Optimal slaughter weight of pigs assessed by means of the asymmetric S-curve

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ABSTRACT: The present study was carried out on 68 barrows equally distributed into two different feeding groups (intensive and restricted). MR tomography was used to obtain data needed for the calculation of optimal slaughter weight. Growth analyses and predictions were performed using an asymmetric S-function. The differences between the predicted and real time needed to achieve 100 kg live weight calculated for the two feeding groups of pigs were not statistically significant. The prediction was fairly accurate in 88% of the cases for the intensive group and 79% of the cases for the restrictively fed pigs. The point of muscle growth saturation (t_C = 51.31 dm^3) calculated for pigs from the intensive group occurred at 164 days of age. Restrictively fed pigs reached this point after 167 days. It was calculated that at 164 days of age intensively fed pigs reached about 126 kg; the pigs from the restricted group reached about 112 kg at 167 days. These weights can be regarded as optimal slaughter weights for pigs from the present study in the sense of maximum utilisation of muscle growth. Since both groups of pigs reach the same muscle volume of 51 dm^3 at the estimated times, the difference in live weights can be attributed to the volume of fat. This makes the intensive system of feeding undesirable in economical pig production. It is concluded that the obtained parameters of the asymmetric S-function can be used for the growth analysis of other pigs, assuming that they are of the same genetic background and reared in the same conditions. It is suggested that the carcass values of pigs slaughtered at optimum live weights proposed here should be compared with the values of pigs slaughtered at other live weights in order to decide between maximum utilisation of muscle growth or achieving the most desirable lean percentage in carcass.

Keywords: pigs; feeding regime; growth; prediction; non-linear models

There are many mathematical models used to describe the growth of domestic animals over time in order to make certain predictions and comparisons. Well known are the logistic function, Richard's function, various forms of generalised logistic functions etc. A comprehensive review of non-linear, time related growth models commonly used in animal science was given by Pfeifer et al. (1984), who thoroughly described and explained Gompertz, logistic, Bertalanffy's and Janoshek's functions and their application to different categories and genotypes of pigs. What these functions have in common is the graph which has a characteristic S-shape, and it is often called "sigmoid" or S-curve. The knowledge of parameters in some models enables to predict the future live weights of animals or their tissues, organs etc. Kuhn et al. (1985) demonstrated the use of the Gompertz function for a description of the growth of muscle, fat and bone contents in the carcasses of pigs from birth until 245 days of life kept on three different feeding intensities. By means of this function, Kuhn et al. (1987) determined the optimum slaughter date for pigs kept on different energy diets with the aim of maximum utilisation

Table 1. Designed feeding regimes

	Start (25–70 kg) (9^{th}–17^{th} week)	Finish (from 70 kg) (from 18^{th} week)
Control group, restricted (BHZP)	*ad libitum*	restricted to 34 MJ ME/day
	13.0 MJ ME	13.0 MJ ME
	17.5% crude proteins	15.0% crude proteins
Experimental group, intensive (new concept)	*ad libitum*	*ad libitum*
	13.8 MJ ME	13.8 MJ ME
	17.5% crude proteins	15.0% crude proteins

of the meat growth potential, simultaneously avoiding the animals to get too fat. Kralik et al. (1993) showed that the asymmetric S-function, as a form of a generalised logistic equation with a variable inflection point, proved to be appropriate in the growth description of boars during the fattening period. The knowledge of function parameters allowed good predictions of the time animals needed to obtain a predefined live weight (100 kg).

Non-invasive techniques such as computer tomography (CT) and magnetic resonance tomography (MRT) are known to be powerful tools for the estimation of muscle and fat tissue in pigs (Vangen and Jopson, 1996; Kolstad, 2001; Tholen et al., 2003; Baulain et al., 2004; Collewet et al., 2005; Monziols et al., 2006). Kusec et al. (2007) used the asymmetric S-function to describe live weight growth patterns of German hybrid pigs, using MRT to determine tissue volumes (muscle and fat) at certain points in time. They found coefficients for constructing the S-curve that could depict the growth pattern of MHS negative (NN) and MHS gene carrier (Nn) pigs from two different feeding regimes. A significant difference in live weight growth characteristics existed between the investigated feeding groups, but genotype had no significant effect. Therefore, the aim of this paper is to customise the S-functions to the feeding groups included in research (intensive and restricted ones), disregarding the genotypes as source of variation. Subsequently, the accuracy of live weight predictions for two feeding groups of common pigs used for fattening in Germany will be tested. Finally, the objective of the present study is to predict an optimum slaughter weight that will allow the maximum utilisation of the muscle growth potential on the basis of muscle growth evaluation by means of the asymmetric S-function.

MATERIAL AND METHODS

Animals used in the experiment

This study was carried out on 68 barrows kept in single pens in the same conditions, but under two different feeding regimes as shown in Table 1. The restricted group represents a feeding regime designed according to the current BHZP recommendations. The intensive group was an experimental

Table 2. Diet composition (%) of the restricted and intensive feeding regime used in the experiment

	Restricted		Intensive	
	start	finish	start	finish
Barley	27.5	34.0	14.3	28.0
Wheat	50.0	50.0	60.0	54.8
Soya	18.6	12.9	18.5	12.2
Soybean oil	0.6	0.3	3.1	1.7
Feed lime	0.5	0.5	0.3	0.5
Mineral	2.0	2.0	2.2	2.0
Lysine	0.6	0.3	1.1	0.5
Methionine	0.1	0.0	0.3	0.1
Threonine	0.1	0.0	0.3	0.1

one, receiving the generous supply of nutrients in order to support the full growth potential (unrestricted feeding system). The diets used for feeding were designed and mixed in the mill of the Institute (FAL) in Mariensee and were composed of the following ingredients: barley, wheat, soybean meal, soybean oil, minerals and additional amino acids: lysine, methionine and threonine (Table 2).

MR imaging

The data needed for the calculation of optimum slaughter weight were acquired with an MR tomograph in the process of magnetic resonance tomography. MRT measurements were performed at 4 week intervals, starting at 10 weeks of age up to the final live weight of approximately 120 kg. The volumes of muscle tissue and fat were calculated by the mathematical method known as the Cavalieri method. This principle is the basis for the volume estimation as used today (Roberts et al., 1993).

Growth analysis

The basis for the pig growth analysis in the present study is a natural law discovered by Nelder (1961) and Lewandowski (1974):

$$\frac{dy}{dt} = cy\,(t) \times \left(1 - \frac{y(t)}{A}\right)^{y}$$

$c > 0; \gamma > 0$

which says that the weight gain of an organism at a certain moment is proportional to the weight of the organism at that moment $y(t)$ and to the biological potential at that moment

$$(A - y(t))$$

where:

A = the chosen maximum weight of the species in question, and where the two factors have a different intensity of action on the weight gain at different time intervals

For modelling the growth dynamics (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 the generalised form of the logistic function was used:

$$f(t) = \frac{A}{(1 - bt^{-cyt})^{1/y}}$$

where:

b, c = calculated on the basis of collected data

A = denotes the maximum live weight under specific conditions (feeding regime in the present study)

γ = the coefficient of asymmetry

More details on the model are given by Jukić and Scitovski (2003). The knowledge of the parameters of the asymmetric S-function (c and γ) for a certain population enables to solve directly a differential equation for some given initial conditions. This means that it is possible to predict the future live weight of an animal when knowing its live weight at a certain moment. The method of discretisation for the initial condition $y(t_0) = y_0$ (the first weight taken for an individual animal) yields the solution:

$$Y_{n+1} - y_n = h \times c \times y_n \times (1 - (y_n/A)^{\gamma})$$

$$h = 1$$

where:

y_n = live weight of an animal at the time n

y_{n+1} = predicted successive live weight at the time $n + 1$

c = parameter of the S-function

γ = coefficient of asymmetry

h = constant

Statistical analysis

Comparisons of the real and predicted live weight of investigated pigs were performed by one-way ANOVA procedure of SAS program package (Version 9.0; SAS, 2002). Graphs and charts presented in this thesis were created using Statistica for Windows 5.0 (StatSoft, 1996) and Microsoft Excel for XP (Microsoft Corporation, 2002) packages.

RESULTS AND DISCUSSION

Prediction of live weights

Using the asymmetric S-function, two different equations were constructed in order to predict the time needed for an animal to reach the live weight of 100 kg on the basis of the live weights at the beginning of the experiment (initial conditions). Since S-curves for different MHS genotypes within the feeding groups of pigs had very similar patterns (Kusec et al., 2007), the mentioned equations were reconstructed regardless of the genotype as follows:

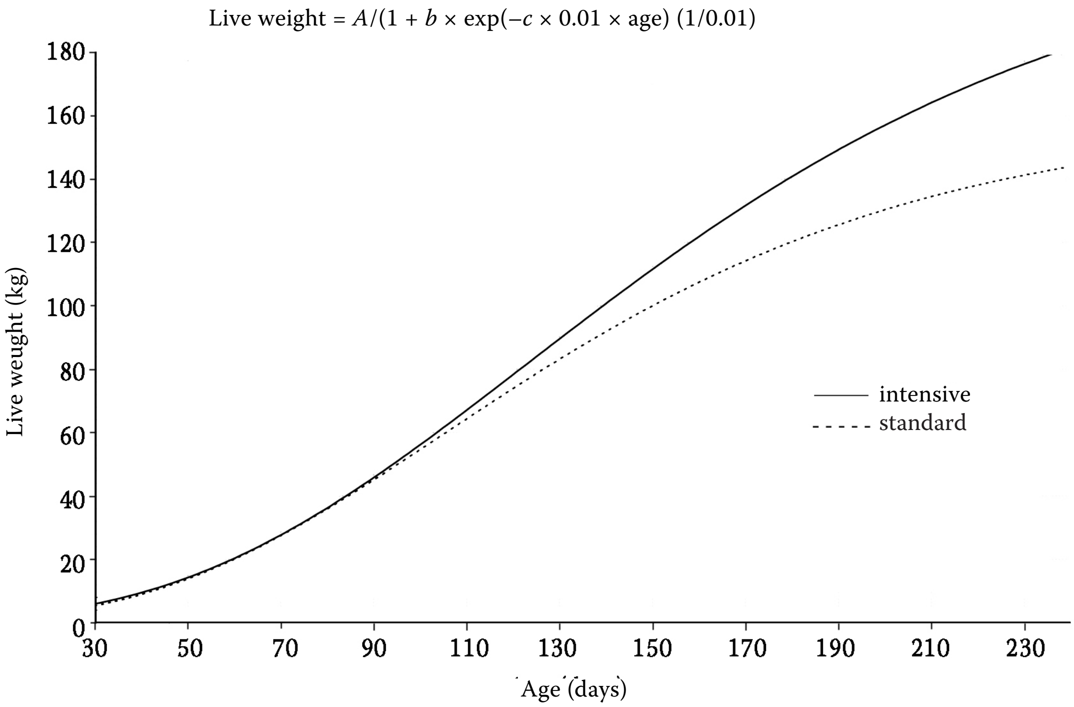

Figure 1. Growth curves for the intensive and restricted group of investigated pigs

Feeding group – intensive:

$$f_{(t)} = \frac{220}{(1 + 0.055914e^{-1.403013 \times 0.01 \times t})^{1/0.01}}$$

Feeding group – restricted:

$$f_{(t)} = \frac{160}{(1 + 0.056774e^{-1.659963 \times 0.01 \times t})^{1/0.01}}$$

The graphs of these functions have characteristic S-shapes as shown in Figure 1. Solutions to the discretisation for the initial condition $y(t_0) = y_{0,}$ i.e. the first weight taken for an individual pig from the intensive and restricted group, were:

$$Y_{n+1} - y_n = 1 \times 1.403013 \times y_n \times (1 - (y_n/220)^{0.01})$$
$$Y_{n+1} - y_n = 1 \times 1.659963 \times y_n \times (1 - (y_n/160)^{0.01})$$

Based on these equations, predicted times were calculated for each pig and compared with the real time needed to reach 100 kg of live weight for the pigs involved in the experiment; the results are presented in Table 3. As expected, there was an evidence of a strong statistical influence ($P < 0.001$) of the feeding system on the duration of fattening period up to 100 kg live weight. The differences between the time predicted to achieve 100 kg live weight and the real observed time within the two feeding regimes were not statistically significant, implying that the calculated parameters enabled a good estimation of live weight growth. This is supported by previous results of Kusec et al. (2005), who found significant differences between the feeding groups of pigs from the same experiment in average daily intake and gain, feed conversion ratio and in final live weights.

Table 3. Means and standard deviations for the predicted and real time needed to achieve the live weight of 100 kg for pigs from the intensive and restricted group

	Intensive		Restricted	
	predicted	real	predicted	real
Mean	76.82[a]	76.03[a]	89.26[b]	87.91[b]
Standard deviation (SD)	4.69	6.1	5.47	8.1

[a,b] $P < 0.001$

Table 4. The accuracy of prediction of the time needed to achieve 100 kg of live weight for pigs from the intensive and restricted feeding group

Real-predicted (days)	Frequency (n = 34)	
	intensive	restricted
0	5	0
1	13	5
2	3	7
3	1	4
4	0	2
5	7	3
6	0	5
7	1	1
8	0	2
9	0	1
10	2	1
11	1	1
12	0	0
13	0	0
14	0	1
>14	1	1

Results presented in Table 4 show the frequency of good (real-predicted = 0 days) and false (misestimates for 1–14 and >14 days) predictions of the time period for achieving the selected live weight. It can be seen that for 25 pigs from the intensive group, discrepancies between the predicted and real time to reach 100 kg live weight fall within the interval of one week; for 5 pigs the prediction was fully accurate. For 3 intensively fed pigs, the inaccuracy of estimation was 10 to 11 days; for one pig, the prediction was inaccurate by more than 2 weeks. The same estimations in the restricted group of pigs were less accurate to some extent. Inaccuracies of up to one week appeared in 27 cases, while for 7 pigs the prediction of the time needed to reach 100 kg of live weight deviated by more than one week (for one of them more than 2 weeks).

The prediction was fairly accurate (i.e. a difference between the predicted and the real time was one week or less) in 88% of the cases for the intensive group and 79% of the cases for the restricted group of pigs (Figure 2). In most cases in which the prediction was inaccurate by more than one week (9 and 18% of the pigs from the intensive and the restricted group, respectively) the pigs were either exceptional in final weights/daily gains or they suffered from health problems followed by severely decreased daily gains. The criteria for excluding an animal from the experiment were the same as those used by testing stations in Germany. Some of the inaccurately predicted pigs were very close to being excluded from the experiment. Kralik et al. (1993) compared the real time periods needed to reach 100 kg with the time predicted by the asymmetric S-function. The differences found by the authors were between 1 to 5 days, which means a very precise prediction. However, it should be taken into consideration that they presented the data on 6 randomly chosen boars from a set of 30 boars investigated. Having in mind that the difference between the predicted and the real time found in the present study was seven days or less for 88% and 79% of the cases for the intensive and restricted group of pigs respectively, it can be stated that the estimation was fairly accurate.

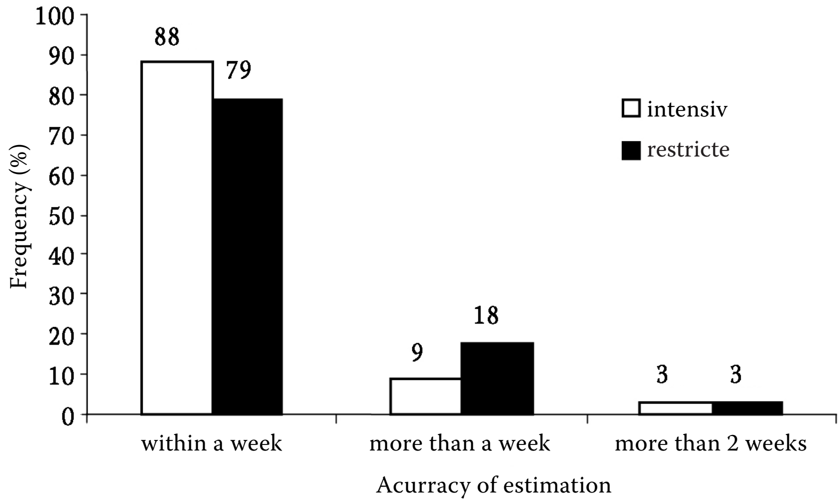

Figure 2. The accuracy of predicted time needed to achieve 100 kg of live weight for pigs from the intensive and restricted feeding group by time units (weeks)

Muscle growth

When the asymmetric S-function was customised to the feeding groups and applied for the depiction of the muscle volume growth of investigated pigs, the following equations were obtained:

Feeding group – intensive:

$$f_{(t)} = \frac{75}{(1 + 0.067451e^{-1.75078 \times 0.01 \times t})^{1/0.01}}$$

Feeding group – restricted:

$$f_{(t)} = \frac{75}{(1 + 0.064666e^{-1.694158 \times 0.01 \times t})^{1/0.01}}$$

Points in the presented graphs determine the stages of muscle growth (Figure 3). Interval ($t < t_B$) is called the stage of preparative growth; ($t_B < t < t_C$) represents the stage of intensive growth and ($t > t_C$) is the stage of growth retardation. In the present study, most important is the point of saturation (t_C = 51.31 dm^3) which denotes the time when the intensive phase of muscle growth ceases and turns to the phase of retardation. For pigs from the intensive group, this moment occurred after 164 days of life (around 101 days in test). It was estimated by the same model that the restricted group of pigs reached the point of muscle growth saturation after 167 days of life or about 104 days in test. After this point pigs tend to gain weight only by fat deposition and there is no use in further fattening. If growth parameters from the live weight analysis are used, it can be calculated by means of the asymmetric S-function that at the age of 164 days intensively fed pigs reached about 126 kg and the pigs from the restricted group reached about 112 kg at 167 days of life. These weights can be regarded as optimum slaughter weights for pigs involved in this experiment in the sense of maximum utilisation of muscle growth potential. Since both groups of pigs reach the same muscle volume of 51 dm^3 at the times mentioned above, the difference in live weights can be attributed to the volume of fat which, according to Kusec et al. (2007), is very near to the peak of growth intensity (point of inflection) in the intensive group of pigs. The same authors also stated that the growth patterns of fat tissue volume markedly differed between the two feeding treatments, being more intense in the intensively fed pigs.

Kuhn et al. (1987) recommended an optimum slaughter age of 210 to 240 days of life (105–118 kg of live weight) using the Gompertz function in order to completely utilise the muscle growth potential of pigs fed a medium energy diet. Even though

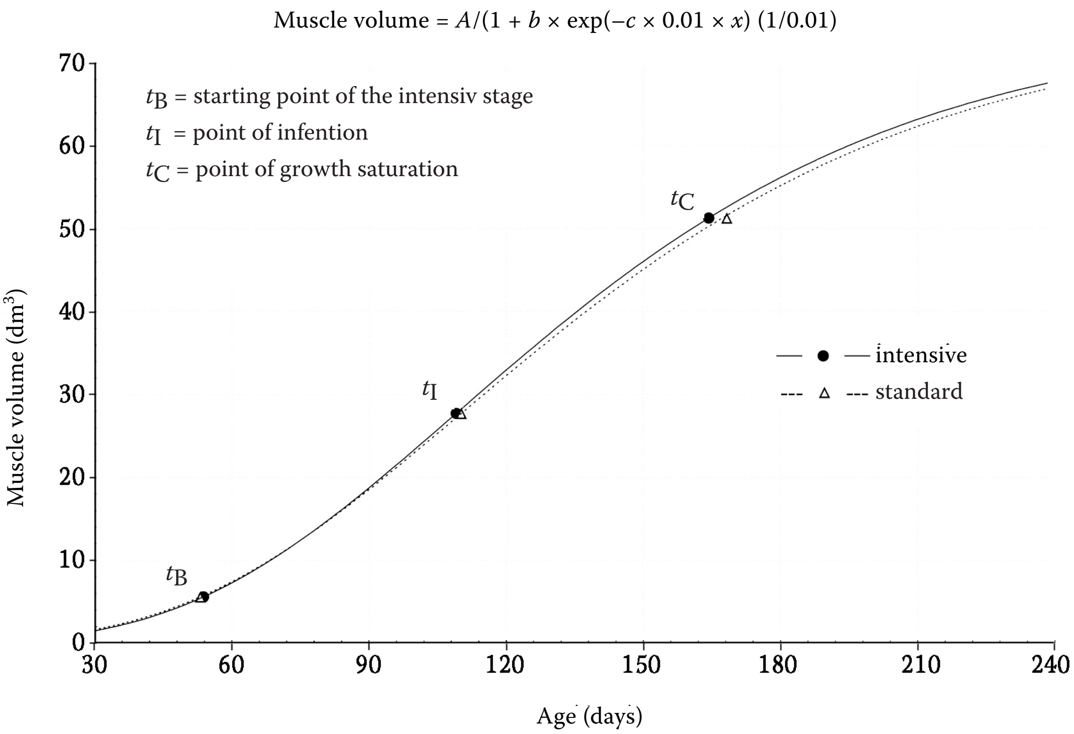

Figure 3. Growth curves for the muscle tissue of pigs from the intensive and restricted group

the trial conducted by the above-mentioned authors is not exactly comparable with the experiment of the present study, the optimum slaughter date (weight) of 164 days (126 kg) in the intensive group and 167 days (112 kg) in the restricted group found in the present study indicate some progress in pig breeding over the past time. The results of the present study are currently well supported by data from practice. They are more congruent in the case of the restricted group because an intensive feeding system is rarely practiced. The progeny-tested barrows are fattened up to a carcass weight of about 85 kg which they reach at 155–170 days of age; e.g. German Landrace reaches 85 kg of carcass weight at 166 days, Large White 85.1 at 162 days, Large White × German Landrace 85.6 kg at 160 days, Duroc × German Landrace 86 kg at 156 days, Piétrain × (Large White × German Landrace) 85.6 at 171 days of age, etc. (Anonymus, 1999).

It would be interesting to estimate the carcass values of pigs fed under the restricted feeding regime and slaughtered at live weights suggested in the present study by the (S)EUROP system, and to compare these results with those obtained for pigs slaughtered at different live weights. This would help to decide if it is better to utilise the maximum muscle growth potential or to program the slaughter weight in such a manner that it achieves the highest lean percentage, which is also strongly influenced by the fat content in carcass.

CONCLUSION

The asymmetric S-function showed to be a good mathematical tool for the prediction of live weight and muscle growth not only within the intervals of the obtained data sets but also along the time scale. The prediction could be calculated for the whole group of animals or individually for each animal on the basis of the initial condition, i.e. first measurement.

Combining the results of the growth analysis performed for live weight and muscle it was possible to establish the optimal slaughter age and live weight (in the sense of maximal utilisation of muscle growth) for the investigated groups of pigs.

Optimum live weight for slaughtering the pigs from the intensive group was about 126 kg at which the muscle gain reaches its peak, but the amount of fat in carcasses also increases. This directs the farmers to decide either on the utilisation of the maximum muscle growth potential of pigs fed in such a manner or on their earlier slaughter, which can also reduce the fat content in carcasses. Since the live weight difference between the investigated groups was mainly in the fat content, intensive feeding is not to be recommended in the present case. The restricted feeding system recommended by BHZP supported the requirements for the normal muscle tissue growth of investigated pigs.

The obtained parameters of the asymmetric S-function should be tested for the growth analysis of other pigs with the same genetic background and reared in the same conditions.

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