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Das, Chamali
Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University

Roy, Bimol Chandra
Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University

Oshima, Ichiro
Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University

Miyachi, Hideyuki
Yokoo & Co, Ltd

他

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Carcass Composition and Skeletal Muscle Distribution in Broilers Produced under Different Nutritional Regimes–1. Male Chicks at Three Weeks of Age

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

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. During early post–hatching growth in chickens, the wing muscles develop rapidly and their size relative to hind limb muscles increases (Iwamoto *et al*., 1975b; Ono *et al*., 1989). The aim of the present study was to assess whether the ratio of hind limb to wing muscle weight at three weeks of age could be altered by nutritional restriction during early growth.
2. Four groups of male chicks were reared on different complete feeds for three weeks. The feeds were: broiler finisher (BF; ME 13.47 MJ/kg, CP 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) and pre–layer (PL; ME 11.72 MJ/kg, CP 140 g/kg) feeds.
3. Growth rate differed among the chick groups; both live weights and carcass weights were highest in BF chicks, followed by LS, LG and PL chicks. There was a 2.4–fold difference in live weight and carcass weight between the BF and PL chicks. The weight of carcass as a percentage of live weight was 81–82% and did not differ among the chick groups.
4. The percentage of the carcass made up of skeletal muscle was positively associated with carcass weight while the percentage made up of viscera was negatively associated with carcass weight. However, the percentage of carcass weight accounted for by bone and skin did not differ among the chick groups. LG and PL chicks had higher proportions of intermuscular and abdominal fats than the other treatment groups.
5. The wing and hind limb muscles generally made up a higher percentage of the heavier carcasses. The weight of hind limb muscle relative to wing muscle in PL chicks was 96.7% while the equivalent value in the other groups was in the range 79.6–83.3%. Shoulder girdle muscle was the major component of wing muscle while the femoral and crural muscles accounted for a large proportion of the total hind limb muscle.
6. Our results suggest that severe restriction of body growth induced by under–nutrition increases the size of the hind limb muscle relative to wing muscle as a result of greater depression of muscle development in the wing than in the hind limb.

INTRODUCTION

White breast meat is composed mainly of white (type ⅡB) myofibers while dark thigh meat contains both red (type Ⅰ and ⅡA) and white myofibers (Suzuki, 1978; Suzuki *et al*., 1985; Ono *et al*., 1993). Myofiber type composition and myofiber size differ between meat–type and egg–type chickens (Aberle *et al*., 1979; Iwamoto *et al*., 1992, 1993). Slow growing chicken genotypes show a higher percentage of dark to white meat than conventional broilers, and have been selected to produce dark meat rather than white meat (Iwamoto *et al*., 1997, 1998; Fanatico *et al*., 2005). The yield of white meat is reduced to a greater extent by growth limitation than that of dark meat (Gordon and Charles, 2002).

During the first two weeks of post–hatching growth, 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*., 1975b). On the other hand, the volume of 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 subpart, myofibers are very small in diameter (5 μm) at hatching time and increase 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 hind limb to wing muscle.

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*., 1998; Nakamura *et al*., 2003). Feeding regimes which increase the relative amount of hind limb meat in chickens would be commercially desirable in Japan. In the present study

[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] Yokoo & Co, Ltd, Tosu–shi, 841–8602, Japan
[§] Scientific Officer, Bangladesh Livestock Research Institute, Savar, Dhaka 1341, Bangladesh
[§§] Assistant Professor, Department of Health and Nutrition, Niigata University of Health and Welfare 1398, Shimami–cho, Niigata–shi, 950–3198 Japan
* Corresponding author (E–mail: shotaro@agr.kyushu–u.ac.jp)

we investigated methods of increasing the relative size of the hind limb muscle through nutritional manipulation. Body growth, carcass composition and skeletal muscle development, at three weeks of age, were compared in broiler chicks grown at different rates by altering the nutrient concentration of their complete feed.

MATERIALS AND METHODS

Experimental Chicks

Red Cornish×New Hampshire (Shaver, Fort Médoc, France) one–day–old chicks were randomly allocated to four different floor pens (25 chicks/pen, 1.8 m×1.8 m) in an experimental facility using litter on a concrete floor. Each of four groups of the chicks 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; ME 11.72 g/kg, CP 140 g/kg) complete feeds (Marubeni Nisshin Feed Co. Ltd, Tokyo, Japan). Feed and water were provided ad libitum with two tube feeders and one drinker in each pen.

At three weeks of age, 12 chicks from the BF group, 8 chicks from the LS group, 8 chicks from the LG group and 8 chicks from the PL group were selected at random and killed by bleeding from a severed carotid artery and jugular vein after a 12 hr overnight fast. Carcasses were placed in a water bath at 60 °C water for 120 sec. prior to plucking the feather and down by hand. Then the carcasses were chilled in ice–water for at least 1hr and weighed after 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

After removing the skin, the carcass was dissected into wing, hind limb and cervicodorsal parts, and the visceral organs and abdominal fat were then separated from the rest of the carcass. The total weights of skin, visceral organs and abdominal fat were measured. Each part was divided into three components, namely, fatty tissue, skeletal muscle and bone (including tendons and ligaments). Total skeletal muscle, intermuscular fat and bone were weighed and expressed as combined totals.

Skeletal muscle from the left side of carcass was divided into four wing subparts, three hind limb subparts and two cervicodorsal subparts by dissection based on gross anatomical construction (Vanden Berge, 1979; Vollmehrhaus, 1992). The wing muscle was comprised of the shoulder girdle (the largest subpart composed of the muscles over the shoulder girdle framework), brachial (muscles of the belly attached to the brachial bone), antebrachial (muscles of the forearm and hand) and abdominal (four abdominal muscles) muscle subparts. The hind limb muscle was comprised of the pelvic (muscles connecting pelvic girdle and the proximal region of femoral bone except for the *obturatorius medialis* muscle), femoral (muscles of the belly on the femoral bone) and crural (muscles of the belly on the tarsotibial bone) muscle subparts. The cervicodorsal region was comprised of the dorsocaudal muscle (dorsal and caudal muscles and *obturatorius medialis* muscle) and the cervical muscle subparts.

The weights of the *pectoralis*, *supracoracoideus*, *triceps brachii*, *biceps brachii*, *iliotrochanterici* (the cranial, caudal and medial heads), *iliotibialis cranialis*, *iliotibialis lateralis*, *femorotibiales* (the lateral, middle and medial heads), *flexor cruris lateralis*, *puboischiofemoralis* (the medial and lateral parts) and *gastrocnemius* (the lateral, medial and intermediate parts) muscles were measured on the right side of the carcass.

Statistical analysis

In this study, all the parameters were expressed as

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 chick's groups at 3 weeks of age

Chick's groups	BF	LS	LG	PL
No of birds	12	8	8	8
Live weight (g)	616±9a	467±5b	318±10c	259±6d
Carcass weight (g)	502±9a	378±7b	262±8c	213±5d
Carcass percentage	81.5	80.9	82.4	82.2
Carcass composition (%)				
Total muscle	43.5±0.5a	41.1±0.8a	36.7±0.5b	34.0±1.0c
Total bone	16.3±0.4a	16.1±0.5a	15.6±0.4a	15.7±0.3a
Total intermuscular fat	2.47±0.22b	2.69±0.17b	3.15±0.13ab	3.58±0.25a
Visceral	23.3±0.3d	26.4±0.5c	29.8±0.8b	32.8±0.6a
Skin	11.8±0.4a	11.2±0.4a	12.1±0.6a	10.7±0.3a
Abdominal fat	1.34±0.11bc	1.14±0.10c	1.67±0.09a	1.56±0.14ab

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

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

Live weight and carcass weight differed significantly among all chick types at three weeks of age (Table 1). The largest live weight and carcass weight were found in BF–fed chicks which were 2.4–fold larger than the smallest group, the PL–fed chicks. The next largest were the LS–fed chicks followed by the LG–fed chicks. The percentage of carcass to live weight was 81–82% in all chick groups.

Carcass composition

The chick groups showing larger body size generally showed a higher percentage of total skeletal muscle weight and a smaller percentage of visceral weight although muscle weight in BF chicks did not differ significantly from LS chicks (Table 1). Total bone and skin weights did not differ among the chick groups. Both intermuscular and abdominal fat weights, expressed relative to carcass weight, were negatively associated with carcass weight.

Skeletal muscle weights

The weight of wing muscle as a percentage of carcass weight was highest (19–20%) in BF and LS chicks, followed by LG chicks (17%), and the smallest percentage (14%) was found in PL chicks (Table 2). The largest percentage (17%) of hind limb muscle was observed in BF chicks and conversely the smallest (14%) was found in LG and PL chicks; LS chicks showed an intermediate percentage (15%). The weight of the hind limb muscle relative to wing muscle was highest in PL chicks (97%) and was significantly higher than in the other groups (80–83%). The percentage of cervicodorsal muscle did not differ among the chick groups.

Shoulder girdle muscle, the largest subpart of the wing, accounted for 78% of the wing muscle in BF chicks, 76% in LS and LG chicks, and 73% in PL chicks. These results suggest that in PL chicks, the low relative weight of the wing muscle can be mainly attributed to severely restricted development of the shoulder girdle muscle (Table 2). The percentage weight of abdominal muscle did not differ among the chick groups. The percentages of brachial and antebrachial muscles were larger in BF and LS chicks than in LG and PL chicks. In the hind limb muscle, the percentage of overall carcass weight accounted for by the femoral and crural muscle changed in the same manner as for the hind limb muscle as a whole among the different chick groups but the percentage of pelvic muscle did not differ among chick groups. In the cervicodorsal muscle parts, the percentage weight of the dorsocaudal subpart in BF chicks was significantly higher than in LG and PL chicks while the relative weight of the cervical muscle did not differ among the chick groups.

Individual muscle weights

The *pectoralis* muscle, which is the largest of the wing muscles, showed marked differences in relative weight among the chick groups, being largest in the BF chicks, followed by the LS chicks, followed by LG chicks, with the lowest relative weight being found in the PL chicks (Table 3). The *supracoracoideus* muscle accounted for around a third of wing muscle weight

Table 2. Comparison of percentage weights of muscle groups and subgroups to carcass weight among the chick's groups at 3 weeks of age

Chick's group	BF	LS	LG	PL
Wing muscles	15.91±0.34a	14.81±0.45a	12.59±0.26b	10.27±0.34c
Shoulder girdle m.	1.89±0.04ab	1.91±0.07a	1.66±0.05bc	1.56±0.09c
Brachial m.	1.65±0.04a	1.65±0.06a	1.41±0.04b	1.26±0.07b
Antebrachial m.	0.96±0.04a	1.00±0.04a	0.94±0.03a	0.99±0.07a
Abdominal m.	20.41±0.38a	19.37±0.47a	16.60±0.32b	14.08±0.47c
Combined				
Hindlimb muscles				
Pelvic m.	1.55±0.04a	1.43±0.10a	1.32±0.05a	1.30±0.08a
Femoral m.	8.16±0.11a	7.57±0.09b	6.85±0.14c	6.64±0.21c
Crural m.	6.98±0.07a	6.43±0.09b	5.74±0.12c	5.69±0.13c
Combained	16.69±0.15a	15.42±0.23b	13.91±0.29c	13.62±0.35c
Cervicodorsal muscles				
Dorsocaudal m.	1.67±0.07a	1.43±0.07ab	1.32±0.04b	1.29±0.05b
Cervical m.	2.21±0.09a	2.32±0.09a	2.18±0.07a	2.32±0.10a
Combained	3.88±0.09a	3.75±0.15a	3.49±0.08a	3.61±0.14a
% of hindlimb to wing muscles	81.8±1.1b	79.6±1.7b	83.3±1.9b	96.7±1.3a

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. Comparison of percentage weights of individual muscle to carcass weights among the chick's groups at 3 weeks of age

Chick's group	BF	LS	LG	PL
M. pectoralis	10.84±0.26a	9.52±0.37b	7.88±0.22c	6.52±0.30d
M. supracoracoideus	3.00±0.06a	2.75±0.11a	2.39±0.06b	2.03±0.05c
M. triceps brachii	0.77±0.02a	0.76±0.04ab	0.65±0.04bc	0.63±0.02c
M. biceps brachii	0.48±0.01a	0.48±0.02a	0.34±0.04b	0.35±0.02b
Mm. iliotrochanterici	1.14±0.02a	1.09±0.05ab	0.99±0.03b	1.00±0.05b
M. iliotibialis cranialis	0.75±0.01a	0.69±0.03ab	0.66±0.02b	0.65±0.02b
M. iliotibialis lateralis	1.95±0.06a	1.75±0.07ab	1.63±0.07bc	1.37±0.09c
Mm. femorotibiales	1.86±0.04ab	1.88±0.03a	1.67±0.03c	1.71±0.06bc
M. flexor cruris lateralis	1.09±0.05a	0.96±0.04ab	0.85±0.03bc	0.73±0.03c
M. puboischiofemoralis	0.81±0.02a	0.74±0.02b	0.74±0.01b	0.76±0.01ab
M. gastrocnemius	2.58±0.06a	2.31±0.10ab	2.25±0.07bc	2.01±0.07c

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

and its relative weight was highest in the BF and LS chick groups, followed by LG group and then the PL group. The *triceps brachii* and *biceps brachii* muscles of the wing parts also generally represented a larger percentage of carcass weight in BF and LS chicks than in LG and PL chicks although the *biceps brachii* was smaller in LG than in PL chicks.

The two largest muscles of the thigh, the *iliotibialis lateralis* and the *femorotibiales*, were generally larger, as a percentage of carcass weight, in BF and LS chicks than in LG and PL chicks. However, the *iliotibialis lateralis* did not differ between LS and LG chicks and the *femorotibiales* did not differ between BF chicks and PL chicks. The relative weight of the *gastrocnemius* muscle in the crural subpart was also higher in BF chicks and smaller in PL chicks with the weight in LS and LG groups being intermediate. The other muscles of BF chicks also accounted for a higher percentage of carcass weight than equivalent weights in the other groups. Conversely, the relative weight of the other muscles was lowest in the PL and LG chick groups.

DISCUSSION

Since feed consumption of chickens is fairly constant regardless of variation in feed energy content, energy intake is increased when a high–energy diet is consumed (Brue and Lasthaw, 1985). A high protein content in feed accelerates the growth rate of chickens but does not lead to the accumulation of abdominal fat provided a constant ratio of energy to protein is maintained (Batrov *et al.*, 1974; Skinner *et al.*, 1992; Aggrey, 2004). In the present study, the feed containing the highest energy led to the most rapid growth of chicks. The PL feed with its high ratio of energy to protein had only minor effects on intermuscular and abdominal fat deposition because of its low energy content. Visceral components decrease as a percentage of carcass weight and conversely skeletal muscle increases as a percentage of carcass weight with body growth (Hayse and Marion, 1973; Moran, 1977; Roy *et al.*, 2007). In this study, the percentage weight of viscera to carcass also decreased and conversely the percentage weight of skeletal muscle increased as body weight increased across the chick groups. However, the percentage of carcasses to live weight did not differ among the chick groups.

In a previous study using Barred Plymouth Rock cockerels at three weeks of age, skeletal muscle as a whole accounted for 32.1% of live weight (Iwamoto *et al.*, 1975a). In the current study, the chicks at three weeks of age showed considerable variation in the overall weight of the muscle as a percentage of carcass weight with values varying from 28% in PL chicks, which were also the smallest chicks, to 35% in BF chicks, which were the largest chicks. Live weight at three weeks of age was low, at 185 g, in the Plymouth Rock chickens but varied from 259 g to 616 g in the chicks in the current study. These results suggest that changes in relative muscle weight depend on differences in body size within a breed but are independent of variation in body size between breeds in chicks. As total muscle weight shows a positive allometric relationship with live weight during the post–hatching growth stage prior to sexual maturation (Iwamoto *et al.*, 1977), it is very important to maintain rapid growth rate at this growth stage by providing suitable environmental conditions for effective production of chickens.

In a previous study using male Barred Plymouth Rock chicks, the relative weight of hind limb to wing muscle changed with growth from 247% at hatching to 112% at one week of age to 76.2% at two weeks of age (Iwamoto *et al.*, 1975b). The relative weight of hind limb to wing muscle was 76.5% in Red Cornish × New Hampshire male broilers at 80 days of age following feeding on broiler feeds and 80–84% at 80, 95 or 108 days old reared with layer feeds (Roy *et al.*, 2007). In the present study, the relative size of hind limb to wing muscle in BF, LS or LG chick groups at three weeks of age was 80–83% while in the PL chicks the equivalent value was 97%. These results suggest that the relative weight of the hind limb muscle can be increased by mild depression of body growth during the early growth period of 0–3 weeks of age. However, to markedly increase the relative size of the hind limb muscle 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 rates after three weeks of age.

In conclusion, we have shown in this study that three–week–old chicks with the highest proportion of hind limb muscle can be produced by feeding a diet with a low nutritional value to severely restrict body growth. However, the carcasses of the light chicks produced by this nutritional restriction had low relative weights of skeletal muscle in most body parts and subparts. For an effective production of broilers the light chicks would need to be subjected to compensatory growth after three weeks.

REFERENCES

ABERLE, F. D., ADDIS, P. B. & SOFFNER, R. N. 1979 Fiber types in skeletal muscles of broiler– and layer–type chickens. *Poultry Science*, **58**: 1210–1212

AGGREY, S. E. 2004 Modeling the effect of nutritional status on pre–asymptotic and relative growth rates in a random–bred chicken population. *Journal of Animal Breeding and Genetics*, **121**: 260–268

BARTOV, I., BOMSTEIN, S. & LIPSTEIN, B. 1974 Effects of calorie to protein ratio on the degree of fatness in broilers fed on practical diets. *British Poultry Science*, **15**: 107–117

BRUE, R. N. & LATSHAW, J. D. 1985 Energy utilization by the broiler chicken as affected by various fats and fat levels. *Poultry Science*, **64**: 2119–2130

FANATICO, A. C., PILLAI, P. B., CAVITT, L. C., OWENS, C. M. & EMMERT, J. L. 2005 Evaluation of slower growing broiler genotypes grown with and without outdoor access: growth performance and carcass yield. *Poultry Science*, **84**: 1321–1327

GORDON, S. H. & CHARLES, D. R. 2002 *Niche and organic chicken products.* Nottingham university press, Nottingham, UK

HAYSE, P. L. & MARION, W. W. 1973 Eviscerated yield, component parts, and meat, skin and bone ratios in the chicken broiler. *Poultry Science*, **52**: 718–722

IWAMOTO, H., TAKAHARA, H. & OKAMOTO, M. 1975a Fundamental studies on the meat production of the domestic fowl. VI. Postnatal growth of skeletal muscle, skin, viscera, bone and fatty tissue of Barred Plymouth Rock chicken. *Science Bulletin of the Faculty of Agriculture, Kyushu University*, **29**: 151–162

IWAMOTO, H., TAKAHARA, H. & OKAMOTO, M. 1975b Fundamental studies on the meat production of the domestic fowl. VII. Postnatal growth of skeletal muscle in some body parts of Barred Plymouth Rock chicken. *Science Bulletin of the Faculty of Agriculture, Kyushu University*, **30**: 119–136

IWAMOTO, H., TAKAHARA, H. & OKAMOTO, M. 1977 Effects of breed and sex on the total weight of skeletal muscle in the chicken. *Japanese Journal of Zootechnical Science*, **48**: 308–314

IWAMOTO, H., HARA, Y., ONO, Y. & TAKAHARA, H. 1992 Breed differences in the histochemical properties of the *M. iliotibialis lateralis* myofibre of domestic cocks. *British Poultry Science*, **33**: 321–328

IWAMOTO, H., HARA, Y., GOTOH, T., ONO, Y. & TAKAHARA, H. 1993 Different growth rates of male chicken skeletal muscles related to their histochemical properties. *British Poultry Science*, **34**: 925–938

IWAMOTO, H., FUKUMITSU, Y., GOTOH, T., ONO, Y. & TAKAHARA, H. 1997 Comparative studies on the histochemical properties of *M. iliotibialis lateralis* from Kumamoto Cochin crossbred roaster and broiler chickens. *British Poultry Science*, **38**: 258–262

IWAMOTO, H., KATOH, F., GOTOH, T., NISHIMURA, S., ONO, Y., NISHIO, Y., FUKUHARA, E. & MURAKAMI, T. 1998 Effects of parent Shamo cocks on the histochemical properties of *M. iliotibialis lateralis* and *M. supracoracoideus* on their crossbred broilers. *British Poultry Science*, **39**: 589–595

MORAN Jr, E. T. 1977 Growth and meat yield in poultry. *Growth and Poultry Meat Production*. K. N. Boorman and B. J. Wilson, ed. British Poultry Science, Ltd., Edinburgh, Scotland, pp. 145–173

NAKAMURA, R., SEKOGUCHI, S. & SATO, Y. 1975 The contribution of intramuscular collagen to the tenderness of meat from chickens with different ages. *Poultry Science*, **54**: 1604–1612

NAKAMURA, Y–N., IWAMOTO, H., TABATA, S., ONO, Y., SHIBA, N. & NISHIMURA, S. 2003 Comparison of collagen content, distribution and architecture among the *pectoralis, iliotibialis lateralis* and *puboischiofemoralis* muscles with different myofiber composition in Silky cocks. *Animal Science Journal*, **74**: 119–128

ONO, Y., IWAMOTO, H. & TAKAHARA, H. 1989 Allometry of body weight, skeletal muscle weight and muscle fiber diameter in the chick. *Japanese Journal of Zootechnical Science*, **60**: 958–964

ONO, Y., IWAMOTO, H. & TAKAHARA, H. 1993 The relationship between muscle growth and the growth of different fiber types in chicken. *Poultry Science*, **72**: 568–576

ROY, B. C., OSHIMA, I., MIYACHI, H. NISHIMURA, S., TABATA, S. & IWAMOTO, H. 2007 Effects of nutritional level and carcase weight on the different anatomical body parts and muscle weights of male broilers. *Journal of Faculty of Agriculture, Kyushu University*, **52**: 43–48

SKINNER, J. T., WALDROUP, A. L. & WALDROUP, P. W. 1992 Effects of dietary nutrient density on performance and carcass quality of broilers 42 to 49 days of age. *Journal of Applied Poultry Research*, **1**: 367–372

STEEL, R. G. D. & TORRIE, J. H. 1980 Principles and procedures of statistics: A biometrical approach (2nd Ed.). McGraw–Hill Inc., New York, USA

SUZUKI, A. 1978 Histochemistry of the chicken muscles. II. Distribution and diameter of 3 myofiber types. *Tohoku Journal of Agriculture Research*, **29**: 38–43

SUZUKI, A., TSUCHIYA, T., OHWADA, S. & TAMATE, H. 1985 Distribution of myofiber types in thigh muscles of chickens. *Journal of Morphology*, **185**: 145–154

VANDEN BERGE, J. C. 1979 Myologia. *Nomina Anatomica Avium.* J. J. Baumel, ed. Academic Press, New York, USA. pp. 175–219

VOLLMEHRHAUS, B. 1992 Anatomie des Bewengungsaparates. *Lehrbuch der Anatomie der Haustiere*, Band V. A. Schmmer & B. Vollmehrhaus, ed. Paul Parey, Berlin, Germany. pp. 54–154