups had not yet reached the body size of a standard broiler, some of the birds in these groups (BSPL–80d and LGLG–80d) were fattened for a further 15 days with PL and LG feed (BSPL–95d and LGLG–95d groups), respectively.

The birds for collection of material were selected at random and killed by bleeding from a severed carotid artery and jugular vein after a 12 h overnight fast. Each carcass was then scalded in hot water at 60 °C for about 2 min prior to plucking the feathers and down. Each carcass was then chilled in an ice–water mixture for at least 1 h, and then weighed following decapitation at the atlanto–occipital joint and removal of the feet at the intertarsal joint.

Dissection of carcass

After removing the skin, the wing and the hind limb parts were taken out. The wing was separated with breast muscles from the body stem by stripping off the cingulum muscles from the dorsal region and cutting apart the joints between the vertebral and sternal costae, and the hind limb was detached from the pelvic girdle. The weights as a whole of the wing part and the hind limb part were measured, and the muscle weight in each part was also measured after cleaning out the bone, fatty tissue, and ligament and tendon. Thus, the wing muscle contained the abdominal muscles, and the hind limb muscle did not include *obturatorius medialis* muscle for the convenience of dissection.

Statistical analysis

Differences in parameters among experimental groups were assessed for statistical significance using a one–way analysis of variance (Steel and Torrie, 1980), and the 95% probability threshold in the Duncan's multiple range test was taken as indicating statistical significance.

RESULTS

Experiment 1

Carcass weight differed significantly among all bird types (Table 1). The largest carcass weight was found in BF–21d chicks, which was 2.4–fold larger than the smallest group, the PL–21d birds. The next largest birds were the LS–21d chicks followed by the LG–21d chicks.

Because of a marked difference in the carcass weight, the total weight and the muscle weight of the wing part and the hind limb part were largest in the biggest BF–21d chicks, and became smaller with decreasing body size (Table 1). The total weight and the muscle weight as a percentage of the carcass weight were also larger in the bird groups with bigger carcasses. The percentage muscle weight relative to the total weight in the hind limb part and the wing part was largest in the BF–21d chicks and smallest in the PL–21d chicks. The percentage muscle weight in the BF–21d and the LS–21d chicks was larger in the wing part than in the hind limb part, but did not differ between the PL–21d and the LG–21d chicks (Table 1).

The percentage of the hind limb part to the wing part in the total weight was significantly larger in the PL–21d chicks (92.9%) when compared with the other groups (82.1–85.5%) (Table 1). The percentage of the

Table 1. Effect of protein and energy content in diets on carcass weight, total weight and muscle weight of wings and hind limbs, and relative size of hind limb to wing in the chicks of 21 days old

Chick groups	BF–21d	LS–21d	LG–21d	PL–21d
No. of birds	12	8	8	8
Carcass weight (g)	616±9a	467±5b	318±10c	259±6d
Wings (A)				
Total weight (g)	143±4 (23.2) a	103±3 (22.1) b	64±3 (20.1) c	47±2 (18.1) d
Muscle weight (g)	109±3 (17.7) a	78±3 (16.7) b	46±2 (14.5) c	33±2 (12.7) d
Percentage muscle weight	76.5±0.5a	75.6±1.1ab	72.8±0.5b	69.1±1.3c
Hind limbs (B)				
Total weight (g)	117±3 (19.0) a	84±3 (18.0) b	54±2 (17.0) c	44±2 (17.0) d
Muscle weight (g)	86±2 (14.0) a	60±2 (12.8) b	38±2 (11.9) c	30±2 (11.6) d
Percentage muscle weight	73.3±0.3a	72±0.8ab	70.7±0.7bc	69.2±0.9c
B/A×100				
Total weight	82.1±1.1b	81.5±1.7b	85.5±1.9b	92.9±1.3a
Muscle weight	78.8±1.1b	77.4±1.8b	83.2±2.5b	93.2±2.0a

Mean ± standard error. The percentage of carcass weight is shown within parenthesis. a, b, c, d Means with the same letter do not differ significantly at 5% level between chick groups. BF=broiler finisher, LS=Layer starter, LG=Layer grower and PL=Pre–layer.

hind limb part to the wing part in the muscle weight was also larger in the PL–21d birds (93.2%) when compared with the other groups (77.4– 83.2%).

Experiment 2

The largest carcass weight was observed in the BSBF–80d broilers reared with feeds of the highest nutritional level (Table 2). Although the LGBF–80d and the PLBF–80d broilers showed a compensatory growth by feeding BF feed after 21 days of age, they did not reach the same body size as the BSBF–80d birds. The carcass weight of the PLBF–80d broilers was significantly larger than that of the LGBF–80d broilers. The BSPL–80d and LGLG–80d birds exhibited the smallest carcass weight.

The total weight and the muscle weight of the wing part increased with increasing carcass weight among the broiler types (Table 2), and the same tendency was also shown for the percentage of carcass weight. The BSBF–80d, LGBF–80d, and PLBF–80d broilers, and also the BSPL–80d and LGLG–80d birds, showed no difference in the percentage muscle weight relative to the total weight in the wing part, while the percentage muscle weight was larger (80%) in the former groups than the latter (77%). The BSBF–80d, LGBF–80d, and PLBF–80d broiler groups had enhanced body growth during the later period (22–80 days) with BF feed, while conversely, the BSPL–80d and LGLG–80d groups had limited body growth with the PL or LG feed. As for those of the wing part, the total weight and muscle weight of the hind limb part also changed among the broiler types depending on the carcass weight. However, these weights as a percentage of the carcass weight were rather larger in the lightest BSPL–80d and LGLG–80d birds than in the LGBF–80d and PLBF–80d birds, although the largest percentages were observed in the biggest BSBF–80d broilers. The percentage muscle weight relative to the total weight in the hind limb part was significantly larger in the BSBF–80d and PLBF–80d (76–77%) birds when compared to the BSPL–80d

Table 2. Effect of protein and energy content in diets on carcass weight, total weight and muscle weight of wings and hind limbs, and relative size of hind limb to wing in the broilers of 80 days old

Broiler groups	BSBF–80d	LGBF–80d	PLBF–80d	BSPL–80d	LGLG–80d
No. of birds	16	7	8	8	6
Carcase weight (g)	2970±58a	2585±59c	2795±40b	2240±85d	2100±124d
Wings (A)					
Total weight (g)	957±22 (32.2) a	796±28 (30.8) b	853±16 (30.5) b	655±27 (29.2) c	581±31 (27.7) c
Muscle weight (g)	761±19 (25.6) a	640±25 (24.8) b	684±13 (24.5) b	506±22 (22.6) c	449±25 (21.4) c
Percentage muscle weight	79.5±0.4a	80.3±0.5a	80.2±0.5a	77.2±0.4b	77.3±0.5b
Hind limbs (B)					
Total weight (g)	772±14 (26.0) a	631±12 (24.4) c	679±13 (24.3) b	576±20 (25.7) cd	521±31 (24.8) d
Muscle weight (g)	591±13 (19.9) a	470±10 (18.2) bc	518±11 (18.5) b	425±16 (19.0) cd	388±24 (18.5) d
Percentage muscle weight	76.5±0.7a	74.0±1.1ab	76.3±0.5a	73.8±0.7b	74.4±0.5b
B/A×100					
Total weight	80.9±1.2b	79.6±2.3b	79.7±1.5b	88.1±1.4a	89.5±1.2a
Muscle weight	77.9±1.3b	73.9±2. 9b	75.9±1.5b	84.3±2.0a	86.3±1.6a

Mean ± standard error. The percentage of carcass weight is shown within parenthesis. a, b, c, d Means with the same letter do not differ significantly at 5% level between broiler groups. BS=Broiler starter, BF=Broiler finisher, LG=Layer grower and PL=Pre–layer.

and LGLG–80d birds (74%). The percentage muscle weight in the LGBF–80d birds did not differ significantly from that in the other groups, but was rather low (74%). The percentage muscle weight was generally larger in the wing part than in the hind limb part, with an especially marked difference in the percentage observed in LGBF–80d broilers.

The relative size of the hind limb part to the wing part in the total weight was significantly larger in the LGLG–80d and BSPL–80d groups (88–90%) when compared to the other groups (80–81%). The relative size of the hind limb part in the muscle weight was also larger in the LGLG–80d and BSPL–80d broilers (84–86%) when compared to the other groups (74–78%).

Experiment 3

The BSPL–95d and LGLG–95d broilers gained 630 g and 380 g in carcass weight (Table 3) compared to the BSPL–80d and LGLG–80d birds (Table 2), respectively. The BSPL–95d broilers had arrived at a similar carcass weight to that of the BSBF–80d group, but the carcass weight in the LGLG–95d group was smaller than the BSBF–80d group.

Because of the difference in carcass weight, the total weights and the muscle weights of the wing part and the hind limb part in absolute values were significantly larger in the BSPL–95d than in the LGLG–95d cockerels, but there was only a small difference between them in the percentage of the carcass weight (Table 3). The percentage muscle weight in each part did not differ between the bird groups, and was larger in the wing part than in the hind limb part. The total weights and the muscle weights of the wing part and the hind limb part as a percentage of the carcass weight had increased slightly for the 15 days elongation of fattening period. The percentage muscle weight relative to the total weight in each part was also increased in the 95 days old birds compared to the 80 days old birds.

The relative size of the hind limb part to the wing part did not differ between the BSPL–95d and LGLG–95d groups, where it was 89–90% for the total weight and 86% for the muscle weight. These values were the same as the highest percentage observed in the 80 days old broilers (BSPL–80d and LGLG–80d groups).

DISCUSSION

Since the feed consumption of chickens is fairly constant regardless of variations in feed energy content, energy intake is increased when a high–energy diet is consumed (Brue and Latshaw, 1985). High protein content in feed accelerates the growth rate of chickens, but does not lead to the accumulation of abdominal fat a constant ratio of energy to protein is maintained (Bartov *et al*., 1974; Skinner *et al*., 1992; Aggrey, 2004). In the present study, the feeds containing the highest energy caused BSBF–80d broilers the most rapid growth, while chicken growth was restricted more severely by feeding the lower energy level diets. However, as the percentage muscle weight relative to the total weight in the hind limb part and the wing part was similar among the broiler groups attaining over 2500 g of carcass weight, and also larger in the chicks fed the BF high energy feed, this suggests that a high energy feed does not lead to development of fatty tissue within the meat of these parts.

In a previous study using male Barred Plymouth Rock chicks, the relative muscle weight of the hind limb part to the wing part changed with growth from 247% at hatching to 112% at one week of age, then to 76.2% at two weeks of age (Iwamoto *et al*., 1975). In Experiment 1 of the present study, the percentage of the hind limb weight relative to the wing weight in the BF–21d, LS–21d, or LG–21d groups was 82–86% in the total weight and 77–83% in the muscle weight, while in the PL–21d group the equivalent values were 93% in both the total and the muscle weights. These results suggest that the percentage of the hind limb weight can be increased by mild depression of body growth during the

Table 3. Effect of protein and energy content in diets on carcass weight, total weight and muscle weight of wings and hind limbs, and relative size of hind limbs to wings in the broilers of 95 days old

Broiler groups	BSPL–95d	LGLG–95d
No. of birds	7	8
Carcass weight (g)	2870±103a	2480±55b
Wings (A)		
Total weight (g)	885±36 (30.8) a	722±15 (29.1) b
Muscle weight (g)	700±32 (24.4) a	578±13 (23.3) b
Percentage muscle weight	79.1±1.1a	80.1±0.5a
Hind limbs (B)		
Total weight (g)	785±27 (27.4) a	652±21 (26.3) b
Muscle weight (g)	598±20 (20.8) a	497±16 (20.0) b
Percentage muscle weight	76.2±0.7a	76.2±0.2a
B/A×100		
Total weight	89.1±2.2a	90.3±1.8a
Muscle weight	86.0±2.8a	86.0±1.9a

Mean ± standard error. The percentage of carcass weight is shown within parenthesis. a, b Means with the same letter do not differ significantly at 5% level between broiler groups. BS=Broiler starter, LG=Layer grower and PL=Pre–layer.

early growth stage of 0–21 days of age. However, to markedly increase the relative size of the hind limb weight the chicks had to be exposed to a severe limitation of early growth. As severe restriction of body growth is not compatible with effective commercial production of broilers, the chicks would need to be reared on a high plane of nutrition to enhance their growth after 21 days of age.

The LGBF–80d and PLBF–80d broilers showed a marked recovery of the carcass weight after being fed the BF high energy feed, and had attained carcass weights of 2585 g or 2785 g, respectively, which were significantly smaller than that of the BSBF–80d conventionally–fed broilers. However, after a compensatory growth from 22 to 80 days the PLBF–80d broilers had already lost the large relative weight of the hind limb part to the wing part observed in PL–21d chicks, and also the LGBF–80d broilers did not show the large relative weight of the hind limb part. On the other hand, BSPL–80d broilers, which were stimulated in the early growth period by feeding BS feed and then were limited in later growth with PL feed, showed a large relative weight of the hind limb part. The LGLG–80d broilers, which were under the moderate growth rate throughout this experimental period, also showed a large relative weight of the hind limb part. When the BSPL–80d and LGLG–80d broilers of the smallest carcass weight were reared for a further 15 days, the BSPL–95d and LGLG–95d broilers reached carcass weights of 2870 g or 2480 g, respectively, and the large percentage weight of the hind limb part relative to the wing part in the BSPL–80d and LGLG–80d birds was maintained by BSPL–95d and LGLG–95d cockerels.

The yield of breast meat from chickens gradually increases in the post–hatching growth stages up to 85 days of age (Havenstein *et al*., 2003). However, the thigh and neck muscles, but not the breast muscle, of broilers respond to variations in the nutritional plane, and thus, vary in terms of their percentage of carcass weight (Shahin and Elazeen, 2005). In the present study, the wing (breast) part of the broilers appeared to respond more readily than the hind limb part. When the LG–21d and PL–21d chicks were fed the BF diet of high energy levels up to 80 days (LGBF–80d and PLBF–80d), the wing part as a percentage of the carcass weight was increased by 11–12% in the total weight or 10–12% in the muscle weight, while the hind limb part increased by only 7% in the total weight or 6–7% in the muscle weight. On the other hand, LGLG–80d broilers on a moderate nutritional plane did not show any difference in the percentage between the wing part and hind limb part (8% in the total weight and 7% in the muscle weight for both parts). Although the LG–21d and PL–21d chicks showed different hind limb part to wing part percentages of 85.5% and 92.9%, respectively, in the total weight, or 83.2% and 93.2%, respectively, in the muscle weight, these marked differences were no longer evident in the LGBF–80d and PLBF–80d broilers. From these results, it appears that the ability of broilers to produce wing part (breast) meat could be improved by feeding on a high nutritional plane during the pre–slaughtering period, regardless of variation in growth rates during the early growth stages. However, details of how the duration of feeding on a high nutritional plane during the pre–slaughtering period influences carcass composition remain to be elucidated.

In the LGLG–80d and BSPL–80d broilers, the percentage weight of the hind limb part relative to the wing part were 88–90% in the total weight or 84–86% in the muscle weight, which were distinctly larger than the values of 81% or 78%, respectively, measured in BSBF–80d birds. The relative weight of the hind limb was also large in the LGLG–95d and BSPL–95d broilers (89–90% in the total weight or 86% in the muscle weight). While in the BSBF–80d birds, the wing part and the hind limb part accounted for 32% and 26%, respectively, of the carcass weight in the total weight, or 26% and 20%, respectively, in the muscle weight, in the LGLG–80d and BSPL–80d broilers the values for the wing part and the hind limb part were 28–29% and 25–26%, respectively, of the carcass weight in the total weight, or 21–23% and 19%, respectively, in the muscle weight. The larger relative weight of the hind limb part in the LGLG–80d and BSPL–80d broilers may have been produced by slow growth of the wing part rather than accelerated development of the hind limb part. From these results, it appears that chickens showing slow growth in the pre–slaughtering stage produce a relatively larger hind limb part. Details of how the duration and extent of growth restriction influence the relative weight of the hind limb remain to be elucidated.

In conclusion, although restricted early nutrition yielded chicks with a relatively larger hind limb part, the relative size of the wing part and the hind limb part returned to normal during an accelerated growth phase from 22 to 80 days. Conversely, a relatively larger hind limb part to wing part in broilers could be obtained from growth limitation in the later stages of growth, and was maintained for a further 15 day elongation of the fattening period. From these results, it appears that broilers produce more dark meat with its tougher and tastier quality by increasing the relative size of the hind limb part under a slow growth regime during the pre–slaughtering period.

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