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Effects of nutritional level and carcass weight on the different anatomical body parts and muscle weights of male broilers

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1. The anatomical constituent of the carcass and the relative distribution of skeletal muscle in the different body parts were compared among male broiler groups reared with broiler foods with high nutritional levels for up to 80 d (H80d), and layer foods with low nutritional levels for up to 80 (L80d), 95 (L95d) and 108 d (L108d).
2. The carcass weight of the low nutrition birds increased from 2470 g in L80d to 3600 g in L108d through 2820 g in L95d, while H80d birds arrived at 2970 g after a 15 d shorter term of fattening compared to L95d. At that stage the carcass of H80d contained 49.2% whole skeletal muscle, similar to 50.9% in L108d, and these values were larger than the 45.8% in L80d and 44.8% in L95d. Conversely, the whole visceral organ was contained at a smaller percentage in H80d and L108d compared to L80d and L95d. The percentage weight of whole bone, intermuscular adipose tissue, skin and abdominal fat did not differ among the bird groups, except for the L108d carcass which contained the smallest percentage whole bone.
3. The forelimbs muscles comprised 25.2% of the carcass in H80d and L108d, which was larger than 22.5–22.7% in L80d and L95d. The muscle percentage of the hind limbs was largest in L108d (21.1%), medium in H80d (19.4%), and smallest in L80d (18.7%) and L95d (18.0%). The antebrachial muscle showed the largest percentage in H80d and the percentages of femoral and crural muscle were largest in L108d. The big shoulder muscle subpart was 20.2–20.3% in H80d and L108d, which was larger than 17.9–18.0% in L80d and L95d.
4. Age-related change of the percentage weight was observed markedly in the *pectoralis*, *iliotibialis lateralis*, *flexor cruris lateralis* and *gastrocnemius* muscles across the low nutrition bird groups with different ages. On the other hand, the H80d birds attained the largest percentage in the *pectoralis*, *supracoracoideus*, and *femorotibiales* muscles.
5. From these results, it was indicated that broiler foods with high nutritional levels do not only promote the growth rate of broiler, but also enhance the meat quality by stimulating the development of skeletal muscle within the valuable breast part.

INTRODUCTION

In domestic chickens, a diet with a high energy content promotes the growth rate and improves the feed efficiency for meat production (Farrell *et al.*, 1976; Waldroup, 1981; Jackson *et al.*, 1982; Sohn and Han, 1983a, b; Bartov, 1992; Leeson *et al.*, 1996), but also is accompanied by the negative consequence of abundant deposition of abdominal fat (Griffin, 1996). Furthermore, it is reported that the carcass fatness does not change as long as the calorie to protein ratio in the diet remains constant (Bartov *et al.*, 1974; Skinner *et al.*, 1992). In pigs, the most important aspect of meat traits, fatness, is affected by several factors such as breed, diet, and muscle type (different myofibre types) (Wood *et al.*, 2004).

The yield of white breast meat decreases more than that of dark meat when the body weight gain is reduced

(Gordon and Charles, 2002). Slow growing genotypic chickens show a lower ratio of white to dark meat than conventional broilers, and are selected to produce dark meat rather than white (Fanatico *et al.*, 2005).

Demands for high quality and further processed convenient meats which are sold as ready to cook in supermarkets have driven the poultry industry to change its marketing practices (Watts and Kennett, 1995; Roenigk and Pederson, 1987; Young *et al.*, 2001). Where the various blocks of chicken are sold separately, the breast may attract a different price and is more valuable than the remainder blocks in numerous markets (Gous *et al.*, 1999). Relative meat yield in the different parts could be altered by several factors such as strain, sex, age, health, nutrition, live weight, duration of feed withdrawal before processing and carcass down grading (McNally and Spicknall, 1949; Schmidt *et al.*, 1964; Bouwkamp *et al.*, 1973; Moran, 1977; Siegel *et al.*, 1984). The baseline information for the general yield pattern in modern broilers was deduced from the regression analysis of edible parts to body weight by Brake *et al.* (1993). More recently, using rabbits with diverse body weights at the same age, indicated that the rabbits of small body size yield 3% greater carcass, 3% larger hind limbs in relative proportion, and 11% larger hind

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limbs in the ratio of meat to bone compared with the animals of large body size (Gondret *et al.*, 2005).

Although merchandising of parts and further processed poultry needs yield information on various parts and components, in chicken only little information on the growth patterns of anatomically defined muscles is available. In the present study, the anatomical constituent of the carcass and the relative distribution of skeletal muscles among the different parts were examined using male broilers reared with broiler foods with a high nutritional level for up to 80 d (H80d), and layer foods with a low nutritional level for up to 80 (L80d, same age as H80d), 95 (L95d, same body weight as H80d), and 108 d (L108d, same percentage of whole muscle to carcass weight as H80d).

MATERIALS AND METHODS

Birds and Foods

Red Cornish × New Hampshire (RN, Shaver, Fort Medoc, France) cockerels were used after being reared with broiler diets with a high nutritional level for up to 80 d (H80d), and layer foods with a low nutritional level for up to 80 (L80d), 95 (L95d), and 108 d (L108d). The chemical composition of those foods is shown in Table 1, of which the starters were fed for the first period of 21d after hatching and thereafter the finishers. Throughout the experimental period, the cockerels were kept within a pen house and had *ad libitum* access to foods and water.

Sixteen birds of H80d, 16 birds of L80d, 8 birds of L95d and 8 birds of L108d were killed by a conventional neck cut to sever the carotid artery and jugular vein, bled completely and scalded at 60 °C for 2 min for plucking the feather and down by hand. The carcasses were subsequently chilled in ice–water for more than 1 hr, and weighed after cutting off the head at atlanto–occipital joint and feet at intertarsal joint.

Total skeletal muscle, bone, intermuscular adipose tissue, visceral organs, skin and abdominal fat

After removing the skin, the skinned carcass was dissected into the body stem with visceral organs and abdominal fat, forelimbs and hind limbs parts. The total weight of skin, and those of the visceral organs and abdominal fat separated from the body stem part were measured. The total weight of intermuscular adipose

tissue was measured as the combined value of the difference between the weights in each part before and after cleaning out the surface and intermuscular fatty tissue. The total skeletal muscle weight was the combined data of the weights in the parts, and also the total weight of bone (containing ligaments and tendons) was assessed from the weights in the parts measured after taking out every muscle.

Measurement of muscle weights in groups, sub-groups and individual muscles

When the carcass was divided into the parts and subparts, the muscle weight in each subpart was measured on the left side, and the weight in each part was calculated as the combined weight of those in the subparts. The carcass was divided into the body stem, forelimbs and hind limbs parts, and the body stem into dorsocaudal subpart (group of dorsal and caudal muscles, and *obturatorius medialis* muscle) and neck subpart (group of cervical muscles), the forelimbs part into an abdominal subpart (group of 4 abdominal muscles), shoulder subpart (the largest subpart composed of the muscle group over the shoulder girdle framework), brachial subpart (group of muscles with the belly on the brachial bone) and antebrachial subpart (group of muscles in the forearm and hand), and the hind limbs part into pelvic subpart (group of muscles connecting pelvic girdle and the proximal region of femoral bone except for *obturatorius medialis*), thigh subpart (group of muscles with the belly on the femoral bone), and crural subpart (group of muscles with the belly on the tarsotibial bone). The weights of the *pectoralis*, *supracoracoideus*, *triceps brachii*, *iliotrochanterici*, *iliotibialis cranialis*, *iliotibialis lateralis*, *femorotibiales*, *flexor cruris lateralis*, *puboischiofemorales* (medial and lateral heads), and *gastrocnemius* muscles were measured on the right side of the carcass.

Statistical analysis

All of the anatomical components and muscle weights were converted into percentage of carcass weight, and were available for comparing the bird groups with different body size. Means and the standard errors were calculated for the birds in each group and used for a *t*-test to find a significant difference between bird groups.

Table 1. Chemical composition of starter and finisher diets in the high and low nutritional group

Composition	High Nutritional Level		Low Nutritional Level	
	Starter	Finisher	Starter	Finisher
Crude protein, (g/kg)	205	161	177	142
Ether Extract, (g/kg)	40.0	44.1	11.0	41.4
Crude Fibre, (g/kg)	50.0	52.1	63.5	50.3
Ash (g/kg)	80.0	75.1	84.0	58.0
Calcium (g/kg)	8.00	5.70	4.15	3.80
Phosphorus (g/kg)	5.0	5.6	2.8	5.4
Metabolisable energy (MJ /kg DM)	13.2	11.9	11.6	11.7

RESULTS

Carcass weight

The birds (H80d) reared on the diets with a high nutritional level showed a rapid growth rate, and consequently gained the greater carcass weight compared with the birds (L80d) fed on low nutritional food (Table 2). The birds (L95d) reared with the low nutritional foods took another 15 days or more to reach the same carcass weight as H80d. The L108d birds had another 780 g addition to the carcass weight as a result of 13 d more fattening compared to the L95d birds, and showed the largest weight of all bird groups.

Total skeletal muscle, bone, intermuscular adipose tissue, visceral organs, skin and abdominal fat

The percentage weights of whole skeletal muscle to carcass weight was significantly larger in H80d birds by 3.4% from that in L80d, and 4.4% from that in L95d; however, it did not differ between H80d and L108d birds (Table 2). Although the carcass weight of L95d birds

reached to the same weight as that of H80d, the percentage weight of the skeletal muscle had not improved by the 15 d elongation of the fattening term. After another 13 d elongation of the term, the muscle percentage in L108d arrived at exactly the same value to that in H80d. Conversely the percentage weight of the whole bone and visceral weights in L108d decreased after growth from 80 d to 108 d. The percentage weight of visceral organs was significantly smaller in L108d and H80d than L80d and L95d. The percentage weight of the whole bone was significantly smaller in L108d than L80d and H80d. The percentage weights of the intermuscular fatty tissue, skin and abdominal fat did not differ among the bird groups.

Muscle weights in groups, subgroups and individual muscles

Group: In this chicken type, the largest forelimbs part containing half the whole skeletal muscle volume was most susceptible to the change in nutritional level of foods (Table 3). The H80d birds had the percentage

Table 2. Carcass weight and its compositional percentages of total muscle, bone, intermuscular adipose tissue, visceral, skin and abdominal fat

Experimental groups	H80d	L80d	L95d	L108d
No. of birds	16	16	8	8
Carcass weight (g)	2970 ± 58b	2470 ± 111c	2820 ± 82b	3600 ± 164a
Total muscle weight	49.2 ± 0.6a	45.8 ± 0.9b	44.8 ± 0.9b	50.9 ± 0.7a
Total bone weight	15.1 ± 0.3a	15.4 ± 0.5a	14.3 ± 0.4ab	13.5 ± 0.7b
Total intermuscular adipose tissue weight	3.1 ± 0.2a	3.2 ± 0.2a	3.6 ± 0.3a	3.3 ± 0.3a
Visceral weight	15.6 ± 0.5b	18.5 ± 0.7a	19.4 ± 0.7a	14.6 ± 0.4b
Skin weight	11.4 ± 0.3a	11.5 ± 0.4a	11.6 ± 0.7a	11.5 ± 0.3a
Abdominal fat weight	3.2 ± 0.3a	3.1 ± 0.3a	3.3 ± 0.7a	3.3 ± 0.4a

Means ± standard errors

H80d; High nutritional chicken group at 80 days of age

L80d, L95d, L108d; Low nutritional chicken group at 80, 95 and 108 days of age, respectively

a, b, c The means with same letter do not differ significantly between chicken groups at 5% level

Table 3. The percentage weight of muscle group to carcass weight in the body parts and subparts

Experimental groups	H80d	L80d	L95d	L108d
Forelimbs part				
Shoulder subpart	20.31 ± 0.40a	17.89 ± 0.44b	17.99 ± 0.37b	20.20 ± 0.58a
Brachial subpart	2.13 ± 0.03a	2.08 ± 0.06ab	1.95 ± 0.03b	2.16 ± 0.05a
Antebrachial subpart	1.83 ± 0.03a	1.77 ± 0.06b	1.60 ± 0.03c	1.67 ± 0.05bc
Abdominal subpart	0.97 ± 0.02a	1.01 ± 0.03a	0.99 ± 0.05a	1.13 ± 0.04a
Combined	25.24 ± 0.40a	22.75 ± 0.54b	22.53 ± 0.38b	25.16 ± 0.60a
Hind limbs part				
Pelvic subpart	1.85 ± 0.03ab	1.79 ± 0.05b	1.66 ± 0.07c	1.93 ± 0.06a
Femoral subpart	9.49 ± 0.13b	8.99 ± 0.21bc	8.63 ± 0.28c	10.03 ± 0.20a
Crural subpart	8.01 ± 0.30a	7.93 ± 0.15a	7.72 ± 0.25a	9.16 ± 0.19a
Combined	19.35 ± 0.25b	18.71 ± 0.31c	18.01 ± 0.54c	21.12 ± 0.29a
Body stem part				
Dorsocaudal subpart	2.06 ± 0.05a	1.88 ± 0.04b	1.92 ± 0.05ab	2.06 ± 0.07a
Neck subpart	2.57 ± 0.06a	2.47 ± 0.08ab	2.34 ± 0.09b	2.57 ± 0.11a
Combined	4.63 ± 0.11a	4.35 ± 0.11b	4.26 ± 0.15ab	4.63 ± 0.15ab

Means ± standard errors

H80d; High nutritional chicken group at 80 days of age

L80d, L95d, L108d; Low nutritional chicken group at 80, 95 and 108 days of age, respectively

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weight of the forelimbs muscle increase by 2.5–2.7% compared to those of L80d and L95d birds. After being reared for an additional 28 d, the forelimbs muscle of the L108d birds arrived at the same percentage as in H80d. On the other hand, in the hind limbs muscle the largest percentage was observed in L108d, the second largest in H80d, and the smallest in L80d and L95d. The body stem muscle was significantly larger in H80d than L80d.

Subgroup: The shoulder subpart occupying 80% of the forelimbs part produced the largest muscle block of all subparts (Table 3). The percentage of shoulder muscle to the carcass weight was larger in H80d birds by 2.3–2.4% from those of L80d and L95d, but no significant difference of the percentage was observed between H80d and L108d. The percentage of the antebrachial muscle was largest in H80d, followed by L80d, and smallest in L95d. The L108d birds showed a medium value between L80d and L95d in the percentage of antebrachial muscle, but did not differ significantly from each of them. The percentage of brachial muscle was significantly larger in H80d and L108d than L95d. The abdominal muscle developed markedly in L108d showing the largest percentage. No significant difference among H80d, L80d and L95d was observed in the percentage of the abdominal subpart.

In the hind limbs part, each of the subparts in L108d was largest in percentage of carcass weight of all bird groups with one exception; the pelvic muscle showed no difference between L108d and H80d. Moreover the femoral muscle exhibited a significantly larger percentage in H80d than L95d, and the pelvic muscle was larger in L80d than L95d. The crural subpart showed a significant difference between H80d and L80d. In the body stem part, the H80d and L108d chickens obtained the largest weight percentage dorsocaudal and neck subparts of all, where in the former subpart they showed a significant difference from L80d and in the latter from L95d.

Individual muscle: The *pectoralis* muscle was biggest in L108d at 13.08% and H80d at 12.92% of the carcass weight, which were significantly larger compared with 10.79% in L80d and 11.15% in L95d. Additionally, the

supracoracoideus was largest in L108d and H80d, where these two muscles belong into the breast meat (Table 4). The *iliotrochanterici*, *iliotibialis lateralis*, *flexor cruris lateralis* and *gastrocnemius* muscles developed well in the L108d birds. The *iliotibialis lateralis*, *femorotibiales* and *gastrocnemius* muscles were significantly larger in percentage weight in H80d than L80d and L95d birds, as well as the *iliotrochanterici* muscles in H80d compared to L95d. The percentage weight of *triceps brachii* muscle did not show a significant difference among the chicken groups, and those of the *iliotibialis cranialis* and *flexor cruris lateralis* muscles did not differ among H80d, L80d, and L95d.

DISCUSSION

While foods with different energy contents can not change the actual food consumption, birds on high energy diets take in more metabolizable energy (Brue and Latshaw, 1985). The high energy diet hastens the chick's growth, and increases yields of the carcass and abdominal fat (Holsheimer and Veerkamp, 1992; Lott *et al.*, 1992; Lei and Van Beeh, 1997; Yalcin *et al.*, 1998). The relative weight of abdominal fat shows a positive interrelation to dietary energy (Yalcin *et al.*, 1998). High protein diets can also stimulate chick growth, but do not stimulate an accumulation of abdominal fat if the calorie to protein ratio remains constant (Bartov *et al.*, 1974; Skinner *et al.*, 1992; Aggrey, 2004). In the present study, the percentage weight of abdominal fat to carcass weight did not differ among the bird groups regardless of the marked difference of carcass weights. Also the percentage weight of intermuscular adipose tissue did not differ among the bird groups.

The gastrointestinal system diminishes its relative size with body growth, and contributes to production of a greater eviscerated yield (Hayse and Marion, 1973; Moran, 1977). The results of this study indicated that the percentage of visceral weight is affected by both nutritional levels of diet and body growth. The H80d birds fed on high nutritional food contained relatively

Table 4. The percentage weight of different muscles in the body parts

Experimental groups	H80d	L80d	L95d	L108d
<i>M. pectoralis</i>	12.92 ± 0.26a	10.79 ± 0.30b	11.15 ± 0.33b	13.08 ± 0.04a
<i>M. supracoracoideus</i>	4.01 ± 0.08a	3.53 ± 0.10b	3.76 ± 0.08ab	4.01 ± 0.12a
<i>M. triceps brachii</i>	0.94 ± 0.02a	0.94 ± 0.03a	0.93 ± 0.04a	0.99 ± 0.05a
<i>Mm. iliotrochanterici</i>	1.26 ± 0.02b	1.26 ± 0.03ab	1.13 ± 0.06c	1.36 ± 0.04a
<i>M. iliotibialis cranialis</i>	0.84 ± 0.04ab	0.76 ± 0.02b	0.82 ± 0.08ab	0.83 ± 0.02a
<i>M. iliotibialis lateralis</i>	2.27 ± 0.05b	2.13 ± 0.05c	2.03 ± 0.07c	2.55 ± 0.10a
<i>Mm. femorotibiales</i>	2.55 ± 0.05a	2.39 ± 0.04b	2.31 ± 0.08b	2.40 ± 0.05ab
<i>M. flexor cruris lateralis</i>	1.26 ± 0.04b	1.18 ± 0.04b	1.17 ± 0.03b	1.45 ± 0.05a
<i>Mm. puboischiofemorales</i>	1.00 ± 0.03a	0.93 ± 0.02b	0.96 ± 0.04ab	0.96 ± 0.04ab
<i>M. gastrocnemius</i>	3.27 ± 0.06b	3.06 ± 0.06c	3.15 ± 0.09c	3.82 ± 0.11a

Means ± standard errors

H80d; High nutritional chicken group at 80 days of age

L80d, L95d, L108d; Low nutritional chicken group at 80, 95 and L108 days of age, respectively

a, b, c The means with same letter do not differ significantly between chicken groups at 5% level

smaller visceral organs compared with L80d and L95d birds, fed on low nutritional food. The L108d birds which were oldest and had the biggest carcass weight, also showed a small visceral content. On the other hand, the percentage weight of whole bone gradually decreased with advancing of age, from H80d and L80d to L108d through L95d birds. The percentage of skin weight did not change during this broiler growth stage ranging between 11.4–11.6%, which is similar to the 11.1% reported by Moran *et al.* (1970).

Chickens with heavy body weight produce a greater percentage breast meat per carcass weight (Frichknecht and Jull, 1946; Marks, 1995; Moran, 1995; Goliomytis *et al.*, 2003). The percentage of breast meat increases rapidly in the early growth stage up to 47–49 d after hatching, and the maximum growth rate was evaluated at 24.4 g/d by Goliomytis *et al.* (2003). In the present study, H80d chickens arrived at the highest percentage of forelimbs muscle during this short growth period, and the L108d birds with slow growth elongated the rearing term more 28 d to attain the same percentage. Between H80d and L108d, the percentage of carcass weight did not differ in the shoulder and brachial subparts. Otherwise, the H80d birds attained the largest percentage in the antebrachial subpart and the L108d in the abdominal subpart. The biggest *pectoralis* and the second biggest *supracoracoideus* muscles in the shoulder subpart were larger in H80d and L108d than L80d and L95d, but the *triceps brachii* muscle in the brachial subpart did not differ among the groups. These muscles are primarily composed of fast-twitch glycolytic myofibres, which show extremely rapid growth for 1 week after hatching, especially in the former two muscles (Ono *et al.*, 1989, 1993).

Goliomytis *et al.* (2003) reported that the percentage of femoral (containing pelvic) and crural muscles increase from 10.6% to 14.9% and from 7.7% to 9.1% respectively in the meat-type cockerels during the growth period of 7 d to 154 d. In the present study, using 80 d to 108 d cockerels, the femoral + pelvic muscle increase was 10.3–12.0% and the crural muscle increase 7.7–8.0%. These data appear to be a little smaller compared with those reported by Goliomytis *et al.* (2003). The percentages could increase with increasing body mass, and change on a relative size of the forelimbs and hind limbs parts (Iwamoto *et al.*, 1992, 1993a, b; Fletcher and Carpenter, 1993; Goliomytis *et al.*, 2003). The L108d chicken, which attained to the largest body mass, showed the largest percentage of hind limbs muscle to carcass weight, and the largest percentage of the pelvic, femoral and crural subparts. The second largest percentage of hind limbs muscle was shown by H80d birds but smaller than the percentage in L108d, which differed from the results in the forelimbs. From these results it is suggested that the foods with high nutritional level promote more muscle development in the forelimbs than the hind limbs.

The hind limbs of L108d birds contained the largest muscles, such as the *gastrocnemius*, *iliotibialis lateralis*, *flexor cruris lateralis* and *iliotrochanterici*, of all

chicken groups. As the big postacetabular part of the *iliotibialis lateralis* muscle and the *flexor cruris* occupy the caudolateral region of the thigh, and the *gastrocnemius* is a strong extensor of the tarsal joint, these muscles play an important role in generating the propulsive power for locomotion. The *iliotrochanterici* muscles function as a protractor muscle of the femur and entire hind limbs. On the other hand, the H80d birds showed the same percentages as L108d in the *femorotibiales*, *puboischiofemorales* and *iliotibialis cranialis* muscles. These muscles occupy the cranio-medial side of the thigh and contain much slow-twitch myofibres for supporting gravity and maintaining posture, which are earlier-maturing than the fast-twitch muscles in the thigh (Suzuki *et al.*, 1985; Iwamoto *et al.*, 1993a, b; Ono *et al.*, 1993). From these results it is suggested that the high nutrition contents of H80d bird's foods could especially stimulate the development of the myofibres, showing a marked increase during the early growth stage regardless of the composition of myofibre types in the forelimbs' *pectoralis* and *supracoracoideus* muscles and the hind limbs' *femorotibiales*, *puboischiofemorales* and *iliotibialis cranialis* muscles (Ono *et al.*, 1989, 1993).

In conclusion, different nutritional levels of the food fed to chickens could change the anatomical composition of the carcass and the relative distribution of skeletal muscles in parts and subparts. Broiler foods with high nutritional level enhanced body growth of broilers, and especially stimulated the breast muscle development. On the other hand, diets with low nutritional levels appeared to enlarge the relative size of the hind limbs' muscles by retarding the development of the forelimbs'.

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