ZNANSTVENO STRUČNI DIO

ALLOMETRIC VS. DYNAMIC MODELS IN THE INVESTIGATION OF PIG GROWTH

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SUMMARY

A total of 68 barrows, divided into 4 groups regarding the MHS genotype and feeding regime (intensive and restrictive). Data on muscle and fat growth were obtained by magnetic resonance imaging (MRI). Allometric growth analysis showed that muscle tissue grew proportionally with the increase of live weight; fat grew faster in relation to live weight in all investigated groups of pigs. Significant differences in growth coefficients for fat were found only between feeding groups. The analysis by asymmetric S-function was more informative. Muscle growth pattern significantly differed between the groups of investigated pigs (Nn pigs performed better under intensive feeding than under restrictive feeding regime, while no difference was found between NN pigs from two feeding regimes). The optimal slaughter weight of pigs calculated on the basis of live weight and muscle growth (130 and 126 kg for intensively fed NN and Nn pigs, respectively, and about 114 kg for both genotypes from the restricted group of pigs). Growth patterns of fat differed significantly only between the feeding groups. It appears that asymmetric S-function is more accurate and informative model than a simple allometric function, providing a more robust base for important decisions in fattening of pigs.

Key words: *Growth models, MRI, pigs*

INTRODUCTION

The phenomenon of growth is is a very complex problem which has been studied from many different approaches, most common of them being allometric or differential growth and temporal growth (the increase in body size per unit of time). The allometric approach was useful in the investigation of relative development of muscle, fat and bone in different types of pigs (Davies and Kallweit, 1979; Fortin et al., 1983; Gu et al., 1992; Kouba et al. 1999). However, Evans and Kempster (1979) criticised the use of simple allometric function arguing that it may be inappropriate in certain stages of growth. The concept of temporal growth, using the functions which have a characteristic S-shape ("sigmoid" or S-curve) may be a good tool to overcome the limitations of linear allometric models. Kuhn et al. (1985) used the Gompertz function, while López et al. (2000) used Gompertz, Richard's and the generalised Michaelis-Menten function to describe the growth of several species. Kralik et al. (1999) showed that the asymmetric S-function was quite appropriate in growth analyses of different pig breeds, allowing accurate predictions of live weight growth. Magnetic resonance imaging (MRI) has been proved as the useful tool to estimate muscle and fat content in pig breeding (Baulain 1997).

The aim of the present study was to compare the growth characteristics of barrows of two different MHS-genotypes kept in two feeding regimes using the allometric and temporal approach.

MATERIAL AND METHODS

A total of 68 male castrated pigs from the Federal Hybrid Pig Breeding Programme from Germany were investigated in this study. The pigs were divided according to MHS-genotype by DNA test on Malignant Hyperthermia Syndrome gene (Hal-1843®) as described by (Fuji et al. 1991) into homozygous negative (NN) and heterozygous carriers and further into two feeding regimes. The first feeding group was intensive (*ad libitum*), designed to support the full growth potential, the second group was fed restrictively by diets designed according to the German recommendations. The data needed for tissue volume determination were obtained in the process of MRI (magnetic resonance imaging). MRT measurements were performed at 4 week intervals, starting at the age of 10 weeks

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up to the final live weight of approximately 120 kg.

For the depiction of differential growth, a simple allometric function of the following form was used: log Y= log a + b * log X, where Y is the weight of tissue or a main part and X is the body weight; *a* is an intercept and *b* is the allometric coefficient in the linear regression model which describes the log-log relationship between two body constituents. If b=1, isometric growth is assumed; Y grows at the same rate as X; if b>1, Y grows faster than X, and the opposite is true if b <1. For modelling the growth dynamic (temporal growth) of the live weight as well as the growth of muscle tissue and fat, an asymmetric S-function with one flexible inflection point as a generalised form of logistic function was used:

$$f(t) = \frac{A}{(1 + b^{\,-cgt})^{1/g}}$$

Parameters b and c in this function were calculated on the basis of collected data, A denotes the maximum live weight or maximal weight of a certain tissue. This value stands for a maximum weight in a period of interest. Symbol γ is the coefficient of asymmetry which regulates the influence of *f (t)* and *(A-f (t))*. The stages of growth are determined by points t_B and t_C, while point of inflection marks the moment at which progressive growth ceases and regressive growth starts. Statistical and mathematical analyses were performed by SAS System for windows (Version 9.0; SAS Inst. Inc., 2002) and STATISTICA program package (version 7.1; StatSoft, Inc. 2005).

RESULTS AND DISCUSSION

Differential growth – allometric model

Relative growth rates of muscle and fat volumes in relation to live weight expressed as monophasic allometric coefficients (b) calculated for pigs of both genotypes (NN and Nn) kept in different feeding regimes are shown in table 1.

It can be seen that the allometric coefficient (b) of muscle tissue was close to unity in all cases, while for fat it was always higher indicating faster development in relation to the live weight as a whole. Significant differences ($p<0.05$) between growth coefficients were found only for fat volume between feeding groups. The allometric relations between the feeding groups are presented in fig1.

Temporal growth - live weight

Parameters of growth functions calculated for the pigs of different MHS genotype kept two different feeding regimes are shown in table 2. The growth curves for both genotypes of intensively and restrictively fed pigs are presented in fig. 2.

The results demonstrate that pig live weight growth patterns are influenced only by the feeding regime since there were no statistically significant differences in growth parameters and estimated S-curve points established between the MHS-genotypes of pigs. The growth of MHS-negative (NN) and carrier (Nn) pigs from the intensively fed group was described by a model with fixed values of A (220 kg), and restricted group had this value set to 160 kg.

Temporal growth - muscle

Parameters of the asymmetric S-function describing muscle growth for pigs of different MHS genotypes, kept

Table 1. Allometric coefficients (b), standard errors (SE_b) and coefficients of determination (R^2) for muscle and fatty tissue of pigs by feeding regime and genotype

Tissue	Intensive			Restrictive		
	NN + Nn			NN + Nn		
	b	SG_b	R^2	b	SG_b	R^2
Muscle	0.973	0.0113	0.979	1.021	0.0128	0.975
Fat	1.288[a]	0.0152	0.978	1.174[b]	0.0153	0.973
	NN			NN		
	b	SG_b	R^2	b	SG_b	R^2
Muscle	0.954	0.0151	0.978	1.027	0.0201	0.969
Fat	1.323	0.0186	0.983	1.193	0.0228	0.971
	Nn			Nn		
	b	SG_b	R^2	b	SG_b	R^2
Muscle	0.995	0.0167	0.980	1.015	0.0159	0.980
Fat	1.249	0.0241	0.974	1.155	0.0204	0.975

a, b = significant at $p<0.05$

Figure 1. Differential growth of muscle (M) and fat (F) of the pigs from two different feeding groups

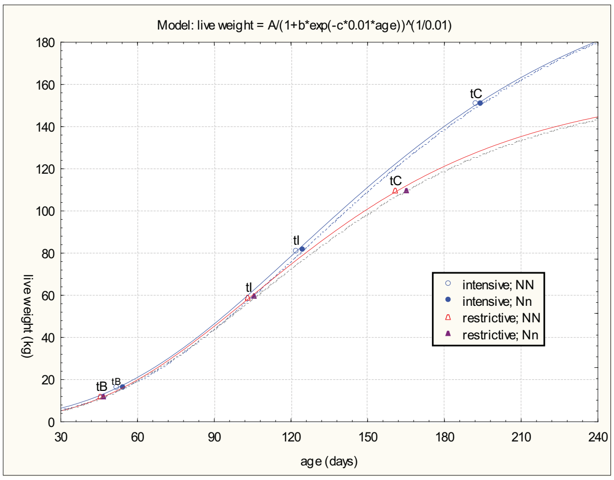


Table 2. Means and standard errors (in brackets) for parameters of growth curves for pigs of different MHS genotype kept in two different feeding systems

Parameters	Intensive		Restrictive	
	NN	Nn	NN	Nn
b	0.081285[a] (0.002751)	0.081469[a] (0.005016)	0.066558[b] (0.004037)	0.065217[b] (0.002318)
c	1.413875 (0.036049)	1.363169 (0.044037)	1.349053 (0.063789)	1.312191 (0.035882)
Points (days)	NN	Nn	NN	Nn
t_I	148.21[a] (2.083696)	152.46[a] (1.808781)	139.85[b] (2.560506)	142.80[ab] (2.250380)
t_B	79.01[a] (1.220355)	80.52[a] (2.095071)	65.22[b] (2.546449)	68.16[b] (1.699829)
t_C	217.41 (3.798824)	224.40 (3.508109)	214.47 (6.369127)	217.45 (4.122154)
$\Delta=t_B-t_C$	138.40 (3.804408)	143.88 (4.506168)	149.25 (8.238664)	149.29 (4.416594)

in two feeding systems are presented in table 3; the muscle tissue growth curves for the intensive and restrictive group of pigs are shown in fig 3. For all investigated pig groups, the A value in the model was set to 70 dm3.

It is evident that, except for the curve parameter b, there were no statistically significant differences in results from muscle growth analysis between the feeding regimes or genotypes of pigs under investigation. The growth pattern related to the b-value significantly differed between genotypes (NN and Nn) within the intensive feeding regime, but also between feeding groups in Nn pigs. At least in the progressive growth phase (up to the inflection point), MHS-gene carriers showed faster muscle growth when fed intensively, estimated by asymmetric S-function.

Intensively fed NN and Nn pigs reached the point of muscle growth saturation in 169 and 167 days, respectively. In the restrictive feeding group of pigs, these values were 169 and 172 days for NN and Nn genotypes, respectively. When live weight curve parameters are used, optimal live

Figure 2. Live weight growth curves of two MHS-genotypes (NN and Nn) of the pigs kept on the intensive and restrictive feeding regime

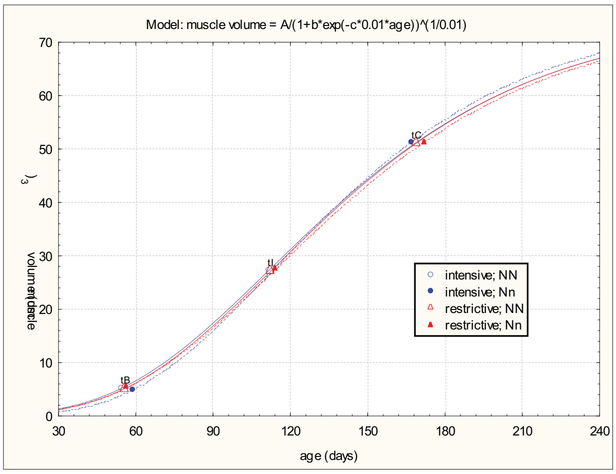


Table 3. Means and standard errors (in brackets) for parameters of growth curves for the muscle tissue of pigs of different MHS genotype kept in two feeding regimes

Parameters	Intensive		Restrictive	
	NN	Nn	NN	Nn
b	0.069[b] (0.003)	0.081[a] (0.006)	0.071[ab] (0.004)	0.070[b] (0.003)
c	1.711 (0.042)	1.834 (0.074)	1.728 (0.040)	1.693 (0.040)
Points (days)	NN	Nn	NN	Nn
t_I	111.94 (0.987)	113.01 (1.971)	112.45 (1.409)	114.39 (1.939)
t_B	54.85 (1.292)	59.080 (2.160)	55.99 (1.882)	56.72 (1.760)
t_C	169.02 (2.037)	166.94 (3.568)	168.91 (1.992)	172.06 (2.931)
$\Delta=t_B-t_C$	114.17 (2.783)	107.86 (4.387)	112.93 (2.660)	115.34 (2.887)

Figure 3. Muscle growth curves of two MHS-genotypes (NN and Nn) of the pigs kept on the intensive and restrictive feeding regime

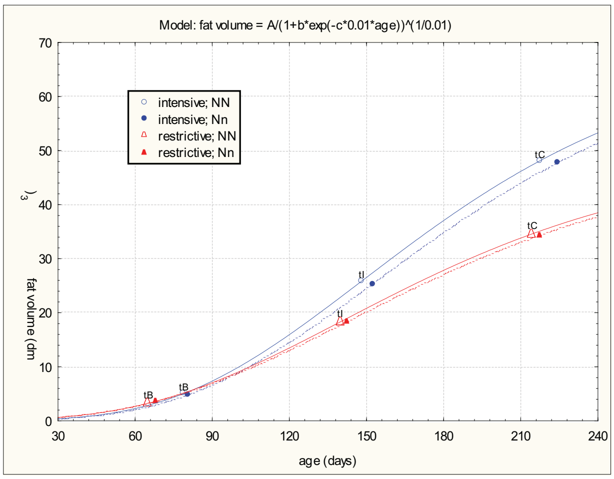
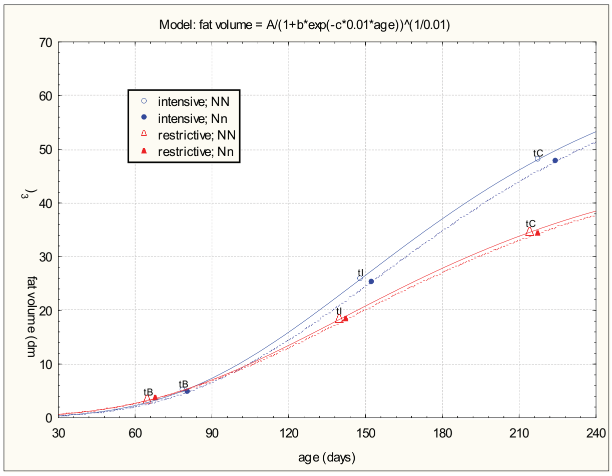


Figure 4. Fat growth curves of two MHS-genotypes (NN and Nn) of the pigs kept on the intensive and restrictive feeding regime



weights were 130 and 126 kg, respectively for intensive group of pigs; while for the restricted group calculated optimal live weight was about 114 kg.

Temporal growth - Fat

The growth curve parameters for fat growth of investigated pigs are presented in table 4; the growth curves are presented in fig 4.

From the results it is obvious that the patterns of fat growth are clearly influenced by feeding regime. Values of parameter *b* were significantly different between the feeding groups (p<0.01), but not between the MHS-genotypes within them. The growth of pigs from the intensive group was described by a model with an A value of 70 dm³, while restrictively fed pigs had a different value of A (50 dm³).

CONCLUSIONS

Analysis of growth by allometric equation and asymmetric S-function confirmed a well known pattern of tissue growth, found not only for pigs. More importantly, it showed that the applied restricted feeding utilized the muscle growth capacity sufficiently compared with the more expensive intensive fattening regime.

Application of the allometric function did not show an influence of MHS genotype (NN vs. Nn) on muscle growth

Table 4. Means and standard errors (in brackets) for parameters of growth curves of fatty tissue of pigs of different MHS genotype kept in two feeding regimes

Parameters	Intensive		Restrictive	
	NN	Nn	NN	Nn
b	0.081285[a] (0.002751)	0.081469[a] (0.005016)	0.066558[b] (0.004037)	0.065217[b] (0.002318)
c	1.413875 (0.036049)	1.363169 (0.044037)	1.349053 (0.063789)	1.312191 (0.035882)
Points (days)	NN	Nn	NN	Nn
t_I	148.21[a] (2.083696)	152.46[a] (1.808781)	139.85[b] (2.560506)	142.80[ab] (2.250380)
t_B	79.01[a] (1.220355)	80.52[a] (2.095071)	65.22[b] (2.546449)	68.16[b] (1.699829)
t_C	217.41 (3.798824)	224.40 (3.508109)	214.47 (6.369127)	217.45 (4.122154)
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of barrows kept in two different feeding systems. However, the analysis of muscle growth by asymmetric S-curves showed significant differences in growth patterns of b coefficients related to progressive phase of growth. In this phase Nn pigs kept under intensive feeding regime performed better than the same pigs from restrictive group. On the other hand, muscle growth of MHS-negative (NN) pigs was not affected by feeding regime and restrictive feeding regime can be recommended as appropriate for MHS-negative pigs.

For intensively fed NN and Nn pigs optimal slaughter weights were 130 and 126 kg, respectively; while for the restricted group optimal live weights were about 114 kg.

Although the allometric equation and the asymmetric S-function showed similar patterns of growth for investigated tissues, the latter proved to be more informative, providing a base for important decisions in fattening of pigs.

ZUSAMMENFASSUNG

UNTERSCHIEDE IN ALOMETRISCHEN UND DYNAMISCHEN MODELLEN BEI FORSCHUNG DES WACHSTUMS VON SCHWEINEN

Die Forschung wurde auf 68 Kastraten, geteilt in 4 Gruppen nach MHS Genotyp und Ernährungsregime (intensiv und restriktiv), durchgeführt. Die Angaben über das Wachstum von Muskel- und Fettgewebe wurden durch die magnetische Resonanz (MR) bestimmt. Die Analyse des alometrischen Wachstums hat gezeigt, dass das Muskelgewebe proportionell mit der Vergrößerung des Körpergewichtes wuchs; das Fettgewebe wuchs schneller in Bezug auf das Gewicht bei allen geprüften Schweinegruppen. Wichtige Unterschiede bei den Koeffizienten für Fettwachstum wurden nur bei Gruppen mit verschiedenen Ernährungsregimen vorgefunden. Die Analyse mit der asymetrischen S-Funktion gab mehr Informationen. Das Muster des Muskelgewebewachstums unterschied sich bedeutend innerhalb der Gruppen der erforschten Schweine (Nn Schweine hatten bessere Resultate unter dem Regime der intensiven Ernährung als der restriktiven Ernährung, während kein Unterschied zwischen NN Schweinen in beiden Ernährungsregimen festgestellt wurde. Das optimale Gewicht der geschlachteten Schweine wurde auf Grund des Gewichtes der lebendigen Schweine und auf Grund des Muskelgewebewachstums festgestellt (130 und 126 kg für intensive Ernährung NN und Nn Schweine und um 114 kg für beide Genotyps aus der restriktiven Schweinegruppe). Die Muster des Wachstums von Fettgewebe haben sich nur bei Gruppen mit unterschiedlichen Ernährungsregimen bedeutend unterschieden. Es scheint, dass die asymetrische S-Funktion ein präziseres und informationsreicheres Modell von der einfachen alometrischen Funktion ist, weil sie eine breitere Basis hinsichtlich Entscheidungen für die Schweinezucht darstellt.

Schlüsselwörter:*Modelle des Wachstums, MRI, Schweine*

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