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Modeling the growth of the Goettingen minipig¹

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ABSTRACT: The Goettingen minipig developed at the University of Goettingen, Germany, is a special breed for medical research. As a laboratory animal it has to be as small and light as possible to facilitate handling during experiments. For achieving the breeding goal of small body size in the future, the growth pattern of the minipig was studied. This study deals with the analysis of minipig BW by modeling growth with linear and nonlinear functions and comparing the growth of the minipigs with that of normal, fattening pigs. Data were provided by Ellegaard Goettingen minipigs, Denmark, where 2 subpopulations of the Goettingen basis population are housed. In total 189,725 BW recordings of 33,704 animals collected from birth (d 0) to 700 d of age were analyzed. Seven nonlinear growth functions and 4 polynomial functions were ap-

plied. The growth models were compared by using the Akaike's information criterion (AIC). Regarding the whole growth curve, linear polynomials of third and fourth order of fit had the smallest AIC values, indicating the best fit for the minipig BW data. Among the nonlinear functions, the logistic model had the greatest AIC value. A comparison with fattening pigs showed that the minipigs have a nearly linear BW development in the time period from birth to 160 d. Fattening pigs have very low weight gains in their first 7 wk in relation to a specific end weight. After 7 wk, fattening pigs have increased growth, resulting in a growth curve that is more sigmoid than the growth curve of the minipig. Based on these results, further studies can be conducted to analyze the growth with random regression models and to estimate variance components for optimizing the strategies in minipig breeding.

Key words: body weight development, growth curve, growth model, Goettingen minipig

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INTRODUCTION

The Goettingen minipig is an important laboratory animal, especially used for the safety assessment of new pharmaceuticals and for surgical purposes and disease models because of its shared anatomic and physiologic characteristics with humans (Brandt et al., 1998). The breed was developed ca. 1960 at the University of Goettingen, Germany. After 30 yr of successful breeding, with a focus on breeding goals like small body size, unpigmented skin, and adequate fertility, 38 pregnant sows were brought to the Ellegaard farm in Denmark in 1992 to develop a new population. Today there are approximately 3,500 Ellegaard Goettingen minipigs whose breeding is controlled by the University of Goettingen.

The main difference between a minipig and a normal-sized pig is the smaller body size of the minipig. Goet-

tingen minipigs should have a mature BW of 35 to 45 kg (Bollen et al., 1998). This small body size is advantageous for the reduction of rearing and breeding costs and for handling of the minipigs during medical research. It can also be assumed that not only does the mature BW of minipigs differ from normal, fattening pigs but also the characteristics of BW development because the fattening pigs have been selected for fast growth in the last two-thirds of the fattening period. Compared with fattening pigs, the growth of minipigs should be slow and occur mainly in the first months after birth, so that the minipigs will have a low BW when entering laboratory facilities at an average age of 3 to 6 mo.

Knowing the growth pattern of minipigs is necessary for genetic research that will be conducted on this issue; e.g., estimation of variance components for growth at a certain age. The aims of this study were the application of different nonlinear and polynomial functions to describe the growth of minipigs and investigation of the difference in BW development compared with that of normal, fattening pigs.

MATERIALS AND METHODS

Animal care and use committee approval was not obtained for this study because the data were obtained

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from the existing database Navision from Ellegaard Goettingen minipigs. The data were acquired from 1995 to 2005.

Growth Curves Modeled over all Data

Data Description. For the analysis of growth, the data were provided from Ellegaard Goettingen minipigs, with a total number of 199,764 BW records of 33,749 animals. In this time period there was no organized selection for BW. Minipigs were selected for breeding because of low inbreeding coefficients and also for adequate exterior traits like white skin and little hair coat.

Because of scarcity, BW data measured after 700 d of age were excluded from the analyses. Outliers of the data set were detected using the influence diagnostics recommended by Belsley et al. (1980). With this method the influence of each observation on the estimates is measured. Influential observations are those that appear to have a large influence on the parameter estimates. The method of Belsley et al. (1980) is incorporated into the REG procedure (SAS Inst. Inc., Cary, NC) by using the INFLUENCE option in the MODEL statement. The Studentized residual was used for analyzing the influence of each weight record and was calculated as follows:

$$RSTUDENT = \frac{r_i}{s_{(i)}\sqrt{(1-h_i)}}$$

where $r_i = y_i - \hat{y}_i$; $s_{(i)}^2$ is the error variance estimated without the i th observation; and h_i is the hat matrix, which is the i th diagonal of the projection matrix for the predictor space. Belsley et al. (1980) suggest paying special attention to all observations with RSTUDENT larger than an absolute value of 2. We discarded all records lying outside the 95% confidence interval [-1.99; 2.15]. This resulted in a total of 189,725 BW records of 33,704 animals that were used for the growth analysis.

The minipigs were weighed routinely at various intervals, without any special treatment like fasting before weighing. On average, there were 5.63 BW recordings per minipig, with a maximum of 23 BW recordings (Figure 1). Nearly all animals were weighed on their day of birth (d 0). Pigs were then weighed at weaning (21 to 28 d of age) and then again at 8 wk of age, when they left the rearing unit. Later, all minipigs were weighed once each month, and each minipig was weighed before it was sold.

On the Ellegaard farm, the minipigs are housed in 2 units. Minipigs from both units have the same ancestors, but there is no genetic exchange between the units. Thus, every unit is an independent subpopulation with a specific environment. Because of these circumstances, the calculations were made for each unit separately. It was then possible to detect potential differences in the

growth curves between unit 1 and 2 due to environmental effects. Within each unit, the growth curve was modeled for each sex. The detailed numbers of analyzed animals and BW records are shown in Table 1.

There were no differences in the feeding regimen used in the 2 units. The minipigs were provided a special minipig diet, with 10.0 MJ of ME/kg and 13.9% CP per kg of DM, fed to the males at a rate of 250 to 500 g/d progressively from 2 to >12 mo of age. Females were fed approximately 80% of the amount offered to the males.

Growth Models. To estimate the body weight at a certain age, four 3-parameter and three 4-parameter nonlinear growth functions as well as 4 polynomial growth functions were fitted to the minipig BW data. The equations for the applied growth models are given in Table 2.

The logistic (Robertson, 1908) as well as the Gompertz function (Gompertz, 1825) were developed in former centuries. They have 3 parameters in the equation, with no flexible point of inflection. The von Bertalanffy function (von Bertalanffy, 1957a) is also a 3-parameter equation, but one in which the point of inflection lies at 30% of the mature BW. A critical assumption of this function is that the anabolic processes of the body are proportional to the surface of the organism, and the catabolic processes are proportional to the BW. These conditions are not necessarily the case during the growth of animals (Schönmutz and Seeland, 1994). The 3-parameter Brody function also has, a priori, no point of inflection (Brody, 1945).

The 4-parameter Richards function was developed as an advancement of the logistic and the Gompertz functions (Richards, 1959). It has a flexible point of inflection and thus is suitable for the application to animal growth. The Janoschek function (Janoschek, 1957) and the Bridges function (Bridges et al., 1986) are also flexible in their points of inflection and are mainly used to describe the postnatal growth of an individual.

The Ali-Schaeffer function (Ali and Schaeffer, 1987) can be interpreted as a fractional polynomial of degree 4, which is mostly used in models for calculating lactation curves of dairy cows. Guo (1998) classified the Ali-Schaeffer function as a function of the mixed-log family.

Linear models with a polynomial structure from second up to fourth order of fit were applied. Higher orders of fit did not achieve a significant influence on the fit of the growth curve ($P < 0.001$, F -statistic, SS Type 1) and were therefore not considered in the analysis.

Statistics and Model Comparison. The estimation of the nonlinear growth curves was carried out using the NLMIXED procedure of SAS. The linear growth curves were calculated with the MIXED procedure. The models were compared by using Akaike's information criterion (AIC; Akaike, 1973):

$$AIC = -2L_m + 2m,$$

where L_m is the maximized log-likelihood and m is the number of parameters in the model. The AIC takes

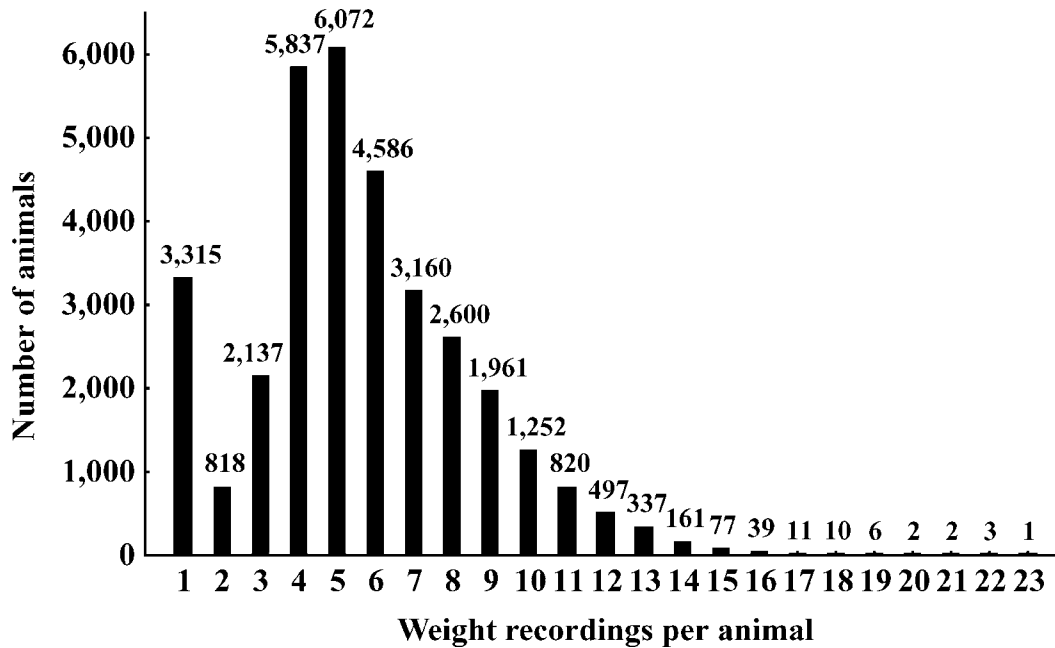


Figure 1. Number of BW recordings per animal and corresponding numbers of animals for all minipigs used in this study.

into account both the statistical goodness of fit and the number of parameters that need to be estimated to achieve this particular degree of fit, by imposing a penalty for increasing the number of parameters. Lower values of the AIC indicate the preferred model; that is, the one with the fewest parameters that still provides an adequate fit to the data.

The AIC is useful for comparing models with different numbers of parameters. It is therefore more advantageous than the R^2 , which increases with increasing numbers of parameters in the models and thus is not useful for the comparison of models with different numbers of parameters. The comparison of different non-nested models with this method determines which model is more likely to be correct and accounts for differences in the number of degrees of freedom. By using the ML method in the MIXED procedure, the AIC values obtained from the MIXED and the NLMIXED procedures can be compared. The model with the smallest AIC value was chosen to be the best for fitting minipig BW data.

Table 1. Number of animals and records per sex and unit used in the calculations

Sex	Unit ¹	No. of animals	No. of records
Male	1	10,717	59,045
	2	6,676	37,012
Female	1	9,848	55,556
	2	6,463	38,112
Total		33,704	189,725

¹Independent subpopulations.

For the model reduction from fourth to second order of fit in the linear polynomial functions, the F -statistic was used.

Comparison of Minipigs to Normal, Fattening Pigs

The results of Kusec (2001) were used for comparing the growth of the minipig with the growth of a normal, fattening pig. This author analyzed the growth of seventy-two 4-line crossbred barrows from an age of 9 to 26 wk. The pigs in the experiment were fed in 2 groups, an intensively fed group and a restrictively fed group. The BW of the pigs was 23 kg at the beginning of the test and 138 kg (intensively fed pigs) and 117 kg (restrictively fed pigs) at the end of the experiment. The barrows had a Piétrain \times Hampshire sire and a Large White \times German Landrace dam. This crossbreed represents standard, fattening pigs of the German Hybrid Pig Breeding Program (Bundes-Hybrid-Zuchtprogramm).

Additionally, 2 genotypes of malignant hyperthermia-susceptible (MHS) pigs were examined within a feeding group. The MHS-gene has a positive effect on the carcass leanness but a negative effect on meat quality. The pig breeders have the option to choose sire lines of different MHS-gene status, whereas the dam lines in Germany are completely MHS-negative. The genotypes of the normal, fattening pigs used in the study of Kusec (2001) were MHS-carrier (Nn) and MHS-negative pigs (NN). Both are frequently used genotypes in crossbred, fattening pig breeding programs in Germany.

Table 2. Functions considered in this study for modeling the growth curve of the minipig

Model	Equation ¹	No. of parameters	Reference
Logistic	$W = \frac{a}{(1 + b \times e^{(-c \times t)})}$	3	(Fekedulegn et al., 1999)
Gompertz	$W = a \times e^{-e^{(b - (c \times t))}}$	3	(Wellock et al., 2004)
von Bertalanffy	$W = \left[\left(\frac{a}{b} - \frac{a}{b - W_0} \right) \times e^{\frac{1}{3} \times b \times t} \right]^3$	3	(von Bertalanffy, 1957b)
Brody	$W = a \times (1 - b \times e^{(-c \times t)})$	3	(Fitzhugh, 1976)
Richards	$W = \frac{a}{(1 + b \times e^{(-c \times t)})^{\frac{1}{m}}}$	4	(Fekedulegn et al., 1999)
Bridges	$W = W_0 + a \times (1 - e^{(-m \times t^p)})$	4	(Wellock et al., 2004)
Janoschek	$W = a - (a - W_0) \times e^{(-c \times t^m)}$	4	(Wellock et al., 2004)
Ali-Schaeffer	$W = d_0 + d_1 \left(\frac{t}{700} \right) + d_2 \left(\frac{t}{700} \right)^2 + d_3 \left(\ln \frac{700}{t} \right) + d_4 \left(\ln \frac{700}{t} \right)^2$	5	(Ali and Schaeffer, 1987)
Polynomials	$W = d_0 + \sum_{i=1}^r d_i \times t^i$	3 to 5	(Hadel, 1974)

¹W = BW; W₀ = initial BW in kg; a = mature BW in kg; t = age in days; b, c, m, and p = parameters specific for the function; r = second to fourth order of fit; d₀ = intercept; d_i = regression coefficients.

In the study of Kusec (2001), the growth curve for BW was modeled with the Richards function so it can be compared with the growth curve of minipigs estimated with the Richards function in this study. On the basis of the estimated parameter values (Table 3) the BW for normal, fattening pigs were calculated for 0 to 700 d of age. For this calculation, the parameter estimates of the Nn-genotype were used because there was no significant difference (*P* > 0.05) between the parameter values of the 2 MHS-genotypes (G. Kusec, Faculty of Agriculture, University J. J. Strossmayer, Osijek, Croatia, personal communication).

First, the BW of minipigs and normal, fattening pigs at d 160 (160-d BW; **160d-W**) were compared. The d 160 is a typical day for slaughtering normal, fattening

pigs in performance tests in Germany. The 160d-W from minipigs and normal, fattening pigs was set to 100% to achieve comparability. Second, the age was detected at which the pigs weighed 40% of the predicted mature BW. Again, the particular BW at 40% of maturity (40% of mature BW; **40% MW**) was set to 100% for the minipigs and the normal, fattening pigs to enable a comparison between the breeds. To simplify the presentation, only the results of male minipigs from unit 1 are used for the comparison of the minipigs with normal, fattening pigs. Results for males in unit 2 and females in both units are not shown, but they were similar to the results of males in unit 1.

RESULTS

Growth Curves Modeled over all Data

Comparing the models by AIC values and the residuals showed the following results (Table 4). The polynomial function of third order of fit had the smallest AIC values for both sexes in unit 1. For unit 2 the smallest AIC values were achieved of the polynomial of fourth order of fit.

The examination of the polynomial models from second to fourth order of fit using the F-Statistic SS type 1 showed that the polynomials of second and third order of fit were significant (*P* < 0.01) in unit 1, whereas the polynomial of fourth order of fit had no significant influence on the estimation of the growth curves for both sexes in unit 1. In unit 2 the polynomial of fourth

Table 3. Parameter values of the Richards function for normal, fattening pigs (Kusec, 2001) and minipigs (males of unit 1)

Parameter ¹	Fattening pigs		Minipigs
	Intensively fed	Restrictively fed	
a	220	160	53.47
b	0.054476	0.057374	-0.9628
c	1.38986	1.688707	0.00202
m	0.01	0.01	-0.7507

¹a = Mature BW, kg; b = biological constant; c = maturing index; m = shape parameter determining the position of the inflection of the curve point.

Table 4. Values of $-2L_m$ (L_m is the maximized log-likelihood), Akaike's information criterion (AIC), and residual variances (res.) for male and female minipigs of both units¹

Criterion/model	Male						Female					
	Unit 1 ²			Unit 2 ²			Unit 1			Unit 2		
	$-2L_m$	AIC	Res.	$-2L_m$	AIC	Res.	$-2L_m$	AIC	Res.	$-2L_m$	AIC	Res.
Logistic	300,146	300,152	3.245	188,756	188,762	3.262	299,771	299,777	3.558	209,908	209,914	3.670
Gompertz	259,874	259,880	2.563	162,297	162,303	2.547	257,226	257,232	2.792	176,895	176,901	2.804
Bertalanffy	248,756	248,762	2.375	154,826	154,832	2.345	245,587	245,593	2.583	168,356	168,362	2.580
Brody	245,935	245,941	2.327	152,812	152,818	2.291	242,906	242,912	2.534	169,792	169,803	2.617
Richards	242,096	242,104	2.262	150,195	150,203	2.220	238,687	238,695	2.458	164,319	164,327	2.474
Bridges	242,415	242,423	2.268	150,346	150,354	2.224	238,931	238,939	2.463	164,480	164,488	2.478
Janoschek	246,106	246,114	2.330	152,588	152,596	2.285	243,274	243,282	2.541	168,597	168,605	2.586
Ali-Schaeffer	240,068	240,078	2.228	149,260	149,270	2.195	236,779	236,789	2.424	163,251	163,261	2.446
Polynomial, second order	217,176	217,184	2.319	135,475	135,483	2.284	208,923	208,931	2.612	144,233	144,241	2.622
Polynomial, third order	214,826	214,836	2.227	134,456	134,466	2.214	206,651	206,661	2.415	142,616	142,626	2.470
Polynomial, fourth order	214,826	214,838	2.246	134,270	134,282	2.204	206,650	206,662	2.453	142,368	142,380	2.455

¹The lowest values for AIC and res. are printed in boldface in each column.

²Unit 1 and unit 2 represent independent subpopulations.

order of fit had a significant influence ($P < 0.01$) on the fit of the growth curve. Thus, the growth curves for unit 1 for both sexes were best fitted using a polynomial of third order of fit and the growth curves for unit 2 were best fitted by a polynomial of fourth order of fit.

The smallest AIC value for the nonlinear models was calculated for the 4-parameter Richards function in both units. If a minipig growth curve is modeled with a 3-parameter model, the Brody function will be implemented according to the AIC value. The logistic function was definitely the model with the greatest AIC value. A graphical comparison of the logistic, the Brody, and the Richards function as well as the polynomial of third order of fit is given in Figure 2. In this Figure 2 only the results for males in unit 1 are displayed as an example without loss of generality because curves of females and for males in unit 2 look very similar.

By comparing all models on the basis of residuals the best fitting model for unit 2 was not the polynomial of fourth order of fit but the Ali-Schaeffer function. For unit 1 the polynomial of third order of fit had the lowest residuals. The Brody function was the best fitting 3-parameter function, and the Richards function was the best fitting 4-parameter function on the basis of the calculated residuals for both units.

Comparison of Minipigs with Normal, Fattening Pigs

According to the calculated BW for the normal, fattening pigs and the predicted BW for the minipigs from the Richards function, Figure 3 shows the relative BW development of the pigs from birth to 160 d of age. The minipigs have an almost linear BW development in this time period. The normal, fattening pigs show very small BW in relation to their particular 160d-W up to 50 d of age. Then after 50 d of age they are increasing BW through to 160 d of age. The restrictively fed pigs are

characterized by a steeper slope of the curve after d 42 in relation to the intensively fed pigs. Thus, compared with the intensively fed pigs, they have greater ADG after 42 d of age.

The birth weights of the analyzed breeds differ in a remarkable way in relation to the 160d-W. At birth and throughout birth to 160 d of age, the proportion of BW to its 160d-W is greater in the minipig compared with the normal, fattening pig.

The second comparative analysis determined the BW development of minipigs and normal, fattening pigs from birth to a stage of 40% of maturity. The BW and ages for minipigs and normal, fattening pigs are shown in Table 5.

The minipigs needed 2.4 times longer than the intensively fed, normal, fattening pig to reach 40% MW. In relation to their 40% MW the minipigs have a greater birth weight than the normal, fattening pigs. It can be observed that the minipigs have a nearly linear BW development until the chosen degree of maturity (data not shown). Further, the minipigs can realize greater ADG from birth up to 50% of age at 40% maturity in relation to the 40% MW than normal, fattening pigs. After 50% of age at 40% maturity the BW development of the normal, fattening pigs increases more rapidly. Restrictively fed, normal, fattening pigs have in all stages until 40% of maturity a lower BW in relation to their 40% MW than the intensively fed, normal, fattening pigs.

DISCUSSION

Modeling growth curves of animals is a necessary tool for optimizing the management and the efficiency of animal production. It is obvious that growth modeling has many advantages for meat-producing animals (Schinckel and de Lange, 1996). As a consequence, many studies dealing with modeling of growth curves

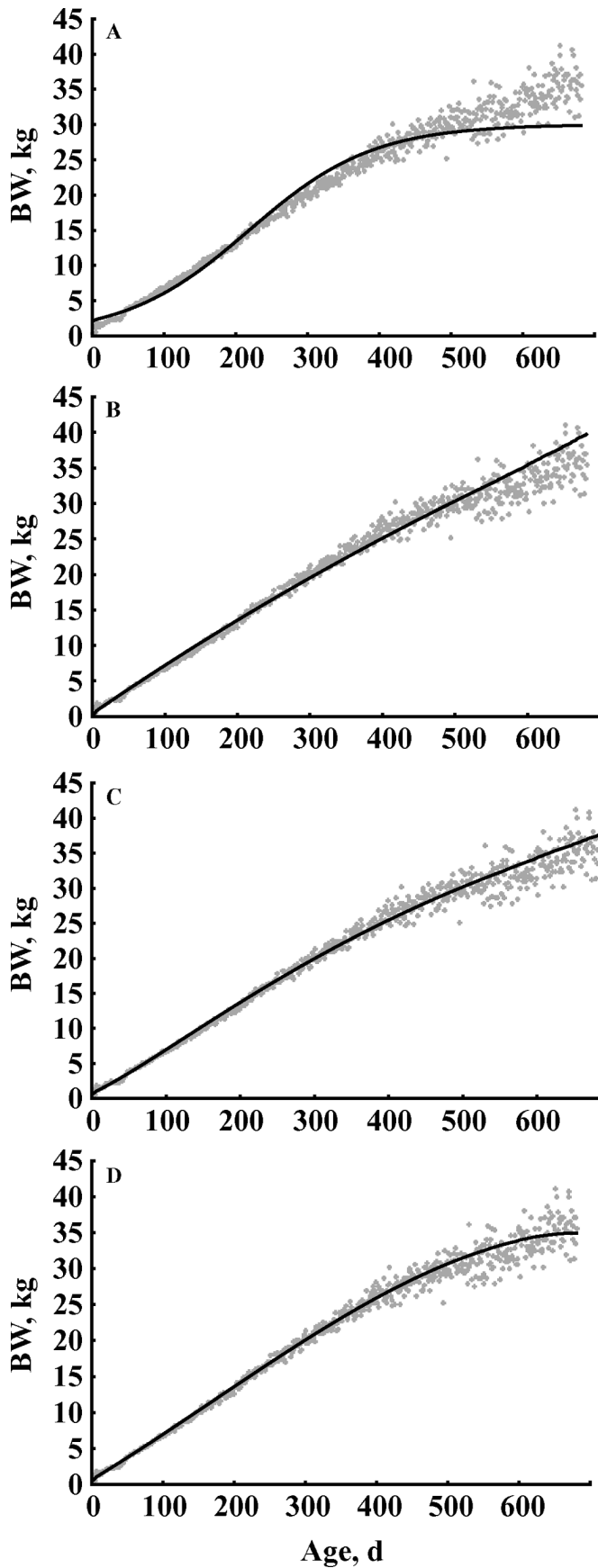


Figure 2. Growth curves of the Goettingen minipig for males in unit 1 as predicted by the logistic (A), Brody (B), Richards (C), and third order polynomial (D) functions.

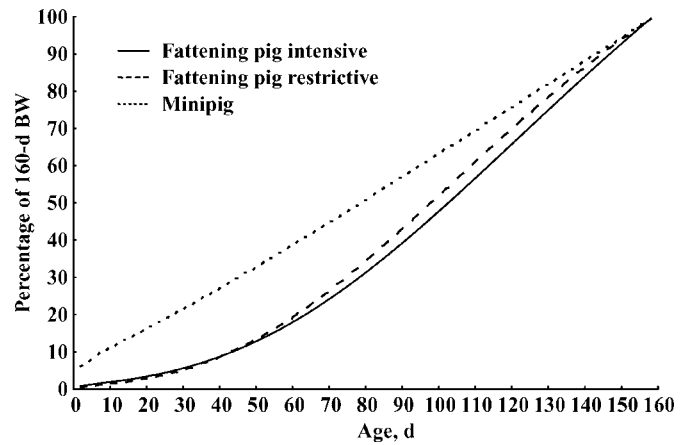


Figure 3. Relative BW development of male minipigs of unit 1 and normal, fattening pigs from birth weight to 160-d BW.

have used pigs (Whittemore, 1986; Krieter and Kalm, 1989; Bastianelli and Sauvant, 1997; Knap et al., 2003; Schinckel et al., 2003; Wellock et al., 2004), cattle (Brown et al., 1976; Lopez de Torre et al., 1992; Menchaca et al., 1996), and poultry (Knizetova et al., 1991b; Sengül and Kiraz, 2005). In the last few years it has become more and more popular to analyze the growth of special livestock, e.g., the Bolivian llama (Wurzinger et al., 2005) and the pearl gray guinea fowl (Nahashon et al., 2006), for providing improvement for their husbandry. Because of the increasing importance of the Goettingen minipig for medical research it is necessary to analyze the BW development of this breed for the well-founded derivation of required space for guidelines of laboratory animals and adjusted feeding regimens. The knowledge of growth pattern in minipigs also facilitates the creation of experimental designs.

The growth of the Goettingen minipig is not the same as the growth of pig breeds for meat production. Apart from the different mature BW the BW development of the minipig should be slower than the BW development of normal pigs, mainly in the first year so that the mature BW of the Goettingen minipig will be achieved later than the mature BW of normal pigs. On the basis of growth parameters of the Richards function estimated in this study and in the study of Kusec (2001)

Table 5. Mature BW and ages at 40% of mature BW (40% MW) of normal, fattening pigs and minipigs (males of unit 1) calculated with parameters of the Richards function

Item	Fattening pigs ¹		Minipigs
	Intensively fed	Restrictively fed	
Mature BW, kg	220 ¹	160 ¹	53
40% MW, kg	88	64	21
Age at 40% MW, d	129	109	310

¹Kusec (2001).

the age at maturity was calculated for minipigs and intensively fed, normal, fattening pigs. Minipigs are expected to have a constant mature BW around 5 yr of age, whereas intensively fed, normal, fattening pigs reach a constant BW with approximately 4.2 yr of age. Thus, the minipigs seem to reach maturity at an older age than normal, fattening pigs. Body measurements, such as length and circumference of skeletal tissue, provide a more exact determination of maturity (Lawrence and Fowler, 2002), and these data should be included when there is a focus on size at maturity.

The application of different nonlinear and linear functions to BW data from Goettingen minipigs is the first study made for this species in such detail. The data set of the current study is unique based on the very large number of animals and BW recordings over a wide range of ages. The results of the nonlinear functions showed that the Richards function was the best for fitting the minipig data according to the AIC values. This is in agreement with Brown et al. (1976) who applied the logistic, Gompertz, von Bertalanffy, Brody, and Richards function to BW data of different cattle breeds. Brown et al. (1976) also noted that the logistic model is worst for fitting their cattle BW data. The Richards function was also considered as best by Knizetova et al. (1991a) for growth analyses in ducks and other poultry, like geese and chicken, after checking the logistic, Gompertz, and Richards function for the growth of poultry in other studies.

Krieter and Kalm (1989) applied the growth model developed from Schnute (1981) for estimating the growth curves of Large White and Piétrain pigs. The pigs were weighed weekly from 25 to 223 kg (Large White) and from 29 to 186 kg (Piétrain), respectively. In the model proposed from Schnute (1981) the nonlinear growth functions logistic, Gompertz, von Bertalanffy, Richards, and others like a linear, quadratic, or exponential function are included. Combining several models into a single model reduces the problem of comparing the different parameters used by each individual model. Intercepts, inflection points, and asymptotic size are no longer essential, although they can be identified easily if they occur. Krieter and Kalm (1989) found that the von Bertalanffy model had the lowest residual standard deviation compared with the Richards and the Gompertz function, which is not in agreement with the results of our study. A focus on the residuals of the nonlinear models suggests that the Richards function is the best fitting model for minipig BW data. Regarding all models, the polynomial of third order of fit was the best fitting model for the minipig BW data from unit 1 and the Ali-Schaeffer function was the best model for unit 2.

The difficulty in comparing the results of this study with other studies dealing with pig growth lies in the different time periods that were examined. For minipigs the whole period of growth from birth to later ages is of interest because the BW at later ages is an important variable for breeding selection. Meat producing breeds like the Large White or Piétrain are observed from 30

to 105 kg of BW in the performance test, i.e., from 90 d of age at the beginning of the fattening period to 160 to 180 d of age at the end of the fattening period (ZDS, 2004). Castrated Large White pigs average 160 d of age at the end of the fattening period (VIT, 2005). Thus, the time between weaning and slaughter at 160 d is the best time to measure growth rate in normal, fattening pigs.

An extreme example is the study of Schinckel et al. (2003), who modeled the growth of pigs from birth to 60 d of age. The authors also applied the Gompertz and the Bridges functions, and additionally the Michaelis-Menten equation and an exponential linear quadratic equation of form $W_{ij} = \exp(b_0 + b_1t + b_2t^2) + e_{ij}$, where W_{ij} is BW; t is age; b_0 , b_1 , and b_2 are regression coefficients; and e_{ij} is the residual term. The different models were compared by using the residual standard deviation. The authors concluded from their results that the exponential linear quadratic equation is the best fitting model for estimating the growth of pigs from birth to 60 d of age. However, the authors mentioned a lack of fit for the exponential equation, resulting in an inaccurate prediction of the birth weight of each pig and that probably a more complex function is needed.

When modeling growth of the normal, fattening pig, numerous studies deal with the pattern of compositional growth (Whittemore, 1986; Bastianelli and Sauvante, 1997). In this case the growth curves for protein growth or lean growth, respectively, and fat growth are modeled separately (Knap et al., 2003), often combined with different levels of feed intake. Therefore the growth curve of BW in the time period of interest has to be modeled. The relationship of the body component (e.g., protein) to the BW has to be fitted. Development of growth curves for body components (e.g., protein and fat) can be a useful tool for management of pork production because it can aid in determining the best time to slaughter animals, and depending on genotype, feed intake can be predicted (Schinckel and de Lange, 1996).

Modeling different growth fractions separately is not necessary for the minipig. The minipig is a laboratory animal and is never used for commercial meat production. If body components were modeled separately it could be used to adjust the feeding regimen (e.g., feeding restrictions) to prevent the minipig from becoming too heavy.

Using estimates from the Richards function, a difference in BW development between minipigs and normal, fattening pigs is observed. From d 0 to 160 d of age, the minipig growth curve is approximately linear (Figure 3). This result is consistent with the minipig growth analysis conducted by Brandt et al. (1997) who modeled the growth of 283 minipig sows from birth to 1,100 d of age with the Boltzmann function. In contrast, the normal, fattening pigs have very low ADG in the beginning and greater ADG from d 50 to the end of the time period. Thus, the growth curve of a normal, fattening pig is sigmoid. Applications of other growth functions apart from the Richards function lead to similar results

as far as these functions have a flexible point of inflection. All functions show a linear growth of minipigs in the first year except the logistic function, which has a fixed point of inflection. Thus, it is also expected that the trajectory of the growth curve of normal, fattening pigs is sigmoid when modeling the growth with growth functions other than the Richards function as far as a flexible point of inflection exists.

It is obvious that the selection on greater ADG in normal, fattening pigs focuses on the last 67% of the period from d 0 to 160 d of age. The minipig growth curve should be changed into a lower level (i.e., the asymptotic BW should be lower). A change from linearity to a more sigmoid trajectory would be advantageous for the first part of the growth curve. If this aim could be achieved, it would be possible to produce minipigs with very small ADG and as a consequence smaller BW in the first few months of their lives, which is the main period for starting medical or pharmaceutical experiments. On the basis of genetic analyses that will be conducted the best time for selecting minipigs for lower BW will be determined. Additionally, it could be determined if a change of the minipig growth curve is possible.

The modeling of growth curves of the Goettingen minipig with different nonlinear and linear functions is a useful tool for the derivation of space and food requirements at different ages. Based on the current study, it is also possible to apply the best fitting models (i.e., linear polynomials) for the estimation and analysis of genetic parameters with random regression models concerning the breeding goal low body weight, which should be obtained especially in the juvenile period, which is the main period for marketing.

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