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Feeding time and feeding rate and its relationship with feed intake, feed efficiency, growth rate, and rate of fat deposition in growing Duroc barrows

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ABSTRACT: Because feed is the major cost to pork production, management practices and breeding strategies are aimed at optimizing feed intake. Knowledge about the shape of feed intake and feeding behavior curves may be of interest for optimization of lean meat production. This study investigated trends based on daily measurements of feeding behavior in 200 Duroc barrows, originating from 5 sires and 200 dams, during growth. Daily values were examined between 88 and 188 d of age. Furthermore, phenotypic correlations between feeding length and feeding rate, and feeding frequency, feed intake, residual feed intake, growth rate, and rate of fat deposition were investigated for a period between 95 and 175 d of age. No differences were observed between sires for parameter estimates of a curvilinear function fitted to data on feeding length as a function of age, but the effect of sire was significant ($P < 0.01$) for values at individual ages up to 132 d of age. Feeding rate (feed ingested for each minute spent eating) increased in a linear fashion with age (average $R^2 = 0.80$) and differently so for different sires ($P < 0.05$ for the intercept and $P < 0.01$ for the regression coefficient). Because the increase in BW is linear over this time period (average $R^2 = 0.99$), the results suggest that feeding rate increased with increased BW and is related to the physical capacity for feed intake. Results indicate that pigs that ate faster also ate more ($r = 0.29, P < 0.001$), grew faster ($r = 0.40, P < 0.001$), and grew fatter ($r = 0.28, P < 0.001$), but had no greater or lower residual feed intake ($r = -0.01$). The linear regression slope of feeding rate on age seemed inherent to the individual and was correlated with feed intake but not with residual feed intake. Feeding length may be selected for in order to regulate absolute feed intake at different stages of growth.

Key words: barrow, feed intake behavior, feeding rate, feeding length, pig, sire effect

INTRODUCTION

Because feed is the major cost to pork production (Mrode and Kennedy, 1993), management practices and breeding strategies are aimed at optimizing feed intake (Hermesch et al., 2003). Over the last decades, the major part of selection pressure in pig breeding programs has been directed toward improvement of lean growth efficiency by selection for ADG, G:F, and leanness (Eissen, 2000; Lonergan et al., 2001). Because carcass leanness is negatively correlated with ADFI, selection for increased leanness and improved G:F has led to a decrease in the feed intake capacity, resulting in lower mean voluntary ADFI and a lower rate of increase in ADFI with BW (Ellis et al., 1983; Cameron and Curran, 1994; Webb, 1996).

Electronic feeders can record detailed information about feed intake behavior in addition to ADFI from group-housed pigs (Von Felde et al., 1996). Knowledge about the shape of feed intake curves is of increasing interest for optimization of lean meat production (Schnyder et al., 2001; Schulze et al., 2002). The same may be true for the shape of feed intake behavior curves as they relate to ADFI. Several studies investigated feed intake behavior traits in pigs (De Haer and De Vries, 1993; Von Felde et al., 1996), but no study has reported on corresponding trends based on daily measurements over time.

The objectives of this study were 1) to investigate trends based on daily measurements of feeding behavior traits in Duroc barrows during growth, and 2) to investigate phenotypic correlations between feeding

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length and feeding rate, and feeding frequency, ADFI, G:F, growth rate, and rate of fat deposition.

MATERIALS AND METHODS

Animals

The experimental procedures were approved by the ethical committee of the institution (Institut de Recerca i Tecnologia Agroalimentàries). The data set consisted of 200 Duroc barrows in 2 batches (n = 98 and 102, respectively). Pigs were born in August through September 2003 (batch 1) and in March through April 2004 (batch 2). Barrows were the castrated sons of 5 sires (15, 34, 39, 41, and 70 sons per sire, respectively) and 200 dams and were born on 3 farms. Sire 1 had offspring in the first batch only because he died before dams of the second batch could be inseminated. There was no particular reason that sire 5 had almost twice as many offspring as the others.

At weaning (15 to 19 d of age), pigs were moved to the test station “Centre de Control Porci” [CCP-IRTA, Monells (Girona, Spain), distributed over 16 pens in 4 rooms, and all were subjected to the same management. At this stage, pigs were housed based on age; pigs that belonged to this experiment were mixed with pigs that did not take part in this experiment, possibly of different breeds and sex. In the second half of November 2003 (batch 1) and in the first half of June 2004 (batch 2), pigs participating in the current study were moved to the fattening and control unit where they were distributed over 10 pens (5 pens at each side of a central corridor in the same barn) in groups of 8 to 12 pigs. Between December 1, 2002, and March 29, 2003 (batch 1), and between June 7 and September 30, 2004 (batch 2), feed intake and feed intake behavior were recorded daily automatically by means of an electronic identification system (Hokofarm, IVO-G, Marknisse, the Netherlands). From these data, feeding frequency or feeding length per visit, missing values for feed intake, feeding length, and feed intake per visit were estimated with a polynomial equation that was fitted to individual data on feed intake, feeding length, and feed intake per visit as a function of age:

\[
\text{TRAIT}_{\text{Age}} = a + (b \times \text{Age}) + (c \times \text{Age}^2),
\]

where \( \text{TRAIT}_{\text{Age}} \) = feed intake (kg), feeding length (min), or feed intake per visit (kg) of the pig at a specific age (d); \( a \), \( b \), and \( c \) are regression coefficients to be estimated. Because no age trend was observed for the feeding frequency or feeding length per visit, missing values were estimated with the corresponding average values over the entire period. Missing values were not estimated before the first and beyond the last actual measurement.

Feeding frequency, feeding length, and feed intake were summed for the period between 95 and 175 d of age for a total of 192 pigs. Because values could only be summed for pigs being observed between the first and the last day of the chosen period, using the period between 88 and 188 d of age would result in 137 observations only. Individual residual feed intake (RFI) was estimated for the period between 95 and 175 d of age from a multiple linear regression of feed intake (kg/80 d) on estimated values of metabolic BW (BW\(^{0.75}\)), BWG, and backfat thickness (Rauw et al., 2006):

\[
FI_i = b_0 + (b_1 \times BW_i^{0.75}) + (b_2 \times BWG_i) + (b_3 \times BFT_i) + e_i,
\]

where \( FI_i \) = feed intake of individual i; \( BW_i^{0.75} \) = average metabolic BW of individual i (kg\(^{0.75}\)); \( BWG_i \) = BW gain of individual i (kg/80 d); \( BFT_i \) = average backfat thickness of individual i (mm); \( b_0 \) = the population intercept; \( b_1 \), \( b_2 \), and \( b_3 \) = partial regression coefficients representing maintenance requirements per metabolic BW, feed requirements for growth, and feed requirements related to body composition, respectively; and \( e_i \) = the error term, which represented the RFI of individual i (kg/period).
mated as the average of the estimated values at the beginning and at the end of the period. Animals with a negative RFI are more feed efficient than the average of the population on which the model is formed, whereas pigs with a positive RFI are less feed efficient.

**Statistical Analysis**

Data were analyzed using SAS (SAS Inst. Inc., Cary, NC). The procedure used to analyze the data was PROC GLM. The procedures used to estimate the phenotypic correlations were PROC GLM (to adjust the data for the effects) and PROC CORR. The model used to analyze the data was

\[ Y_{ijklm} = \mu + Sire_i + Batch_j + Pen(Batch)_k + StudyDay_l + e_{ijklm}, \text{ } \] 

where \( \mu \) = the population intercept, \( Sire_i \) = the effect of sire \( i \) (1 to 5), \( Batch_j \) = the effect of batch \( j \) (1, 2), \( Pen(Batch)_k \) = the effect of pen (1 to 10) nested within batch \( k \), \( StudyDay_l \) = the effect of day of study \( l \), and \( e_{ijklm} \) = the residual error term of pig \( m \) \( [e_{ijklm} \sim NID(0, \sigma^2_e)] \). The effect of day of study was included because not all pigs were of the same age at the same day of the study. All effects except the residual error term were considered fixed. The traits tested under this model were denoted by \( Y_{ijklm} \), as measured on pig \( m \) of sire \( i \) born in batch \( j \), housed in pen (nested within batch) \( k \), and tested on day of study \( l \): daily values by age and trends in feed intake, feeding length, feeding rate, feeding frequency, feed intake per visit, feeding length per visit, RFI, BWG, and backfat thickness. Initially, the effect of farm of origin was also included in the analysis, but because this was not significant for any of the traits, it was excluded from further analysis. Because the effect of day of study was not significant for any of the estimated regression parameters, phenotypic correlations were estimated after adjusting values for the effects of batch and pen only.

**RESULTS AND DISCUSSION**

Figure 1 shows a linear regression fitted to data on BW (a) and backfat thickness (b) as a function of age, for each sire (S1 to S5). Corresponded to the age of 88 to 188 d. Table 1 presents average parameter estimates according to Model 1 (body weight, backfat thickness, and feeding rate) and Model 2 (feed intake, feeding length, and feed intake per visit as a function of age) and the \( P \)-value of the effects of sire, batch, and pen.

No trends could be distinguished for feeding frequency or feeding length per visit. Average feeding frequency was 6.92 ± 0.177, and average feeding length per visit was 19.0 ± 0.427 min. There were no differences between sires for either trait. The feed intake per visit increased in a curvilinear fashion but in 74 pigs only; all other 126 pigs showed no trend for feed intake per visit. Therefore, individual \( R^2 \) values according to Model 2 ranged from 0.00 to 0.45 (0.13 ± 0.0664).

Feed intake can be described by linear and nonlinear functions. Lorenzo Bermejo et al. (2003) compared several functions fitting feed intake patterns in growing pigs. Polynomials do not reflect the actual stabilization of feed intake at the end of the period, and early feed intake is also poorly represented by polynomials (Lo-
In the current study, however, individual feed intake curves did not always reach the asymptotic value, resulting in distorted parameter value estimates for several individuals when using a growth function (Rauw et al., 2006). Therefore, for the purpose of investigating whether trends differed by sire, polynomials were fitted to the individual data of the current study. The range of individual $R^2$ values according to Model 2 was 0.00 to 0.91 (0.55 ± 0.015). Low fits for any of the regression equations generally resulted from a lack of trend for that individual. The average is higher than previously reported by Rauw et al. (2006) for a Von Bertalanffy growth equation fitted to data on FI against day on study for pigs of the first batch only (average of 0.46). The reason is that curves fitted better to feed intake values in batch 2 than it did to feed intakes in batch 1; the polynomial equation fitted data of the first batch pigs slightly worse (0.44) than did the Von Bertalanffy function. Results do not indicate the existence of variation between sires for parameter estimates. Schnyder et al. (2000) estimated heritabilities for polynomial feed intake curve parameters of 0.29 (intercept), 0.05 (linear regression), and 0.06 (quadratic regression).

Feeding length (Figure 1b) increased to about 113 d of age and decreased thereafter. The range of individual $R^2$ values according to Model 2 was 1 to 82% (41.2 ± 1.35%). There were no differences between sires for any of the 3 parameters (Table 1). However, the effect of sire was significant ($P < 0.01$) for values at individual ages up to 132 d of age (with exception of 92, 101, 113, and 114 d of age). After 175 d of age, differences were nonsignificant ($P > 0.05$). These results suggest an influence of sire during the first stages of postweaning growth, which slowly decreased with age.

Feeding rate, which is the feed ingested for each minute spent eating, increased in a linear fashion with age, with individual $R^2$ values ranging from 0.07 to 0.98 (0.80 ± 0.012). Because increase in BW is linear over this time period (Figure 1A), results suggest that feeding rate increases with increased body size and is related to the physical capacity of feed intake. According to a linear regression fitted to data on feeding rate against BW (results not presented), feeding rate increased about 0.47 g/min per kg increase in BW. The effect of sire was significant for parameter estimates of the linear regression on data of feeding rate as a function of age (Table 1) and of feeding rate as a function of BW ($P = 0.003$ for the regression coefficient; results not presented).

Table 2 presents phenotypic correlations, adjusted for effects of batch and pen, between feeding frequency, feeding length, feeding rate, feed intake, growth rate, rate of fat deposition, and RFI estimated for the period between 95 and 175 d of age. The correlation between feeding frequency and feeding length was close to zero and nonsignificant (Table 2). This result is comparable with estimates in pigs of batch 1 only, estimated over 106 study days ($r = -0.08$; Rauw et al., 2006). Unexpected is the negative correlation between feeding frequency and feed intake, which was about zero in the study of Rauw et al. (2006; $r = -0.06$) and not a result of an outlier. Because feed intake is strongly correlated with BW gain and rate of fat deposition (Table 2), the correlation between feeding frequency and these 2...
Table 1. Mean (SE) parameter estimates of a linear regression equation\(^1\) fitted to data on BW, backfat thickness, and feeding rate against age and of a polynomial equation\(^2\) fitted to data on feed intake (FI), feeding length per visit, and FI per visit against age, and \(P\) values of the effects of sire, batch, and pen nested within batch

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter</th>
<th>Mean (SE)</th>
<th>Sire</th>
<th>Batch</th>
<th>Pen(Batch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW, kg</td>
<td>a</td>
<td>−46.5 (0.858)</td>
<td>0.380</td>
<td>0.003</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.887 (0.00878)</td>
<td>0.960</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>Fat thickness, mm</td>
<td>a</td>
<td>−10.7 (0.464)</td>
<td>0.232</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.183 (0.00399)</td>
<td>0.956</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>c(^3)</td>
<td>−3.12 (0.141)</td>
<td>0.630</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Feed intake, kg</td>
<td>a</td>
<td>−5.20 (0.239)</td>
<td>0.992</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.103 (0.0037)</td>
<td>0.880</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>c(^3)</td>
<td>−3.12 (0.141)</td>
<td>0.630</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Feeding length per visit, min/d</td>
<td>a</td>
<td>−4.28 (6.82)</td>
<td>0.651</td>
<td>&lt;0.001</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>1.50 (0.102)</td>
<td>0.795</td>
<td>&lt;0.001</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>c(^3)</td>
<td>−65.0 (3.73)</td>
<td>0.682</td>
<td>&lt;0.001</td>
<td>0.009</td>
</tr>
<tr>
<td>Feeding rate, FI/min</td>
<td>a</td>
<td>−0.0184 (0.000967)</td>
<td>0.033</td>
<td>0.350</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>b(^3)</td>
<td>4.22 (0.0871)</td>
<td>0.003</td>
<td>0.617</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>FI per visit, kg</td>
<td>a</td>
<td>−1.50 (0.154)</td>
<td>0.839</td>
<td>0.966</td>
<td>0.158</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.0276 (0.00239)</td>
<td>0.893</td>
<td>0.205</td>
<td>0.178</td>
</tr>
<tr>
<td></td>
<td>c(^3)</td>
<td>−0.786 (0.0870)</td>
<td>0.768</td>
<td>0.278</td>
<td>0.199</td>
</tr>
</tbody>
</table>

\(^1\)\(\text{TRAIT}_{\text{Age}} = a + (b \times \text{Age})\).
\(^2\)\(\text{TRAIT}_{\text{Age}} = a + (b \times \text{Age}) + (c \times \text{Age}^2)\).

Table 2. Phenotypic correlations, adjusted for the effects of batch and pen, between feeding frequency (Frequency), feeding length (Length), feeding rate (Rate), feed intake (FI), growth rate (BWG), rate of fat deposition (FG), and residual feed intake (RFI)

<table>
<thead>
<tr>
<th>Item</th>
<th>Frequency</th>
<th>Time</th>
<th>Rate</th>
<th>FI</th>
<th>BWG</th>
<th>FG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>−0.06</td>
<td>−0.31***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate</td>
<td>−0.10</td>
<td>0.28***</td>
<td>0.26***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FI</td>
<td>−0.19**</td>
<td>0.19**</td>
<td>0.38***</td>
<td>0.76***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BWG</td>
<td>−0.20**</td>
<td>0.21***</td>
<td>0.29***</td>
<td>0.68***</td>
<td>0.66***</td>
<td></td>
</tr>
<tr>
<td>FG</td>
<td>−0.01</td>
<td>0.15*</td>
<td>0.47***</td>
<td>−0.06</td>
<td>0.17*</td>
<td></td>
</tr>
</tbody>
</table>

***\(P < 0.001); **\(P < 0.01); *\(P < 0.05).
daily feed intake and indicated that changes of the overall feed intake level are easier to achieve than changes of slope or inflexion of feed intake curves.

Results of the current study indicate that feeding frequency, feeding length per visit, and feed intake per visit show little to no variation over time or between sires. Von Felde et al. (1996) estimated heritabilities of 0.43, 0.42, and 0.51 for these traits, respectively, in Landrace and Large White boars between 100 and 170 d of age. However, in the current study, trends were observed for feeding length and feeding rate, and a genetic background is suggested by the sire effect for feeding length, which decreases with age, and for the regression of feeding rate on age. Von Felde et al. (1996) reported heritabilities of 0.43 for feeding length and 0.44 for feeding rate. Linear regression of feeding rate on age results in one single value, the slope, that seems inherent to the individual, positively correlated with feed intake, but not negatively correlated with feed efficiency. Because of its linearity, only few data points would be needed for estimation of the slope. Secondly, feeding length may be selected for in order to regulate absolute feed intake at different stages of growth.

The data set of the current study was not sufficiently large for accurate estimation of heritabilities and genetic correlations. Knowledge on genetic parameters is needed in order to further discuss the possibility of incorporating feeding length and feeding rate in the selection objectives. However, results of the current study indicate that, when sufficiently heritable, feeding length and feeding rate may be used to improve feed intake capacity in pigs during growth.

**LITERATURE CITED**


