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Comparison of fixed effects and mixed model growth functions in modelling and predicting live weight in pigs

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ABSTRACT

The objective of the present study was to compare alternative growth functions fitted to pig live weight data, with particular emphasis on the function's ability to predict future animal live weight. The final dataset consisted of 51,893 live weight records from 10,201 pigs aged between 61 and 200 days. Fixed effects models and mixed models were applied to the three different growth functions: von Bertalanffy, Gompertz, and Richards; fixed and mixed model polynomial equations were also considered. The growth function's ability to predict future live weight was determined by excluding a selection of animal live weight records post 160 days of age and comparing the predicted live weight to actual live weight. Irrespective of whether a fixed or mixed model framework was used, the Gompertz function best modelled the full dataset, with an accuracy squared for the full dataset (r_w^2) of 0.997 and root mean square error (RMSE) of 1.60 kg for the fixed effects model and r_w^2 of 0.995 and RMSE of 2.25 kg for the mixed model equation. The Gompertz mixed model also achieved the greatest accuracy squared of predicting ($r_{w\hat{w}}^2$) future live weight records, with an $r_{w\hat{w}}^2$ of 0.846 and RMSE of 5.35 kg. A strong positive correlation was estimated between asymptotic mature weight (A; $r=0.83$ to 0.96) across the three growth functions for all considered equations. A strong negative correlation was estimated between parameters A and k (rate of maturation) for the Gompertz fixed effects model (−0.88) and mixed model (−0.70). Results from this study could be used to implement a decision support tool for pork producers, offering extra information when they are making important feeding, slaughter and breeding decisions.

1. Introduction

The final live weight of an animal, plus the rate and age at which an animal reaches this target, is of economic importance (Emmans and Kyriazakis, 2000). Growth may be defined as the relationship between age and lifetime weight of an animal, and can be mathematically modelled using growth functions (Fitzhugh, 1976; Kucuk and Eyduran 2009). Growth functions have the ability to condense the weight–age relationship into a few biologically interpretable parameters (Brown et al., 1976; Goonewardene et al., 1981).

Several different growth models have been used to describe the growth pattern and development of body weight in pigs (Knap, 2000; Wellock, 2004; Koivula et al., 2008), cattle (Brown et al., 1976; Beltran et al., 1992; Berry et al., 2005), and sheep (Lewis et al., 2002; Gbangboche et al., 2006; Gbangboche et al., 2008). Fixed (Afolayan et al., 2006) and random polynomial regression (Meyer, 2005)

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Table 1
Equations for each growth function, fitted as a fixed effects model, with corresponding accuracy squared values and root mean square error values (RMSE) for both the exploratory (r^2_w) dataset set (which included all animals from the original file) and the forward prediction ($r^2_{w\hat{w}}$) dataset.

Function	Equation	Dataset			Forward prediction	
		No. of animals	r^2_w	RMSE (kg)	$r^2_{w\hat{w}}$	RMSE (kg)
von Bertalanffy	$Y_t = A(1 - B\ \exp^{-kt})^3$	6,503	0.9967	1.66	0.7657	6.95
Gompertz	$Y_t = A\exp(-B\ \exp - ^{kt})$	8,739	0.9968	1.60	0.6828	8.51
Richards	$Y_t = A\ (1 - B\ \exp^{-kt})^m$	5,615	0.9892	5.52	0.0361	99.45
Polynomial	Linear	10,201	0.9923	2.64	0.8725	6.00
	Quadratic	10,201	0.9963	1.73	0.6466	11.16
	Cubic	10,201	0.9987	0.91	0.3534	20.13

Y_t represents the observed weight of the animal at age t expressed in days; A represents the limit for each animal as its age approaches infinity, it does not approximate the heaviest weight attained by the animal; B represents the integration constant when Y_0 and $t_0 \neq 0$; k is a maturing rate parameter defining the ratio of maximum growth rate to mature weight; m relates the inflection point to A.

have also been used. Model selection to predict growth in livestock is, nonetheless, a challenging task given the broad variety of growth functions, complicated biology in different environments, and criteria to assess goodness of fit. The most useful purpose of a growth function is to predict the animal's future growth, rather than simply describing the animal's growth heretofore (Koivula et al., 2008). Parametric growth functions, such as von Bertalanffy (Bertalanffy, 1957), Gompertz (Winsor, 1932) and Richards (Richards, 1959) are considered suitable to describe and forward-predict growth throughout an animal's life.

Considerable research has been undertaken on the genetic parameters of growth function parameters in pigs (Schinkel and de Lange, 1996; Knap, 2000; Wellock, 2004; Koivula et al., 2008) and implementing them into breeding programmes. Little information in the literature exists, however, on the modelling of phenotypic live weight data and quantifying a growth function's ability to predict future phenotypic live weight using either fixed effects or mixed model equations.

The objective of this study was to compare different mathematical models fitted to pig live weight data, with particular emphasis on the ability of the growth function to predict future live weight during the test period of 160 to 200 days of age. Results from this study will provide better knowledge of the shape of a pig's growth curve, providing pork producers with extra information when they are making important feeding, slaughter and breeding decisions.

2. Materials and methods

2.1. Data

A total of 61,715 live weight records from 12,768 pigs, between the years 2006 and 2012, inclusive, were obtained from the Finnish pig breeding company Figen Oy. All animals were on trial in the Figen test station in Finland. The pigs evaluated in the test station are included in the Finnish national breeding evaluation. Animals ranged from 61 to 102 days of age at entry into the test station and included boars, gilts, and barrows. Animals were housed in groups according to their date of entry to the station. Pens of animals were fed based on the mean weight of the test group (Koivula et al., 2008). The number of live weight records per animal ranged from three to eight, recorded over a 7 to 99 day test period. Animals with less than five live weight records during the test period ($n = 1{,}034$) were discarded, as were animals that failed to remain on test for at least 86 days ($n = 100$). A total of 150 individuals with recorded weight loss between consecutive test-day weight measurements, taken on average two weeks apart, were removed. Only animals that were recorded as finishing the test period alive without any record of sickness throughout the test period were retained (1,283 animals omitted). The final dataset consisted of 51,893 live weight observations from 10,201 animals, with an average age of 88 days on entry.

2.2. Models

Three different growth functions were fitted to the data for each individual animal. These models included the von Bertalanffy (Bertalanffy, 1957), Gompertz (Winsor, 1932) and Richards (Richards, 1959). All models are described in Table 1. Each of the three growth functions included a dependent variable (Y_t) representing the observed weight of the animal at day t of age, and three unknown parameters; A, B and k. Richards growth function included an additional parameter m. Parameter A (kg) describes the weight of the animal as its age approaches infinity and represents the asymptotic mature weight; it does not approximate the heaviest weight attained by the animal in each growth function, but is the estimated mean live weight that will be achieved by the animal. Parameter k (kg/d per kg mature weight) represents the maturing rate defining the ratio of maximum growth rate to mature weight. Parameter B for the Gompertz function is defined as the logarithm of the ratio of mature weight to birth weight. For the von Bertalanffy and Richards functions parameter B represents the constant of integration. The parameter m ($m \geq 1$) in the Richards growth function is used to describe the growth function's inflection point in relation to A: the coordinates for the point of inflection are x coordinate $= \log_e(B\ m)/k$ and y coordinate $= A(1 - 1/m)^m$.

Age in days was scaled prior to the analysis by multiplying the age of the animal by a scaling factor (0.015). This scaling factor was derived as the average rate of maturation (k) obtained from preliminary analysis of the data with the