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ASYMMETRIC S-FUNCTION IN THE PREDICTION OF GROWTH CHARACTERISTICS OF HYBRID PIGS

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ABSTRACT

The present study was carried out on 47 barrows equally distributed into two different feeding groups (intensive and restricted). MR tomography was used to obtain the data needed for calculation of optimal slaughter weight. Growth analyses and predictions were performed using asymmetric S-function. Feeding regime had significant effect on the growth of live weight and fat volume ($P < 0.05$); the influence on muscle volume growth was not detected ($P > 0.05$). The optimal slaughter weight in the sense of maximal utilisation of the muscle growth was 130 kg in the case of intensively fed pigs; and 114 kg in the case of restrictive feeding. The power of prediction of the established models was satisfactory. The accuracy of live weight prediction at the age of 154 days was lower in the intensively fed pigs (error ~6 days on average) than in the restrictive group of pigs (error ~4 days on average). Since average divergence from actual live weights was less than one week, the models could be considered fairly accurate.

Key words: pigs / growth / non-linear models / prediction

NAPOVEDOVANJE LASTNOSTI RASTI PRI HIBRIDNIH PRAŠIČIH Z ASIMETRIČNO S-FUNKCIJO

IZVLEČEK

V študijo je bilo vključenih 47 kastratov, enakomerno razporejenih v dve skupini z različnim krmljenjem (intenzivno in restriktivno). Za določitev optimalne telesne mase ob zakolu smo uporabili MR tomografijo. Analizo in napoved rasti smo naredili s pomočjo asimetrične S-funkcije. Režim krmljenja je značilno vplival na rast žive telesne mase in na volumen maščobe ($p < 0,05$); vpliv na rast volumna mišic ni bil potrjen ($p > 0,05$). Optimalna masa ob zakolu v smislu maksimalnega izkoriščanja rasti mišic je bila 130 kg v primeru intenzivno krmljenih prašičev in 114 kg v primeru restriktivnega krmljenja. Napoved predstavljenih modelov je bila zadovoljiva. Točnost napovedovanja žive telesne mase pri starosti 154 dni je bila manjša pri intenzivno krmljenih prašičih (napaka v povprečju ~6 dni) kot v skupini restriktivno krmljenih prašičev (napaka v povprečju ~4 dni). Ker je bil povprečni interval med meritvami žive telesne mase manjši kot en teden, bi modele lahko obravnavali kot zadovoljivo natančne.

Ključne besede: prašiči / rast / nelinearni modeli / napoved

INTRODUCTION

There are many mathematical models used in the description of animal growth over time in order to make useful predictions. Often used are the Gompertz, Bertalanffy's, Richard's function and various forms of generalised logistic functions such as asymmetric S-function. Knowing the

parameters in such models enables the prediction of the future live weights of an animal or their tissues, organs etc. Kuhn *et al.* (1985) demonstrate the use of the Gompertz function in the prediction of the growth of muscle, fat and bone contents in the carcasses of pigs. By means of the same function, Kuhn *et al.* (1987) determined the optimum slaughter date for pigs kept on different energy diets with the aim of maximum utilisation of the meat growth potential. Kralik *et al.* (1993) showed that the asymmetric S-function was appropriate in growth description of boars during the fattening period. Knowledge of function parameters allowed good predictions of the time animals needed to obtain a predefined live weight (100 kg). Using the same function, Kusec *et al.* (2007) studied the growth of hybrid pigs by means of magnetic resonance imaging (MRI) to obtain the data on muscle and fat content in the body. The authors showed that asymmetric S-function was appropriate for the depiction of pig growth. The aim of this study is to use the asymmetric S-function to establish the model for description of the growth characteristics of pigs kept in two different feeding regimes. Finally, the objective is to examine the accuracy of predictions made by proposed models.

MATERIAL AND METHODS

The present study was performed on 47 barrows kept in two different feeding regimes; 24 pigs were fed intensively (*ad libitum*) and 23 pigs were fed restrictively (according to BHZP recommendations). The pigs were 4-way-crosses with a Piétrain × Hampshire sire and a Large White × German Landrace dam. Data on muscle and fat growth were obtained by magnetic resonance imaging (MRI). For modelling the growth dynamics of the live weight, muscle tissue and fat, an asymmetric S-function was used:

$$f(t) = \frac{A}{(1 + be^{-c\gamma t})^{1/\gamma}},$$

where *b* and *c* were calculated on the basis of collected data, *A* denotes the maximum live weight under specific condition (feeding regime in present study). Symbol γ is the coefficient of asymmetry (0.01). The inflection point marks the moment at which progressive growth ceases. It is determined by the following expressions:

$$I = \left(\frac{1}{c\gamma}\ln\frac{b}{\gamma}\ ;\ \frac{A}{(1+\gamma)^{1/\gamma}}\right)$$

The stages of growth are determined by t_B and t_C points calculated by the following formulas:

$$t_B = \frac{1}{c\gamma}\ln\frac{2b}{\gamma(\gamma+3)+\gamma\sqrt{(\gamma+1)(\gamma+5)}} \qquad t_C = \frac{1}{c\gamma}\ln\frac{2b}{\gamma(\gamma+3)-\gamma\sqrt{(\gamma+1)(\gamma+5)}}$$

Interval ($t < t_B$) is called the stage of preparing growth; ($t_B < t < t_C$) represents the stage of intensive growth and ($t > t_C$) is the stage of growth retardation. The function parameters and points (t_B, t_I, t_C) were obtained on the 18 pigs from intensive and 17 pigs from restrictive fattening group. The knowledge of the parameters of the asymmetric S-function for a certain population enables direct solving of a differential equation for some given initial condition, e.g. the first weight taken for an individual animal. This means that it is possible to predict the future live weight of an animal by knowing its live weight at a certain moment. The remaining 6 pigs from each group were used to verify the prediction power of obtained models. Growth curve parameters and points that determine stages of growth were calculated for each animal individually by use of STATISTICA 7.1 program package (StatSoft, Inc. 2005). Statistical analysis of these values was performed by two way ANOVA from the GLM procedure of SAS 9.0 program package (SAS Institute Inc., 1989).

RESULTS AND DISCUSSION

Live weight growth

The parameters of the asymmetric S-function depicting the growth of pigs from investigated feeding groups are presented in Table 1 and Fig. 1 shows their growth curves.

Table 1. Means and standard errors (in brackets) for parameters of growth curves and points that determine the stages of live weight growth for pigs kept in two different feeding systems

Parameters	Intensive feeding	Restrictive feeding
b	0.054 (0.002)	0.058 (0.002)
c	1.382[a] (0.026)	1.686[b] (0.028)
Points (days)		
t_I	122.13[a] (0.955)	103.57[b] (1.386)
t_B	51.75[a] (1.322)	45.98[b] (1.624)
t_C	192.50[a] (1.823)	161.15[b] (1.704)
$\Delta = t_C - t_B$	140.75[a] (2.550)	115.17[b] (1.843)

Values within rows with a different superscript differ at the level of $P < 0.05$.

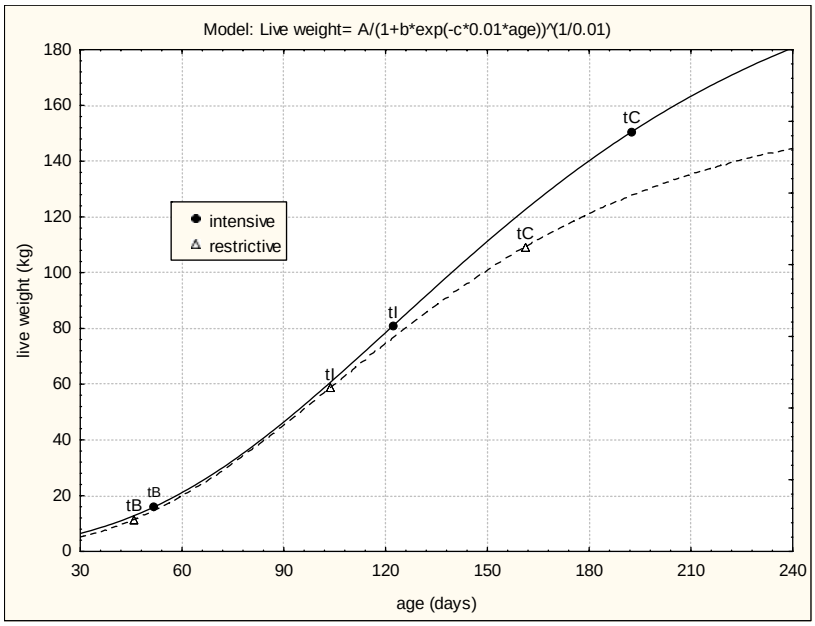

Figure 1. Growth curves for the live growth of intensively and the restrictively fed pigs.

From the presented results it is obvious that feeding regime had significant effect on growth characteristics of investigated pigs. The model used in the description of growth of intensively

fed pigs had the asymptotic maximum value set to 220 kg. Growth of the pigs kept in the restrictive feeding system was described by the model with asymptotic final weight of 160 kg which resulted in lower values of the points that separate different phases of growth (t_B, t_I, t_C). The function used in present study has the flexible inflection point determined by the coefficient of asymmetry, $\gamma = 0.01$, and empirical value taken from literature (Kralik *et al.*, 1993; Jelen, 1998; Kralik *et al.*, 1999). This coefficient means that the S-function is negatively asymmetric leading to inflection point lower than A/2 as it would have been if $\gamma = 1$, like in the logistic function.

Muscle growth

The asymmetric S-function describing the muscle growth of pigs from investigated groups had the parameters and points as presented in Table 2; Fig. 2 presents the growth curves resulting from those models.

Table 2.. Means and standard errors (in brackets) for parameters of growth curves and points that determine the stages of muscle growth for pigs kept in two feeding regimes

Parameters	Intensive feeding	Restrictive feeding
b	0.069 (0.003)	0.071 (0.004)
c	1.711 (0.042)	1.728 (0.040)
Points (days)		
t_I	111.94 (0.987)	112.45 (1.409)
t_B	54.85 (1.292)	55.99 (1.882)
t_C	169.02 (2.037)	168.91 (1.992)
$\Delta = t_B - t_C$	114.17 (2.783)	112.93 (2.660)

Values withn rows with a different superscript differ at the level of $P < 0.05$

The value of A was set to 70 dm^3 for both group of pigs. The results show that there were no significant differences between the investigated groups of pigs in the function parameters, nor in the points determining the phases of muscle growth. In present study, the pigs from both feeding regimes reached the point of muscle growth saturation (t_C) at the age of approximately 169 days. After this age, the most of the live weigh gain is accomplished by fat deposition. When parameters of live weight growth are applied for the respective feeding groups, than it can be seen that useful growth is finished at the live weight of 130 kg in the case of intensively fed pigs; and at 114 kg in the case of restrictive feeding. This points can be regarded as optimal slaughter weight (age) for the pigs from current study.

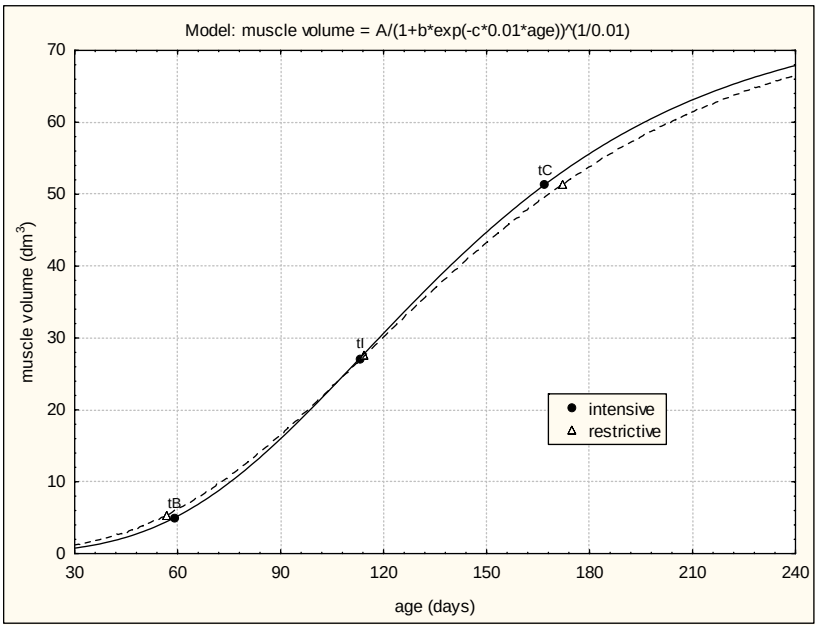

Figure 2. Growth curves for the muscle volumes of intensively and the restrictively fed pigs.

The growth of fat

Table 3 show the parameters of S-curves (Fig. 3) calculated for the intensively and restrictively fed pigs. From the results presented it is obvious that feeding system had significant effect on the growth of fat. There were significant differences between the investigated groups of pigs in parameter b ($P < 0.01$), and in the points t_B i t_I ($P < 0.01$). The fact that there were no significant differences in the points of saturation (t_C) should be taken with caution. The growth of pigs from the intensive group was described by a model with an A value of 70 dm^3, while restrictively fed pigs had a different value of A (50 dm^3). The models set up in this manner showed very high goodness of fit and converged well for all of the animals. Intensively fed pigs needed 148 days to reach the inflection point of 25 dm^3 of fat volume; while the restrictively fed pigs reached approximately 18 dm^3 fat in about 140 days.

Table 3. Means and standard errors (in brackets) for parameters of growth curves and points that determine the stages of fatty tissue growth for pigs kept in two feeding regimes

Parameters	Intensive feeding	Restrictive feeding
B	0.081[a]	0.067[b]
	(0.003)	(0.004)
C	1.414	1.349
	(0.036)	(0.064)
Points (days)		
t_I	148.21[a]	139.85[b]
	(2.083)	(2.561)
t_B	79.01[a]	65.22[b]
	(1.220)	(2.546)
t_C	217.41	214.47
	(3.799)	(6.369)
$\Delta = t_B - t_C$	138.40	149.25
	(3.804)	(8.239)

Values withn rows with a different superscript differ at the level of $P < 0.05$

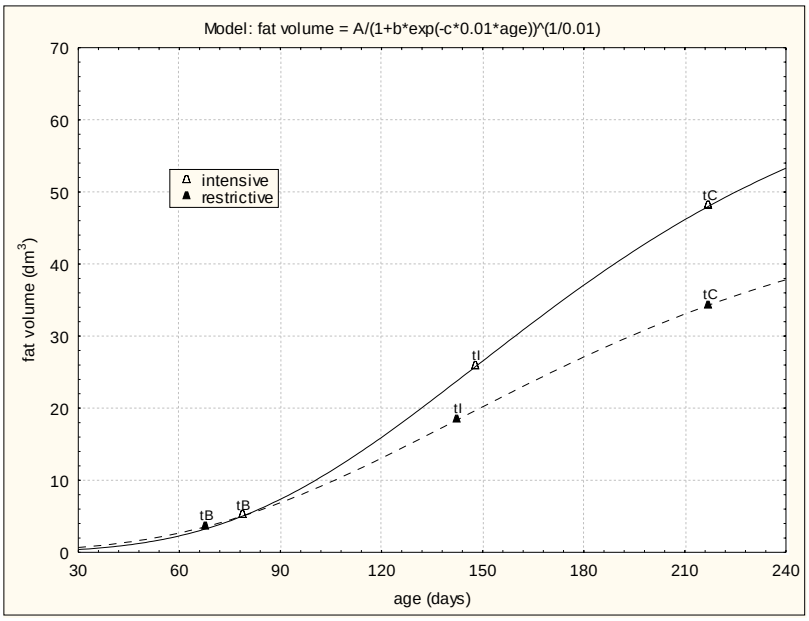

Figure 3. Growth curves for the fat volumes of intensively and the restrictively fed pigs

The power of prediction

The optimal time and live weight for slaughtering of the pigs from present study was stated above. Unfortunately, because of the size of the pigs at these points they could not fit the tube of NMR tomography device so the prediction of optimal slaughter weight/age could not be verified. Instead, the prediction power of the model was examined for live weights of the pigs that were recorded at the last MR imaging. To complete this task, the method of discretisation for the initial condition $y(t_0) = y_0$ (the first weight taken for an individual animal) was used. This yielded the solution: $y_{n+1} - y_n = h \times c \times y_n \times (1 - (y_n / A)^{\gamma})$; h = 1, where y_n is the live weight of an animal at the time n, y_{n+1} is the predicted successive live weight at the time n+1, c is the parameter of the S-function, γ is the coefficient of asymmetry and h is constant. Using respective parameters from the Table 1, the pigs from investigated groups were individually evaluated in order to predict live weight at the age of 154 days. Since individual weights of pigs at mentioned age were recorded, the estimated time they needed to reach them could be calculated. Subtraction of the age of pigs at the weighing (154 days) from the age predicted in described manner gave the accuracy of the model presented in Table 4. From this table it is obvious that the prediction accuracy was lower in the intensively fed pigs, ~6 days on average; in the restrictive group of pigs, misestimates of live weight predictions were on average ~4 days. Since average divergence from actual live weights was less than one week, the model could be considered fairly accurate.

Table 4. Individual live weights at 154 days of age and the differences between that age and the predicted one by the respective mathematical expression

Animal	Intensive		Restricted	
	LW, kg	Age Δ, days	LW, kg	Age Δ, days
1	95	−13	108	3
2	107	−2	103	−2
3	116	−4	113	4
4	119	3	111.5	8
5	123.5	6	114	6
6	110.5	−8	105	−2

CONCLUSIONS

On the basis of present study following can be concluded:

- Growth of the pigs kept in the intensive and restrictive feeding system was described by the models with asymptotic final weight of 220 and 160 kg. The analysis by those models showed that the feeding regime had significant effect on live weight growth of investigated pigs.
- There were no significant differences between the investigated groups of pigs in the function parameters, nor in the points determining the phases of muscle growth. The pigs from both feeding regimes reached the point of muscle growth saturation (t_C) at the age of approximately 169 days. Since after this age the most of the live weigh gain is accomplished by fat deposition this could be considered as the optimal slaughter age. The live weight of intensively and restrictively fed pigs at this age was 130 kg and 114 kg, respectively.The growth of fatty tissue was significantly affected by the feeding regime.
- The power of prediction of the established models was satisfactory. The accuracy of live weight prediction at the age of 154 days was lower in the intensively fed pigs (error ~6 days on average) than in the restrictive group of pigs (error ~4 days on average). Since average divergence from actual live weights was less than one week, the models could be considered fairly accurate.

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