

Original article

Sources of shared variability in muscle and bone weight distribution and estimation of carcass meatiness and bone utilizing orthogonal carcass traits derived from factor analysis in Japanese quail

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Summary — A factor analysis with a varimax rotation was applied to 10 highly intercorrelated meatiness and bone traits in 110 Japanese quail to disclose the main sources of shared variability, to deduce the factors that control muscle and bone distribution and to predict total carcass muscle and bone content from orthogonal carcass traits. Most of the common variability (88.2%) in muscle and bone weight distribution could be accounted for by factors representing, in a decreasing order of contribution in total variance: meatiness; limb bones (skeletal support system); neck; and breast bone. The correlation coefficient between the meatiness rotated factor and carcass muscle was 0.91 and that between the skeletal support factor and total carcass bone was 0.75. The rotated factors derived from quail in the present study and from Pekin duckling in a previous study (Shahin, 1996a, *Ann Zootech* 45, 173–184) were compared. It is shown that common factors control meatiness and bone development in both species.

muscle weight variations / bone weight variations / multicollinearity / factor analysis / Japanese quail

Résumé — Origines de la variabilité conjointe de la distribution corporelle du muscle et du squelette et de leur estimation en utilisant les variables orthogonales dérivées d'une analyse factorielle chez la caille japonaise. Une analyse factorielle utilisant une rotation varimax a été appliquée à dix caractéristiques de muscles et d'os sur 110 cailles Japonaises afin de : i) identifier les principales sources de variabilité commune, ii) déterminer les facteurs contrôlant la répartition des muscles et des os de la carcasse, iii) prédire la quantité totale de muscles et d'os dans la carcasse à partir des caractéristiques de la carcasse orthogonale. L'essentiel de la variabilité (88,2 %) de la répartition

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tition pondérale des muscles et des os pourrait être attribué à quatre facteurs : les muscles (I), les os des membres (II), le cou (III) et les os pectoraux (IV). Le coefficient de corrélation entre le facteur I de la rotation varimax et les muscles de la carcasse était de 0,91 ; celui du facteur II et des os de la carcasse de 0,75. Les facteurs de la rotation varimax déterminés pour les cailles, dans la présente étude, et pour les canards Pékin, dans une étude précédente (Shahin, 1996a), ont été comparés. Il est montré que des facteurs communs contrôlent le développement des muscles et des os dans les deux espèces.

répartition pondérale / muscle / os / analyse factorielle / caille japonaise

INTRODUCTION

Independent factor scores derived from the factor analysis technique have been used advantageously as predictors of total carcass muscle and bone and other live performance traits and as a selection criterion for genetic improvement of muscle weight distribution (Cook, 1966; Ricard, 1980; Shahin et al, 1993; Shahin, 1996a,b).

The objective of this study on Japanese quail was to evaluate the relationships involving the weight of muscle and bone in various carcass cuts, with the weight of the corresponding tissue in the carcass by applying the factor analysis method and simple and multiple regressions. The main sources of shared variability and the factors that control muscle and bone distribution were also studied.

MATERIALS AND METHODS

Source of data

One-hundred-and-ten (56 males and 54 females) Japanese quail (*Coturnix coturnix japonica*), the progeny of 33 sires raised at the Faculty of Agriculture, Tanta University, Egypt, were used in this study. A growth diet containing 24% protein with a metabolizable energy of 2931 kcal/kg from hatching to 6 weeks of age was used. Feed and water were provided *ad libitum* and conventional brooding and rearing practices were followed.

Traits considered

At 6 weeks, the birds were killed and the head was removed at the atlanto-occipital articulation. The right side of the carcass was jointed into the following commercial cuts: thigh, drumstick, wing, breast and neck. In each cut, fat (skin plus subcutaneous and intermuscular fat), muscle and bone were dissected and weighed. The sum of the weights of these parts over all the cuts gave the weight of the total side muscle, bone and fat. The data from males and females were combined as their dispersion matrices did not prove to differ significantly.

Statistical analysis

The original (non-independent) variables were initially described in terms of means, phenotypic variation and intercorrelations. The data were then subjected to the factor analysis procedure (SAS, 1988) where the main source of shared variation among correlated muscling and bone variables (P) was expressed in terms of fewer mutually uncorrelated common factors (latent variables) F_1, \dots, F_q (where $q < p$) than the original variables (Darton, 1980).

The model used was as follows:

$$X = \Lambda F + U$$

where: X , a $p \times 1$ vector of observable variables; Λ , a $p \times q$ matrix of factor loading 'factor- variate correlations';

F , a $q \times 1$ vector of factors and; U , a $p \times 1$ vector of specific 'unique' factors.

A built-up step-wise multiple regression was used to evaluate the relative contribution of the original meatiness and bone variables and their varimax rotated factors to total side muscle weight (TSM) and total side bone weight (TSB).

RESULTS AND DISCUSSION

Original 'non-independent' variables

The muscle and bone weights relative to body weight were estimated at 39.7% and 9.6% respectively in Japanese quail (table I) and 27.9% and 11.8% in Pekin ducklings

Table I. Means, standard deviations (SD), coefficient of variability (CV%) and minimum and maximum values for live and carcass traits.

	Mean	SD	CV%	Range
Live weight (g)	123.94	22.59	18.23	80–170
Total carcass muscle (g)	49.62	11.90	23.98	24.1–79.2
Total carcass bone (g)	11.70	1.71	14.62	8.2–15.8
Total carcass fat (g)	7.00	1.92	27.43	3.2–13.2
<i>Percentage of live weight</i>				
Total muscle	39.71	3.51	8.84	29.5–48.1
Total bone	9.62	1.57	16.32	7.1–14.8
Total fat	5.61	0.94	16.76	3.6–8.8
<i>Percentage of carcass weight</i>				
Total muscle	72.22	3.06	4.24	61.6–77.9
Total bone	17.57	2.89	16.45	12.6–28.0
Total fat	10.21	1.60	15.67	7.2–15.6
<i>Percentage of total muscle</i>				
Drumstick muscle	10.80	1.02	9.44	8.2–14.6
Thigh muscle	22.92	1.68	7.33	19.5–26.9
Breast muscle	47.20	2.64	5.59	41.2–53.6
Wing muscle	10.64	1.32	12.41	7.3–14.9
Neck muscle	3.81	0.67	17.59	2.3–5.8
Leg muscle	33.72	2.18	6.47	28.2–38.7
<i>Percentage of total bone</i>				
Drumstick bone	13.09	1.12	8.56	10.2–16.2
Thigh bone	26.30	2.11	8.02	20.7–31.4
Breast bone	19.53	2.82	14.44	13.2–26.8
Wing bone	19.05	1.47	7.72	13.9–23.1
Neck bone	10.15	1.21	11.92	7.4–13.5
Leg bone	39.39	2.55	6.47	33.9–47.1
<i>Muscle: bone ratio</i>				
Drumstick	3.50	0.67	19.14	1.8–5.6
Thigh	3.71	0.74	19.95	2.0–5.1
Breast	10.43	2.43	23.30	5.8–16.2
Wing	2.37	0.50	21.10	1.2–3.7
Neck	1.58	0.31	19.62	0.9–2.3
Whole carcass	4.23	0.75	17.73	2.2–6.1

(Shahin, 1996a). There was a much higher TSM:TSB ratio in the quail.

The variability of muscle in the limbs appears to be higher than in the breast in Japanese quail (table I) and lower in Pekin ducklings (Shahin, 1996a). The variability of the muscle was comparable to that for bone in the leg, but was much lower in the breast.

The relationship with TSM and TSB

The weight of muscle or bone in the individual cuts appeared to be highly correlated with the total weight of the corresponding tissue in the carcass (table II).

The separable muscle in the thigh was associated with 90% of the variation in TSM in quail (table II) and 72% in Pekin ducklings (Shahin, 1996a). Breast muscle weight alone accounted for 96.6% of the variability in TSM in Japanese quail (table III) and 89% in Pekin ducklings (Shahin, 1996a). Slight improvements in the accuracy of the TSM estimates in quail (table III) appeared with a stepwise addition of the weight of muscle occurring in thigh, wing and drumstick.

For TSB 76% of the variability was explained by thigh bone in quail (table IV) and 65% by wing bone in Pekin ducklings (Shahin, 1996a). The improvement in the accuracy of the TSB estimates in quail (table IV) was more obvious with stepwise inclusion of the weight of the bone found in the breast, wing, drumstick and neck.

Varimax rotated 'independent' factors

Their interpretation

The principal initial factors and the final varimax solutions are presented in table V. Four common factors (one for meatiness and the others for skeletal structures) have been identified, which contribute 88% of

the variability of the 10 original variables, leaving 12% to the 10 'special' factors.

The first factor ('meatiness': I) is characterized by high positive loadings on meatiness traits (table V; Rouvier and Ricard, 1967; Ricard, 1980; Shahin, 1996a). The variables that are associated with drumstick muscle and thigh muscle have the highest loadings, followed by the breast and wing muscle. This factor accounted for 63% of the variation of the original variables in quail (table V) and 54% in Pekin ducklings (Shahin, 1996a). Compared with ducks, quails seemed to vary more in meatiness and less in skeletal structure (table V; Shahin, 1996a).

The second factor ('skeletal support system': II), giving relatively high weight to limb bones, accounted for an additional 14.7% of the total variation. The variables associated with drumstick bone and thigh bone had the highest loadings followed by those associated with wing bone. In White Leghorn fowls the leg and wing measurements are affected by a common factor which was independent of that of the head (Wright, 1954).

The third factor ('neck factor': III) accounted for 5.5% of the total variation with high loadings on the neck muscle and bone. The neck structures enable the bird to maintain its balance by shifting the center of gravity during running and flying. A neck factor explaining 8.8% of the total variation in meatiness and bone traits was also identified in Pekin ducklings (Shahin, 1996a).

Species differences seemed to exist in relation to the fourth factor (breast bone: IV) which acted on breast bone in quail and on drumstick bone 'tibia' in Pekin ducklings (Shahin, 1996a). The way the weight is distributed over the body and genetic adaptations to physiological needs might be reasons for the difference in this factor (Goss, 1981).

Table III. Step-wise multiple regression of total side muscle weight (g) on original muscle traits and on orthogonal factor scores.

Step	Independent variables (predictors)	Intercept	Regression coefficient		R ²	Residual standard deviation
			b	SE		
<i>(I) Original muscle traits as independent variables</i>						
1	Breast muscle	3.18	1.84	0.03	0.966	1.13
2	Breast muscle	1.64	1.24	0.04	0.992	0.56
	Thigh muscle		1.51	0.08		
3	Breast muscle	1.06	1.11	0.03	0.995	0.43
	Thigh muscle		1.40	0.06		
	Wing muscle		1.04	0.12		
4	Breast muscle	0.50	1.06	0.03	0.997	0.34
	Thigh muscle		1.09	0.06		
	Wing muscle		0.96	0.09		
	Drumstick muscle		1.17	0.14		
5	Breast muscle	0.30	1.05	0.03	0.997	0.32
	Thigh muscle		1.06	0.06		
	Wing muscle		0.95	0.09		
	Drumstick muscle		1.14	0.14		
	Neck muscle		0.70	0.22		
<i>(II) Orthogonal factor scores as independent variables</i>						
1	FC1	24.89	5.51	0.24	0.830	2.52
2	FC1	24.89	5.51	0.19	0.897	1.96
	FC2		1.58	0.19		
3	FC1	24.89	5.51	0.15	0.939	1.52
	FC2		1.58	0.15		
	FC4		1.25	0.15		
4	FC1	24.89	5.51	0.09	0.976	0.95
	FC2		1.58	0.09		
	FC4		1.25	0.09		
	FC3		1.17	0.09		

Table VI shows the coefficients of congruence between the Japanese quail of the present study and the Pekin ducklings of Shahin (1996a) for the four varimax rotated factors. Factors I and III controlled the same traits in Japanese quails and Pekin ducklings. However, factor II, which acted on all bones of the extremities in Japanese quails, matched

factor IV for the ducks very well. This factor acted specifically on the drumstick bone in Pekin ducklings. Factor IV which controls breast bone development in Japanese quails corresponded to factor II in Pekin ducklings. It appeared that the muscle and bone weight distribution in both species were largely controlled by the same orthogonal factors.

Table IV. Step-wise multiple regression of total side bone weight (g) on original bone traits and on orthogonal factor scores.

Step	Independent variables (predictors)	Regression			R ²	Residual standard deviation
		Intercept	coefficient b	SE		
<i>(I) Original bone traits as independent variables</i>						
1	Thigh bone	1.35	2.93	0.16	0.762	0.42
2	Thigh bone	1.15	1.94	0.12	0.911	0.26
	Breast bone		1.49	0.11		
3	Thigh bone	0.39	1.41	0.09	0.960	0.17
	Breast bone		1.09	0.08		
	Wing bone		1.83	0.16		
4	Thigh bone	0.38	1.06	0.10	0.971	0.15
	Breast bone		1.11	0.07		
	Wing bone		1.36	0.16		
	Drumstick bone		1.37	0.22		
5	Thigh bone	0.28	0.97	0.08	0.980	0.12
	Breast bone		1.06	0.06		
	Wing bone		1.06	0.14		
	Drumstick bone		1.36	0.18		
	Neck bone		1.08	0.16		
<i>(II) Orthogonal factor scores as independent variables</i>						
1	FC2	5.87	0.64	0.05	0.563	0.56
2	FC2	5.87	0.64	0.04	0.778	0.40
	FC4		0.39	0.04		
3	FC2	5.87	0.64	0.03	0.878	0.30
	FC4		0.39	0.03		
	FC1		0.27	0.03		
4	FC2	5.87	0.64	0.01	0.970	0.14
	FC4		0.39	0.01		
	FC1		0.27	0.01		
	FC2		0.26	0.01		

Shared variability

The results (table V) indicated that about 81% to 94% of the variation in meatiness and bone traits were brought about by the common factors, whereas 6% to 19% of their variation were contributed by unique factors specific for each trait. The relatively

high estimates of common variance for meatiness traits indicated that improving any one of them could result in the simultaneous improvement in the remaining muscling traits.

In terms of highest communalities (table V and Shahin (1996a)) the values

Table V. Explained variation associated with unrotated and rotated factor analysis along with communalities and unique factor for each variable. Correlations between factor score coefficients and original variables.

	<i>Unrotated common factors</i>				<i>Rotated common factors</i>				<i>Communalities</i>	<i>Unique factor</i>
	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>		
Drumstick muscle	0.856	-0.370	-0.185	-0.121	0.901	0.302	0.102	0.068	0.918	0.082
Thigh muscle	0.885	-0.339	-0.147	-0.052	0.889	0.301	0.142	0.147	0.923	0.077
Breast muscle	0.883	-0.352	-0.056	0.048	0.872	0.225	0.213	0.231	0.910	0.090
Wing muscle	0.815	-0.361	-0.078	0.145	0.828	0.152	0.158	0.297	0.822	0.178
Neck muscle	0.745	-0.252	0.358	-0.138	0.698	0.101	0.573	0.007	0.826	0.174
Drumstick bone	0.726	0.540	-0.178	-0.231	0.205	0.903	0.147	0.161	0.905	0.095
Thigh bone	0.751	0.468	-0.168	-0.217	0.268	0.858	0.158	0.163	0.859	0.141
Breast bone	0.725	0.305	-0.042	0.567	0.284	0.390	0.168	0.825	0.942	0.058
Wing bone	0.797	0.417	0.025	0.052	0.277	0.686	0.319	0.405	0.813	0.187
Neck bone	0.738	.252	0.542	-0.039	0.244	0.423	0.778	0.245	0.904	0.096
% of variance	63.1	14.7	5.5	4.9						
Description					Meati- ness	Limb bones	Neck	Breast bone		

Table VI. Coefficients of congruence between varimax factors of muscle and bone variation in Japanese quail and Pekin ducklings¹.

<i>Factors for Japanese quail</i>	<i>Factors for Pekin ducklings</i>			
	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>
I	0.8972	-0.3839	-0.2874	-0.4522
II	-0.6146	0.2668	-0.1556	0.8021
III	-0.5863	-0.2415	0.8838	-0.2822
IV	-0.1350	0.7659	-0.1776	-0.3187

¹ Shahin, 1996a.

were higher in quail than in duck (thigh muscle: 92.3% vs 82.4%; breast bone: 94.2 vs 84.5%). This indicated that the musculature of the thigh and the skeletal development of the breast could reflect other meat and bone characteristics in the quail than in the duck. Wing muscle and bone had the

lowest communality with the greatest uniqueness of their own (table V). About 81–82% of the variation in wing muscle and bone was controlled by common factors, whereas 18–19% of their variation was contributed by the unique factor specific for either the wing muscle or wing bone.

Their relationship with TSM and TSB

The meatiness factor score (FC1) alone accounted for 83% of the variation in total side muscle weight in Japanese quail (table III), and 81% in Pekin ducklings (Shahin, 1996a). Results of the stepwise multiple regression of the total side muscle weight on the four varimax factor scores showed that R^2 increased from 0.90 to 0.94 to 0.98 and RSD of the estimate decreased from 1.96 to 1.52 to 0.95 g as FC2, FC4 and FC3 orthogonal factor scores were added in step-wise.

The limb bones factor score (FC2) alone accounted for 56% of the variation in total side bone weight (table IV). R^2 increased from 0.78 to 0.88 to 0.97 and the RSD of the estimate decreased from 0.40 to 0.30 to 0.14 g with the step-wise inclusion of FC4, FC1 and FC3 orthogonal factor scores.

CONCLUSION

The results of this study on Japanese quail confirmed those found with Pekin ducklings (Shahin, 1996a), demonstrating the advantages of the factor analysis technique versus the multiple regression technique for consolidating several intercorrelated meatiness and bone traits into a few interpretable independent factors. These then help to clarify the relationship of the weight of muscle and bone in the various cuts with the total weight of the corresponding tissue in the

carcass. Also, factor analysis helped to show that the structural tissues of the body (muscular and skeletal 'bone') in quail and ducks were largely controlled by the same orthogonal factors.

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