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Food intake and live growth performance of pigs measured automatically and continuously from 25 to 115 kg live weight

Darren M Green,[1]* Susan Brotherstone,[2] C Paddy Schofield[3] and Colin T Whittemore[1]

[1]*School of Geosciences, The University of Edinburgh, Agriculture Building, The King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK*

[2]*School of Biological Sciences, The University of Edinburgh, Ashworth Laboratories, The King's Buildings, Mayfield Road, Edinburgh EH9 3JR, UK*

[3]*BBSRC Silsoe Research Institute, Wrest Park, Silsoe, Bedford MK45 4HS, UK*

Abstract: Continuous automatic measurement and electronic recording provided data for individual pig live weight and food intake on a daily basis for a total of 74 pigs representing three commercially available crossbred types of mixed genetic origin, which were kept under commercial farming conditions to determine practical expectations for food intake and performance characteristics over the whole of the growth range from 25 to 115 kg live weight. The pig types were named as 'Landrace' type, 'Pietrain' type and 'Meishan' type, having been chosen to represent 'lean', 'meaty' and 'fatty' types. The pigs were fed *ad libitum* and serially slaughtered in groups at 32, 42, 63, 82 and 112 kg live weight (*W*). Results are presented in the order of pig type as above. Daily live weight gains at 80 kg live weight were 0.93, 0.94 and 0.91 kg day^{-1} and at 100 kg were 1.04, 0.81 and 0.75 kg day^{-1}. Food intake curves differed with respect to both position and shape, with 'Pietrain' type pigs showing a lower increase with increasing live weight. Significant differences were found in the levels of fatness, as measured by P2 backfat depth, of the three pig types across the weight range examined ($P < 0.001$), in order of fatness 'Pietrain' type < 'Landrace' type < 'Meishan' type.

Keywords: growth of pigs; pig food intake

INTRODUCTION

The optimisation of nutrient supply to growing pigs demands as exact a definition as possible of the pig's production capacity, particularly with regard to the potential for food intake and for growth in live weight. Large differences exist between pig performance on farm and under research conditions. However, accurate measurement of on-farm performance as pigs grow is difficult. The food consumption of individual pigs cannot be obtained and daily determination of live weight by conventional means is not practicable. Provision, within pens of group-housed pigs, of individual electronic pig identification and automatic food and pig weighing devices allows continuous data collection, thus giving a complete record under commercial conditions and without disruption.

European genotypes may be arbitrarily typed into two groups: female lines and male lines. Amongst the female lines the Large White/Landrace cross predominates, but recently alleles from the markedly fat but prolific Meishan importations have been introduced into some conventional stocks. Amongst the male lines the Pietrain exemplifies the source of meaty (blocky) characteristics. These three types may thus provide examples of 'lean', 'fatty' and 'meaty' pigs presently available to commercial producers.

The reports of Quiniou *et al*[1–3] would indicate that Pietrain × Large White pigs may eat less, grow live weight at a similar rate, but retain more protein daily than Large White pigs, while the Meishan pig may grow slower than the Large White. It is also clear that stage of growth influences the response to increasing

* Correspondence to: Darren M Green, School of Geosciences, The University of Edinburgh, Agriculture Building, The King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK
E-mail: Darren.Green@ed.ac.uk
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food intake and that this response is dependent on pig type. These authors concluded that to simulate the consequences of feeding strategies there is a need for more information on 'specific relationships that take into account growth potential of pigs'. Thompson *et al*[4] reported on the performance of five genotypes, while not describing the provenance of the sires involved. These workers found differences between genotypes for food intake and the absolute rate and curve parameters for protein accretion as a function of pig live weight.

The purpose of the present work was to study the live weight growth and food intake for three different breed combinations kept under commercial conditions of feeding, housing and management, by continuous measurement from 25 to 115 kg live weight. Determination of food intake on farm is discussed by Whittemore *et al*.[5]

MATERIALS AND METHODS

Pig type

The pigs were of commercial provenance, being lines of mixed (and not pure-bred) genetic origin. The three pig types were the progeny of primiparous dams mated by AI with semen from PIC lines chosen to create types with tendencies to be 'lean', 'meaty' or 'fatty'. The dams were Large White/Landrace crossbred (JSR Genepacker 90). The sires were respectively Landrace ('Landrace' type progeny; 0.75 Landrace, 0.25 Large White), Pietrain ('Pietrain' type progeny; 0.50 Pietrain, 0.25 Landrace, 0.25 Large White) and 0.5 Meishan synthetic ('Meishan' type progeny; 0.25 Meishan, 0.375 Landrace, 0.375 Large White). To reduce within-type variation, a single male of each type was used. These aspects of the genetic origins of the three pig types were expected to be adequate to provide the variation sought between lines. All 75 pigs placed on test were identified by earmark and by electronic ID tag for individual identification within the feeding station.

Nutrition

The objective was to provide a non-limiting, but practical, nutritional environment. Pigs were fed *ad libitum* a diet comprising (g kg^{-1}): barley, 150; wheat, 461; soya 49, 175; rapeseed ext, 124; peas, 25; molasses, 20; fat, 23; limestone, 7; dicalcium phosphate, 5; salt, 3.2; lysine (50%), 3.8; premix, 3. The chemical composition of the diet (g kg^{-1} fresh weight) was: dry matter, 883; oil (ether extractives), 41.2; protein ($6.25 \times N$), 194; starch and sugar, 425; ash, 49.6; lysine, 11.4; NDF, 112; calculated DE, $14.5\ \text{MJ kg}^{-1}$.

Determination of live weight

Animal weight (W) was measured by use of a platform balance located as an integral part of the electronic feeding station (FIRE® Feeder, Osborne (Europe) Ltd, Newcastle upon Tyne, UK) in each pen. This weighs pigs at each time of their entry to the feeder. The median of all the visit weights is used as the daily weight. An analysis of the usefulness of this method of determining live weight as compared with a conventional weigh scale was completed as part of the preparation for the present experiment.[6] The conclusion was reached that the data from the FIRE® Feeder load cell system may be used with confidence.

In the case of the continuous daily data set a number of aberrant values were removed on the criterion of a step change of 5 kg or more in weight over a 24 h period. Weights under 10 kg were discarded. Out of 3922 pig-days of data, 3838 data were used in the subsequent analyses.

Determination of food intake

The FIRE® Feeder station provides a continuous supply of food to the group of animals on test. When an animal enters the station, its ID tag is detected; when the animal leaves the station (no ID detected), the feed intake of the pig at that visit is determined as the difference between the final and the initial weight of the trough during that visit. If the same animal re-enters the station within 5 min of the end of the previous visit, the visits are merged into a single visit. The individual visit meals are added to provide a value for daily food consumption.

The occasional negative food intake of greater than minus $0.1\ \text{kg day}^{-1}$ was removed. The final daily food intake from each pig was also removed from the data set, as these food intakes may correspond to less than a full day. Data for two consecutive days were removed completely, as they showed a consistent bias due to known fault with the equipment on those days. Six data points were removed, as the registered intakes were infeasible. Out of 3922 pig-days of data, valid data for both weight and food intake amounted to 3741 data.

Determination of fatness

Fatness was measured by mechanical intrascope probe (SFK Ltd, Hvidovre, Denmark) (which measures the distance between the skin surface and the muscle/fat interface) on the hot carcass. Measurement was at the P2 position 65 mm from the mid-line at the point of the last rib.

Housing

Pigs were loose housed in groups of up to 20 animals at the start, in six fully slatted pens. Groups were created to ensure that there were 14 pigs per group at the end of the trial period. Each pen was equipped with a FIRE® Feeder. The pigs were maintained in their type groups for reasons of welfare and performance optimisation. Pen differences in the performance of the feeding stations were continuously monitored. The building had a fully controlled environment. The pigs were stocked to comply with Livestock Regulations. Ventilation was by means of Optimavent (TFS Ltd, Oakhan, UK) units that circulate the air in the rooms as well as mixing incoming air with the circulating air. The temperature at the start of the trial period was 22 °C and was reduced by 0.5 °C every week until a temperature of 18 °C was reached. Gas heating was used where necessary to achieve the desired temperature. Water was available through two bite-type drinkers per pen.

Experimental design

The experiment was planned to run from 25 to 115 kg live weight. Twenty-five 'Landrace', 25 'Pietrain' and 24 'Meishan' type female pigs completed the experiment. They were allocated to five slaughter groups according to Table 1. The number of days elapsed from the start of the experiment to the point of slaughter for each group is given in parentheses. Table 2 gives the start and end weights for the five groups. Removal of pigs from the experiment in series in this way was for the purpose of allowing carcass measurement throughout the course of growth.

Statistical analysis

A random regression model[7] was used to analyse the live weight data, as is common with data concerning animal growth and breeding.[8] Such models include a fixed regression to describe the average shape of the growth curve, and a random regression for each animal to account for deviations from the fixed regression.[9] Individual animals can therefore have different coefficients for the growth curve.

Analysis was by residual maximum likelihood, and data for each type of pig were analysed separately. The model included pen as a fixed effect, and a fourth-order (cubic) orthogonal polynomial function as a fixed regression of weight on age, in days, at weighing. The choice of the order of the fixed polynomial was made based on the significance of the coefficients. The curves for individual pigs were allowed to deviate from this overall trend curve, and deviations were modelled by orthogonal polynomials of order three. The choice of the order of these random polynomials was based on a likelihood ratio test. Convergence problems with the 'Meishan' type data forced a reduction in the order of the random polynomials to two. The statistical package used provided standard errors for predicted values from the model solutions, based on the variances of the curve coefficients and on the covariances between them.

For food intake, again, a random regression model was used and data for each type of pig were analysed separately. Pen was included in the model as a fixed effect, and a fourth-order orthogonal polynomial function of feed intake on weight was used to model the trend curve. Deviations from this trend curve, at the individual pig level, were modelled using orthogonal polynomials of order three, although convergence problems again dictated a reduction in the order of the polynomials for the 'Meishan' type analysis to two.

For P2 fat depth, linear and non-linear functions were fitted using least squares regression in SIGMAPLOT 5, a product of SPSS Science (Chicago, IL, USA). ANCOVA models were used to test for pig type and weight effects.

To obtain indicative values for potential food intake, quantile regression was used. For each pig type, all data points were sorted according to increasing pig weight, and groups of 11 adjacent data points were examined. From each group the mean pig weight and the 90th percentile of food intake (the second largest of the 11 food intake measurements) were extracted. This method does not pick the 90th percentile pig, but the 90th percentile of data points in the selected cohort. An advantage of this statistical method is that it is buffered against infrequent small food intake records, as only the ranks, but not the absolute values, of these food intakes contribute to the percentiles. The numbers of data available in this analysis were 103, 124 and 124 for 'Meishan' 'Pietrain' and 'Landrace' type pigs respectively, and a random regression-type analysis was not possible. Allometric[10] and linear functions were fitted to these data by regression.

Table 1. Numbers of pigs allocated to groups, with days elapsed from start of experiment in parentheses

	Group 1	Group 2	Group 3	Group 4	Group 5
'Landrace' type	5 (17)	5 (31)	5 (52)	5 (73)	5 (101)
'Pietrain' type	5 (17)	5 (37)	5 (58)	5 (79)	5 (107)
'Meishan' type	5 (13)	5 (34)	5 (48)	4 (69)	5 (104)

Table 2. Start and end weights (kg) of pigs in each group (with standard errors of means in parentheses)

	Group 1	Group 2	Group 3	Group 4	Group 5
Start weight					
'Landrace' type	27.8 (1.50)	25.4 (1.22)	26.6 (0.872)	27.2 (1.98)	29.6 (2.46)
'Pietrain' type	25.2 (1.71)	25.8 (1.02)	24.4 (0.678)	29.0 (1.34)	29.6 (1.72)
'Meishan' type	26.8 (0.583)	27.2 (1.36)	28.2 (0.735)	28.0 (1.78)	28.0 (1.00)
End weight					
'Landrace' type	36.0 (2.02)	35.0 (3.21)[a]	63.0 (1.97)	77.6 (5.87)	115.8 (5.14)
'Pietrain' type	31.2 (1.85)	45.4 (2.32)	64.4 (1.72)	84.4 (2.99)	116.2 (2.08)
'Meishan' type	29.6 (1.08)	45.4 (2.93)	62.0 (2.02)	84.5 (4.21)	104.8 (4.19)

[a] Pigs were assigned to groups prior to the experiment. Random variation resulted in a low end weight for this group.

Table 3. Coefficients for random regression models of live weight as a function of age (with standard errors of coefficients in parentheses). Explanation given in main text

Term	'Landrace' type	'Pietrain' type	'Meishan' type
μ	22.5 (1.14)	18.5 (1.04)	20.9 (1.27)
b_1	0.570 (0.0702)	0.385 (0.0403)	0.432 (0.0328)
b_2	0.00208 (7.91×10^{-4})	0.00867 (4.52×10^{-4})	0.00825 (5.25×10^{-4})
b_3	2.36×10^{-6} (4.03×10^{-6})	-4.36×10^{-5} (2.17×10^{-6})	-4.50×10^{-5} (3.16×10^{-6})

RESULTS

Live weight gain determined from continuously collected data

The data collected through daily automatic weighing of the pigs were analysed by random regression as described above. The coefficients for the fixed effects of the models for the three pig types are shown in Table 3. These coefficients correspond to the equation $y = \mu + b_1x + b_2x^2 + b_3x^3$, where $x = 0$ corresponds to a pig age of 61 days. Table 4 shows the solutions for live weight at set ages for the three pig types, along with their standard errors. These solutions are graphed in Fig 1. There are few significant differences in these solutions. The 'Pietrain' type pigs were found to be lighter than both the other types up to 70 days and lighter than the 'Landrace' type pigs up to 80 days.

Table 4. Predicted live weights (kg) at set pig ages according to models given in Table 3. Standard errors are indicated in parentheses. Where significant differences ($P < 0.05$) exist between types, these are indicated by different suffixes

Age (days)	'Landrace' type	'Pietrain' type	'Meishan' type
65	24.8 (0.89)a	22.2 (0.62)b	24.6 (0.83)a
70	27.7 (0.96)a	24.6 (0.63)b	27.2 (0.83)a
80	34.0 (1.3)a	30.6 (0.76)b	33.6 (0.90)ab
90	40.7 (1.7)	37.9 (0.95)	41.1 (1.0)
100	47.9 (2.0)	46.1 (1.1)	49.4 (1.2)
110	55.6 (2.3)	55.0 (1.3)	58.4 (1.4)
120	63.8 (2.6)	64.4 (1.6)	67.7 (1.6)
130	72.5 (2.9)	74.0 (1.7)	77.0 (1.8)
140	81.6 (3.3)	83.4 (2.0)	86.1 (2.1)
150	91.3 (3.7)	92.6 (2.2)	94.8 (2.3)
160	101 (4.2)	101 (2.6)	103 (2.5)

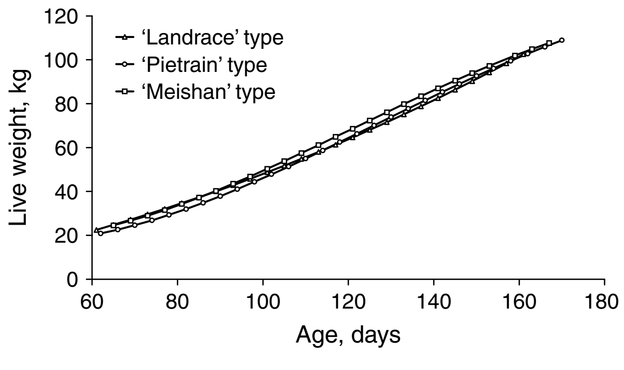

Figure 1. Relationship between age and live weight for the three pig types. Coefficients of regression equations are given in Table 3 and standard errors along the curves in Table 4.

On examining the first and second differentials of the above growth curves, the points of inflection can be located. The 'Meishan' type pigs were found to reach a maximum growth rate of 0.94 kg day^{-1} at 68 kg live weight. Likewise, the 'Pietrain' type pigs had a maximum growth rate of 0.96 kg day^{-1} at 68 kg live weight. The growth of the 'Landrace' type pigs did not reach a point of inflection during the growth period studied.

Backfat depth (P2)

P2 backfat depth is likely to increase with live weight, and the slope of this increase might be expected to be dependent upon pig type. ANCOVA showed a significant effect of both live weight at slaughter and pig type upon P2 depth (live weight: $F_{1,68} = 231$, $P < 0.001$; live weight × breed interaction: $F_{2,68} = 12.0$, $P < 0.001$). Table 5 shows the parameters resulting from the fitting of linear and allometric equations to P2 backfat depth as a function of live weight. As can be seen from the r^2 values, there is little difference in the goodness of fit of the linear and allometric models. Variation in backfat depth was noticeably greater at the end of the test, particularly in the 'Meishan' type pigs, as can be seen from the somewhat larger RMS for this type. From these regressions (Fig 2) it may be concluded that although the 'Pietrain' type pigs started as fat as the other types, they fattened more slowly than the other types. The 'Meishan' type pigs, however, fattened rather rapidly, albeit also rather variably.

Food intake determined from continuously collected data

The FIRE® feed station data were analysed by random regression as described above to provide equations for

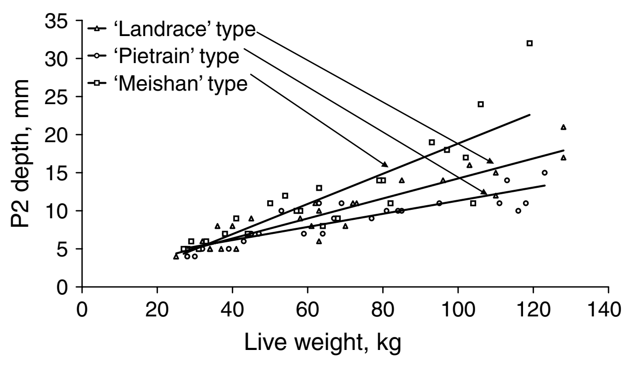

Figure 2. Relationship between backfat depth and live weight for the three pig types. Regression equations are given in the Table 5.

Table 5. Parameters for fitted linear ($y = a + bx$) and allometric ($y = ax^b$) equations used to describe P2 backfat depth as a function of live weight for the three pig types, together with r^2 (proportion of variance explained by model) and RMS (square root of mean squared error) statistics

	a	*b*	r^2	RMS
Linear equation				
'Landrace' type	1.13 (0.791)	0.131 (0.0109)	0.863	1.69
'Pietrain' type	2.72 (0.717)	0.0861 (0.0096)	0.778	1.45
'Meishan' type	−0.975 (1.74)	0.198 (0.0248)	0.744	3.37
Allometric equation				
'Landrace' type	0.236 (0.0842)	0.891 (0.0807)	0.861	1.70
'Pietrain' type	0.541 (0.182)	0.661 (0.0767)	0.800	1.39
'Meishan' type	0.0877 (0.0651)	1.17 (0.164)	0.752	3.32

Table 6. Coefficients for random regression models of food intake as a function of live weight (with standard errors of coefficients in parentheses). Explanation given in main text

Term	'Landrace' type	'Pietrain' type	'Meishan' type
μ	−0.215 (0.310)	−1.08 (0.178)	−1.71 (0.243)
b_1	0.0520 (0.0171)	0.0992 (0.00978)	0.135 (0.0126)
b_2	-1.17×10^{-4} (2.58×10^{-4})	9.52×10^{-4} (1.63×10^{-4})	−0.00132 (2.09×10^{-4})
b_3	0.92×10^{-4} (1.26×10^{-4})	3.24×10^{-4} (0.90×10^{-4})	4.37×10^{-4} (1.04×10^{-4})

daily food intake (kg day^{-1}) for the three pig types. The coefficients for the model fixed effects are shown in Table 6. These coefficients again correspond to the equation $y = \mu + b_1x + b_2x^2 + b_3x^3$, where x is live weight (kg). The solutions at set live weights are shown in Table 7, along with their standard errors, and these solutions are graphed in Fig 3.

In general, the 'Pietrain' type pigs ate less than the other two types, whose food intake curves were more similar. From 40 to 70 kg the 'Landrace' type pigs ate significantly less than the 'Meishan' type pigs, though the lines crossed and they ate significantly more at 20 kg. The 'Landrace' type pigs ate significantly more than the 'Pietrain' type pigs from 20 to 30 kg, and the 'Pietrain' type pigs ate significantly less than the 'Meishan' type pigs from 40 to 50 kg. The food intake curves reached plateaux in the order 'Meishan', 'Landrace' and 'Pietrain' type.

The parameters relating the 90th percentile of food intake to live weight are shown in Table 8. We believe this to give an instructive insight into the likely food intake potential for the type. There was a significant ($P < 0.01$) difference between the 'Meishan' and the other two pig types in the coefficients, and the exponent for the 'Landrace' type pigs was different from that for the 'Meishan' type pigs ($P < 0.05$).

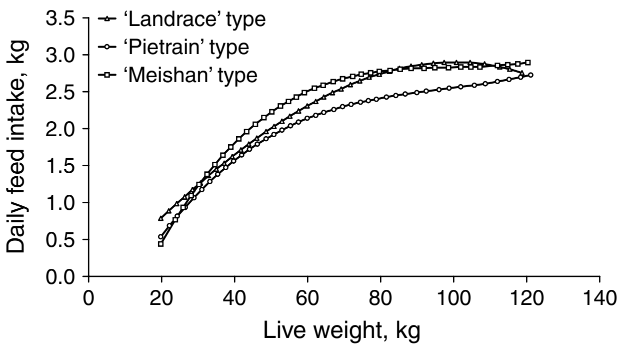

Figure 3. Relationship between daily feed intake and live weight for the three pig types. Coefficients of regression equations are given in Table 6 and standard errors along the curves in Table 7.

Table 7. Predicted daily food intakes (kg day^{-1}) at set pig live weights according to models given in Table 6. Standard errors are indicated in parentheses. Where significant ($P < 0.05$) differences exist between types, these are indicated by different suffixes

Weight (kg)	'Landrace' type	'Pietrain' type	'Meishan' type
20	0.79 (0.062)a	0.535 (0.048)b	0.440 (0.075)b
30	1.23 (0.033)a	1.11 (0.028)b	1.21 (0.039)ab
40	1.64 (0.049)a	1.56 (0.029)a	1.79 (0.037)b
50	1.99 (0.056)a	1.89 (0.033)a	2.21 (0.057)b
60	2.30 (0.079)a	2.13 (0.033)ab	2.50 (0.086)b
70	2.55 (0.147)a	2.30 (0.036)ab	2.68 (0.119)b
80	2.74 (0.257)	2.41 (0.047)	2.78 (0.155)
90	2.86 (0.408)	2.50 (0.072)	2.83 (0.191)
100	2.91 (0.599)	2.56 (0.117)	2.84 (0.227)
110	2.88 (0.840)	2.62 (0.184)	2.85 (0.265)
120	2.77 (1.13)	2.71 (0.279)	2.89 (0.317)

DISCUSSION

The continuous nature of the data set allowed analysis by regression over the whole growth period. The

Table 8. Parameters for fitted allometric equations ($y = ax^b$) used to describe 90th percentile of food intake as a function of live weight for the three pig types, together with r^2 (proportion of variance explained by model) and RMS (square root of mean squared error) statistics

	a	*b*	r^2	RMS
'Landrace' type	0.155 (0.0183)	0.703 (0.0285)	0.861	0.325
'Pietrain' type	0.154 (0.0144)	0.665 (0.0226)	0.888	0.238
'Meishan' type	0.215 (0.0230)	0.614 (0.0260)	0.858	0.259
All	0.172 (0.0126)	0.661 (0.0177)	0.822	0.327

trial was established for the comparison of pigs of expectedly different characteristics, as exemplified by the 'Landrace', 'Pietrain' and 'Meishan' types used. It was likely that pig type would influence food intake, growth rate and fatness of meat pigs.[11,12]

For random regressions of both live weight versus time and food intake versus live weight the standard errors at the predicted points in Tables 4 and 7 are seen to increase through the trial. This is largely due to the serial slaughter nature of the trial: the density of data is higher at the start where more pigs were on trial. This results in differences of similar magnitude between pig types being less significant at the higher ages or weights.

Other authors[3,13] have commended none other than a straight line relationship for live weight as a function of time over the live weight range studied in this experiment. Random regression found significant non-linear trends in this study, though the equation solutions show little difference in pig types across this age range. The point of inflection was found to be similar for the 'Meishan' and 'Pietrain' type pigs, and lower than that for the 'Landrace' type pigs, which lay above the range of live weights examined. A lower point of inflection may have been expected for the 'Meishan' type pigs, as Meishan pigs are earlier maturing, however, the pigs used in this study contained only 25% Meishan alleles.

For small pigs the rate of change of food intake with increasing weight is highest for the 'Meishan' type and lowest for the 'Landrace' type pigs, as can be seen from the b_1 values in Table 6 and from Fig 3. Figure 3 shows that at 50 kg live weight the 'Pietrain' and 'Landrace' type pigs have similar feed intakes; at 100 kg live weight the 'Pietrain' type pigs eat less, though this is not significant. This ordering of food intake is consistent with the findings of van Milgen *et al*.[14] Metabolic rate has been frequently related to the three-quarter power of body weight, therefore a useful comparison can be made between food intake and metabolic body weight ($W^{0.75}$). Where food intake is assumed to be directly related to metabolic body weight, potential food intakes were estimated, by use of the 90th percentile regression as described in the 'Materials and methods' section, to be 0.128, 0.108 and $0.123 \times W^{0.75}$ for 'Landrace', 'Pietrain' and 'Meishan' types respectively. The *ad libitum* food intakes of all the pig types found under commercial conditions should be noted as being substantially less than those of around $0.12 \times W^{0.75}$ that might have been expected from research results.[5]

As measured by the backfat depth at the P2 site, fatness at the heavier live weights was markedly variable in the case of the 'Meishan' type. Solution of the regression of fat depth on live weight suggests that, under the conditions of *ad libitum* feeding prevailing in this experiment, a P2 backfat depth of 12 mm (often the critical level in grading schemes) would be reached by the 'Meishan' type at 66 kg live weight, by the 'Landrace' type at 83 kg live weight and by the 'Pietrain' type at 107 kg live weight.

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