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.