Effect of average daily gain between weaning and slaughter (105 kg) on the meat quality of fast growing Landrace/Large White pigs

by

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Executive Summary

A total of one hundred and three Landrace x Large White pigs were selected to represent a spectrum of average daily gains between weaning and slaughter. The mean average daily gain of pigs between weaning and slaughter was 756 g/day with a standard deviation (SD) of 55.6 g/day. The average daily gain of pigs covered a 300 g/day range from 616 to 943 g/day. All pigs were reared under similar management conditions however, their diet varied by way of diet density i.e. some pigs received diets with a higher energy and protein content compared with others. Diet affected the average daily gain of pigs between weaning and slaughter but not meat quality. The average slaughter weight of pigs was 107.2 kg with an SD of 7.2 kg and average age at slaughter was 158 days with an SD of 3.8 days.

There were no significant or strong relationships between the average daily gain of pigs between weaning and slaughter, 10 weeks of age and slaughter or 20 weeks of age and slaughter and any meat quality parameters. Therefore, average daily gain did not explain the variability in meat quality that was observed. A modelling exercise suggested that back fat depth at P_2 is a key production variable determining shear force and colour parameters (L*, a*, b*, Hue angle and Chroma). Furthermore, back fat depth at P_2 and birth weight are key production parameters to determine ultimate pH, sarcomere length, drip loss % and cooking loss %. However, a validation exercise is required to test how much variability these models can account for and how accurate the models are. The models established to determine shear force, L* and sarcomere length were less effective than the models to explain the other meat quality parameters measured.

Overall it is concluded that back fat depth at P_2 and birth weight, which appear to be interrelated, have a greater influence on meat quality than average daily gain. In this study, using fast growing Landrace x Large White pigs, the variability in average daily gain (over a 300 g/day range) did not explain the variability in meat quality that was observed which was itself high and should be of concern.

Introduction

The eating quality of pork is considered poorer than of bygone years. It has been suggested that genetic selection for rapid lean growth has adversely affected the juiciness, flavour, tenderness and general acceptability of pork meat products (Kemp *et al*., 2007; Ngapo and Gariépy, 2008). One key problem with pork is variability in quality. O'Mahony *et al*. (1995) observed that 40% of Irish consumers thought that the quality of pork varied a lot and Kemp *et al*. (2007) reported that the variation in pork tenderness should be of concern to the pig industry. It is recognised that the growth rate between pigs also varies considerably. Magowan *et al*. (2007) noted that between Northern Irish farms, growth rate variation could range from 9 to 21%. Latorre *et al*. (2008) noted that information on the relationship between meat eating quality traits and growth and body composition traits was still limited and somewhat contradictory. In general, correlations between growth rate and meat quality have been found to be generally small and negative and their magnitude appears to be dependant on breed (de Vries *et al*., 1994; Bidanel and Ducos, 1995). In agreement Latorre *et al*. (2008) suggested that meat quality attributes are correlated with performance measurements to a limited extent and that breed has a large influence on the strength of the correlation. Meinert *et al*. (2007) noted that age variations had an effect on meat quality which may explain some contradictory conclusions obtained between studies as meat from older animals is normally tougher than meat from young animals due to a higher degree of collagen cross-linking (Ellis and McKeith, 1995). Some workers have also found the birth weight of piglets to have an effect on meat quality (Gondret *et al*., 2005; Gondret *et al*., 2006; Rehfeldt and Kuhn, 2006). Rehfeldt *et al*. (2008) found that light weight pigs at birth (1.08 kg) had a poorer meat quality (tenderness and water holding capacity) than medium (1.37 kg) weight piglets but the IMF content of meat from low birth weight piglets was highest. On the other hand, Kim (2007) commented on work conducted by MLC/Newcastle which clearly indicated a strong relationship between the growth rate that a treatment imposed and the tenderness of the resulting meat. They commented that the results of the Stotfold phase feeding study also showed a clear relationship between age of animal at slaughter and tenderness, with tenderness decreasing with increasing animal age at a constant slaughter weight.

The aim of the current study was to investigate the relationship between variable growth rate and variable meat quality of fast growing Landrace/Large White pigs slaughtered at a similar age and slaughter weight.

Materials and methods

Production management

Pigs were housed indoors using normal commercial housing and fully slatted flooring. Pigs were weaned at 4 weeks of age and offered one of two dietary regimes post weaning. After weaning pigs were offered a starter diet allocation of either 6 (‘Low’) or 12 (‘High’) kg per pig (Table 1). All pigs were then offered a grower diet to 11 weeks of age (Table 1). From 11 weeks of age pigs were offered one of two finishing diets – special or normal (Table 1), which were based on similar ingredients but differed in energy and protein content. In total, between weaning and finishing there were four dietary regimes: ‘Low + Normal’, ‘Low + Special’, ‘High + Normal’, ‘High+ Special’. At weaning pigs were penned in groups of 20 and when they were transferred to the finishing accommodation at 10 weeks of age the groups were split to form groups of 10. The live weight of pigs was measured at weaning, 7, 10, 11, 15, 20 weeks of age and finish (day before slaughter). The average daily gain (ADG) of pigs between these time points was then calculated. Depending on their average daily gain, weight and age, a total of 103 pigs were selected for meat quality analysis. These 103 pigs were sent for slaughter over 5 time periods.

Table 1 The ingredients and composition of the diets used from weaning to finish

	Diet				
	Starter 1	**Starter 2**	**Grower**	**Normal Finisher**	**Special Finisher**
Ingredient (g/kg)					
Wheat	✓	✓	**700**	**360**	**500**
Barley				**394**	**227**
Maize	✓	✓			
Cooked cereal	✓	✓			
Soya	✓ **(Toasted)**	✓ **(Toasted)**	**217**	**188**	**185**
Rice Protein	✓	✓			
Sugar		✓			
Whey	✓	✓			
Molaferm			**30**	**20**	**20**
Vegetable Oil Blend				**10**	**15**
Soya Oil	✓	✓	**20**		**26**
Limestone	✓	✓	**11**	**11.5**	**8.5**
Mono DCP	✓	✓	**7.5**	**6.1**	**6.5**
Salt	✓	✓	**1.5**	**2.8**	**1.2**
Lysine	✓	✓	**4.6**	**2.3**	**4.5**
Methionine	✓	✓	**1.4**	**0.4**	**0.4**
Devicare (Mins and vits)	✓	✓	**5**	**5**	**5**
Emulsifier		✓			
Lignosulphate binder	✓	✓			
Chemical analysis as formulated					
Dry matter (g/kg)	**904**	**888**	**867**	**870**	**872**
Digestible energy (MJ/kg)	**15.8**	**15.5**	**14.0**	**13.5**	**14.5**
Crude protein (g/kg)	**200**	**200**	**186**	**167**	**166**
Oil A (g/kg)	**9.7**	**8.4**	**32**	**25**	**55**
Fibre (g/kg)	**18**	**22**	**24**	**34**	**30**
Ash (g/kg)	**65**	**55**	**48**	**48**	**42**
Total lysine (g/kg)	**16**	**15**	**12**	**9.5**	**11**

[1] The diets were commercially manufactured by Devenish Nutrition Ltd (Belfast) (Starter Diets 1 & 2) and John Thompson and Sons Ltd (Grower, Normal and Special Finisher). The exact amount of each ingredient cannot therefore be disclosed, however a 'tick' represents the presence of the raw material in the diet.

Slaughter and sampling

Pigs were weighed and slap marked on the day prior to slaughter. Pigs were offered feed *ad libitum* up to the point when they were removed from the pen. Pigs were removed from their pens and loaded onto a lorry at 8.00 am. Pigs from different pens would have been mixed at this stage. The journey to the abattoir took 1 hr and pigs were held in lairage for 1 hr. Water was sprayed over the pigs while they were in lairage. Pigs were stunned using CO_2 gas before exsanguination. After slaughter, pigs were subjected to standard factory procedures. The hot weight and back fat depth of the empty pig carcasses were measured 45 minutes post slaughter. The back fat depth was measured 65 mm from the top line at the level of the last rib (P_2) using the Ulster Grading probe. Carcasses were then chilled rapidly and were held at 2-4°C for 24 hr after which they were de boned and split into primal cuts. Representative chops from the *L. dorsi* of each pig carcass were removed and meat quality analysis was performed on the fresh pork chops. Tenderness, colour, drip loss, cooking loss, ultimate pH and sarcomere length were determined as described by Beattie *et al*. (1999).

Statistical analysis

To develop models for each meat quality parameter using production variables/factors the method commonly known as “Best Subsets Regression” was applied to the fitting of random effects models.

A common statistical method when trying to develop explanatory models is to use a stepwise approach (either forward selection, backward elimination or a combination to both). However, this results in only one model and alternative models with an equivalent or even better fit are easily overlooked. In observational studies with many correlated (or non-orthogonal) variables, there can be many alternative models, and selection of just one well-fitting model may be unsatisfactory and perhaps misleading. A preferable method may be to fit all possible regression models, and to evaluate these according to some criterion in order to differentiate between competing models. In this case we have employed the widely used Akaike Information Criterion (AIC).

However, the fitting of all possible regression models is very computer-intensive. It should also be used with caution, because models can be selected that appear to have a lot of explanatory power, but contain only noise variables. This may occur particularly when the number of parameters is large in comparison to the number of units. Models should therefore not be selected on the basis of a statistical analysis alone, but rather in conjunction with what makes sound scientific sense.

In our current situation we employed a variation on this method as we fitted random effects models to our data using rep (slaughter date) as a random effect. The hierarchical generalised linear model procedures available in GenStat were used to fit the various models as they allowed the determination of appropriate log-likelihoods used in the calculation of the AIC values for the comparison of competing models.

In order to reduce the fitting of possible models only variables/factors with a probability value less than 0.3 (in a univariate analysis) were considered as candidates for subsequent multivariate models. This probability was determined by means of a Wald test. Also a practical limit of 6 was put on the maximum number of independent variables allowed.

For each 1 variable, 2 variable model etc. the best eight models (in terms of the AIC value) were printed out, and a final model for each meat quality parameter was determined based not only on the model with the lowest AIC value and low probability values (again using Wald tests), but with what also made sound biological sense. In some cases more than one model was chosen to explain the meat quality parameter since some variables could be more practically attained than others.

In addition to the variables listed in Table 1, sex (boars and gilts) and diet were also accounted for in the statistical analysis.

Results

The data set and interrelationships

Table 2 reports the minimum (Min), maximum (Max) and average values within each variable and the standard deviation (SD) and the coefficient of variation (CV%) of the data set regarding each variable. The same values are reported for the meat quality parameters that were measured. The average daily gain of pigs between weaning and slaughter ranged from 616 g/day to 943 g/day and had a high standard deviation of 55.6. Although finish weight spanned a range of 30 kg, the majority of values fell within a 15 kg range (approximately 103 kg – 118 kg) (Figure 1). The back fat depth of pigs at P_2 also spanned a wide range and values were evenly dispersed across this range (Figure 1).

Figure 1 Relationship between slaughter weight and back fat depth at P_2

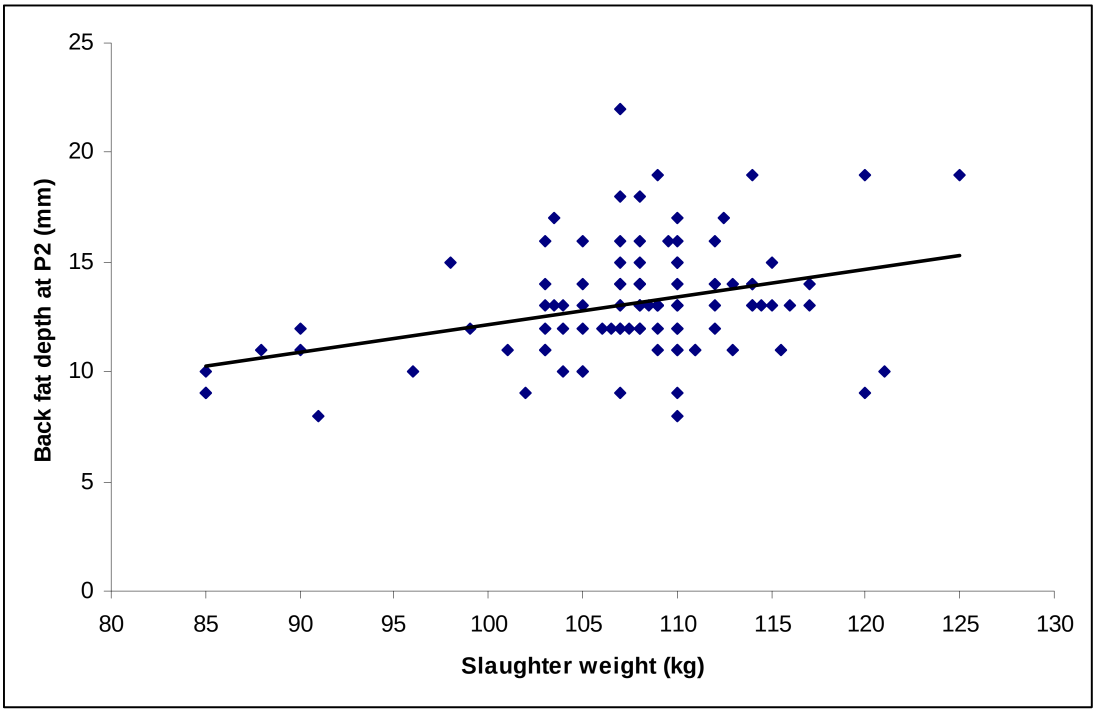

Table 2 The data range attained from the 103 pigs used in the experiment

Variable:	Minimum	Maximum	Average	SD	CV%
Birth weight	0.56	2.38	1.6	0.3	20.3
Wean weight	6.3	15.4	9.3	1.5	16.1
10-week weight	22	40.5	29.9	3.5	11.6
15-week weight	39	71	55.6	6.0	10.7
20-week weight	70	110	88.2	7.1	8.0
Finish weight	85	125	107.2	7.2	6.7
Cold weight	50	97.4	82	6.9	8.4
ADG wean – 10	333	754	504	71.2	14.1
ADG 10-15	431	1056	725	118	16.2
ADG 15-20	514	1294	947	134	142
ADG 10-20	654	1255	992	122	12.3
ADG 10-finish	681	1060	883	75.2	8.5
ADG 20-finish	450	1500	1070	199	18.6
ADG wean-finish	943	616	756	55.6	7.4
Back fat depth at P_2	8	22	13.1	2.6	19.7
Age at finish	153	174	157.9	3.8	2.4
Kg mean	2.81	7.37	4.4	0.9	20.0
L*	41.8	63.4	55.4	4.1	7.4
a*	-2.4	4.9	1.3	1.4	104.1
b*	3.89	11.11	7.1	1.5	20.6
Hue	63.6	117.1	80.6	9.8	12.2
Chroma	3.9	11.6	7.3	1.6	22.0
Drip Loss	1.96	14.24	5.9	3.0	50.8
pH Homo	5.1	5.8	5.5	0.1	1.8
Cooked Loss	21.9	39.5	30.2	4.5	15.0
Sarcomere	1.71	2.44	1.9	0.2	8.1

Table 3 reports relationships between the different variables measured. Birth weight was significantly, but not strongly correlated with wean weight and 10-week weight. Birth weight or wean weight were not significantly correlated with average daily gain between weaning and slaughter. The average daily gain of pigs between weaning and slaughter was significantly and highly correlated with finish weight. Finish weight was also significantly correlated (P<0.001) with back fat depth but the relationship was weak (R^2 = 0.351).

Table 3 Correlations between some key variables (103 degrees of freedom for all).

Production Variable 1	Production Variable 2	R	P value
Birth weight	Wean weight	0.455	<0.001
Birth weight	10-week weight	0.444	<0.001
Birth weight	20-week weight	0.185	0.059
Birth weight	ADG wean - 10 weeks	0.314	0.001
Birth weight	ADG wean-finish	0.175	0.074
Birth weight	Backfat depth	-0.1887	0.054
Birth weight	KO%	0.046	0.64
Wean weight	10-week weight	0.566	<0.001
Wean weight	20-week weight	0.244	0.012
Wean weight	ADG wean-10 weeks	0.205	0.036
Wean weight	ADG wean - finish	-0.045	0.649
Wean weight	Backfat depth	0.038	0.7
Wean weight	KO%	0.107	0.276
10-week weight	20 week weight	0.5774	<0.001
10-week weight	ADG 10 – finish	-0.078	0.431
10-week weight	ADG wean – finish	0.314	0.001
10-week weight	Backfat depth	0.185	0.059
10-week weight	KO%	0.074	0.4523
20-week weight	ADG wean-finish	0.822	<0.001
20-week weight	Backfat depth	0.279	0.004
20-week weight	KO%	0.109	0.269
Finish weight	ADG wean-finish	0.892	<0.001
Finish weight	Backfat depth	0.351	<0.001
Finish weight	KO%	0.151	0.124
Wean-finish ADG	Backfat depth	0.241	0.01
Wean-finish ADG	KO%	0.039	0.694
Wean-10 weeks ADG	Wean - finish ADG	0.383	<0.001
10 week-finish	Wean - finish ADG	0.896	<0.001
Backfat depth	KO%	0.218	0.025

In this study there were 4 dietary regimes imposed and they had a significant effect (P<0.022, SED 14.6) on the average daily gain of pigs between weaning and slaughter. Pigs offered the 'Low + Special' dietary regime had a higher average daily gain (784 g/day) between weaning and finish than pigs on the other dietary treatments (average across treatments was 750 g/day). However, dietary treatment had no significant effect on any meat quality parameter. This may be a key reason why the relationships between weight and subsequent growth rate are weak, although significantly, correlated in many cases. The identification of parameters which were inter-related aided the selection of models to go forward for further analysis and aided interpretation.

Key variables affecting meat quality parameters

The average daily gain of pigs between 10 weeks of age and finish or between 20 weeks of age and finish did not significantly affect any meat quality parameters. Overall there was no significant relationship between the average daily gain (ADG) from weaning to finish and shear force, the colour measurements of L*, a*, b* and chroma, drip loss % or cooking loss %, ultimate pH or sarcomere length (Table 4). There was a significant relationship between the average daily gain (weaning and finish) and Hue angle (P=0.035) but the relationship was very weak (R^2 = 0.067) with Hue angle decreasing by 0.3 degrees for every 10 g/day increase in average daily gain. Overall, average daily gain between weaning and finish did not explain the variability in meat quality observed.

Table 4 The effect of ADG from weaning to finish on meat quality parameters

Meat quality parameter	**F pr**	**Slope**
Kg mean	0.827	-0.000256
L*	0.757	-0.002225
a*	0.133	0.003329
b*	0.437	0.001896
Hue	0.035	-0.03179
Chroma	0.421	0.002177
Drip Loss %	0.972	-0.0001446
Ph Homo	0.827	0.00003531
Cooked Loss %	0.459	-0.003894
Sarcomere length	0.740	0.0002171

Table 5 outlines the production variables which had the most significant effect (*P*<0.3) on each meat quality parameter following analysis. Subsequent analysis then used these variables to identify models with low AIC values to predict the meat quality parameters. Kill out percentage was found to be a significant variable in the models for Kg mean and L*. KO% is not a practical measurement to be taken routinely in normal commercial practice on a pig-by-pig basis. The subsequent choosing of models therefore took both a practical and scientific approach.

Tables 6 to 15 outline the models chosen with respective AIC values and the significance of variables within the models to predict the various meat quality parameters. Models, using easily determined production parameters, to explain the meat quality parameters of a*, ‘b*, Hue, Chroma, Ph Homo, Drip Loss % and Cooking Loss % were effective as demonstrated by the variables within the models being significant. Models to explain shear force, L* and sarcomere length were less effective. A common factor in all effective models was back fat depth at P_2. Birth weight was also a common parameter in models to explain drip and cooking loss, ultimate pH and sarcomere length. The sex of the pig had a significant influence within the models to explain drip loss %, ultimate pH and sarcomere length. In the models corrections needed to be made if the meat was derived from gilts but no correction was required if the meat was derived from boars. The weight of the pig was a common production parameter in many of the models but only three models included growth rate variables (Tables 9 and 15).

Table 5 Production variables with significance (P value) under 0.3 to be considered within models for each meat quality determinant (in bold)

	AIC	F pr		AIC	F pr
Kg mean:			**Chroma:**		
Wean weight	209.2	0.149	Back fat depth	377.6	0.007
10-week weight	209.8	0.221			
Back fat depth	208.6	0.107			
KO%	208.5	0.089			
			Drip Loss:		
L*:			Birth weight	468.8	0.001
Cold weight	586.4	0.157	Back fat depth	471.7	0.007
Back fat depth	585.7	0.119	Sex	475.2	0.05
KO%	584	0.04			
a*:			**Ph Homo:**		
15-week weight			Birth weight	-211.5	0.044
20-week weight	340.5	0.043	10-week weight	-209.4	0.142
Finish weight	341.9	0.109	Back fat depth	-218.3	0.001
ADG wean-finish	342.2	0.13	Sex	-214.5	0.007
ADG 10 - 20 weeks	340.6	0.045			
ADG 10 - finish	342.5	0.157			
Cold weight					
Back fat depth	341.1	0.069			
			Cooked Loss:		
			Birth weight	524.6	0.014
b*:			10-week weight	529.4	0.255
Wean weight	361.7	0.3	15-week weight	527.1	0.063
Back fat depth	354.7	0.004	20-week weight	529.3	0.234
			ADG wean 10		
			ADG 10 - 15	527.5	0.074
			Back fat depth	522.8	0.005
Hue:					
10-week weight					
15-week weight	743.9	0.034			
20-week weight	739.6	0.003	**Sarcomere**		
Finish weight	743.1	0.022	Birth weight	-140.5	0.197
ADG wean – finish	743.8	0.033	KO%	-141.1	0.125
ADG wean-10 weeks			Sex	-144.2	0.037
ADG 10 - 15 weeks					
ADG 15 - 20 weeks	745.1	0.071			
ADG 10 - 20 weeks	741.3	0.007			
ADG 10 - finish					
ADG 20 - finish					
Cold weight					
Back fat depth					

Table 6 ‘Best fit’ models to predict Kg mean

	Variable	Significance of variable (P)	Constant	Slope
2 variable model (AIC 207.5)	10-week weight	0.214	4.35	0.0318
	Ulster Probe	0.049		-0.0516
3 variable model (AIC 205.5)	10-week weight	0.210	4.35	0.029
	Ulster Probe	0.047		-0.059
	KO%	0.057		0.0358

Table 7 ‘Best fit’ models to predict ‘L*’

	Variable	Significance of variable (P)	Constant	Slope
1 variable model (AIC 584.0)	KO%	0.043	55.5	-0.2326
1 variable model (AIC 585.7)	Ulster Probe	0.123	55.5	-0.2412
2 variable model (AIC 584.4)	Ulster probe	0.117	55.5	-0.192
	KO%	0.074		-0.208
2 variable model (AIC 587.0)	Cold weight	0.164	55.5	-0.0569
	Ulster probe	0.260		-0.1884

Table 8 ‘Best fit’ models to predict ‘a*’

	Variable	Significance of variable (P)	Constant	Slope
2 variable model (AIC 335.1)	20-week weight	0.040	1.481	0.0489
	Ulster Probe	0.009		-0.1299
2 variable model (AIC 337)	Finish weight	0.103	1.453	0.0429
	Ulster Probe	0.013		-0.1264
2 variable model (AIC 338)	ADG wean - finish	0.124	1.471	0.00494
	Ulster probe	0.017		-0.1198

Table 9 ‘Best fit’ models to predict ‘b*’

	Variable	Significance of variable (P)	Constant	Slope
1 variable model (AIC 354.7)	Ulster Probe	0.006	7.21	-0.1458

Table 10 ‘Best fit’ model to predict ‘Hue’

	Variable	Significance of variable (P)	Constant	Slope
2 variable model (AIC 736.6)	20-week weight	0.003	79.57	-0.4198
	Ulster Probe	0.032		0.7197

Table 11 ‘Best fit’ model to predict ‘Chroma’

	Variable	Significance of variable (P)	Constant	Slope
1 variable model (AIC 377.6)	Ulster Probe	0.009	7.44	-0.1534

Table 12 ‘Best fit’ models to predict ‘Drip Loss’

	Variable	Significance of variable (P)	Constant	Slope
2 variable model (AIC 464.6)	Birth weight	0.001	6.25	2.06
	Ulster probe	0.017		-0.208
3 variable model (AIC 463.7)	Sex	0.037	5.94	B: 0.0000 G: 0.671
	Birth weight	<0.001		3.21
	Ulster probe	0.048		-0.256
	Sex x birth weight	0.086		
	Sex x Ulster Probe	0.609		

Table 13 ‘Best fit’ models to predict ‘Ph Homo’

	Variable	Significance of variable (P)	Constant	Slope
2 variable model (AIC -222.6)	10-week weight	0.118	5.47	-0.00594
	Ulster probe	<0.001		0.01303
2 variable model (AIC -219.6)	Birth weight	0.032	5.47	-0.0475
	Ulster Probe	0.002		0.01045
3 variable model (AIC -222.9)	Sex	0.005	5.47	B: 00000 G: -0.02571
	10-week weight	0.267		-0.00755
	Ulster probe	0.001		0.0205
	Sex x 10-week weight	0.828		
	Sex x Ulster probe	0.015		B: 0.0000 G: -0.01636
3 variable model (AIC -222.4)	Sex	0.005	5.48	B: 0.000 G: -0.03882
	Birth weight	0.027		-0.0585
	Ulster probe	0.012		0.0165
	Sex x Birth weight	0.592		
	Sex x Ulster probe	0.018		B: 0.0000 G: -0.01621

Table 14 'Best fit' models to predict 'Cooked Loss'

	Variable	Significance of variable (P)	Constant	Slope
3 variable model (AIC 517.7)	Birth weight	0.012	30.8	2.49
	15-week weight	0.009		-0.0954
	Ulster Probe	0.069		-0.2106
4 variable model (AIC 510.8)	Birth weight	0.014	30.3	3.722
	10-week weight	0.050		9.771
	15-week weight	0.371		-9.983
	ADG 10 - 15 weeks	0.019		0.3517
6 variable model (AIC 510.4)	Birth weight	0.014	30.3	3.814
	10-week weight	0.056		9.334
	15-week weight	0.384		-9.805
	ADG wean - 10 weeks	0.220		0.0146
	ADG 10 - 15 weeks	0.020		0.3454
	Ulster probe	0.167		-0.1574

Table 15 'Best fit' models to predict 'Sarcomere length'

	Variable	Significance of variable (P)	Constant	Slope
2 variable model (AIC -145.9)	Sex	0.037	1.96	B: 0.0000 G: -0.07873
	Birth weight	0.136		0.1034
	Sex x birth weight	0.693		
2 variable model (AIC -141.9)	Birth weight	0.149	1.924	0.0721
	KO%	0.152		-0.0136

Discussion

Effect of average daily gain on meat quality

Magowan *et al.* (2007) demonstrated that growth rate can vary considerably within a herd. In this study growth rate between weaning and finish ranged from 616 to 943 g/day which equated to a variance of 7%. This growth rate and variation within growth rate was similar to that of the 'top' performing herds in the study by Magowan *et al.* (2007). However, this study, using Landrace x Large White pigs, suggests that variable growth rate, within this range, does not explain the variability in meat quality that can be observed from these pigs. Indeed the variability in shear force, which is an indication of tenderness, varied by 20% and drip loss (%) varied by 50% across the 103 samples. The results from this study, in that there was little, if any, relationship between the average daily gain of pigs and shear force (kg), colour (L*, a*, b*, and Chroma), ultimate pH, drip loss, cooking loss or sarcomere length are in agreement with other workers (for example Latorre *et al*., 2008, Correa *et al*., 2006, McCann *et al*., 2008). Latorre *et al*. (2008) found that overall meat quality attributes were correlated with performance measurements to a limited extent. They found that average daily gain, average daily feed intake and the average daily deposition rate of protein explained only 35% of the variance observed between the meat samples. They suggested that the relationships between average daily gain and meat quality parameters were dependant on the breed of pig. Correa *et al*. (2006) also found no effect of growth rate (fast (young) vs slow (older)) on the meat quality (drip loss, colour, pH, marbling, intramuscular fat, total or soluble collagen) of pigs slaughtered at either 107, 115 or 125 g.

Average daily gain as an independent variable

Few studies have specifically correlated the growth rate of the animal with the quality of its meat. Within studies the effect of average daily gain is often confounded with factors such as birth weight, weight and age at slaughter and breed. The current study was specially designed to control these factors and hence investigate the effect of variable average daily gain as an independent variable. The following discussion provides evidence to demonstrate how the average daily gain in this study could be considered as an independent variable to birth weight, slaughter weight and age and breed.

The breed of pig has often been found to significantly affect meat quality (for example Brewer *et al*., 2002 and Wood *et al*., 2004). All pigs in the current study were Landrace x (Landrace x Large White) which eliminated any effect of breed.

There is a perception that pigs with a light birth weight generally grow slower than pigs with a heavy birth weight. Birth weight, as will be examined later, has been found to have an effect on meat quality, in particular tenderness and intramuscular fat (Rehfeldt *et al*., 2008; Gondret *et al*., 2006). It is therefore extrapolated that low birth weight pigs, with slower growth rate, have poorer meat quality. However, the difference in the growth rate of pigs with light or heavy birth weights is not always significantly different. Quiniou *et al*. (2002) found that for every 100 g increase in birth weight when pigs are around 1 kg at birth normally equated to a weaning weight advantage of 400 g but for pigs weighing 2 kg at birth, the same value equated to only a 200 g advantage. Therefore, the light birth weight pigs had a better growth rate potential as a proportion of their body weight during the pre weaning stage than pigs with a heavier birth weight. Gondret *et al*. (2005) using pigs with a birth weight of 0.97 or 1.91 kg found that, although their growth rate during the suckling and post weaning periods differed, their growth rate during the grow/finishing period was similar with light pigs achieving 787 g/day and heavy birth weight pigs achieving 816 g/day. Bee (2004) found no difference in the post weaning or grow/finish average daily gain of pigs with birth weights of either 1.27 or 1.76 kg. In contrast Gondret *et al*. (2006) using pigs with a birth weight of either 1.05 or 1.89 kg found that on average growth rate between birth and slaughter differed by 40 g/day which was significant. Similarly Rehfeldt *et al*. (2008) comparing pigs with a birth weight of 1.08 kg and 1.67 kg found a 40 g/day difference in average daily gain between weaning and slaughter. However, a difference of 40 g/day is minimal compared to the variation often observed within a group of light or heavy weight pigs. In this study, the birth weight of pigs was significantly correlated with wean weight but neither birth or wean weight were significantly correlated with the overall average daily gain of pigs between weaning and slaughter (P=0.074 and 0.649 respectively). Therefore, in this study, the effect of average daily gain can be considered as an independent variable from birth or weaning weight.

The age of the pigs at slaughter, in this study, was similar (average = 158 days with standard deviation of 3.8 days). By restricting the feed intake of pigs Candek-Potokar *et* *al*. (1998) compared the meat quality from pigs slaughtered at different ages but at a similar slaughter weight. The difference in age was on average 28 days and their results indicated that this age difference had no significant impact on pork quality after it was aged for 4 days.

In this study, the slaughter weight of pigs varied by 6.7% and was highly correlated with average daily gain between weaning and finish ($R^2 = 0.7975$) ($P<0.001$). The majority of pigs fell within a 15 kg weight band (103 – 118 kg). In this study finish weight was not a common variable within the models to predict the various meat quality attributes which suggests that the range used did not have a significant influence on meat quality. This is in agreement with Correa *et al*. (2006) who slaughtered pigs at either 107, 115 or 125 kg and found no evidence that increasing slaughter weight reduced meat quality. Furthermore, Piao *et al*. (2004) found no differences in meat quality when comparing pigs slaughtered at 110 or 120 kg and suggested that pigs between these slaughter weights optimised both carcass and meat quality. This slaughter weight range would represent a range in carcass weight of approximately 77 to 88 kg. Weatherup *et al*. (1998) and Beattie *et al*. (1999), using pigs from the same herd and the same genetic nucleus, as those in this study found no practical difference in the ultimate pH, drip loss, shear force or colour of meat from pigs slaughtered to achieve carcass weights of 70, 80, 90 or 100 kg. It is therefore suggested that the finish weight of pigs in this study did not have a significant impact on meat quality which further supports the fact that the average daily gain of the pigs in this study could be considered as an independent variable.

Factors that did affect meat quality

The back fat depth of pigs at P_2 (at the level of the last rib and 65 mm from the midline) was a common variable within the models to explain shear force and colour measurements (L*, a*, b*, Hue and Chroma). However, a validation exercise is required to test how much variability these models can account for and how accurate the models are. The models to explain shear force and L* could not be considered as effective as the models to predict a*, b*, Hue and Chroma since the variables in them were either non-significant or approaching non-significance. The kill out percentage of pigs was also a common, although non-significant, variable in models to predict shear force and L*. The inclusion of kill out % improved the AIC value of the models. However, biologically it is not clear why kill out percentage would have an effect and practically, it would be almost impossible for the kill out percentage of every individual pig slaughtered to be measured. Only models which exclude kill out percentage are therefore discussed.

Back fat depth was a significant factor in the 2 variable model (AIC of 207.5) to predict shear force. The 10-week weight of the pig was the other variable. Shear force is a measure of how easily the meat is cut and therefore gives an indication of how tender the meat is (Platter *et al*., 2003). Unfortunately the intramuscular fat of the meat was not measured in this study but the back fat depth of pigs has been found, in some cases, to be positively correlated with intramuscular fat content (Wood *et al*., 2004). However, although significant (P=0.049), the model indicates that, when holding 10-week weight constant, for every 1 mm decrease in back fat depth, shear force increases by 0.05 kg. This ratio is biologically very small. This result is similar to that of Rincker *et al*. (2008) who found a negatively significant but weak relationship between shear force and the extractable lipid from pork chops. From the graph presented by Rincker *et al*. (2008) it is extrapolated that for every 1% increase in extractable lipid, shear force decreased by 0.2 kg. Wood (1993) and Longergan *et al*. (2001) demonstrated that tenderness and juiciness of the meat were reduced in genotypes which had a high lean meat percentage, and hence low back fat depth and intramuscular fat content, which describes many of the pigs in current commercial production. However, Rincker *et al*. (2008) noted that many of the studies which found a relationship between high intramuscular fat content and superior tenderness and juiciness were conducted using Duroc pigs. They suggested the muscle fibre type of Duroc pigs, which is different from other genotypes, had as much of an influence on eating quality as the intramuscular fat content. In the study by Rincker *et al*. (2008) they suggested that intramuscular fat content had little influence on eating quality. Furthermore, a review of the literature by Ngapo and Gariépy (2008) concluded that the role of IMF in the sensory quality of pork is far from understood. This study, in which Landrace cross Large White pigs were used, would suggest that although back fat depth appeared to have a significant influence when determining shear force (tenderness), the size of the influence was minimal.

Back fat depth at P_2 was also a common variable in the models to describe the colour measurements L* (lightness), a* (redness), b* (yellowness), Hue angle and Chroma. The Hue angle and Chroma are based on calculations using the values of a* and b* (Beattie *et al*., 1999). Therefore, it is not surprising that if back fat depth affects a* and/or b* it will also have an effect on Hue angle and Chroma. In this study, using a 1 variable model with AIC 585.7, when back fat depth increased by 1 mm, lightness (L*) deceased by 0.24 degrees. The most effective model (AIC 335.1) to predict a* (redness) used the variables of 20-week weight (*P*=0.04) and back fat depth (*P*=0.009). In this model when back fat depth was increased by 1 mm, a* decreased by 0.13 degrees when holding the 20-week weight constant. A one variable model with back fat depth (*P*=0.006) was the most effective (AIC 354.7) to explain b* (yellowness). In this model when back fat depth increased by 1 mm, b* decreased by 0.15 degrees. A two variable model best explained Hue angle where hue angle increased by 0.72 degrees for every 1 mm increase in back fat depth while holding 20-week weight constant. Chroma decreased by 0.15 degrees for every 1 mm increase in back fat depth (*P*=0.009).

Few studies have focused on the direct effect of back fat depth on the colour of meat. It is hypothesised that the meat within a fatter carcass will chill more slowly than that from a lean carcass. A slower chilling rate will not only lead to a greater drip loss but also the meat will be lighter in colour (higher L* value). The inverse relationship between back fat depth and L* observed in this study does not support this theory but is in agreement with Latorre *et al*. (2004). Latorre *et al*. (2004) examined the effect of slaughter weight on the colour of the meat. As a result of increasing slaughter weight (116 vs 124 vs 133 kg) the back fat depth (between the 3rd and 4th last ribs on the midline) of pigs also increased (22.1, 25.7, 27.0 mm respectively). They found that L* decreased when the pigs got heavier (fatter). They also noted that a* increased but there was no effect on b*. Using pigs from the same genetic nucleus as those used in this study, Beattie *et al*. (1999) also found an increase in subcutaneous fat depth when carcass weight increased. However, they did not find any differences in L* whereas a* and b* increased as carcass weight (and subcutaneous fat) increased. Contrary to the results of Beattie *et al*. (1999) and Latorre *et al*. (2004), this study found an inverse relationship between back fat depth and a* and b*, i.e. as back fat depth at P_2 increased, a* and b* decreased. It should be noted that the range of colour values found within this study were not of any practical significance regarding acceptability to the consumer. Furthermore, the variability in a* values equated to 104% across the 103 pigs. It is questionable if any true results regarding a* could be attained from this degree of variability within this pool of data. It appears that back fat depth may have an effect on the colour of the meat, albeit not of practical significance, but the relationship is still unclear. The 20-week weight of the pig was also a significant variable within the models for a* and Hue angle. Oxidative fibres within muscle appear redder (higher a* values) while glycolytic fibres appear paler (higher L* value). The birth weights of pigs have been found to affect the proportion of oxidative and glycolytic fibres in the muscle of slaughtered pigs (Bee, 2004). In this study the birth weight and 20-week weight tended to be positively correlated (P=0.059) although very weakly. It is possible that lighter pigs at 20 weeks had more oxidative fibres and hence the meat was 'redder' compared with pigs of heavier weight.

Models to explain drip loss, ultimate pH and cooking loss could be considered as more effective compared with those to explain sarcomere length. Birth weight and back fat depth were common significant variables within these models. The most effective model (AIC 463.7) to explain drip loss also included sex as a variable. In this model birth weight was highly significant (P<0.001) and when birth weight increased by 0.1 kg, drip loss increased by 0.32%, while holding the sex and back fat depth of the pig constant. Back fat depth at P_2 was also significant within this model (P=0.048) and when back fat depth at P_2 increased by 1 mm, drip loss decreased by 0.25%, while holding birth weight and sex constant.

Studies indicate that pigs with a low birth weight are fatter at slaughter than pigs with a high birth weight (Rehfeldt *et al*., 2008; Gondret *et al*., 2006, Bee 2004). Therefore, birth weight and fatness appear to be interrelated and in agreement with the aforementioned workers, in this study, birth weight tended (P=0.054) to be negatively correlated (r=-0.19) with back fat depth, albeit very weakly. Furthermore, pigs with a low birth weight have been found to have a lower meat quality in terms of tenderness pH and water holding capacity (drip loss) (Gondret *et al*., 2006; Rehfeldt *et al*., 2008 and Rehfeldt and Kuhn, 2006). Intrauterine growth retardation results in pigs with a low birth weight and these pigs appear to have a lower total number of skeletal muscle fibres compared with their heavier littermates (Gondret *et al*., 2006). It has been suggested that this low number of muscle fibres, restricts potential for postnatal lean growth and therefore, these light birth weight pigs deposit increased amounts of fat (Rehfeldt and Kuhn, 2006). The poorer meat quality that has tended to be observed from light birth weight pigs has been associated with accelerated muscle fibre hypertrophy due to the low fibre number and formation of giant fibres, which are known to correlate inversely with good pork quality (Fiedler *et al*., 2004). However, Rehfeldt *et al*. (2008) found that the meat quality from ‘middle birth weight’ pigs (birth weight of 1.37 kg) was optimum and that from light (1.08 kg) and heavy (1.67 kg) birth weight pigs declined from the optimum. The meat quality of light weight pigs was particularly poorer regarding pH and drip loss, whereas that from heavy weight pigs was poorer regarding conductivity and lightness. With regard to the relationship between back fat depth and drip loss and pH, it is possible that the increased fat cover on the pig carcass, insulated the carcass to a greater extent than a lean carcass and the meat within the carcass chilled at a slower rate. A slower chill rate would result in meat with a lower ultimate pH and a higher drip loss.

Conclusions

In conclusion, the average daily gain of the Landrace x Large White pigs representing a range of average daily gains from 616 to 943 g/day from weaning to finish did not explain the variability in meat quality observed in this study and was not considered as a major factor determining any meat quality parameters. However, using mainly back fat depth and the weight of pigs at various stages of growth, especially birth weight, it was possible to establish effective models to explain the colour parameters of a*, ‘b*, Hue, Chroma, and meat quality parameters of drip loss %, pH and cooking loss %. Models to explain shear force, L* and sarcomere length also used back fat depth at P_2 and birth weight but were less effective. It is suggested that the back fat depth at P_2 and birth weight of pigs, which are interrelated, play a larger role determining meat quality than the average daily gain of pigs. However, back fat depth at P_2 and birth weight do not fully explain the variability in meat quality that can be observed. Furthermore, the variability in shear force observed in this study, where pigs were of the same breed and reared under similar managerial practices should be of major concern for the pig industry regarding producing a consistent product.

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