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<https://doi.org/10.5109/10070>

出版情報：九州大学大学院農学研究院紀要. 53 (1), pp.55-59, 2008-02-28. 九州大学大学院農学研究院
バージョン：
権利関係：

Carcass Composition and Skeletal Muscle Distribution in Broilers Produced under Different Nutritional Regimes–3. Male Broilers Showing Maximum Early Growth and Restricted Later Growth

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(Received September 18, 2007 and accepted November 30, 2007)

1. In this study we investigated feeding methods which would lead to a high hind limb to wing muscle ratio in broilers. One group of male chicks was reared with a layer grower feed (LG, ME 11.92 MJ/kg, CP 170 g/kg) from 1 to 80 (LG80d) or 95 (LG95d) days of age. A further group of chicks was reared with a broiler starter feed (BS, ME 13.18 MJ/kg, CP 205 g/kg) from 1 to 21 days and then with a pre-layer feed (PL, ME 11.72 MJ/kg, CP 140 g/kg) up to 80 (BSPL80d) or 95 (BSPL95d) days.
2. LG80d (2490 g live weight) and BSPL80d (2648 g) birds did not attain sufficient body size (3 kg) to slaughter at 80 days. LG95d (2979 g) and BSPL95d (3409 g) birds needed 15 extra days to attain a body size similar to conventionally-fed broilers. The rapid early growth induced by feeding the BS diet contributed greatly to increasing the ultimate body size of the broilers.
3. Carcass weight as a percentage of live weight was 83–85% in all broiler groups. Skeletal muscle as a whole accounted for 45–51% of carcass weight and the largest percentage was found in BSPL95d birds which were also the largest birds.
4. Wing muscle represented 21–23% of the total carcass weight. Hind limb muscle accounted for 18–21%, and cervicodorsal muscle, 4.5–4.9% of total carcass weight. The hind limb weight as a percentage of wing muscle weight was similar among the chicken groups at 85–88%, and this is larger than the value of 76% found in previous work (Das *et al.*, 2008b) and in conventionally-fed broilers (Roy *et al.*, 2007).
5. From these results, it seems that the relative size of the hind limb to wing muscle is increased by restricting broiler growth during the pre-slaughter period and that early maximum growth has a positive effect on meat production by increasing carcass weight without altering the relative size of hind limb to wing muscle.

INTRODUCTION

The skeletal muscles that make up the breast meat of chicken, especially large muscles such as the *pectoralis* and *supracoracoideus*, are composed mainly of white (type IIB) myofibers while those in the thigh are made up of a range of myofiber types (type I, IIA and IIB) in the various individual muscles (Suzuki, 1978; Suzuki *et al.*, 1985; Iwamoto *et al.*, 1998; Roy *et al.*, 2007). Rapid growth rate of muscle tissue arises from extensive development of existing myofibers (Mizuno and Hikami, 1971; Iwamoto *et al.*, 1993; Ono *et al.*, 1993); the white myofibers of the *pectoralis* muscle respond markedly to the nutritional level of the feed (Henkel, 1991; Tesseraud *et al.*, 1996; Velotte and Crasto, 2004; Roy *et al.*, 2006). In a general broiler, the

iliotibialis lateralis muscle in the thigh also contains a high proportion of white myofibers ensuring its rapid growth in birds on a high nutritional plane (Iwamoto *et al.*, 1997, 1998).

Although limiting early growth rate results in relatively larger hind limb muscles in 3 week-old chicks, the muscle distribution of chicks' returns to normal in broilers after 3 weeks as a result of compensatory growth (Das *et al.*, 2008a, b). In birds which show rapid growth rates in the later stage, the wing muscle recovers its superior size regardless of variation in its relative size in chicks at 3 weeks of age. It is possible that the relative size of the hind limb muscle of broilers could be increased relative to the size of wing muscle by limiting growth rate in chickens during the pre-slaughter phase.

In the present study, chicks were either fed a diet which limited growth throughout the experimental period or a diet which severely limited growth after the maximum growth phase in the first 3 weeks. Since neither group of broilers attained their target body weight (3 kg) by 80 days, some of the birds were reared until 95 days of age. Body size, carcass composition and skeletal muscle distribution were compared between the treatment groups and with previous data (Das *et al.*, 2008a, b).

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MATERIALS AND METHODS

Experimental chicks

One group of male chicks (Red Cornish × New Hampshire, Shaver, Fort Médoc, France) was subjected to a slow growth rate by feeding a layer grower complete feed (LG; metabolizable energy 11.92 MJ/kg, crude protein 170 g/kg) (Marubeni Nisshin Feed Co. Ltd, Tokyo, Japan) throughout the experimental period up to 80 days (LG80d) or 95 days (LG95d). In a further group of the chicks, maximum growth during the first 3 weeks after hatching was ensured by feeding a broiler starter complete feed (BS; ME 13.18 MJ/kg, CP 205 g/kg) followed by a slower growth period which was achieved by feeding a pre-layer complete feed (PL; ME 11.72 MJ/kg, CP 140 g/kg) until 80 (BSPL80d) or 95 days (BSPL95d). Throughout the experimental period, the cockerels were kept within a pen house and had *ad-libitum* access to experimental feeds and water.

Six of the LG80d, 8 of the LG95d, 8 of the BSPL80d and 7 of the BSPL95d cockerels were selected at random and killed by bleeding with a conventional neck cut following a 12hr overnight fast. Each carcass was then immersed in water at 60 °C for 120 sec. prior to plucking feathers and down. Each carcass was then chilled in an ice-water mixture for at least 1 hr and weighed following decapitation at the atlanto-occipital joint and removal of the feet at the intertarsal joint. Carcass weight as a percentage of live weight was then calculated.

Dissection of carcass

Details of the dissection method for carcasses are given in a previous paper (Das *et al.*, 2008a). Total weight of skin, visceral organs and abdominal fat were measured. Wing, hind limb and cervicodorsal parts were dissected into skeletal muscle, intermuscular fat and bone tissues and the weight of each part was measured

from the combined weight of these tissue components.

Skeletal muscle weight was measured in 4 subparts of the wing, 3 subparts of the hind limb and 2 subparts of the cervicodorsal portion on the left side of the carcass (Vollmehrhäus, 1992). The 4 subparts of wing muscle were shoulder girdle, brachial, antebrachial and abdominal muscles. The hind limb muscle was composed of pelvic, femoral and crural subparts and the cervicodorsal muscle was divided into the dorsocaudal and cervical muscle subparts.

The weights of the *pectoralis*, *supracoracoideus*, *triceps brachii*, *biceps brachii*, *iliotrochanterici*, *iliotibialis cranialis*, *iliotibialis lateralis*, *femorotibiales*, *flexor cruris lateralis*, *puboischiofemoralis* and *gastrocnemius* muscles were measured on the right side of the carcass.

Statistical analysis

In this study, all the parameters were expressed as relative weight (%) of carcass. Differences in parameters among experimental groups were assessed for statistical significance using one-way analysis of variance (Steel and Torrie, 1980) and the 95% probability threshold was taken as indicating statistical significance.

RESULTS

Live weight and carcass weight

The feeding systems used in this study did not lead to sufficient body size of broilers by 80 days of age and a further 15 days of growth were required to attain slaughter weight (Table 1). The highest live weight was observed in BSPL95d cockerels, followed by LG95d birds, BSPL80d birds, and finally LG80d birds. Carcass weight as a percentage of live weight was 83–85% in all chicken groups.

Table 1. Comparison of live weight, carcass weight and percentage, and percentages of total muscle, bone, intermuscular fatty tissue, viscera, skin and abdominal fat on carcass weight among the broilers

Broiler groups	LG80d	LG95d	BSPL80d	BSPL95d
No of birds	6	8	8	7
Live weight (g)	2490±155c	2979±67b	2648±98c	3409±116a
Carcass weight (g)	2098±124c	2479±55b	2241±84c	2871±103a
Percentage of carcass	84.3	83.2	84.6	84.2
Carcass composition (%)				
Total muscle	45.0±0.9b	49.0±0.6a	46.7±0.6b	50.5±1.3a
Total bone	15.2±0.5a	14.6±0.3a	16.1±0.5a	15.2±0.6a
Total intermuscular fat	3.11±0.28a	2.69±0.12a	3.01±0.24a	3.39±0.40a
Visceral	20.1±0.4a	17.5±0.6b	18.4±0.5ab	14.94±0.34c
Skin	11.9±0.4a	11.7±0.3a	11.3±0.6a	11.3±0.6a
Abdominal fat	3.27±0.52a	3.02±0.22a	2.95±0.40a	3.04±0.45a

Means±standard errors

LG80d and LG95d; Broilers fed Layer grower diet by 80 or 95 days.

BSPL80d and BSPL95d; Broilers fed Broiler starter diet by 21 days and then Pre-layer diet up to 80 or 95 days.

a, b, c; Means with the same letter did not differ significantly between chick's groups at 5% level.

Carcass composition

Skeletal muscle as a whole accounted for a higher percentage (49–51%) of the carcass in BSPL95d and LG95d broilers with their larger body size than in LG80d and BSPL80d birds (45–47%; Table 1). The weight of the viscera as a percentage of carcass weight was highest (20%) in LG80d birds; these birds also had the smallest body size of all the broiler groups. The relative weight of the viscera was 18–14% in the other broilers and differed significantly among groups except LG95 and BSPL80 birds. The total weight of bone as a percentage of carcass weight was higher in BSPL80d than in LG95d birds. Skin represented 11–12% of carcass weight in all broiler groups; intermuscular and abdominal fats accounted for 2.7–3.4% and 2.7–3.3% of carcass weight respectively.

Skeletal muscle weight in parts and subparts

The relative size of hind limb to wing muscle was

85.4–87.6% in all broiler groups (Table 2) and this was greater than the values of 75.9–76.5% recorded in a previous study for chickens grown rapidly following a period of severe growth limitation during early growth (Das *et al.*, 2008b) and the value of 76.5% recorded in normal feeding broilers (Roy *et al.*, 2007). The wing muscle accounted for a larger percentage of carcass weight in the larger-bodied broilers and differed significantly only between the large BSPL95d birds and the small LG80d birds. The hind limb muscle also accounted for a higher percentage of carcass weight in larger broilers (BSPL95d). The cervicodorsal muscle accounted for a larger percentage of carcass weight in LG95d compared with LG80d birds.

The wing muscle consisted of one large shoulder girdle subpart and three small subparts with the large one representing 76–78% of the total weight. In the hind limb muscle, the femoral subpart was a little larger than the crural subpart, and the former accounted for

Table 2. Comparison of percentage weights of muscle groups and subgroups to carcass weight among the broiler groups

Broiler groups	LG80d	LG95d	BSPL80d	BSPL95d
Wing muscles				
Shoulder girdle m.	15.99±0.28b	17.43±0.34ab	16.83±0.41ab	18.43±0.66a
Brachial m.	2.09±0.05a	2.23±0.07a	2.19±0.04a	2.12±0.06a
Antebrachial m.	1.89±0.03a	1.95±0.07a	1.91±0.04a	1.91±0.09a
Abdominal m.	0.97±0.01a	1.00±0.03a	1.03±0.03a	1.02±0.04a
Combined	20.94±0.44b	22.61±0.35ab	21.96±0.38ab	23.48±0.88a
Hindlimb muscles				
Pelvic m.	1.57±0.12a	1.72±0.06a	1.74±0.09a	1.79±0.09a
Femoral m.	9.01±0.24b	9.44±0.23ab	9.07±0.15b	10.08±0.24a
Crural m.	7.69±0.18b	8.49±0.18ab	7.94±0.11ab	8.71±0.28a
Combined	18.27±0.35c	19.65±0.33ab	18.75±0.27bc	20.58±0.46a
Cervicodorsal muscles				
Dorsocaudal m.	1.71±0.05b	2.10±0.05a	1.88±0.04ab	1.98±0.05a
Cervical m.	2.75±0.09a	2.81±0.10a	2.89±0.08a	2.75±0.11a
Combined	4.46±0.17b	4.91±0.14a	4.77±0.16ab	4.73±0.06ab
% of hindlimb to wing muscles	87.2±1.2a	86.9±1.7a	85.4±1.4a	87.6±2.2a

Means±standard errors

BF; Broiler finisher fed birds, LS; Layer starter fed birds, LG; Layer grower fed birds, and PL; Pre-layer fed birds.

a, b, c; Means with the same letter did not differ significantly between chick's groups at 5% level.

Table 3. Percentage weights of individual muscle to carcass weights in the broilers

Broiler groups	LG80d	LG95d	BSPL80d	BSPL95d
<i>M. pectoralis</i>	9.82±0.25b	10.78±0.24ab	10.43±0.41ab	11.91±0.44a
<i>M. supracoracoideus</i>	3.27±0.06b	3.59±0.08ab	3.31±0.08b	3.87±0.15a
<i>M. triceps brachii</i>	0.90±0.05a	0.96±0.03a	0.90±0.03a	0.95±0.03a
<i>M. biceps brachii</i>	0.48±0.03a	0.49±0.02a	0.51±0.01a	0.52±0.02a
<i>Mm. iliopsoas</i>	1.25±0.09a	1.38±0.05a	1.23±0.07a	1.42±0.03a
<i>M. iliotibialis cranialis</i>	0.72±0.03a	0.76±0.03a	0.75±0.02a	0.82±0.04a
<i>M. iliotibialis lateralis</i>	1.93±0.12ab	1.91±0.06b	1.83±0.02b	2.16±0.05a
<i>Mm. femorotibiales</i>	2.34±0.10b	2.76±0.04a	2.45±0.04ab	2.51±0.09ab
<i>M. flexor cruris lateralis</i>	0.99±0.07b	1.07±0.06ab	1.01±0.03b	1.30±0.10a
<i>M. puboischiofemorialis</i>	0.94±0.03b	1.06±0.02a	0.96±0.02ab	1.03±0.02ab
<i>M. gastrocnemius</i>	2.82±0.11c	3.35±0.07b	3.13±0.07b	3.53±0.06a

Means±standard errors

BF; Broiler finisher fed birds, LS; Layer starter fed birds, LG; Layer grower fed birds, and PL; Pre-layer fed birds.

a, b, c; Means with the same letter did not differ significantly between chick's groups at 5% level.

48–49% of the hind limb muscle while the latter accounted for 42–43%. The cervicodorsal muscle was composed of a larger cervical subpart and a smaller dorsocaudal subpart.

Individual skeletal muscles

A notably large *pectoralis* muscle accounted for the largest percentage of carcass weight in the largest BSPL95d birds, followed by the LG95d and the BSPL80d broilers; the smallest percentage of carcass weight was found in the LG80d broilers which were also the smallest birds (Table 3). Changes in the size of the *supracoracoideus* and *gastrocnemius* muscles relative to carcass weight changed after the same manner as the *pectoralis* muscle among all the broiler groups. The *iliotibialis lateralis* and *flexor cruris lateralis* muscles were largest in BSPL95d birds and the *femorotibiales* and *puboischiofemorales* muscles were largest in LG95d birds. The size of the other small muscles relative to carcass weight did not differ among the different group of broilers.

DISCUSSION

Live weight was greater in BSPL80d than in LG80d broilers. Live weight was also greater in BSPL95d than in LG95d birds demonstrating that the larger body size induced by feeding a high nutrition feed (broiler starter) similar to broiler finisher diet for 3 weeks post-hatching (Das *et al.*, 2008a) was maintained through to slaughter. On the other hand, chicks on a restricted plane of nutrition during the first 3 weeks showed compensatory growth after 3 weeks on a broiler finisher feed with a high nutritional content (Das *et al.*, 2008b). Nutritionally-rich diets such as broiler feeds can accelerate growth whenever they are fed regardless of the growth stage and they play an important role in determining the ultimate body size of broilers. Carcass weight as a percentage of live weight was 84% and did not differ among the broiler groups in this or previous studies regardless of body size (Das *et al.*, 2008b). However, skeletal muscle as a whole accounted for a higher percentage of heavier carcasses. As skeletal muscle shows a positive allometric relationship with body weight (Iwamoto *et al.*, 1977, 1993; Ono *et al.*, 1989), the change in carcass weight from 2098 to 2871 g across the broiler groups led muscle weight as a percentage of carcass weight to increase from 45.0% to 50.5%. In a recent trial, broilers reared with a conventional broiler feed reached a carcass weight of 2970g by 80 days of age and skeletal muscle accounted for 49.2% of carcass weight (Roy *et al.*, 2007).

In the current study, hind limb weight relative to wing muscle weight was 75.9–76.5% in broilers fed on a high nutritional plane in the later growth stages after severe restriction of early growth compared to a value of 76.5% in broilers fed conventionally and killed at 80 days (Roy *et al.*, 2007; Das *et al.*, 2008b). Moreover, in broilers at 80 days of age which were reared with a layer starter feed for the first 3 weeks and then a layer grow-

er feed, hind limb weight relative to wing muscle weight was 82.2% (Roy *et al.*, 2007). In LG80d and BSPL80d broilers, the relative weight of hind limb muscle to wing muscle weight was 85.4–87.2% which is distinctly larger than the value of 76.5% measured in conventionally-fed broilers. While in normal broilers the wing and hind limb muscles account for 25.2% and 19.4% of carcass weight respectively, in LG80d and BSPL80d birds, values for wing muscle were 20.9–22.0% and for hind limb muscle, 18.3–18.8%. In particular, the shoulder girdle muscle of the wing in the LG80d and BSPL80d birds made up 16.0–16.8% of carcass weight and this value was lower than the 20.3% value measured in conventionally-fed broilers (Roy *et al.*, 2007). The larger relative size of the hind limb muscle in both types of broilers in the present study may have been produced by slow growth of the wing muscle rather than accelerated development of the hind limb muscle. The wing muscle seemed to be more responsive to variation in body growth induced by feeding diets with different nutrient concentrations compared with the hind limb muscle. However, the relative size of hind limb to wing muscle in LG95d and BSPL95d birds was maintained at a high level (86.9–87.6%) while the percentage of total muscle weight to carcass weight increased to 49.0–50.5%. From these results, it appears that chickens showing slow growth in the pre-slaughter stage produce relatively larger hind limb muscles. Details of how the duration and extent of growth restriction before slaughter influence hind limb muscle weight of broilers remain to be elucidated.

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). Major muscles of the breast (shoulder girdle) such as the *pectoralis* and *supracoracoideus* are typical white muscle composed of white myofibers (Suzuki, 1978; Ono *et al.*, 1993; Iwamoto *et al.*, 1998) which are characterized by an effective response to nutritional condition in chickens (Tesseraud *et al.*, 1996). Variation in *pectoralis* volume is caused solely by changes in the cross sectional area or diameter of white myofibers (Roy *et al.*, 2006). Japanese native crossbred broilers or roasters grow slowly but produce a darker meat in the thigh where the *iliotibialis lateralis* muscle contains red (type IIA) myofibers at higher frequency than found in general broilers (Iwamoto *et al.*, 1997; 1998). Since white myofibers in thigh muscles respond effectively to the nutritional plane of chickens in the same way as for breast muscles, crossbred broilers would appear to be suitable for production of chickens with relatively larger hind limb parts compared to general broilers.

In conclusion, the observed relatively larger hind limb to wing muscle ratio appears to have resulted from growth limitation in the later stages of growth after 3 weeks of age. Variation in growth rate during the first 3 weeks post-hatching altered ultimate body weight of broilers but did not alter the relative size of hind limb muscle. From these results, it appears that broilers such as Japanese native crossbred birds produce more

dark meat by increasing the relative size of hind limb muscle under a slow growth regime during the pre-slaughter period.

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