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The Relationship between Age and Genotype and the Growth of Commercial Meat Strain Chickens (42348)

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Abstract. Sex-linked dwarf male (*dw*/*dw*) and female (*dw*/−) chickens from a commercial meat strain, grew significantly slower than genetically normal broilers (*Dw*/*Dw*). The differences were evident at 2 weeks of age and they remained constant with age, at least through 8 weeks. The dwarfs in turn grew significantly faster than genetically normal (*Dw*/*Dw*) but slow-growing roaster strain chicks. Heterozygous (*Dw*/*dw*) normal, fast-growing male broilers grew significantly faster than the normal and roaster chicks but weighed 8% less than the normal broilers at 8 weeks. Abdominal fat accretion was greatest in the dwarf chicks and least in the slow-growing roaster strain when comparisons were made at the same age and the same body weight. Pectoralis muscle growth was greater in the broiler strain when equal age and weight comparisons were made. Gastrocnemius muscle growth, however, was greatest in the slow-growing roaster chicks.

The study of growth and development in poultry has become an area of active research interest. Much of this interest has been generated from studies of unique genetic stocks that have been selected for differences in weight gain (1), obesity (2, 3), feed efficiency (4, 5), and feed intake (4). Likewise, comparisons of commercial strains (i.e., broilers, leghorns) that have been developed for a different set of biologic and/or economic traits have also contributed to the literature in this area (6–8).

A recessive, sex-linked dwarfing gene (*dw*) in chickens was initially described by Hutt (9). The *dw* gene has been introduced into a number of closed genetic lines (10–12) and selected growth, metabolism, and endocrine characteristics of these dwarf lines have been reported (11–16). The dwarfing gene is recessive to the gene for normal growth such that when dwarf dams (*dw*/−) are mated to normal sires (*Dw*/*Dw*), all resulting female chicks are normal (*Dw*/−) and the heterozygous (*Dw*/*dw*) male chicks are phenotypically normal. For this reason, commercial poultry breeders have introduced the dwarf gene into fast-growing broiler strains to try and take economic advantage of a smaller broiler breeder hen without sacrificing progeny performance.

Reddy and Siegel (17) showed quite clearly that the expression of the *dw* gene can be modified quite dramatically by the background genotype into which it is introduced Furthermore, in commercial normal and dwarf meat lines the phenotypic expression o the *dw* gene may be further modified by continued selection pressure. The results from studies comparing commercial strains may be quite different therefore in contrast to studies where the *dw* gene was introduced into a closed, less selected genetic stock. Additionally, the *dw* gene also results in slower growth and the contribution of differences in growth to differences in carcass traits has not been addressed in other studies.

The *dw* gene is an example of a specific allele that may have economic importance, but conventional population genetics has also been used to develop other distinct lines that serve specific markets within the poultry meat industry. An example of this would be roaster strain chickens. Birds from this strain are reared to very heavy body weights and have been selected for improved carcass conformation and carcass yield but not rapid growth

An initial objective of these studies was to study and compare carcass traits in normal and dwarf broiler strain chickens. To better understand the relationship between slower growth and phenotypic expression of the *dw* gene, slow-growing genetically normal roaster

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strain chicks were also compared with dwarf and normal broilers in subsequent studies.

Materials and Methods. *Experiment 1.* Male and female chicks from commercial broiler and sex-linked dwarf meat strains were hatched, banded by sex and strain, and brooded together from 0 to 4 weeks. From 4 to 8 weeks of age, the dwarf male and female chicks were reared separately but adjacent to the pen with the broiler chicks. All chicks were fed a commercial broiler starter diet (Agway Inc., Syracuse, N.Y.) throughout the experiment.

At 2, 4, 6, and 8 weeks of age, 20 chicks from each sex and strain were weighed and killed by cervical dislocation. The shank was measured to the nearest 0.5 cm. At the last three ages, the right half of the pectoralis major muscle and the entire abdominal fat pad were excised and weighed.

Experiment 2. Male chicks from four commercial meat strains were studied. The strains were (1) homozygous normal (F-*Dw*/*Dw*) fast-growing broilers, (2) heterozygous normal (*Dw*/*dw*) broilers, (3) homozygous normal (S-*Dw*/*Dw*) slow-growing roasters, and (4) homozygous recessive (*dw*/*dw*) sex-linked dwarfs. All chicks were hatched and brooded together from 0 to 4 weeks. From 4 to 8 weeks, the homozygous and heterozygous broilers were reared together in a separate pen but adjacent to the dwarf and roaster chicks.

Body weight and shank length (0.5 cm) measurements were taken at 1 day of age and at 2, 4, 6, and 8 weeks of age. At the last four ages the gastrocnemius muscle, pectoralis major muscle (right half), and abdominal fat pad were excised and weighed.

Experiment 3. Male chicks from strains 1, 3, and 4 as described for Experiment 2 were again studied. The objective of this experiment was to characterize carcass and skeletal development in the three strains at similar body weights rather than at equal ages as in the first two experiments. Tibia length (0.5 cm) and pectoralis minor muscle weight (right half) were added to the measurements described for Experiment 2.

Statistical analysis. In Experiment 1, the data from each sex were analyzed separately. All the data from within each age group were analyzed by analysis of variance using the GLM procedure of the Statistical Analysis System (17). In Experiments 2 and 3, if there was a significant main effect due to strain for each variable, means were separated using Duncan's new multiple range comparisons.

Results. *Experiment 1.* The sex-linked dwarf males and females were significantly lighter at 2 weeks of age (Table I). Both sexes weighed only 66 and 68% as much as the normal male and female broilers respectively at this age. These differences remained relatively consistent at 4, 6, and 8 weeks. Shank length

TABLE I. THE EFFECT OF SEX AND AGE ON BODY WEIGHT AND SHANK LENGTH IN NORMAL AND DWARF STRAINS OF BROILER CHICKENS: EXPERIMENT 1

		Sex			
		Female		Male	
Age (weeks)	Strain	Body wt (g)	Shank length (cm)	Body wt (g)	Shank length (cm)
2	Normal	282 ± 5*	8.40 ± 0.05*	294 ± 8*	9.00 ± 0.05*
	Dwarf	192 ± 6	7.70 ± 0.05	195 ± 7	8.20 ± 0.05
4	Normal	838 ± 14*	12.70 ± 0.05*	941 ± 27*	12.60 ± 0.10*
	Dwarf	551 ± 9	11.20 ± 0.05	640 ± 16	11.70 ± 0.05
6	Normal	1450 ± 22*	14.90 ± 0.05	1691 ± 34*	15.90 ± 0.05*
	Dwarf	983 ± 15	12.60 ± 0.05	1125 ± 24	13.60 ± 0.05
8	Normal	2212 ± 36*	15.70 ± 0.10*	2766 ± 41*	17.70 ± 0.10*
	Dwarf	1503 ± 32	13.00 ± 0.10	1858 ± 32	14.30 ± 0.10

Note. Values are means ± SE.

* Significantly different from dwarf, $P < 0.05$.

was decreased by 10% at 2 weeks and this difference grew to 18–20% by 8 weeks of age.

The dwarf males and females had more abdominal fat at all ages (Table II). There was an increase in abdominal fat (g/100 g body wt) with age in the male and female dwarfs and female broilers but not in the male broilers. The weight of the pectoralis major muscle followed the same trend seen for body weight gain. The pectoralis in the dwarf chicks was only 56–58% as large as in the normal broilers at 4 weeks and these same approximate differences were evident at 8 weeks.

Experiment 2. The dwarf (*dw*/*dw*) and slow-growing roaster males (S-*Dw*/*Dw*) weighed significantly less than the homozygous (F-*Dw*/*Dw*) and heterozygous (*Dw*/*dw*) normal broilers at 1 day of age (Table III). There were no differences in shank length, however. The significant differences in body weight between the fast-growing and slower growing strains remained through 8 weeks of age.

At 2 weeks, the (*dw*/*dw*) and (S-*Dw*/*Dw*) chicks had similar body weights and shank lengths. The dwarfs weighed 12–15% more than the (S-*Dw*/*Dw*) chicks at 4, 6, and 8 weeks of age and the homozygous (*Dw*/*Dw*) broilers weighed 8–12% more than the heterozygous (*Dw*/*dw*) broilers at the same ages. Shank length in the S-*Dw*/*Dw* males was less than in the dwarfs until 8 weeks of age. There were no differences in shank length between the commercial broiler crosses.

The growth of the pectoralis major muscle (g/100 g body wt) followed the same trends observed for body weight (Table IV). The muscle in the dwarf males was the smallest at 2 weeks but at the latter three ages, the only strain differences in pectoralis muscle weight were between the two fast- and two slow-growing lines. The S-*Dw*/*Dw* males had a larger gastrocnemius muscle (g/100 g body wt) at 6 and 8 weeks of age and significantly less abdominal fat at all ages.

Experiment 3. The dwarf males had significantly smaller pectoralis muscles (major and minor) at 200, 400, and 800 g body wt (Table V). The dwarf and S-*Dw*/*Dw* roaster males had similar pectoralis major weights at 1600 g body wt but the pectoralis minor continued to be smaller in the dwarfs up to 2400 g. The homozygous commercial broilers (F-*Dw*/*Dw*)

TABLE II. THE EFFECT OF SEX AND AGE ON PECTORALIS MAJOR MUSCLE WEIGHT AND ABDOMINAL FAT IN NORMAL AND DWARF STRAINS OF BROILER CHICKENS: EXPERIMENT 1

Age (weeks)	Strain	Sex							
		Female				Male			
		Abdominal fat		Pectoralis major		Abdominal fat		Pectoralis major	
		g	g/100 g body wt	g	g/100 g body wt	g	g/100 g body wt	g	g/100 g body wt
4	Normal	17.7 ± 0.9*	2.11 ± 0.09*	37.5 ± 0.9*	4.47 ± 0.08*	18.6 ± 1.0*	1.97 ± 0.09	42.3 ± 1.2*	4.54 ± 0.18*
	Dwarf	14.0 ± 1.1	2.50 ± 0.17	21.2 ± 0.6	3.85 ± 0.05	13.4 ± 1.0	2.06 ± 0.12	24.7 ± 0.7	3.86 ± 0.07
6	Normal	28.4 ± 1.8*	1.96 ± 0.12	66.5 ± 1.4*	4.58 ± 0.06*	29.4 ± 1.7*	1.73 ± 0.08*	74.6 ± 2.3*	4.39 ± 0.08*
	Dwarf	22.6 ± 1.2	2.29 ± 0.12	42.7 ± 1.0	4.34 ± 0.06	22.6 ± 1.2	2.01 ± 0.10	45.8 ± 1.1	4.08 ± 0.06
8	Normal	52.5 ± 3.9	2.36 ± 0.17*	117.6 ± 2.9*	5.29 ± 0.09*	54.4 ± 2.6*	1.97 ± 0.08	139.0 ± 2.9	5.00 ± 0.08*
	Dwarf	43.4 ± 2.8	2.89 ± 0.18	67.6 ± 2.1	4.49 ± 0.07	40.3 ± 3.3	2.15 ± 0.15	81.8 ± 1.8	4.41 ± 0.07

Note. Values are means ± SE.
* Significantly different from dwarf, $P < 0.05$.

TABLE III. EFFECTS OF GENOTYPE AND AGE ON BODY WEIGHT AND SHANK LENGTH IN FOUR GENOTYPES OF COMMERCIAL MEAT CHICKENS: EXPERIMENT 2

Age (weeks)	Strain	Body wt (g)	Shank length (cm)
0	*dw/dw*	37.0 ± 0.5 A	4.80 ± 0.05
	S-*Dw/Dw*	40.0 ± 0.5 B	4.80 ± 0.05
	F-*Dw/Dw*	44.0 ± 0.8 C	4.80 ± 0.10
	Dw/dw	42.0 ± 0.4 C	4.80 ± 0.05
2	*dw/dw*	192 ± 9 A	7.60 ± 0.10 A
	S-*Dw/Dw*	175 ± 4 A	7.30 ± 0.05 A
	F-*Dw/Dw*	299 ± 8 B	8.50 ± 0.10 B
	Dw/dw	301 ± 18 B	8.50 ± 0.10 B
4	*dw/dw*	531 ± 15 B	11.70 ± 0.10 A
	S-*Dw/Dw*	461 ± 13 A	11.10 ± 0.10 B
	F-*Dw/Dw*	904 ± 14 D	13.30 ± 0.10 C
	Dw/dw	804 ± 15 C	13.10 ± 0.10 C
6	*dw/dw*	1076 ± 29 B	14.10 ± 0.10 A
	S-*Dw/Dw*	961 ± 19 A	14.10 ± 0.10 A
	F-*Dw/Dw*	1699 ± 37 D	16.50 ± 0.10 B
	Dw/dw	1588 ± 27 C	16.30 ± 0.10 B
8	*dw/dw*	1693 ± 73 B	14.90 ± 0.10 A
	S-*Dw/Dw*	1511 ± 31 A	15.60 ± 0.10 B
	F-*Dw/Dw*	2610 ± 38 D	18.60 ± 0.10 C
	Dw/dw	2415 ± 63 C	18.20 ± 0.10 C

Note. Values are means ± SE. Values followed by different letters are significantly different, $P < 0.05$.

had the largest pectoralis major at the three heaviest weights but there were no strain differences in the size of the pectoralis minor up to 2400 g body wt. There were no strain differences in gastrocnemius weight at 200 g but the S-*Dw/Dw* roaster males had a significantly larger gastrocnemius at all subsequent weights. Broiler and dwarf gastrocnemius weights were not significantly different at the heavier body weights. The dwarfs had the greatest quantity of abdominal fat at all body weights and the S-*Dw/Dw* males had the least.

Tibia length was actually longer in the dwarf males at 200 g but there were no strain differences at 400 g (Table VI). The S-*Dw/Dw* males had the longest tibia at all subsequent body weights. Shank lengths were variable at 200 and 400 g but the effect of the dwarfing gene became more apparent at the heavier body weights. There were no differences between the two genetically normal strains (S-*Dw/Dw*, F-*Dw/Dw*) at the heavier weights.

Discussion. The sex-linked dwarf meat strain chickens studied in the first two experiments weighed significantly less than the commercial broilers at a very young age. The differences at 1 day of age in Experiment 2 are most likely a function of egg size (age of dam) rather than strain characteristics. The differences in body weight at 2 weeks were close to the 33% reduction reported by Merat (18) and appear to be unique to the normal and dwarf broiler lines studied in these experiments. In experiments with dwarf leghorns (11) and other slow-growing meat-type dwarfs (13), the body weight differentiation did not become evident until at least 4 weeks of age. Our data are important because they demonstrate for the first time that certain phenotypic expressions resulting from the *dw* gene (i.e., reduced body weight) may be maximally expressed at a young age, depending again upon *dw* × genotype interactions.

The genetically normal but slow-growing roasters (S-*Dw/Dw*) weighed 10–12% less than the dwarfs at all ages in Experiment 2. Shank length, however, was similar in both strains until the effect of the *dw* gene became evident at 8 weeks. This shows that while the *dw* gene may significantly influence skeletal development, there can still be considerable progress made in selection for commercially important traits such as body weight gain.

The presence of the dwarfing gene in the heterozygous normal (*Dw/dw*) broiler did slow down growth slightly in these birds (7–8%) compared with the homozygous (*Dw/Dw*) broilers. There were no differences in shank length, however. The fact that body weight was depressed in the *Dw/dw* broilers is commonly seen in the commercial broiler industry and has been reported previously (10, 19–21). Our results are different, however, from those of Stewart and Washburn (15). The contradictions between the two sets of data are probably a reflection of the background genotype into which the *dw* gene was originally introduced and the selection pressures exerted on these lines. The growth rate data from these experiments provide important insight into the expression of the *dw* gene when introduced into commercial broiler stock. The time course of expression and the effect on growth in heterozygous normal chicks accentuate the importance of the genetic base in conducting any studies with normal and sex-linked dwarf chicks.

TABLE IV. Effect of Genotype and Age on the Growth of Selected Muscles and Abdominal Fat Deposition: Experiment 2

Age (weeks)	Strain	Pectoralis major Weight (g)	Pectoralis major Relative weight (g/100 g body wt)	Abdominal fat (g)	Abdominal fat (g/100 body g wt)	Gastrocnemius Weight (g)	Gastrocnemius Relative weight (g/100 g body wt)
2	*dw/dw*	4.7 ± 0.4 C	2.42 ± 0.83 A	—	—	0.66 ± 0.04 A	0.35 ± 0.02 A
	S-*Dw/Dw*	5.1 ± 0.4 C	2.88 ± 0.07 B	—	—	0.59 ± 0.02 A	0.34 ± 0.20 A
	F-*Dw/Dw*	10.7 ± 0.4 A	3.55 ± 0.07 C	—	—	1.05 ± 0.04 B	0.35 ± 0.01 A
	Dw/dw	9.6 ± 0.3 B	3.28 ± 0.10 C	—	—	0.97 ± 0.03 B	0.33 ± 0.01 A
4	*dw/dw*	17.9 ± 0.8 C	3.33 ± 0.07 C	6.4 ± 0.4 A	1.22 ± 0.07 AB	2.03 ± 0.07 A	0.38 ± 0.01 A
	S-*Dw/Dw*	15.3 ± 0.5 D	3.33 ± 0.40 C	4.9 ± 0.5 A	1.05 ± 0.08 A	1.86 ± 0.09 A	0.41 ± 0.02 A
	F-*Dw/Dw*	36.6 ± 0.7 A	4.05 ± 0.06 A	12.4 ± 0.7 B	1.36 ± 0.06 BC	3.41 ± 0.06 C	0.38 ± 0.01 A
	Dw/dw	30.8 ± 0.7 B	3.83 ± 0.05 B	12.6 ± 0.8 B	1.55 ± 0.07 C	2.96 ± 0.09 B	0.37 ± 0.01 A
6	*dw/dw*	40.0 ± 1.9 C	3.68 ± 0.15 A	18.2 ± 1.3 B	1.65 ± 0.11 A	4.8 ± 0.2 A	0.45 ± 0.02 A
	S-*Dw/Dw*	35.7 ± 1.1 C	3.71 ± 0.09 A	10.5 ± 0.8 A	1.08 ± 0.08 B	5.2 ± 0.2 A	0.55 ± 0.02 B
	F-*Dw/Dw*	72.8 ± 2.4 A	4.27 ± 0.08 B	24.9 ± 1.7 C	1.45 ± 0.08 A	7.6 ± 0.3 B	0.45 ± 0.01 A
	Dw/dw	66.4 ± 1.5 B	4.18 ± 0.07 B	26.2 ± 1.9 C	1.63 ± 0.10 A	7.5 ± 0.3 B	0.47 ± 0.02 A
8	*dw/dw*	63.4 ± 3.2 B	3.75 ± 0.11 A	26.2 ± 1.7 B	1.54 ± 0.08 A	7.4 ± 0.4 A	0.45 ± 0.03 AB
	S-*Dw/Dw*	53.3 ± 1.4 A	3.53 ± 0.06 A	15.1 ± 2.1 C	0.97 ± 0.12 B	7.4 ± 0.4 A	0.49 ± 0.02 A
	F-*Dw/Dw*	112.3 ± 2.6 D	4.29 ± 0.07 B	44.3 ± 4.5 A	1.69 ± 0.16 A	10.7 ± 0.3 B	0.41 ± 0.01 B
	Dw/dw	101.9 ± 2.9 C	4.24 ± 0.01 B	38.9 ± 3.5 A	1.61 ± 0.13 A	10.2 ± 0.3 B	0.42 ± 0.09 B

Note. Values are means ± SE. Values followed by different letters are significantly different, $P < 0.05$.

TABLE V. EFFECT OF GENOTYPE ON THE WEIGHT OF SELECTED MUSCLES AT A CONSTANT BODY WEIGHT: EXPERIMENT 3

Strain	Body wt (g)	Pectoralis major (g)	Pectoralis minor (g)	Gastrocnemius (g)
dw/dw	183 ± 5 B	3.0 ± 0.2 B	0.67 ± 0.03 C	0.69 ± 0.04 A
S-*Dw/Dw*	190 ± 3 AB	4.7 ± 0.1 A	1.06 ± 0.06 A	0.74 ± 0.03 A
F-*Dw/Dw*	194 ± 2 A	4.4 ± 0.2 A	0.89 ± 0.04 B	0.64 ± 0.02 A
dw/dw	379 ± 4 A	10.2 ± 0.2 C	2.1 ± 0.1 C	1.40 ± 0.04 B
S-*Dw/Dw*	386 ± 4 A	12.3 ± 0.2 A	3.1 ± 0.1 A	1.53 ± 0.04 A
F-*Dw/Dw*	381 ± 4 A	11.3 ± 0.2 B	2.6 ± 0.1 B	1.28 ± 0.03 C
dw/dw	788 ± 4 A	23.9 ± 0.4 C	5.6 ± 0.2 C	2.65 ± 0.08 C
S-*Dw/Dw*	795 ± 4 A	25.8 ± 0.5 B	6.7 ± 0.2 B	3.30 ± 0.06 A
F-*Dw/Dw*	795 ± 4 A	29.6 ± 0.5 A	7.6 ± 0.2 A	3.05 ± 0.07 B
dw/dw	1552 ± 22 A	45.2 ± 1.9 B	11.5 ± 0.9 C	5.6 ± 0.2 B
S-*Dw/Dw*	1526 ± 9 A	46.6 ± 0.8 B	14.0 ± 0.4 B	7.0 ± 0.2 A
F-*Dw/Dw*	1545 ± 11 A	64.0 ± 1.5 A	17.5 ± 0.5 A	6.0 ± 0.2 B
dw/dw	2352 ± 36 AB	84.8 ± 2.0 AB	24.1 ± 1.1 A	10.3 ± 0.4 B
S-*Dw/Dw*	2324 ± 32 B	82.6 ± 1.8 B	25.1 ± 0.9 A	11.3 ± 0.3 A
F-*Dw/Dw*	2425 ± 30 A	90.2 ± 2.2 A	26.1 ± 0.6 A	9.4 ± 0.3 B

Note. Values are means ± SE. Values followed by different letters are signifcantly different, $P < 0.05$.

The increased deposition of abdominal and carcass fat associated with the *dw* gene has been previously reported, and the data from the first experiment confirm these findings. In Experiment 2, however, the data are somewhat equivocal. The (*dw/dw*) males have a lesser amount of abdominal fat at 4 and 8 weeks compared with that of the homozygous broilers but a greater amount at 6 weeks of age. The dwarf males weighed approximately the same at 6 weeks of age in Experiments 1 and 2 and the same was true of the homozygous

TABLE VI. EFFECT OF GENOTYPE ON SKELETAL GROWTH AND ABDOMINAL FAT DEPOSITION AT A CONSTANT BODY WEIGHT: EXPERIMENT 3

Strain	Body wt (g)	Abdominal fat (g)	Tibia (cm)	Shank (cm)
dw/dw	183 ± 5 B	—	5.70 ± 0.10 A	7.50 ± 0.10 AB
S-*Dw/Dw*	190 ± 3 AB	—	5.50 ± 0.05 B	7.40 ± 0.10 B
F-*Dw/Dw*	194 ± 2 A	—	5.50 ± 0.10 B	7.60 ± 0.10 A
dw/dw	379 ± 4 A	3.7 ± 0.2 A	7.10 ± 0.05 A	9.40 ± 0.10 A
S-*Dw/Dw*	386 ± 4 A	2.0 ± 0.2 C	7.20 ± 0.10 A	9.60 ± 0.10 A
F-*Dw/Dw*	381 ± 4 A	2.9 ± 0.2 B	7.20 ± 0.10 A	9.50 ± 0.10 A
dw/dw	788 ± 4 A	12.9 ± 0.8 A	9.20 ± 0.10 B	11.90 ± 0.10 B
S-*Dw/Dw*	795 ± 4 A	5.5 ± 0.4 C	9.40 ± 0.05 A	12.30 ± 0.10 A
F-*Dw/Dw*	795 ± 4 A	9.2 ± 0.5 B	9.00 ± 0.10 C	12.10 ± 0.10 AB
dw/dw	1552 ± 22 A	34.2 ± 4.9 A	11.90 ± 0.10 B	14.50 ± 1.67 B
S-*Dw/Dw*	1526 ± 9 A	16.2 ± 1.6 B	12.70 ± 0.10 A	15.50 ± 1.62 A
F-*Dw/Dw*	1545 ± 11 A	19.4 ± 1.3 B	11.70 ± 0.10 B	15.30 ± 0.10 A
dw/dw	2352 ± 36 AB	70.6 ± 4.3 A	13.20 ± 0.10 C	16.50 ± 0.10 B
S-*Dw/Dw*	2324 ± 32 B	42.0 ± 2.1 C	14.60 ± 0.10 A	18.10 ± 0.10 A
F-*Dw/Dw*	2425 ± 30 A	51.3 ± 2.7 B	13.90 ± 0.10 B	18.00 ± 0.10 A

Note. Values are means ± SE. Values followed by different letters are significantly different, $P < 0.05$.

normal broilers. In Experiment 2, however, body weight gain from 6 to 8 weeks was not so great, and perhaps this had a greater effect on abdominal fat accretion in the dwarf line. The heterozygous (*Dw*/*dw*) normal chicks have more abdominal fat than the homozygous (*Dw*/*Dw*) normal broilers, and this supports the observations of Stewart and Washburn (15). In Experiment 2, the slow-growing roaster chicks had the least quantity of abdominal fat, and this is not surprising because of the relationship between growth rate and fat accretion in genetically normal meat-type chickens (22, 23).

Muscle development within each strain may be the result of several factors. The pectoralis major is a muscle of considerable economic importance to the poultry industry, and selection for improved breast conformation has been a major goal of commercial breeders. Development of the pectoralis major is correlated with growth rate in chickens (24) and other avian species as well (25). The intense selection for growth rate and breast yield in commercial broilers probably accounts for the differences in pectoralis major size even when the strains were sampled at the same body weight. All muscles do not respond in a similar manner to differences in growth rate, however, and the gastrocnemius is an example of this. The differential responses of the pectoralis and gastrocnemius muscles raise the question as to what effect manipulations of total carcass protein might have on constituent muscle groups of economic importance.

Growth and development characteristics that were independent of body weight gain were studied in the final experiment. In terms of physiologic age (body weight), tibia length in the dwarf males was not affected as early nor to the same extent as shank length. Tibia length in the slow-growing (S-*Dw*/*Dw*) chicks was significantly greater than in the other strains at the heavier weights and perhaps this contributes to the lower incidence of leg abnormalities observed in these birds under commercial growing conditions.

The carcass component data shows that each strain has developmental traits which are independent of rate of growth. The dwarfs have significantly more abdominal fat at all weights and this supports the earlier experiments. The S-*Dw*/*Dw* males have less abdominal fat than the broilers at similar ages and body weights and therefore growth rate differences alone are not accounting for strain differences in fat accretion. Appetite has been implicated as a major contributor to improved rates of gain and excess body fat accumulation (26). If this is true, then even at the same body weight the commercial broilers have probably consumed excess energy beyond the needs for maintenance and protein deposition and therefore are still fatter.

Selection for growth rate (body weight gain/time) in commercial broiler strains appears to be somewhat independent of pectoralis muscle development, at least when comparisons are made at similar weights. The S-*Dw*/*Dw* roaster chicks had larger pectoralis muscles at lighter body weights but the broiler chicks (F-*Dw*/*Dw*) had the largest breast muscles at the heavier weights. Fowler *et al.* (25) reported that quail selected for increased weight gain had larger pectoralis muscles and a concomitant increase in total muscle protein, DNA, and RNA when compared with those of a control population. If this could be extrapolated to slow- and fast-growing, genetically normal (*Dw*/*Dw*) meat strains of chickens, perhaps at the physiologically older (heavier) body weights, the broilers have increased muscle protein synthesis resulting from a combination of faster growth and selection for improved conformation.

The gastrocnemius muscle is significantly heavier in the S-*Dw*/*Dw* chicks. In a developing animal, bone growth and muscle growth are synergistic events and the fractionally longer bones in the S-*Dw*/*Dw* line may be contributing to the larger gastrocnemius muscle.

In summary, sex-linked dwarf, slow-growing and fast-growing meat strains of chickens have distinct developmental traits which can only be partially accounted for by differences in growth rate. The phenotypic expression of *dw*-associated traits is quite different in commercial meat strain dwarfs compared with other dwarf stocks. This should be taken into consideration when interpreting any results that may be influenced by the sex-linked dwarfing gene, *dw*.

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