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Use of simple body measurements and allometry to predict the chemical growth and feed intake in pigs

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ABSTRACT

The paper provides a practical procedure to estimate the chemical composition of pigs, their compositional growth and the expected feed intake from measurements of body weight (BW) and backfat thickness (P2) serially performed *in vivo*. A farm data set provided information on 920 individuals including BW, measured at 71 ± 4 (t_1), 126 ± 5 (t_2) and 184 ± 5 (t_3) days of age, of P2 at t_2 and t_3, and of voluntary daily feed intake (FI), recorded over the period from t_2 to t_3 by automated IVOG feeders. Body lipid mass was estimated as L= (9.17 + 0.70*P2) *BW/100 and the other chemical constituents were predicted from fat free empty body mass using Gompertz growth functions and allometry. Using individual changes of body composition from age t_2 to t_3, energy requirements for maintenance and growth and the corresponding predicted feed intakes (PFI) were estimated. Measured FI were analysed for the effects of month, batch (within month), BW_{t2}, $P2_{t2}$, average metabolic weight, average daily gain and variation of P2 from t_2 to t_3. The same model was run again replacing the direct simple body measurements (BW and P2) with the estimated values of PFI as source of variation. Results. The Gompertz estimates of mature protein mass (Pm), relative growth rate parameter (B) and lipid to protein ratio at maturity were 43.5 ± 5.8 kg, 0.0116 ± 0.0011 d^{-1} and 1.81 ± 0.30, respectively. The current protein mass averaged 18.5 + 1.6 kg and the daily retentions of protein and lipid were 177 ± 21 and 239 ± 62 g/d, respectively. FI and PFI averaged 2.824 ± 0.448 and 2.814 ± 0.393 kg/d, respectively. In the ANOVA of the FI data, the replacement of direct body measurements by PFI did not change the proportion of variance explained (83%) and the RSD (0.199 g/d). The two sets of residual feed intake values obtained from the two ANOVA were highly correlated (RSD = 0.043 kg/d; R^2= 0.961). Agreement between predicted and determined feed intakes provided a reasonable guarantee to the estimated (based on BW and P2) changes of body composition. Thus, a scheduled protocol of measurement of BW and P2 over the course of growth, coupled with the use of allometry, can be proposed to estimate *in vivo* the change of the chemical status of pigs kept under non limiting conditions.

Key Words: Pigs, Body composition, Growth, Feed intake, Mathematical models.

RIASSUNTO

IMPIEGO DI SEMPLICI MISURE CORPOREE E FUNZIONI ALLOMETRICHE PER LA STIMA DELLA CRESCITA DELLE COMPONENTI CHIMICHE CORPOREE E DELL'INGESTIONE ALIMENTARE NEI SUINI

*Nel lavoro si propone una procedura per stimare le variazioni di composizione chimica corporea e dell'ingestione alimentare di suini, allevati in condizioni non limitanti, basata su rilievi di peso vivo (BW) e di spessore del grasso dorsale (P2) ripetuti a diverse età. Si è utilizzata una banca dati riguardante 920 suini ibridi maschi (Goland) alimentati ad libitum che ha fornito informazioni individuali di BW, misurato a 71 ± 4 (t_1), 126 ± 5 (t_2) and 184 ± 5 (t_3) giorni di età, di P2, misurato alle età t_2 e t_3, e di ingestioni alimentari (FI), registrate nell'intervallo di tempo tra t_2 e t_3 mediante stazioni di alimentazione automatizzate (IVOG). La massa corporea di lipidi (kg) è stata stimata con l'equazione L= (9,17 + 0,70*P2)*BW/100 e gli altri costituenti corporei sono stati calcolati dal peso vivo netto meno la frazione lipidica, utilizzando funzioni di allometria. Dai cambiamenti stimati di composizione corporea tra le età t_2 e t_3 sono stati quindi valutati i fabbisogni di energia per il mantenimento e per la crescita ottenendo i corrispondenti quantitativi di mangime previsti per il periodo di crescita in esame (PFI) per ciascun individuo. I valori misurati di consumo alimentare (FI) ottenuti dalle stazioni IVOG sono stati sottoposti ad analisi della varianza per gli effetti: mese, partita (entro mese), BW_{t2}, $P2_{t2}$, accrescimento medio giornaliero e variazioni di P2 nel periodo tra t_2 e t_3. I valori di FI sono stati anche analizzati sostituendo, come fonti di variazione, le misure corporee dirette con stime derivate di PFI. Risultati. L'approccio seguito ha consentito di stimare i parametri delle curve di Gompertz che definiscono la crescita proteica potenziale di ciascun individuo, la massa proteica matura (Pm, kg), il coefficiente di accrescimento relativo (B, d^{-1}) e il rapporto lipidi:proteine a maturità (Lm/Pm), risultati in media pari a 43,5 ± 5,8 kg, 0,0116 ± 0,0011 d^{-1} e 1,81 ± 0,30, rispettivamente. Nel periodo compreso tra t_2 e t_3 la massa proteica mediamente presente è risultata pari a 18,5 + 1,6 kg e le ritenzioni medie di proteine e lipidi sono state in media pari a 177 ± 21 e 239 ± 62 g/d, rispettivamente. I valori medi di FI e di PFI sono stati, rispettivamente, pari a 2,824 ± 0,448 and 2,814 ± 0,393 kg/d. Nel modello di analisi statistica la sostituzione delle misure corporee dirette con i valori di PFI non ha modificato la proporzione di varianza spiegata (83%) né i valori di deviazione standard residua (0,199 g/d). I valori di "residual feed intake" risultanti dall'applicazione dei due modelli di analisi sono risultati altamente correlati (RSD= 0,043 kg/d; R^2= 0.961). L'approccio impiegato ha quindi consentito di ottenere una buona interpretazione biologica della varianza dei valori di FI associata alle diverse misure corporee. La sostanziale coincidenza tra valori misurati e stimati di ingestione alimentare ha fornito una ragionevole garanzia sulla validità dei valori di composizione corporea stimati. Così, un protocollo di misure ripetute di peso vivo e di spessore del lardo dorsale nel corso della crescita, accoppiato ad elaborazioni di tipo allometrico, può essere proposto per stimare in vivo lo stato chimico corporeo di suini allevati in condizioni ritenute non limitanti.*

Parole chiave: *Suini, Composizione corporea, Accrescimento, Ingestione alimentare, Modelli matematici.*

Introduction

Prediction of feed intake as a function of requirements was addressed by Emmans and Fisher (1986) and Emmans (1989). The mechanistic proposition suggested by these authors is that given an effective description of energy needs for maintenance and for the components of growth, feed intake can be calculated as the simple sum of needs. A number of mathematical models have been developed with the purpose of predicting the growth, and in some cases the voluntary feed and water intake, of a pig kept under different feeding and environmental conditions (Moughan *et al.*, 1987; Pomar *et al.*, 1991; Ferguson *et al.*, 1994; Black, 1995; Schiavon and Emmans, 2000).

The application of these models in practice can be very useful for the interpretation of farm performance, the identification of possible constraints, and the prediction of pigs' response to interventions (Whittemore *et al.*

2001a; ASPA, 2003), but adequate descriptions of the pig population, of the environment and of the feed are required (Emmans, 1995). The problem of describing a given pig, in terms of potential growth of its chemical constituents, remains the more relevant and critical aspect (Emmans, 1989; Schinckel, 1999). It has been suggested (Emmans and Fisher 1986, Ferguson and Gous, 1993a, 1993b) that pig genotype can be described by only three parameters, estimable from Gompertz growth equations: the mature protein mass (Pm), the rate of maturing of the pig (B) and the lipid to protein ratio at maturity (Lm/Pm). The distribution of the values of these parameters within the population is also of great relevance, since there can be a marked difference in the response of the average individual in the population and the mean population response, which is an average of all individuals (Ferguson *et al.*, 1997).

This information is not easily available under practical circumstances, since the direct measurement of body composition through dissection, grinding, chemical analysis of serially slaughtered pigs is too expensive to be routinely conducted on an adequate number of pigs. An approach to predicting body composition and feed intake in growing pigs using simple body measurements was suggested by Whittemore *et al.* (1995). Following this idea, under ideal growing circumstances, some attempts to achieve operational values to describe a given pig population can be conducted from measurements of body weight and fat thickness at different points in the course of growth, from using these data to estimate body composition by means of functions of allometry, and from studying the evolution of the chemical constituents over the time by means of Gompertz growth functions. If the change of body composition is predicted with sufficient accuracy and the feed and the environment are properly described, then feed intake can be estimated by using a set of relationships such as those described by Ferguson *et al.* (1994). When the feed intake is recorded, the correspondence between observed and predicted values of feed intake can be used as criterion to evaluate the accuracy of the estimates of body composition. In this work simple body measurements from a farm data set, representing 920 crossbred male pigs fed *ad libitum*, were used to evaluate the evolution of body composition, the Gompertz growth curve parameters and the correspondence between measured and predicted values of feed intake.

Material and methods

Description of the available data set

A private farm dataset (Gorzagri, Riese Pio X, Italy) providing information about the growth performance of 920 white crossbred male pigs (Goland, progeny of 26 sires), recorded over three years of performance test, was used. The animals were reared in conditions intended to be the best possible. The piglets received for the first 28 days of age the mother's milk and they had free access to a weaner feed (Table 1).

They received continual heating above their sleeping area. From 28 to 71 ± 4 days of age the piglets were housed in weaning rooms where the environmental temperature was maintained not lower then 25 °C, by means of an automated system of heating and ventilation.

They continued to receive, *ad libitum*, the weaner feed up to 45 days of age, successively the feed was gradually changed to a grower feed (Table 1). At 71 + 4 days of age the pigs were moved to grower rooms and housed in pens, in groups of about 9 ± 1 subjects. At 126 ± 4 days of age the pigs were moved to other pens, even in groups of 9 subjects, equipped with 10 IVOG-stations described by De Haer *et al.* (1992). During this last period they received a finisher feed (Table 1).

The automated feeding stations allowed the daily recording of individual *ad libitum* feed intake, with negligible feed spillage, up to a final age 184 ± 5 d.

Table 1. Ingredients and composition of feeds (g/kg).

		Weaner	Grower	Finisher
Yellow maize meal		147	201	330
Barley meal			100	150
Barley flakes		150	100	
Wheat meal		72		210
Wheat flakes		150	100	
Wheat bran		100		100
Rice middling			100	
Soybean meal		30	128	121
Whole soybean		50	71	
Whey, dehydrated, acid		84	80	
Herring meal		53	20	17
Sugar cane molasses		20	15	16
Sugar beet pulp		30	30	
Milk for piglets		70		
Soybean oil			17	18
Premix		44	38	38
Metabolizable energy[a]	MJ/kg	13.5	13.3	13.0
Crude protein		175	175	145
Lysine		12.5	11.5	8.0
Methionine + cystine		7.7	7.5	5.4
Treonine		8.1	7.5	5.2

[a] *Metabolizable energy was estimated from the proportion of each single ingredient in the diets and the tabulated values proposed by National Research Council (1988).*

From about 71 to 184 days of age the air temperature within the rooms was maintained not lower than 21 °C, however, in some periods of the summer season some groups of pigs could have been exposed to environmental temperatures ranging from 21 to 28 °C.

During the whole period of growth all animals were individually given as much fresh food as they cared to consume, therefore, environmental and competitive constraints were presumed low or absent. Body weight (BW) was recorded at 71 ± 4, 126 ± 4 and 184 ± 5 days of age. Backfat thickness was ultrasonically measured (Lean meater ®, Renco Corporation, Minneapolis, USA), by a single trained operator, at the last rib on the back of each pig (P2), but only at 126 ± 4 and 184 ± 5 days of age. The P2 measurement was performed from either side of the backbone at a distance from the midline ranging from 50 to 90 mm according to the size of the pigs (65 mm at around 100 kg of BW). Hair at the side of measurement was removed and water was applied to the cleaned skin two minutes before measuring.

Average values and standard deviation of growth performance and feed intake realized by the 920 pigs are given in Table 2. Body weight ranged from a minimum of 20 to a maximum of 183 kg, P2 ranged from a minimum of 6 to a maximum of 23 mm.

Table 2. Measured values of body weight (BW), backfat thickness (P2) and feed intake of 920 male growing pigs. Values are means ± SD.

Age	days	71 ± 4	126 ± 4	184 ± 5
BW	kg	30.4 + 3.9	77.4 ± 7.4	136.6 ± 12.8
P2	mm		8.3 ± 1.2	13.5 ± 2.4

Feed intake measured between 126 ± 4 and 184 ± 5 days of age averaged 2.824 ± 0.448 kg/d.

Development of an equation to relate body lipid percentage to backfat thickness from an another data set regarding heavy pigs

With the purpose of developing a relationship to estimate body lipid percentage from measurements of backfat thickness and body weight on heavy pigs, another dataset (Prandini *et al.*, 1996, and other experimental data obtained by Prandini *et al.*), collected for an unrelated purpose, was used. Data originated from two trials, where two groups of 36 pigs were fed two maize-soybean diets differing for crude protein content (135 and 110 g/kg of crude protein) from about 80 to 160 kg of BW.

The amounts of feed received by the pigs were adjusted weekly to be maintained at 8% of metabolic weight. Ultrasonic measurement (Lean Meater®, Renco Corporation, Minneapolis, USA) of backfat thickness (P2) was taken, following the same procedure described above, by a trained operator at the last rib on the back of each pig, immediately before slaughtering. Pigs were grown and serially slaughtered at about 80, 120 and 160 kg of BW, in three groups of 24 subjects each.

Whole body chemical composition was obtained after analysis of the half carcass of each subject for dry matter, protein, lipid and ash contents. Body lipid mass was expressed as percentage of BW (L%) and the individual values were regressed against the corresponding backfat thickness measurements by trial and sex. The t-test was used to test the hypothesis that the intercepts and the slopes obtained for each trial and each sex significantly differed from the values found for the pooled equation.

No significant differences due to the trial and the sex were found. The parameters of the pooled equation (L % = 9.17 + 0.70*P2) did not significantly differ from those achieved from a re-analysis of the Tullis data (Tullis, 1981). Tullis data concerned 15 trios of subjects fed *ad libitum* and serially slaughtered from 23 to 205 kg of BW (from 52 to 332 days of age).

As discussed later, this suggested that the equation achieved from the dataset of Prandini *et al.* (1996) could hold for large variations of BW and body lipid percentage and it was therefore applied for the following analysis.

Estimation of chemical body composition and growth parameters from body measurements

Body lipid mass (L) of pigs (Gorzagri dataset) at different points in the course of growth was estimated from the measurements of BW and backfat depth (P2). The relationship used, developed from the original dataset of Prandini *et al.* (1996), as previously described, was:

1) $L = (9.17+0.70*P2)*BW/100$ kg

Assuming that gut fill contributes for 5% of BW (de Lange, 1995), lipid free empty body weight (LFEBW) was consequently computed as:

2) $LFEBW = BW*0.95-L$ kg

Since for each subject only 3 data points for body weight (around 71, 126, 184 days of ages) and 2 data points for the backfat thickness (around 126 and 184 days of age) were available it was assumed that:

a) at birth all the piglets had a BW of 1.5 kg. This value was based on previous observations made on the same farm. For the newborn piglets an average body lipid percentage of 4% (Whittemore, 1993) and a gut fill of 5% of LW were assumed.

In previous analysis, different values for these parameters have been tested (i.e. gut fill of 2% of BW and body lipid percentage from 4 to 8%), but the effects on the estimated parameters of Gompertz growth curves were negligible. Thus for the newborn piglets lipid mass was estimated as:

3) $L=0,04*BW$ kg

b) at 71 days of age an average body protein content (P) for all pigs of 16% of empty BW was assumed (Whittemore, 1993). The weights of the other lean chemical constituents were computed using allometry: body ash was estimated as $Ash= 0.2*P$ and body water as $W= 5.193*P^{0.855}$ (Emmans and Kyriazakis, 1995). The value of lipid mass (L) was estimated as:

4) $L=BW*0.95- (P + 0,2*P + 5.193*P^{0.855})$ kg

Thus, L was: assumed to be 4% of BW at birth; estimated with the equation 3 at 71 days of age; estimated with equation 1 at the following 2 ages. This made it possible to estimate all the individual values of $LFEBW_i$ at the four ages (i).

The 4 estimates of $LFEBW_i$ obtained for each subject and each age were run, using the NLIN PROC, DUD method (SAS 1988), to simultaneously solve the following system of equations for the values of Pm, the mature protein mass, and of B, the rate of decline of relative growth rate:

5) $LFEBW_i= 1.2*P_i+5.193*P_i^{0.855}$ kg

6) $P_i = Pm*exp(-exp(-B*(t_i- t^{\wedge}))$ kg

where P_i was the protein content at a given age (i), t_i= age and t^=age at the inflexion point is a time constant, in days, defined where P = Pm/e (Emmans, 1988); e is the constant (2.71828) of the natural logarithm. The Gompertz function 6, describing the growth of protein over the time, is that described by Emmans (1989) and Whittemore (1994).

The mature lipid mass (Lm) and its relative growth rate (B_l) was estimated by running a similar equation on the individual data of L (Emmans, 1989):

7) $L_i= Lm*exp(-exp(-B_l*(t_i-t^{\wedge}))$ kg

As suggested by Ferguson *et al.* (1997), simple correlations between Pm, B, and the lipid to protein ratio at maturity (Lm/Pm) were computed. Since a strong and negative correlation between Pm and B was expected (animals with high Pm will have a low B value), an additional scaled growth rate parameter ($B^* = B*Pm^{0.27}$), which is theoretically not correlated to Pm (Ferguson *et al.,* 1997), was also considered in the correlation analysis. Errors of prediction will result if this correlation is ignored. The scaled rate parameter B* holds B and Pm in a fixed relationship and would, therefore, prevent such errors from occurring (Ferguson *et al.*, 1997).

The individual values of Pm and B were subsequently used to plot the 920 Gompertz curves for protein and to estimate the corresponding amounts recovered in each pig at the 4 different ages. Consequently, W and Ash at different ages were evaluated as: $W_i = 5,193*P_i^{0,855}$ and $Ash_i = 0,2*P_i$. The weights of P_i, W_i and L_i were added to those of L_i resulting from the application of equations 1, 3, 4 and body weights were re-computed assuming a contribution of gut fill of 5% of BW. These values were compared with the measured values of BW by linear regression.

Table 3. Linear relationships between body lipid percentage (y) and backfat thickness (x) (P2 in mm) from dataset of Prandini *et al.* (1996) and Tullis (1981). Standard errors are in brackets[7].

Dataset[1]	Trial	Sex[2]	Feeding regime[3]	Genotipe[4]	Obs[5].	$\hat{Y}$[6] %	Intercept %	Slope	RSD %	Ranges: Body weight, kg	Ranges: x	Ranges: y
Prandini	1	C	Restricted CP	Dx(LWxLD)	18	27.8	11.80 (3.11)	0,60 (0.11)	3.2	74 to 169	17 to 37	14 to 33
"	1	G	"	"	18	25.6	8.84 (2.62)	0,75 (0.11)	2.6	72 to 165	18 to 33	16 to 30
"	2	C	Restricted LP	LDx(LW xLD)	18	25.0	7.14 (1.35)	0.78 (0,06)	1.7	73 to 160	16 to 36	13 to 36
"	2	G		"	18	23.3	8.87 (1.93)	0.70 (0,09)	2.3	75 to 168	18 to 31	14 to 33
Tullis	3	B	Ad libitum HP	LWx(LW xLD)	14	19.8	8.43 (1.44)	0.66 (0,06)	2.9	12 to 196	6 to 30	4 to 38
"	3	C	"	"	14	25.7	8.25 (2.46)	0.68 (0,08)	4.7	20 to 207	9 to 44	4 to 52
"	3	G	"	"	14	23.6	8.94 (1.53)	0.72 (0,06)	3.2	15 to 198	8 to 37	4 to 45
Prandini	Pooled	All	Restricted	Pooled	72	25.4	9.17 (1.06)	0.70 (0,04)	2.5	73 to 169	17 to 37	13 to 36
Tullis	Pooled	All	Ad libitum	LWx(LW xLD)	42	23.0	8.81 (1.11)	0.69 (0,04)	3.9	12 to 207	8 to 44	4 to 52

[1] *Dataset: Prandini et al. (1996) and other experimental data obtained by Prandini et al.; Tullis (1981).*

[2] *Sex: C = Castrated males; G= Gilts; B = Boars.*

[3] *CP = feed containing a conventional crude protein content (13.3 % as fed); LP = feed containing a low crude protein content (10.7 % as fed); HP = feed containing a high crude protein content (23.0 % as fed).*

[4] *Dx(LWxLD) = Duroc x (Large White x Landrace); LWx(LW xLD) = Large White x (Large White x Landrace).*

[5] *Obs. = number of observations.*

[6] *$\hat{Y}$ = average values of y.*

[7] *The t-test was used to test the hypothesis that the intercepts and the slopes values obtained for each trial and sex significantly differed from the values found for the pooled equations within and between data set. No significant differences due to the dataset, the trial and the sex were found.*

Feed, energy needs and predicted feed intake

To describe the energy content of the finisher feed used over the period of IVOG test (t_2 to t_3), the effective energy system (EE) described by Emmans (1994) was preferred to those based on the expression of net energy. The EE system allows a description of the feed which is independent from the animal effects and it takes into account different energetic efficiencies for maintenance, protein retention and lipid retention. The effective energy content of a feed (EEC) is the metabolizable energy corrected for zero nitrogen retention, minus the amount of work associated with eating, the amount of work associated with urea synthesis, the amount of energy lost because of fermentation. The value is then corrected for the differences in the efficiency of use of metabolizable energy in forming body lipid from lipid and non-lipid feed. The EEC of the feed was computed as suggested by Emmans (1994). The resulting EEC of the feed was 11.9 MJ/kg of feed.

Effective energy requirement for maintenance (MH), over the test period (t_2 to t_3), has been computed as a function of the current protein mass (Pc) and Pm as suggested by (Emmans, 1999):

8) $MH = 1.63*(Pc/Pm)*Pm^{0.73}$ MJ/d

To estimate the average Pc over the test period, protein mass was integrated using the following equation from age t_2 to t_3:

9) $\int_{t_2}^{t_3} Pm*exp(-exp(-B*(-ti-t^\wedge)))dt_i$ kg

The calculated current protein mass was expressed on daily basis by dividing by the duration of the test period (t_3-t_2).

Average daily gains of lipid (Lr) and protein (Pr) over the period from 126 ± 4 (t_2) to 184 ± 5 (t_3) days of age were evaluated as:

10) $Lr = (L_{t3} - L_{t2})/(t_3-t_2)$ kg/d

11) $Pr = (P_{t3} - P_{t2})/ (t_3-t_2)$ kg/d

The corresponding average daily amounts of effective energy used for growth were estimated as (Emmans, 1999):

12) $EEG = 50*Pr + 56*Lr$ MJ/d

Predicted daily mean feed intake (PFI) was estimated as (Ferguson *et al.*, 1994):

13) $PFI = (MH+EEG)/EEC$ kg/d

Analysis of variance for the measured and the predicted feed intake

Since a preliminary ANOVA showed that between 126 to 184 days of age the measured value of FI and PFI did not differ significantly, two different models of ANOVA were compared.

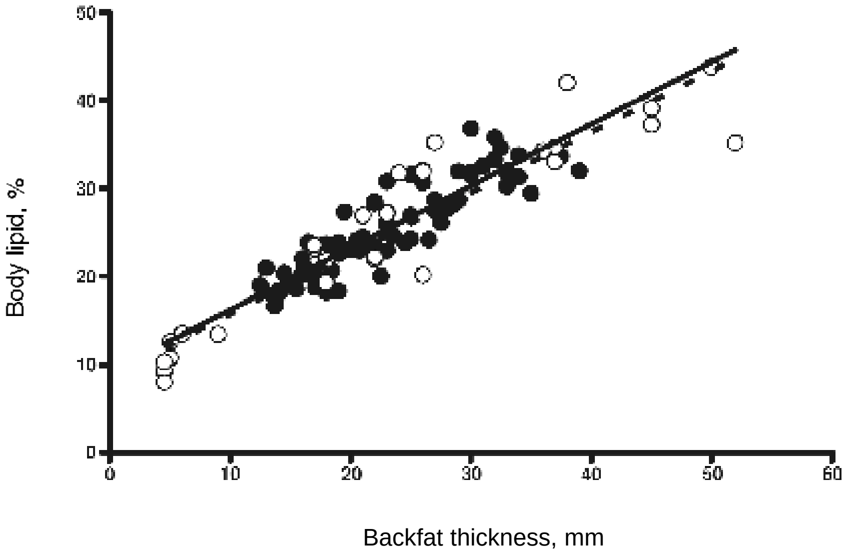
In the first model (Model 1) the measured values of FI were analysed for the effects of month, batch(within month), initial body weight at age t_2, average metabolic weight, initial value of P2 at age t_2, average daily gain, variation of P2 from t_2 to t_3. In a second model the direct simple body measurements (BW_{t2}, average metabolic weight, $P2_{t2}$, average daily gain and change of P2 from t_2 to t_3) were replaced by the values of PFI, as combined source of variation. The two models were compared in terms of sum of squares associated to the different sources of variations. The residual "feed intakes" achieved from the two models were analysed by linear regression.

Results

Backfat thickness and body lipid percentage

The relationship between the two variables resulting from the complete dataset provided by Prandini *et al.* (1996 and additional data), is given in Figure 1. There were no significant differences due to the sex and the trial (Table 3). The overall equation, considering all the 72 data points, explained 79% of total variability. The slope of regression indicated that the increase of 1 mm of backfat thickness was associated to an increase of body lipid percentage of 0.70.

Figure 1. Relationships between body lipid (%) and backfat thickness (mm) from a re-analysis of data of different origin.



¸ *, continuous line, dataset of Prandini* et al. *1996;* ¹ *, dotted line, dataset of Tullis, 1981.*
The values of the parameters of the relationships are given in Table 3.

Body lipid percentage ranged from 16.6 to 36.8 and backfat thickness ranged from 19 to 48 mm.

This range differed from that observed on the 920 pigs of the farm data set, which showed values ranging only from 6 to 23 mm.

Nevertheless, this equation was very similar to that obtained by the re-analysis of the slaughtering data reported by Tullis (1981) (L% = 8.81 + 0.69*P2) regarding subjects with backfat thickness and body lipid percentage ranging from 4.5 to 52 mm, and 8 to 44 %, respectively.

Mature protein and lipid masses and relative growth rate parameters

The average values of Pm and B, resulting from the use of the Gompertz growth function, were 43.5 ± 5.8 kg and 0.0116 ± 0.0011 d^{-1}, respectively (Table 4). The coefficients of variation (CV) of Pm and B were respectively 13.6% and 10%. RSD and R^2 of the 920 curves, which reflected the variation associated to the estimates of LFEBW, averaged 1.4 ± 1.3 kg and 0.997 ± 0.003, respectively.

The values of Lm and B, obtained from fitting the individual L data against time with the Gompertz curve averaged 78.5 ± 15.7 kg and 0.0100 ± 0.0002 d^{-1}, respectively. RSD and R^2 values were 1.54 + 1.08 kg and 0.993 + 0.010, respectively. The ratio Lm/Pm was 1.81 ± 0.30. In Figure 2 the values of the average animal characteristics of the pig population have been plotted against age, to describe the waves of daily growth of the various body constituents (first derivate of the Gompertz curve for each body constituent).

The correlations between the values of the growth parameters of pig population are given in Table 5.

A strong and negative correlation was found between Pm and B (r = -0.58) and the correla-

Table 4. Gompertz growth parameters[a] for protein and lipid in the population investigated (920 pigs).

		Protein		Lipid	
Items		Mean	SD	Mean	SD
Pm	kg	43.5	5.8		
B	d^{-1}	0.0116	0.0011	0.0100	0.0002
$B^{\hat{\imath}}$	d^{-1}	0.0319	0.0027		
Lm	kg			78.4	15.7
Lm/Pm				1.81	0.30
R^2 of the 920 Gompertz curves		0.997	0.003	0.993	0.010
RSD of the 920 Gompertz curves	kg	1.41	1.33	1.54	1.08

[a] *Pm protein weight at maturity; B=rate of maturing; $B^{\hat{\imath}}$ = scaled rate of maturing; Lm = lipid weight at maturity; Lm/Pm = ratio of lipid to protein at maturity.*

Table 5. The correlation coefficients (r) between growth parameters (B, B*, Pm and Lm/Pm)[a] in the population investigated (920 pigs).

	Pm	B	B*
B	-0.58		
$B^{\hat{\imath}}$	-0.24	0.93	
Lm/Pm	-0.17	0.29	0.29

[a] *B = rate of maturing; $B^{\hat{\imath}}$ = scaled rate of maturing; Pm = protein weight at maturity; Lm/Pm = ratio of lipid to protein at maturity.*

tion between B and B* was 0.93. The correlations between Pm and B* (r = -0.24) and between Pm and Lm/Pm (r = -0.17) were much weaker. These results, in agreement with those obtained by Ferguson *et al.* (1997), indicated that the estimates of Pm and B were acceptable.

Body composition, daily gains of protein and lipid and effective energy requirements

The estimates of body composition at the 4 different ages are given in Table 6. The sums of the various body constituents (x) were highly correlated with the observed (y) values of BW. The corresponding relationship was y= 0.23+1.003*x; RSD= 1.44 kg and R^2 = 0.9992.

Daily retention of nutrients and the mean degree of maturity (Pc/Pm) over the period of age from 126 ± 4 to 184 ± 5 are given in Table 7. Protein and lipid retentions averaged 177 and 239 g/d. Protein retention showed a value of standard deviation, 21 g/d, which was markedly lower then that observed for lipid, 62 g/d. EE requirements for maintenance and growth were estimated to be 11.2 and 22.3 MJ/d, respectively.

Table 6. Estimated amounts of protein (P)[a], water (W)[a], ash[a], lipid (L)[b] recovered by the 920 growing pigs at different ages and body weight resulting from their sum (BW)[c,d]. Values are means ± SD.

Age	days	0	71 ± 4	126 ± 5	184 ± 5
P	kg	0.27 ± 0.11	4.50 ± 0.63	13.04 ± 1.25	23.21 ± 2.00
W	"	1.67 ± 0.61	18.77 ± 2.26	46.64 ± 3.82	76.35 ± 5.65
Ash	"	0.05 ± 0.02	0.90 ± 0.13	2.61 ± 0.25	4.64 ± 0.40
L	"	0.06 ± 0.00	4.13 ± 0.88	11.53 ± 1.56	25.27 ± 4.11
BW= [(P+W+Ash + L)/0.95]	"	2.17 ± 0.79	29.79 ± 4.04	77.70 ± 7.06	136.3 ± 12.11

[a] *The estimates were achieved from plotting the individual Gompertz curves.*

[b] *The estimates were achieved from the following relationships:*

*- for age 0: L = 0,04*BW, were BW was assumed to be 1.5;*

- for age 71: $L= BW*0.95-(1,2*P + 5.193*P^{0.855})$*, assuming P = 16% of the measured BW;*

*- for ages 126 and 184 d: L = (9.16 + 0.70*P2)*BW/100, where P2 (backfat thickness) and BW were measured. See the text for details.*

[c] *The relationship between the measured (y) and the estimated (x) values of BW was y=-0.23+1.003*x; RSD= 1.44 kg,* R^2*= 0.9992.*

[d] *The statistics included both the among animals variation and the variation associated with age.*

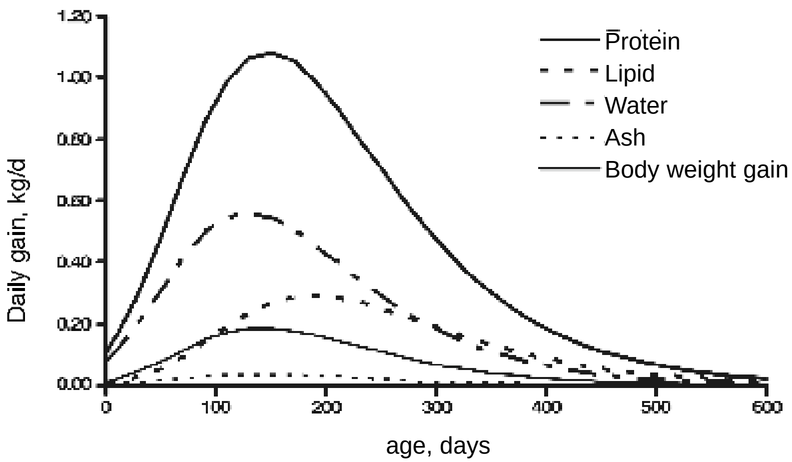
Table 7. Means and SD of the estimates for protein (Pr) and lipid (Lr) retentions, average current protein mass (Pc) and degree of maturity (Pc/Pm) over the test period, effective energy requirements for maintenance (MH) and growth (EEG) and predicted feed intakes for the 920 pigs from 126 to 184 days of age.

		Mean	SD
Pr	kg/d	0.177	0.021
Lr	"	0.239	0.062
Pc	kg	18.47	1.60
Average degree of maturity (Pc/Pm)	kg/kg	0.432	0.061
MH	MJ/d	11.18	0.94
EEG	"	22.30	4.32
Total effective energy requirements	"	33.48	4.68
Predicted feed intake	g/d	2.814	0.393

Correspondence between measured and predicted feed intake

The corresponding PFI was 2.814 ± 0.393 kg/d. PFI did not significantly differ from measured FI. As expected, measured FI analysed with model 1 was significantly affected by month and batch (within month), reflecting the environmental effects not considered in the set of equations used (Table 8). Among the various direct body measurements only metabolic weight, initial live weight

Figure 2. Waves of potential growth of protein, lipid, water and ash and live weight obtained applying the average values of the gompertz curves parameters achieved for the 920 pigs.



The curves are the first derivate, with respect to age, of the Gompertz functions.

and backfat thickness variation absorbed significant proportions of variance. The model absorbed 83% of the total variance with a residual standard deviation of 0.199 kg/d.

The replacement of the direct body measurements of BW and P2 by PFI in model 2 did not change the explained proportion of variance, the sum of squares due to the other sources of variations and the RSD (0.200 kg/d). The two sets of residual feed intakes were highly correlated (R^2 = 0.961), the slope of the regression was very close to 1, the intercept was zero and the RSD was only 0.043 kg/d (Figure 3).

Discussion

Backfat thickness and body lipid

Backfat thickness is considered a relatively good predictor of carcass composition; it is the basis of many carcass grading systems and it is often used as a indirect measure of body lipid (de Greef, 1995). It can be measured accurately and easily. In principle, there could be a variety of relationships relating backfat thickness to the pig lipid content.

The genetic background, the stage of growth and the nutritional history can influence the depth and the area of the backfat tissue as well as the distribution of lipid within the body (Rook *et al.*, 1987; de Greef, 1995). One of the major shortcomings of the empirical relationships between backfat thickness and body lipid is the problem to differentiate body weight from body composition. However, some experimental results have shown that the apparent effect of body weight is, at least partially, removed by expressing the lipid weight relative to body weight (lipid percentage) (de Greef, 1995). In this paper the regression parameters, the slope and the intercept, obtained from the analysis of the Prandini *et al.* (1996) dataset resulted similar to those obtained from the re-analysis of the Tullis (1981) data. Both datasets regarded white crossbred pigs slaughtered over a wide range of body weight. However Tullis's data (1981) concerned pigs fed *ad libitum* with high

Table 8. Sources of variation, degrees of freedom (DF), sum of squares (SSQ) and Fisher values (F) for the observed values of feed intake (kg/d) taking into account the measured in vivo traits (model 1) or using the predicted feed intake obtained from the proposed procedure (model 2).

Sources of variation	Model 1			Model 2		
	DF	SSQ	F	DF	SSQ	F
Month	11	7.9	18***	11	7.2	16***
Batch (within month)	103	20.1	4.9***	103	21.6	5***
Initial body weight	1	0.2	4.9*			
Metabolic weight	1	0.3	6.5*			
Initial value of P2	1	0.0	0.0			
Average daily gain	1	0.1	3.0			
Variation of P2	1	9.2	231***			
Predicted feed intake				1	67.2	1655***
Error	800	31.7		804	32.6	

** = P<0.05; ** = P<0.01; *** = P<0.001; The two models had the same R2 (0.827) and the same RSD (0.199 kg/d).*

protein levels, those from Prandini *et al.* (1996) concerned pigs that received restricted diets with moderate or low levels of protein. The indication that an increase of one percentage unit of lipid content was related to an approximately 0.7 mm increase in backfat thickness was also in agreement with the results of de Greef (1995), concerning groups of pigs fed *ad libitum* and slaughtered between 45 to 105 kg of BW. These agreements suggested that for white crossbred groups of pigs the relationship used might hold over an ample range of body weight and for different feeding conditions.

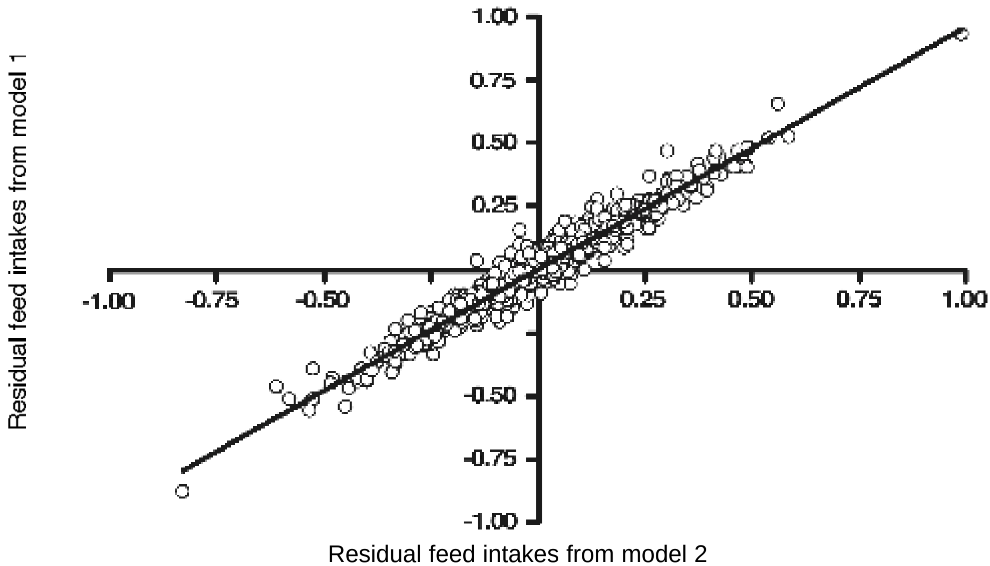
However, caution must be made in the evaluation of single subjects because the residual variability associated with this relationship was rather high.

Gompertz growth parameters and body composition

The approach to estimate body composition and the growth parameters adopted in this paper is certainly less accurate with respect to other approaches based on serial slaughtering and chemical analysis (Ferguson and Gous, 1993a, 1993b; Schinckel, 1999). However, it has the advantage that it can be performed on-farm on a large number of pigs and that the measurements can be repeated on the same subject at different points over the time. Since the measurements were about two consecutive growth periods of ample duration it was found convenient to apply a non-linear procedure of analysis rather then the linear log regression analysis proposed by Ferguson and Gous (1993a, 1993b). The main shortcomings of the farm data set were about the low number of measurements of P2 (2 points) and BW (3 points), which made inevitable the recourse to some assumptions to run the model.

This could have probably introduced some degree of bias in the estimates. Nevertheless, the values of mature protein mass and relative growth rate were reasonable. The average values of Pm and B were similar to those found by Ferguson and Gous (1993a), obtained from a re-

Figure 3. Residual feed intakes (kg/d) resulting from the analysis of variance of the observed feed intakes with model 1 (y) or model 2 (x). Model 1 considered as sources of variation the simple body measurements; in model 2 the simple body measurements were replaced by the predicted values of feed intake.



*The relationship between the two set of residuals was: y = 0.000 + 0.997*x, RSD = 0.043 kg/d;* R^2 *= 0.961. See the text and Table 8 for details.*

analysis of Campbell and Taverner data (1988) which were 43.7 kg and 0.0113 d^{-1} , respectively, and to those suggested by Emmans and Kyriazakis (1999) for improved pig genotypes which were 45 kg and 0.0125 d^{-1}, respectively.

Currently no data are available from which the distribution of Pm, B and B* can be estimated for pigs of a given sex and strain, although Emmans and Fisher (1986) and Emmans (1988) did speculate, in the case of broilers, general coefficients of the genetic variation (SD/mean) for Pm of 6 to 10 % and for B* of 2 to 4%. In pigs, Ferguson *et al.* (1997), taking data from literature, simulated coefficient of genetic variation for Pm and B*, respectively, of 5 and 2%. In the present analysis the coefficients of variation of Pm, B and B* were 13.6, 10 and 8.4%, but they reflect the phenotypic variation and not the genetic one. Part of this variability is certainly due to the low accuracy of the equation used to relate backfat thickness to body lipid percentage as well as to the assumptions made to run the analysis. The Gompertz growth parameters for protein obtained in this analysis (Table 5) are unlikely to represent the true potential values, nevertheless they can give some indication of the potential protein growth achievable under the real farm circumstances.

The corresponding values of body composition, given in Table 6, were close to the expected and the good correlation between the actual and the estimated values of body weight was considered as a first partial confirmation that these estimates were a reasonable starting point in the attempt to connect feed intake to the changes of body composition.

The estimates of Gompertz growth parameters obtained for lipid (Lm and B_l) were lower than previous findings. The lipid to protein ratio at maturity (Lm/Pm) was only 1.82, which is somewhat lower with respect to other figures given in literature. Ferguson and Gous (1993a), analysing data of Whittemore *et al.* (1988) and of Campbell and Taverner (1988), found a Lm/Pm ratio of 2.1 and 2.6, respectively. Emmans and Kyriazakis (1999), for male pigs with a Pm value of 45 kg, suggested a Lm/Pm ratio of 2.8.

In addition, in the present work, the estimated average B value for lipid was significantly lower than that achieved for protein (0.0100 vs 0.0116, respectively; P<0.01). A similar result was explained by Ferguson and Gous (1993b) as: "protein growth is less likely to be adversely affected by conditions that are not perfect for the realization of potential growth than is lipid growth, which is dependent on prevailing nutritional and environmental conditions.

The difference in the estimates in the B values, therefore, probably suggests that some nutritional or environmental conditions were not perfect to allow the protein and lipid growth to proceed at their potential during the growth period."

In agreement with Ferguson *et al.*, (1997) and Black *et al.*, (1999), these results therefore suggest that the pigs of the investigated population, in particular those having the greater potential for growth, could have not achieved their "desired" feed intake perhaps because of hot temperatures and/or the bulk of some feeds used during some periods of growth.

Therefore, the description of the pigs, at least for their "desired" lipid growth, remained doubt and the possibility of extending the prediction of the desired feed intake of this population under more general conditions of feeding and climate remains a guess.

Predicted and measured feed intakes

Individual estimates of body chemical status and its changes have been subsequently used to evaluate the corresponding amounts of feed required to support the maintenance and the estimated retention of protein and lipid from 126 ± 4 to 184 ± 5 days of age. Concepts and functions taken from the effective energy system proposed by Emmans (1994) have been used to describe the flows of energy from the feed to the pigs. EE for maintenance, scaled and computed as proposed by Emmans (1999), averaged 11.18 ± 0.94 MJ/d and accounted for individual difference due to mature protein mass and degree of maturity. This value corresponds to about 0.366 ± 0.016 MJ of metabolizable energy (ME) per kg of $BW^{0.75}$, which is much lower than the more commonly used values ranging from 0.444 to 0.504 MJ ME/$BW^{0.75}$ (Whittemore *et al.*, 2001b).

The reasons for this difference are due to the effective energy system used, which allocates some of the energy costs, those arising as a direct consequence of eating the food, in the description of feed rather than in the maintenance requirements. Details are given by Emmans (1999). The predicted amount of EE used for growth, on average 22.33 ± 4.32 MJ/d, is based on the assumption, not necessarily true, that with this energy system the efficiencies with which the EE is deposited in lipid and protein can be treated as nutritional constants (Kyriazakis and Emmans 1999).

The resulting estimates of feed intake were very similar, and not significantly different, to the measured ones, notwithstanding the various assumptions and approximations made to run the available data. The agreement between predicted and observed feed intakes indicated that the estimates of body composition were reasonable and this was also confirmed by the analysis of the variance of FI. The proportion of explained variance (82%), and its composition, did not change when in the statistical model of analysis the effects of simple body measurements were replaced by the predicted feed intake as source of variation. The two set of residual feed intake were normally distributed, according to de Haer *et al.* (1993), and highly correlated. Thus, the approach used offered a good biological interpretation of the proportion of variance of FI associated to the various body measurements. The mean residual feed intake was only 7% of the average FI, a value very close to that of 6% reported by Foster *et al.* (1983) and much lower than that of 11% found by de Haer *et al.* (1993). Part of this residual variability was surely due to the assumptions made to run the model, to the low precision of the relationship relating backfat thickness to body lipid percentage and to possible errors in measuring backfat thickness, body weight and feed intake. Residual variability also reflects some differences among subjects in the energy expenditure for thermoregulation, for the level of physical activity and for sub-clinical diseases, not excluding some contribution due to individual differences in the digestive and metabolic efficiency.

Conclusions

The results support the proposition that, assuming the composition of gain is determinable, feed intake is predictable as a simple sum of needs. The good correspondence between predicted and observed values of feed intake was a confirmation that the approach followed to estimate body composition was sufficiently good. Thus, a scheduled protocol of measurement of body weight and backfat thickness over the course of growth, coupled with the use of allometry, can be proposed to estimate *in vivo* the chemical status of pigs. Under conditions as close as possible to the ideal the procedure can be used to achieve operational values to describe the potential growth of the pig population under control, although these values will unlikely to be considered as potential true values. From the analysis of available dataset reasonable estimates of the mature mass, the rate of maturing of protein and of their distribution within the pig population were obtained. Less convincing were the estimates of the lipid to protein ratio at maturity. Some improvement of the recording farm protocol should be considered in order to reduce possible bias and errors in the estimates. Among these, the use of many data points as possible throughout the whole period of growth, the introduction of better control and description of the physical environment as well as the use of less bulky feeds are the major ones.

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REFERENCES

ASPA, COMMISSION "NUTRIENT REQUIREMENTS OF HEAVY PIG", 2003. A methodological approach to assess nutrient requirements of heavy pigs in Italy. Ital. J. Anim. Sci. 2:73-87.

BLACK, J.L., 1995. The evolution of animal growth models. In: P.J. Moughan, M.W.A. Verstegen, M.I. Visser Reyneveld (eds.) Modelling growth in the pig. EAAP Publ. N. 78, Wageningen Agricultural University, Wageningen, The Netherlands, pp 3-9.

BLACK, J.L., BRAY, H.J., GILES L.R., 1999. The thermal and infectious environment. In: I. Kyriazakis (ed.) A quantitative biology of pig. CABI publishing, Oxon, UK, pp 71-97.

CAMPBELL, R.G., TAVERNER, M.R., 1988. Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. J. Anim. Sci. 66:676-686.

DE GREEF, K.H., 1995. Prediction of growth and carcass parameters. In: P.J. Moughan, M.W.A. Verstegen, M.I. Visser-Reyneveld (ed.) Modelling growth in the pig. EAAP Publication N. 78, Wageningen Agricultural University, Wageningen, The Netherlands, pp 151-163.

DE HAER, L.C.M., MERKS, J.W.M., KOOPER, H.G., BUITING, G.A.J., VAN HATTUM, J.A., 1992. A note on the IVOG-station: a feeding station to record the individual food intake of group-housed growing pigs. Anim. Prod. 54:160-162.

DE HAER, L.C.M., LUITING, P., AARTS, H.L.M., 1993. Relations among individual (residual) feed intake, growth performance and feed intake pattern of growing pigs in group housing. Livest. Prod. Sci. 36:233-253.

DE LANGE, C.F.M., 1995. Framework for a simplified model to demonstrate principles of nutrient partitioning for growth in the pig. In: P.J. Moughan, M.W.A. Verstegen, M.I. Visser-Reyneveld (eds.) Modelling growth in the pig. EAAP Publication N. 78, Wageningen Agricultural University, Wageningen, The Netherlands, pp 71-85.

EMMANS, G.C., 1988. Genetic components of potential and actual growth. In: R.B. Land, G. Bulfield, W.G. Hill (eds.) Animal breeding opportunities. Publication N. 12, British Society of Animal Production, Edinburgh, UK, pp 153-181.

EMMANS, G.C., 1989. The growth of turkey. In: C. Nixey, C.T. Grey (eds.) Recent Advances in Turkey Science. Butterworths, London, UK, pp 135-166.

EMMANS, G.C., 1994. Effective energy: a concept of energy utilization applied across species. Br. J. Nutr. 71:801-821.

EMMANS, G.C., 1995. Problems in applying models in practice. In: P.J. Moughan, M.W.A. Verstegen, M.I. Visser-Reyneveld (eds.) Modelling growth in the pig. EAAP Publication N. 78, Wageningen Agricultural University, Wageningen, The Netherlands, pp 223-227.

EMMANS, G.C., 1999. Energy flows. In: I. Kyriazakis (ed.) A quantitative biology of pig. CABI publishing, Oxon, UK, pp 181-197.

EMMANS, G.C., FISHER, C., 1986. Problems in nutritional theory. In: C. Fisher, K.M. Boorman (ed.) Nutrient requirements of poultry and Nutritional Research. Butterworths, London, UK, pp 9-39.

EMMANS, G.C., KYRIAZAKIS, I., 1995. A general method for predicting the weight of water in the empty bodies of pigs. Anim. Sci. 61:103-108.

EMMANS, G.C., KYRIAZAKIS, I., 1999. Growth and body composition. In: I. Kyriazakis (ed.) A quantitative biology of pig. CABI publishing, Oxon, UK, pp 181-197.

FERGUSON, N. S., GOUS, R.M., 1993a. Evaluation of pig genotypes. Theoretical aspects of measuring genetic parameters. Anim. Prod. 56:233-243.

FERGUSON, N.S., GOUS, R.M., 1993b. Evaluation of pig genotypes 2. Testing experimental procedures. Anim. Prod. 56 245-249.

FERGUSON, N.S., GOUS, R.M., EMMANS, G.C., 1994. Preferred components for the construction of a new simulation model of growth, feed intake, and nutrient requirements of growing pigs. S. Afr. J. Anim. Sci. 24:10-17.

FERGUSON, N.S., GOUS R.M., EMMANS G.C., 1997. Predicting the effects of animal variation on growth and food intake in growing pigs using simulation modelling. Anim. Sci. 64:513-522.

FOSTER, W.H., KILPATRICK, D.J., HEANEY, I.H., 1983. Genetic variation in the efficiency of energy utilization by the fattening pigs. Anim. Prod. 37:387-393.

NATIONAL RESEARCH COUNCIL, 1988. Nutrient requirements of swine. 9th rev. ed. National Academy Press, Washington, DC, USA.

KYRIAZAKIS, I., EMMANS G.C., 1999. Voluntary food intake and diet selection. In: I. Kyriazakis (ed.) A quantitative biology of pig. CABI publishing, Oxon, UK, pp 229-248.

MOUGHAN, P.J., SMITH, W.C., PEARSON, G., 1987. Description and validation of a model simulating growth in the pig (20-90 kg live weight). New. Zeal. J. Agr. Sci. 30:481-489.

POMAR, C., HARRIS, D.L., MINVIELLLE, F., 1991. Computer simulation model of swine production systems. I. Modelling the growth of young pigs. J. Anim: Sci. 69:1468-1488.

PRANDINI, A., MORLACCHINI, M., MOSCHINI, M., PIVA, A., FIORENTINI, L., PIVA, G., 1996. Growth performance and carcass composition of heavy pigs from 80 to 160 kg of live weight. Ann. Zootech. 45:75-87.

ROOK, A.J., ELLIS, M., WHITTEMORE C.T., PHILLIPS, P., 1987. Relationships between whole body chemical composition, physically dissected carcass parts and backfat measurements in pigs. Anim. Prod. 44:263-273.

SAS, 1988. SAT/STAT User 's Guide (Release 6.093). SAS Institute Inc, Cary, NC, USA.

SCHINCKEL, A.P., 1999. Describing the pig. In: I. Kyriazakis (ed.) A quantitative biology of pig. CABI publishing, Oxon, UK, pp 9-38.

SCHIAVON, S., EMMANS, G.C., 2000. A model to predict water intake of a pig growing on a known environment on a known diet. Br. J. Nutr. 84:873-883.

TULLIS, J.B., 1981. Protein growth in pigs. PhD thesis, University of Edinburgh, Edinburgh, UK.

WHITTEMORE C.T., 1993. The Science and the practice of pig production. Longman Scientific and Technical., Essex, UK.

WHITTEMORE, C.T., 1994. Growth and the simulation of animal responses. In: D.J.A. Cole, J. Wiseman, M.A. Varley (ed.) Principles of pig science. Nottingham University Press, Loughborough, Leicestershire, UK, pp 55-73.

WHITTEMORE, C.T., TULLIS J.B., EMMANS G.C., 1988. Protein growth in pigs. Anim. Prod. 46:437-445.

WHITTEMORE, C.T., KERR, J.C., CAMERON, N.D., 1995.

An approach to prediction of feed intake in growing pigs using simple body measurements. Agr. Syst. 47:235-244.

WHITTEMORE, C.T., GREEN D.M., KNAP, P.W., 2001a. Technical review of the energy and protein requirements of growing pigs: food intake. Anim. Sci. 73:3-17.

WHITTEMORE, C.T., GREEN D.M., KNAP, P.W., 2001b. Technical review of the energy and protein requirements of growing pigs: energy. Anim. Sci. 73:199-215.