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Organ growth of selected lines of chickens and their F_1 crosses to a common body weight or age

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Summary. Organ growth of male chickens selected for high and low 56-day body weight and their reciprocal F_1 crosses was compared at a common age (56 days) or at a common body weight (180 g). Organs that differed at a common body weight included weights of proventriculus, small intestine, lungs, feathers and abdominal fat and length of esophagus. Organ weights that differed at a common age included esophagus, gizzard, heart, liver, lungs, breast, legs, feathers and abdominal fat, and lengths of shank, esophagus and small intestine. Heterosis for most organs was less than 15%. Those exhibiting heterosis greater than 30% included weights of fat depots and feathers, plus lengths of the esophagus, small intestine and shank. Heterosis for these traits, however, varied depending on whether comparisons were made at common body weight or age. These results imply that biological functions of organs at specific ages may not reflect the situations at common body weights and suggest differences in resource allocations among populations.

Key words: Selection – Organ weight – Organ length – Common weight and age – Heterosis

Introduction

Body weight of an individual is a function of cumulative growth of organs (e.g., Latimer 1924; Butterfield et al. 1983; Lilja 1983). Variability among organs exists at various points in life. In chickens, some anatomical parts, such as the digestive organs, mature rapidly, establishing a "supplying" foundation for future growth of the whole body. In contrast, muscles and feathers mature slowly because they are dependent on the "supply" organs for development. Other organs maintain a constant proportion to total body weight (e.g., heart) or show growth early in life and then regress (e.g., bursa of Fabricius). Accordingly, partitioning of resources for growth and development of various organs occurs as an orderly progression depending on physiological needs established during the history of the species, the population and the individual.

Differences in growth patterns among populations of chickens are well documented (see review by Siegel and Dunnington 1987). Selection for high and low 56-day body weight modified growth curves (Zelenka et al. 1986) and delayed onset of sexual maturity (Dunnington et al. 1983; Zelenka et al. 1986). Due to dissimilarities of growth patterns for these lines, comparisons of organ size at the same chronological age may not correct for differences in organ size due to unequal body weights and vice versa. The objective of this study was to compare anatomical relationships among chickens bidirectionally selected for juvenile body weight and their reciprocal crosses at a common body weight and age.

Materials and methods

Chickens used in this study were males from lines selected for 27 generations for high (HH) and low (LL) body weight at 56 days of age (Siegel 1978; Dunnington and Siegel 1985) and their reciprocal (HL and LH) crosses (line of the sire is given first and the dam second). Chicks from age-contemporary parents were hatched on the same day, wingbanded, vaccinated for Marek's disease, vent-sexed and floor-reared under continuous lighting with feed and water provided ad libitum. The diet fed was that under which selection had been practiced and con-

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tained 20% crude protein and 2,685 kcal/kg of metabolizable energy (Siegel 1962). Four cockerels from each population were randomly selected and examined when the mean live weight for the population was approximately 180 g. Also, four cockerels from each population were randomly selected and examined at 56 days of age. Previous data (Katanbaf et al. 1988) indicated that sample sizes for this study were sufficient based on variability of traits measured. The same LL males were used in the common age and common weight comparisons. Fifty-six days was chosen as the common age because this was the age when selection was made for body weight in the selected lines. The common weight of 180 g was used because it was the weight of LL males at selection age. Results may have differed for other weights and/or ages.

Each individual was weighed to the nearest gram, killed by sodium penobarbital injection and the following organs were dissected immediately: esophagus, proventriculus, gizzard, small intestine, caecum-colon, heart, liver, lungs, left shank, wings, legs, breast, feathers, gizzard fat and abdominal fat. Weights of these organs were obtained to the nearest 0.01 gram. Weights of digestive organs were obtained after contents were removed. Also, lengths to the nearest millimeter were obtained for shank, esophagus and small intestine. To minimize diurnal effects, data were obtained between 08.00 and 12.00 h.

Analyses

Weights and lengths were expressed as a proportion of total empty body weight (g or mm of organ/100 g body weight). Organ weight to body weight ratios were transformed to arc sine square roots prior to analysis (Snedecor and Cochran 1967). Data for a common age or a common body weight were analyzed by one-way analysis of variance with populations as the main effect. When significant ($p < 0.05$) differences were found, comparisons among means were assessed by Duncan's multiple range test. Percentage of heterosis was calculated for each organ measurement at a common age or weights as

$$\% \text{ Heterosis} = \frac{(HL + LH) - (HH + LL)}{(HH + LL)} \cdot 100$$

and tested for significance by nonorthogonal linear contrasts (Scheffe 1970).

Results and discussion

Comparisons at 180 g body weight

At the projected common body weight, actual means were 175, 176, 184 and 182 g for populations HH, HL, LH and LL, respectively. These weights were attained on days 15, 24, 20 and 56, respectively. Percentages of organ to live weight were similar for all populations for: weight of shank (1.40), esophagus (0.91), gizzard (4.38), caecum-colon (1.06), heart (0.61), liver (4.17), breast (10.91), wings (6.13), legs (14.85), gizzard fat (0.48) and length (mm per 100 g body weight) of shank (23.80) and small intestine (52.17). Although selection for high and low body weight resulted in differences in growth, these organs remained a constant portion of body weight at 180 g body weight regardless of differences in posthatch age.

Weights and lengths of organs (as a percentage of body weight) that differed among populations are presented in Table 1. Proventriculus and small intestine weights were lower for population LL than for the others, which were similar. Birds and mammals with higher rates of gain usually develop relatively heavier small intestines (Lilja et al. 1985; Ricklefs and Marks 1985; Eisen 1986). Our data strongly support this conclusion, because it was observed in spite of a fourfold age difference between populations HH and LL. Small intestine for HH, HL and LH cockerels were heavier but similar in length to those of LL cockerels, suggesting larger diameters and perhaps an increased number of villi per unit length in small intestines of HH, HL and LH chickens. The pattern was reversed for lung weight and esophagus length where values were greater for population LL than the other populations, which were similar. Perhaps these organs followed growth patterns influenced more by chronological age than body weight. The small abdominal fat pad for population HH relative to the other populations was expected because HH chicks were only 15 days of age at this body weight and deposition of abdominal fat had just started (March and Hansen 1977; Burgener et al. 1981). Although all chicks were early feathering, relative feather weights were lowest for population HH, highest for LL and intermediate for both crosses. Differences in feather cover were influenced by age (Mueller et al. 1952) and quantitative genetic variation (Siegel et al. 1957). Replacement of feathers follows a specific chronology (Mueller et al. 1952) and comparisons at equal body weights were at ages where post juvenile feathers were more developed for LL chicks than for those in the other populations. Reciprocal effects (HL vs LH) for proventriculus, small intestine, lungs, feathers, abdominal fat depot and esophagus length were absent.

Comparisons at 56 days of age

Mean body weights for HH, HL, LH and LL populations at 56 days of age (selection age) were 1,378 g, 765 g, 781 g and 182 g, respectively. Mean relative weights of shank (1.58), proventriculus (0.54), small intestine (3.08), caecum-colon (0.86), wings (6.65) and gizzard fat (0.62) were similar for all populations. In contrast, relative weights of esophagus, gizzard, heart, liver, lungs and feathers were generally greater for population LL than

Table 1. Mean ±SE for organs (relative weights and length) significantly different among populations (HH, HL, LH, LL) when all populations were at 180±5 g live body weight. Means in a row with no letters (a, b, c) in common are significantly different ($P<0.05$)

Organ	HH	HL	LH	LL
Weight[a]				
Proventriculus	0.96±0.03a	0.90±0.10a	0.83±0.06a	0.65±0.02b
Small intestine	5.84±0.33a	4.78±0.20a	5.69±0.69a	3.51±0.50b
Lungs	0.85±0.03b	0.87±0.02b	0.75±0.04b	1.10±0.05a
Feathers	2.61±0.20c	4.60±0.32b	3.82±0.10b	11.54±0.66a
Abdominal fat	0.24±0.07b	0.54±0.08a	0.44±0.09ab	0.50±0.04a
Length[b]				
Esophagus	44.28±3.53b	46.50±3.10b	35.76±5.28b	59.57±8.68a

[a] (g organ/100 g body weight)
[b] (mm organ/100 g body weight)

Table 2. Means ±SE for organs (relative weights and lengths) significantly different among populations (HH, HL, LH, LL) when compared at selection age (56 days). Means in a row with no letters (a, b, c) in common are significantly different ($P<0.05$)

Organ	HH	HL	LH	LL
Weight[a]				
Esophagus	0.53±0.04b	0.72±0.12ab	0.63±0.05b	0.94±0.10a
Gizzard	2.22±0.05c	2.94±0.34b	2.52±0.09bc	4.16±0.40a
Heart	0.44±0.01b	0.47±0.04b	0.46±0.02b	0.61±0.03a
Liver	3.53±0.21ab	3.04±0.22b	3.23±0.14b	4.43±0.53a
Lungs	0.81±0.02c	0.76±0.03c	0.88±0.03b	1.10±0.05a
Breast	14.34±0.52a	13.88±0.26a	13.44±0.38a	10.12±0.69b
Legs	19.08±0.49a	19.09±0.80a	18.75±0.18a	15.40±0.64b
Feathers	6.79±0.10c	8.80±0.34b	8.35±0.19b	11.54±0.66a
Abdominal fat	1.40±0.11a	0.74±0.17b	0.76±0.11b	0.50±0.04b
Length[b]				
Shank	6.26±0.56b	9.76±0.83b	9.63±0.43b	27.58±3.27a
Esophagus	13.24±1.09b	18.88±1.04b	17.47±0.69b	59.57±8.68a
Small intestine	122.80±14.52b	176.02±20.93b	166.60±8.78b	463.68±85.13a

[a] (g organ/100 g body weight)
[b] (mm organ/100 g body weight)

the other populations (Table 2). This pattern was also evident for shank, esophagus and small intestine lengths. These observations may reflect a lower body weight for LL chicks and/or a higher degree of maturity for these organs in relation to the rest of the body for this population. Relative breast, legs and abdominal fat depot weights were greater for HH then LL chicks, demonstrating a trade-off in investment of resources in development of anatomical parts resulting from divergent selection. Tinch and McKay (1987) compared weight, fiber diameter and nuclei number of pectoralis muscle at a common age and weight for broiler and layer strains of chickens. On a chronological age basis, the heavier strains had a larger pectoralis, with greater fiber diameter and increased number of nuclei. On an equal muscle weight basis, however, differences were not significant, suggesting that selection for increased body weight had increased rate of muscle growth but had not altered development of muscle components.

Reciprocal effects (HL vs LH) were not evident, except for lung weight where the crosses were similar to the sire parental population. For other organs, crosses resembled parental populations HH, with the exception of feathers that were intermediate to the parental populations and abdominal fat similar to LL.

Gene action

Type of gene action differed among traits, and for some traits varied if calculated on a common weight or common age basis. There was significant heterosis for proportional weights of liver and abdominal fat, and proportional lengths of shank, esophagus and small intestine at a common age and for weight of proventriculus at a common body weight. Percentages of heterosis at common body weights were plotted against those at common ages for each organ (Fig. 1) with circles marking radii of

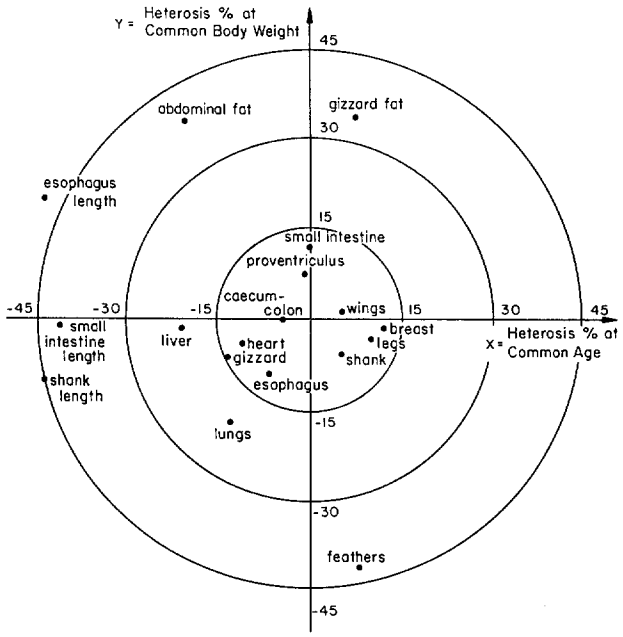

Fig. 1. Percentages of heterosis for various organs at a common age (*X axis*) and a common body weight (*Y axis*)

15%, 30% and 45%. Most organs, including those for muscles, were in the inner circle, suggesting additivity as the major type of gene action regardless of weight or age comparison. Heterosis for weight of liver and lungs was between 15% and 30% and was located in quadrant 3, i.e., negative for common weight and age. Weights of fat depots and feathers, and lengths of esophagus, small intestine and shank exceeded 30% heterosis under at least one criterion (i.e., common age or weight). Gizzard fat and abdominal fat had high positive heterosis at a common weight. Heterosis at a common age, however, was low and positive for gizzard fat and high but negative for abdominal fat. These observations were consistent with the view expressed earlier that development of fat depots follows a specific chronology. At a similar body weight, population HH was at an age when deposition of these fat depots had just begun, while the other populations were well beyond that age (March and Hansen 1977; Burgener et al. 1981).

Feather weights had low positive heterosis at common age and high negative heterosis at common weight. Crosses resembled parental population HH for feather weight at common body weight but not common age. Thus, at common body weight, ages of chicks were such that those from population LL had obtained post juvenile feathers while those in the other populations lacked a full set of such plumage. Small intestine, esophagus and shank lengths exhibited high negative heterosis at the common age. At the common weight, however, heterosis was moderate for esophagus length and low for small intestine and shank length. It appears that lengths were influenced more by chronological age than body weight. Resemblance of both crosses to parental population HH suggests that genes with dominant/recessive mode of action were influencing these traits.

General

Gene action influencing a trait at a common age may be different than that at a common weight. For example, heterosis for age at sexual maturity is considerably greater than heterosis for weight at sexual maturity (Zelenka and Siegel 1987; Zelenka et al. 1987). In the experiment reported here, heterosis for age at 180 g body weight was −38% while that for body weight at 56 days of age was −1%, demonstrating again that heterosis, an expression of nonadditive genetic variation, differs depending on the type of comparison. Our results are consistent with several theories on mechanisms regulating growth of different organs. These include the "target-seeking mechanism", where the organ stabilizes as it reaches its final target size (Tanner 1963) and the "feed back mechanism", where growth of the organ is regulated in response to physiological cues (Bullough 1975). Both theories agree that these mechanisms have a genetic basis. For the chicks used in our experiment, genetic selection was applied on total body weight, which may be viewed as a reflection of cumulative growth of various organs. Although it is well documented that feed intake has been changed due to selection (Siegel et al. 1984; Dunnington et al. 1987), differences in timing and patterns of growth for various organs among these populatins have also occurred (Cherry and Siegel 1978; Cherry et al. 1987). For detecting changes in organ size and gene action, equal age comparisons presented one picture and equal body weight comparisons provided another view. Because resource allocations vary according to stage of life cycle (Siegel and Dunnington 1987), when populations of different size and growth patterns are being compared, biological functions for each organ at a specific chronological age may not reflect the situation at a common body weight.

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