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ALLOMETRIC GROWTH OF COPPER, ZINC, MANGANESE AND IRON IN SLOW- AND FAST-GROWING YOUNG CHICKENS

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Abstract

ZELENKA JIŘÍ: *Allometric growth of copper, zinc, manganese and iron in slow- and fast-growing young chickens.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 1, pp. 237–241

Allometric growth of body microminerals was examined in slow-growing laying-type cockerels (SG) and in fast-growing male broiler hybrids (FG) during the growing period from hatch to Day 22. Allometric coefficients for dry matter, copper, zinc, manganese and iron in relation to body weight were 1.0914, 1.0429, 1.2743, 1.0299 and 1.0730 for SG chickens and 1.0752, 0.9450, 1.0459, 1.0779 and 1.0059 for FG chickens, respectively. Allometric coefficients describing the relationships of Cu, Zn, Mn and Fe with dry matter weight were 0.9495, 1.1654, 0.9390 and 0.9772 for SG chickens and 0.8754, 0.9698, 0.9981 and 0.9336 for FG chickens, respectively. High allometric coefficient for Zn in SG genotype likely indicate a rapid growth of skeletal tissues which requires an adequate mineral nutrition during this period of growth. The deposition of Zn relative to live body and dry matter weights was higher ($P < 0.01$) in SG chickens thus suggesting that the relative growth of this trace element may be affected by genotype.

age, growth rate, chemical allometry, Cu, Zn, Mn, Fe

Requirement for concentration of an available mineral in the diet for growing poultry depends on the inevitable mineral losses, the growth rate, the mineral concentration in gained body weight, and the feed conversion ratio. Mineral concentration in body weight is quantitatively the most important (Rodehutscord, 2006), but it can be studied with reasonable effort by a whole body analysis. We have studied retention of calcium, phosphorus, magnesium, sodium and potassium in laying and meat type chickens (Zelenka, 2012) recently, and we want to pay attention to some microminerals now.

Copper is essential for haemoglobin formation and also plays a role in many enzyme systems, such as cytochrome oxidase, which is important in oxidative phosphorylation (Leeson, 2009). The reduced elasticity of the vessels in copper-deficient chickens is responsible for ruptures of the aorta (Hill *et al.*, 1967). Copper also has a role in the crosslinking of collagen and elastin, which gives bone its tensile strength and elasticity (Dibner *et al.*, 2007).

Zinc is required constituent of several hundred metalloenzymes and therefore impacts a wide array of basic cellular functions. In the form of zinc finger proteins is involved in the regulation of DNA transcription (Dibner and Richards, 2006). The element participates in regulation of hydroxyapatite crystallization, collagen synthesis, and the cellular invasion of the cartilage matrix by the osteoblasts (Dibner *et al.*, 2007).

Manganese plays both structural and catalytic roles in metalloproteins (Scrutton *et al.*, 1966). It is necessary for the normal development of bone. The ground substance of tissue, particularly the proteoglycan matrix in which collagen and elastin are embedded, requires manganese for glycosylation of its protein core molecule (Dibner and Richards, 2006). The manganese requirements of poultry are appreciably higher than those of other domestic livestock and manganese deficiency as a practical production problem is largely confined to these species (Suttle, 2010).

Iron has a role in cellular oxidative energy metabolism, it is a component of oxygen transport proteins haemoglobin and myoglobin and of specific redox enzymes. Iron-containing catalase and peroxidases remove potentially dangerous products of metabolism, while iron-activated hydroxylases influence the connective tissue development (Suttle, 2010).

It is generally accepted that from the prediction of body weight growth the growth of body constituents can be calculated by allometric equations (Emmans, 1981).

At hatch, the chick skeleton is poorly mineralized. Growth and mineralization occur most rapidly in the first weeks of life. Except for Ca, the embryo had limited access to minerals. Leg problems, especially in broilers, are often the results of fast early growth. Chickens with slower early growth rate have less problems with skeletal development (Angel, 2007).

Mohanna and Nys (1998) determined concentration of Zn, Fe, Mn and Cu in the whole body of broilers in the first three weeks of life. Age affected the trace element body concentration. At Days 0, 4, 11 and 21 Zn concentrations were 14.4, 17.3, 19.2, 15.3, Fe 34.0, 30.1, 36.4, 23.8, Mn 0.27, 2.81, 1.38, 0.68 and Cu 1.22, 1.99, 1.58, 1.24 mg/kg of fresh body weight, respectively.

The aim of the present experiment were to study relative growth rates of whole body microminerals copper, zinc, manganese and iron in broilers and laying type chickens during the first 22 days of their postembryonal life. To evaluate the effect of age as exactly as possible, it is necessary to carry out estimates in short time intervals.

MATERIALS AND METHODS

Animals and procedures

The animal procedures were reviewed and approved by the Animal Care Committee of the Mendel University in Brno. Chickens of two contrasting genotypes were used: slow-growing male chicks of hybrid combination Isa Brown (SG; 95 birds) and fast-growing Ross 308 cockerels (FG; 52 birds). The diet contained (mg/kg diet) copper 19.01, zinc 67.15, manganese 35.23 and iron 265.90. For details about the environment including the composition of the diet see our paper about the retention of protein, amino acids, fat and minerals (Zelenka *et al.*, 2011). The chickens used in the present study originated from the same experiment. During the whole experiment, all chickens were fed *ad libitum*.

In two-day intervals from hatch until the age of 22 days, body weight of the chickens was recorded and samples of chickens (each of them containing at least 4 chickens) were selected from each group so that their body weight was approximately the same as the mean body weight of the group. The selected chickens were euthanized by carbon dioxide gas and the content of the digestive tract was removed. The chickens were then autoclaved for 6 hours at 130 °C and 270 kPa pressure, freeze-dried, finely ground and stored for subsequent analyses.

Chemical analyses

The diet and whole body of chickens were analyzed for moisture, copper, zinc, manganese and iron. Trace elements were estimated after decomposition in the microwave digestion system Ethos 1 (Milestone, Italy) in the presence of nitric acid and hydrogen peroxide on high resolution continuum source atomic absorption spectrometer ContrAA 700 (Analytik, Jena, Germany) at wavelengths 213,857 nm (Zn), 279,482 nm (Mn), 248,327 nm (Fe) and 324,754 nm (Cu). All analyses were performed using the methods specified by Commission Regulation (EC) No. 152/2009.

Calculations and statistical analysis

For the expression of the accelerating growth phase of chickens or their body components, the exponential function suggested by Brody (1945) was used: $Y = Ae^{kt}$, where Y = body or analyte weight at time t, A = extrapolation of the weight for time 0, e = base of natural logarithms, k = rate of growth, and t = time from hatching (in days). Weights of microminerals were calculated by multiplying their concentrations in the whole body by live weights of chickens. Allometric relationships were calculated using the power function of Brody (1945): $Y = aX^b$, where Y = content of the body component in g, X = live body weight or dry matter weight of chicken in g, a = extrapolation of Y for $X = 1$, and b = allometric coefficient, ratio of percentage change in Y to the corresponding percentage change in X. The significance of differences between the data for the two genotypes was evaluated by a paired t-test. The statistical analyses were performed using Statgraphic Plus package (version 3.1, Statistical Graphic Corp., Rockville, MD, USA).

RESULTS AND DISCUSSION

Both types of chicken hybrids were raised under identical environmental and dietary conditions. At the end of experiment, body weights of FG chickens were about three times higher than those of SG chickens, 782 g and 258 g, respectively.

The contents of microminerals determined immediately after hatching calculated per 1 kg of fresh weight are shown in Tab. I. For comparison there are also shown the data for chicken at hatching determined by Mohanna and Nys (1998) and summarised from literature by Romanoff (1967).

Parameters of exponential growth function (Brody, 1945) of chicken live body weight and dry matter, copper, zinc, manganese and iron growth are shown in Tab. II.

Parameter estimates for the allometric relationships of dry matter and microminerals weight with live body weight are summarized in Tab. III. As indicated by the allometric coefficients, I: *Concentration of microminerals in chicks immediately after hatching (mg/kg fresh weight)*

Whole body composition	Romanoff, 1967	Mohanna and Nys, 1998	Present experiment	
			Genotype[1]	
			SG	FG
Cu	1.55	1.22	0.85	0.95
Zn	-	14.40	14.26	15.98
Mn	0.29	0.27	0.32	0.34
Fe	48.48	34.00	22.91	28.27

[1] SG – slow-growing chick, FG – fast-growing chick

II: *Growth functions $Y = Ae^{kt}$ in two chicken genotypes*

Y	Genotype[1]					
	SG			FG		
	A	**k**	I_{YX}	**A**	**k**	I_{YX}
Body weight (g)	35.14	0.0975	0.979**	47.27	0.1365	0.963**
Dry matter (g)	7.688	0.1060	0.978**	10.529	0.1464	0.950**
Cu (mg)	0.0371	0.1022	0.967**	0.0507	0.1287	0.941**
Zn (mg)	0.5760	0.1257	0.955**	0.8158	0.1428	0.954**
Mn (mg)	0.0157	0.1018	0.944**	0.0189	0.1469	0.930**
Fe (mg)	0.9104	0.1056	0.982**	1.2130	0.1376	0.958**

[1] SG – slow-growing chickens, FG – fast-growing chickens
Y – live body weight or analyte weight
k – rate of growth
t – time from hatching (days)
I_{YX} – index of correlation
** Significance of I_{YX} P < 0.01

III: *Allometric functions $Y = aX^b$ for relations between microminerals and live body weight or dry matter weight in two chicken genotypes*

Y	Genotype[1]					
	SG			FG		
	a	**b**	I_{YX}	**a**	**b**	I_{YX}
Relations to live body weight (g)						
Dry matter (g)	0.15947	**1.0914** [a]	0.996**	0.16403	**1.0752** [a]	0.999**
Cu (mg)	0.00092	1.0429 [a]	0.990**	0.00131	**0.9450** [a]	0.993**
Zn (mg)	0.00638	**1.2743** [a]	0.992**	0.01430	1.0459 [b]	0.985**
Mn (mg)	0.00041	1.0299 [a]	0.986**	0.00029	**1.0779** [a]	0.994**
Fe (mg)	0.02048	**1.0730** [a]	0.996**	0.02489	1.0059 [a]	0.995**
Relations to dry matter weight (g)						
Cu (mg)	0.00545	0.9495 [a]	0.990**	0.00650	**0.8754** [a]	0.994**
Zn (mg)	0.05482	**1.1654** [a]	0.996**	0.08390	0.9698 [b]	0.983**
Mn (mg)	0.00237	0.9390 [a]	0.989**	0.00182	0.9981 [a]	0.996**
Fe (mg)	0.12690	0.9772 [a]	0.995**	0.13612	**0.9336** [a]	0.992**

[1] SG – slow-growing chickens, FG – fast-growing chickens
X – live body weight or dry matter weight
Y – analyte weight
b – allometric coefficient
I_{YX} – index of correlation
[a,b] highly significant (P < 0.01) difference between genotypes
** Significance of I_{YX} P < 0.01
Boldfacing values are significantly (P < 0.05) different from the unity

the proportion of dry matter in the chicken bodies increased with the increasing age of birds. Allometric coefficients were significantly (P < 0.05) different from the unity. Similar results were reported by Kwakkel *et al.* (1997), Mohanna and Nys (1998) and Gous *et al.* (1999).

From monitored trace elements, allometric coefficients were significantly different from the unity ($P < 0.05$) only in zinc and iron in SG and copper and manganese in FG chickens. The deposition of Zn, Mn and Fe in both genotype and Cu in SG chickens was higher and that of Cu in FG chickens lower than the rate of body weight growth. Except for Mn these differences were more pronounced in SG than in FG chickens, but significantly ($P < 0.01$) only for Zn.

Zelenka and Fajmonová (2000) investigated utilization of Mn and Cu within 15 subsequent, three-day balance periods using Ross hybrid chickens during the growth period from the 12th to the 56th day of age. Similarly as in the present experiment in broilers content of Mn per 1 g of live body gain significantly ($P < 0.01$) increased with age. Dependence of concentration of Cu in body gains on age were parabolic with the minimum values at 26–34 days.

The bones of slow growing chickens are obviously more robust than those of fast-growing broilers (Stojcic and Bessei, 2009). Zinc and copper are required for normal bone development. Zinc finger protein is also associated with the changes in gene transcription that accompany ossification (Dibner *et al.*, 2007). The results of the present experiment support the hypothesis that the relative growth of skeleton-forming element zinc in broilers is slower than that in laying-type chickens due to a lower proportion of bones.

Allometric coefficients describing the relationships of mineral weights to dry matter weight (Tab. III) indicated that the deposition of Zn in SG genotype was considerably ($P < 0.01$) faster than that of dry matter while the opposite was true for Cu and Fe in FG chickens. Allometric coefficients for these values were significantly ($P < 0.05$) different from the unity. Consequently, adequate zinc nutrition during this period of growth is of particular importance. Growth of zinc in dry matter was significantly ($P < 0.01$) faster in SG than in FG genotype, the allometric coefficients being 1.165. When the relative growth of body constituents was expressed as a function of dry matter weight, the results showed that Cu, Mn and Fe in SG genotype and Zn and Mn in FG chickens developed proportionally to body dry matter weight (*b* value close to 1.0).

REFERENCES

ANGEL, R., 2007: Metabolic disorders: Limitations to growth of and mineral deposition into the broiler skeleton after hatch and potential implications for leg problems. *Journal of Applied Poultry Research,* 16, 138–149.

BRODY, S., 1945: *Bioenergetics and Growth.* 1st Ed. Reinhold Publishing Corporation, New York, 1023 pp.

Commission Regulation (EC) No. 152/2009 of 27 January 2009 laying down the methods of sampling and analysis for the official control of feed. 26.2.2009 *Official Journal of the European Union* L 54/1.

DIBNER, J. J., RICHARDS, J. D., 2006: Mineral metabolism and chelated minerals for hatchlings. In: *Recent Advances in Animal Nutrition 2005*. Ed. Gansworthy P. C. and Wiseman J., Nottingham University Press, Nottingham, U.K. 390 pp.

DIBNER, J. J., RICHARDS, J. D., KITCHELL, M. L., QUIROZ, M. A., 2007: Metabolic challenges and early bone development. *The Journal of Applied Poultry Research,* 16, 126–137.

EMMANS, G. C., 1981: A model of the growth and feed intake in *ad libitum* fed animals, particularly poultry. In: Hillyer, G. M., Whittemore, C. T., Gunn, R. G. (eds): *Computers in Animal Production.* Occasional Publication No. 5. British Society of Animal Production, Cambridge, UK, 103–110.

GOUS, R. M., MORAN, E. T., STILBORN, H. R., BRADFORD, G. D., EMMANS, G., 1999: Evaluation of the parameters needed to describe the overall growth, the chemical growth, and the growth of feathers and breast muscles of broilers. *Poultry Science,* 78, 812–821.

HILL, C. H., STARCHER, B., KIM, C., 1967: Role of copper in the formation of elastin. *Federation Proceedings,* 26, 129–133.

KWAKKEL, R. P., VERSTEGEN, M. W. A., CUCRO, B. J., 1997: Diphasic allometric growth of body components in White Leghorn pullets fed *ad libitum* and restricted diets. *Poultry Science,* 76, 1020–1028.

LEESON, S., 2009: Copper metabolism and dietary needs. *World's Poultry Science Journal,* 65, 353–366.

MOHANNA, C., NYS, Y., 1998: Influence of age, sex and cross on body concentrations of trace elements (zinc, iron, copper and manganese) in chickens. *British Poultry Science,* 39, 536–543.

RODEHUTSCORD, M., 2006: Optimising the use of phosphorus sources in growing meat ducks. *World's Poultry Science Journal,* 62, 513–523.

ROMANOFF, A. L., 1967: *Biochemistry of the Avian Embryo.* 1st ed. John Willey & Sons Inc., New York, 398 pp.

SCRUTTON, M. C., UTTER, M. F., MILDVAN, A. S., 1966: Pyruvate carboxylase. 6. The presence of tightly bound manganese. *Journal of Biological Chemistry,* 241, 3480–3487.

STOJCIC, M. D., BESSEI, W., 2009: The effect of locomotor activity and weight load on bone problems in fast and slow growing chickens. *Archiv für Geflügelkunde,* 73, 242–249.

SUTTLE, N. F., 2010: *Mineral Nutrition of Livestock*. 4th ed. CABI, Wallingford, UK. 587 pp.

ZELENKA, J., FAJMONOVÁ, E., 2000: Effects of sex and age upon utilization of manganese and copper in chickens. *Archiv für Geflügelkunde,* 64, 175–179.

ZELENKA, J., HEGER, J., KRÁČMAR, S., MRKVICOVÁ, E., 2011: Allometric growth of protein, amino acids, fat and minerals in slow- and fast-growing young chickens. *Czech Journal of Animal Science,* 56, 127–135.

ZELENKA, J., 2012: Allometric growth of calcium, phosphorus, magnesium, sodium and potassium in slow- and fast-growing young chickens. *Czech Journal of Animal Science,* 57, 557–561.

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