Assessment of Novel Sire Lines for Meat Quality Traits

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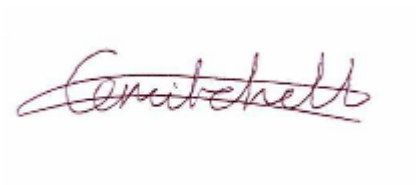
AUTHOR'S DECLARATION

I declare that the work in this dissertation was carried out in accordance with the regulations of the University of Bristol. The work is original except where indicated by special reference in the text and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the University of Bristol.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

Signed Date 8th September 2010



Assessment of Novel SireLines for Meat Quality Traits.

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Abstract

The aim of this project was to investigate whether there is a significant difference in meat eating quality as assessed by shear force, drip loss and pH, between progeny sired by different sire lines crossed with the same dam line. The effects of terminal sire genotype (H line, RN^- Hampshire; E line, Large White x Pietrain; F line, Large White x Duroc; M line, Duroc x Pietrain) on meat quality characteristics of 91 pigs slaughtered at 104-107kg live weight was measured. Data was analysed using both age at slaughter and hot carcass weight as a covariate. Meat from H line pigs was more tender, had a higher percentage moisture than the other lines and more intramuscular fat than the E and F lines. There was no significant difference between lines for percentage drip loss or percentage chill loss.

Keywords — Sire Line, Meat Quality, Duroc, Hampshire, Pietrain.

INTRODUCTION

Within the pig industry dam animals are selected based on their mothering abilities, prolificacy, longevity and the production system that they will be in. Sire animals are selected based on what is desired from the final commercial progeny e.g. large loin eye area, large ham muscle or further processing ability. The inclusion of at least 50% Duroc genetics, whilst having no effect on daily live weight gain or lean tissue conversion ratio (Blanchard *et al,*. 1999b) results in significantly darker meat, firmer fat and increased marbling (Blanchard *et al.,* 1999b). The MLC (1992) Blueprint recommends a minimum of 50% Duroc inclusion for improved pork tenderness and juiciness.

The Hampshire breed is a known carrier of the Rendement Napole (RN^-) gene and as a result slaughter progeny carrying the gene are associated with acid meat (Fenandez *et al*, 1992; Bertram, Petersen & Andersen, 2000). Carriers of the RN- gene have a high glycogen content in the muscles which makes a lower ultimate pH possible

(Bertram, Petersen & Andersen, 2000). A low ultimate pH in meat is also associated with a reduced water holding capacity (Bendall and Swatland, 1988). In addition muscles from the Hampshire breed have been shown to have a darker, redder colour, which is due to having higher concentrations of myoglobin, the pigment in muscle (Monin & Sellier, 1985; Warriss, 2000).

Commercially the halothane gene is of interest since its presence is associated with an increased content of lean meat in the carcass (Fisher *et al*, 2000). However, the gene is also linked to porcine stress syndrome in pigs (PSS) which results in increased levels of PSE in meat (Fisher *et al*, 2000; Oliver *et al*, 1993).

Different sire lines have been bred and improved by different genetics companies to meet differing requirements of producers, processors and retailers. Sire lines are selected by the producer to maximise their return based on their payment scheme e.g. supply of pigs 75-85kg dead weight with a P2 <12mm. However, progressive producers are increasingly using consumer acceptability as a key factor of influence when selecting sire lines for commercial progeny, aiming at meeting specifications for UK supermarkets' premium pork ranges. To achieve the best eating quality possible research suggests the following criteria need to be met:

- Progeny must have ≥ 50% Duroc Genetics (Blanchard *et al*, 1999b)
- Hampshire Sires used need to be either RN^-/RN^- or rn^+/RN^- (Huiid, 2002; Lindahl *et al*, 2001)
- The sire lines need to be Halothane negative to prevent PSE meat. (Fisher *et al*, 2000).

Research suggests that animals sired by Duroc have lower shear force values (Channon *et al*, 2004) and animals sired by RN^- animals show higher levels of drip loss and lower pH ultimate values (Bertram, Petersen & Andersen, 2000). Hence, the aim of this project was to investigate whether there is a significant difference in meat eating quality as assessed by shear force, drip loss and pH, between progeny sired by different sire lines crossed with the same dam line.

MATERIALS AND METHODS

2.1. Animals

Commercial Pigs, from four different sire lines, were bred and reared at Harper Adams. The slaughter progeny were bred from Large White x Landrace sows crossed with either a RN- Hampshire (H line), Large White x Pietrain (E line), Large White x Duroc (F line), or Duroc x Pietrain (M line) sire. All Pietrain animals were homozygous halothane negative (NN). All animals were tagged with an individual tag at birth and all production data was recorded. Of the progeny reared at Harper Adams 91 gilts (24 RN^- H Cross, 24 E Cross, 24 F Cross and 19 M Cross) were then sent for slaughter at Bristol University.

The animals were selected for slaughter once they had reached a live weight of approx 100kg. Harper Adams use a batch farrowing system, as a result the 91 Gilts used in this trial reached the slaughter weight in staggered groupings. The animals were sent to slaughter in 7 batches between 1st February 2010 and 18th May 2010. All batches were sent to the abattoir on a Monday with the selected pigs being weighed before loading.

2.2. Slaughter line data collection

For every animal the time of slaughter was recorded along with the individual animal tag ID and slap. At 45 minutes post slaughter the pH_{45} and temperature$_{45}$ (T_{45}) were recorded using a calibrated Testo 205 pH meter (Testo Ltd, Alton, Hampshire, England). At this point the P2 and hot carcass weight were also recorded. P_2 was measured using an optical probe inserted 6.5cm from the dorsal midline at the level of the last rib. Carcasses were transferred to the chiller (4°C and 1ms^{-1} wind speed) where they were left to cool overnight.

The next day the carcasses were taken out of the chiller, weighed and the cold weight was recorded. Killing out percentage was calculated using live weight and hot carcass weight. Percentage chill loss was calculated using the hot and cold carcass weights. A sample of the loin was then taken, removing a 15-20cm section of the *Longissimus dorsi* (LD) muscle from the left hand side of the animal at the P2 point measuring towards the shoulder. The loin sample was then broken down into 3 parts. A 2cm

thick chop near the P2 point was removed, the freshly cut surface was used for measurements and hence was uppermost when placed on a polystyrene tray. The chop was covered with overwrap and placed in a chiller to bloom for one hour. The next 2cm chop was removed from the loin sample and used to measure drip. The remaining section of the loin sample was vacuum packed and aged for 10 days at 1°C before being frozen. Once all samples had been collected and frozen they were analysed for texture and intramuscular fat (IMF).

2.3. Bloomed colour, pH_{24} and drip loss measurement

The colour of the bloomed chop (L*a*b*, CIE, 1976) was measured using a Konica Minolta CR-400 Meter (Konica Camera Company, Milton Keynes, UK). The chops were then used to measure pH_{24} using the calibrated Testo 205, vacuum packed and frozen for subsequent analysis of IMF.

Drip loss was measured using the bag suspension method (Honikel, 1998). The 2cm chop was trimmed of all subcutaneous fat and rind and weighed, threaded onto string near the top of the eye muscle, placed in a net bag and suspended in a plastic bag which was inflated around the chop. The bag was sealed ensuring that the bag did not contact the meat surface and suspended in a cold room for 48hours at +1°C.

After 48 hours had passed the chops were removed from both the plastic and net bags, gently blotted and re-weighed. Percentage drip loss was calculated as follows:

((weight before – weight after) / weight before)*100 = % drip or g/100g meat

2.4. Fat and moisture determination

The frozen chops were thawed in cold water in their bags for 20 minutes. All external fat and connective tissue was removed and the remaining eye muscle was cut into cubes and blended in a food processor until smooth. Any drip that remained on the chopping board or in the vacuum bag was reincorporated during blending.

A 25g blended sample was weighed into a pre-weighed plastic pot which was lidded and frozen overnight and stored at -20°C until ready to freeze dry in an Edwards

Modulyo Freeze dryer (-40°C, 10^{-1}mBar) for 3 days. Pots and contents were reweighed and moisture content calculated:

((Pot & Wet Muscle Weight – Pot & Dry Muscle Weight) / (Pot & Wet Muscle Weight – Empty Pot Weight)) * 100 = % Moisture

The dried muscle sample was ground into a fine dust, transferred into a cellulose extraction thimble (Fisherbrand FB59483, Range 0007N0028 28mmx80mm) and plugged with cotton wool. Fat was extracted by the Soxhlet method (British Standard, BS 4267: part 10, 1994,) using 40-60°C petrol ether (Analytical reagent grade, Fisher Scientific P/1760/17)

(Buchi Flask & Extracted Fat Weight – Empty Buchi Flask Weight) / (Pot & Wet Muscle Weight – Empty Pot Weight)) * 100 = % Fat

2.5. Statistical Analysis

All data was analysed using the General Linear Model procedure of GenStat version 12.1 (VSN International Ltd). The data was analysed four times using four different models. The first model used Line as a factor, the second used Line and date of slaughter as factors and the final two models had covariates. One model used age at slaughter as the covariate the other used hot carcass weight as a covariate.

The model for line as a factor:

$$Y_{ik} = \mu + L_i + e_{ik}$$

Where Y_i is the phenotypic value on the trait for animal $_k$. μ is the mean. L_i is the fixed effect of Line$_i$ (1,...4). e_{ik} is a random residual.

The model for line and date of slaughter as a factor:

$$Y_{ijk} = \mu + L_i + D_j + e_{ijk}$$

Where Y_{ijk} is the phenotypic value on the trait for animal $_k$. μ is the mean. L_i is the fixed effect of Line$_i$ (1,...4). D_j is the fixed effect of date of slaughter $_j$ (1,…7). e_{ijk} is a random residual.

The model for slaughter weight as a covariate:

$$Y_{ijk} = \mu + L_i + D_j + bA_{ijk} + e_{ijk}$$

Where Y_{ijk} is the phenotypic value on the trait for animal $_k$. μ is the mean. L_i is the fixed effect of Line$_i$ (1,...4). D_j is the fixed effect of date of slaughter $_j$ (1,…7). A_{ijk} is the age at slaughter and b is the linear regression coefficient of A_{ijk} on the trait**.** e_{ijk} is a random residual.

The model for Hot carcass weight as a covariate:

$$Y_{ijk} = \mu + L_i + D_j + bW_{ijk} + e_{ijk}$$

Where Y_{ijk} is the phenotypic value on the trait for animal $_k$. μ is the mean. L_i is the fixed effect of Line$_i$ (1,...4). D_j is the fixed effect of date of slaughter $_j$ (1,…7). W_{ijk} is the hot carcass weight and b is the linear regression coefficient of W_{ijk} on the trait**.** e_{ijk} is a random residual.

RESULTS

Table 1 shows the number of samples, unadjusted means, standard deviation (SD) and sed for each sire line. There is no significant difference between sire line treatments for live weight, hot carcass weight, pH_{45}, $Temperature_{45}$. P2, cold carcass weight, percentage chill loss, $pH_{ultimate}$, $Temperature_{24}$, percentage drip, *a**, or Chroma.

Table 1. Selected descriptive characteristics of the four different sire line progeny.

Measurements	Sire line Mean (±Standard deviation)				sed
	H	E	F	M	
No	24	24	24	19	
Age at Slaughter	149.29^{a} (6.26)	160.25^{b} (10.41)	160.67^{b} (12.42)	156.89^{b} (8.96)	2.835
Live Weight	106.6 (5.48)	106.88 (5.78)	106.42 (5.88)	104.53 (4.29)	1.57
Hot Carcass Weight (kg)	85.2 (5.14)	86.3 (4.56)	85.4 (4.91)	83.7 (3.24)	1.32
KO%	79.87^{a} (1.400)	80.72^{b} (1.27)	80.27^{ab} (1.33)	80.08^{ab} (1.45)	0.039
pH_{45}	6.28 (.287)	6.44 (.308)	6.47 (.384)	6.36 (.343)	0.095
$Temperature_{45}$ (°C)	36.7 (1.79)	36.6 (1.90)	36.0 (1.38)	36.9 (1.20)	0.47
P2	12.4 (2.32)	12.0 (2.22)	12.6 (2.60)	12.9 (2.05)	0.67
Cold Carcass Weight (kg)	82.9 (5.12)	84.0 (4.52)	83.0 (4.96)	81.4 (3.26)	1.32
% Chill Loss	2.69 (0.307)	2.64 (0.374)	2.81 (0.330)	2.78 (0.274)	0.094
$pH_{ultimate}$	5.41 (.093)	5.42 (0.729)	5.39 (.113)	5.39 (.072)	0.026
$Temperature_{24}$ (°C)	6.6 (.93)	6.7 (1.01)	6.8 (1.04)	6.3 (.84)	0.28
% Drip	4.20 (1.881)	3.23 (1.852)	3.48 (2.362)	3.90 (2.061)	0.591
*L**	53.0^{ab} (2.74)	52.9^{ab} (2.23)	53.9^{a} (3.03)	51.9^{b} (2.91)	0.79
*a**	6.88 (1.294)	6.55 (1.016)	6.99 (1.016)	7.27 (1.473)	0.346
*b**	4.35^{a} (1.252)	4.88^{ab} (.710)	5.26^{b} (1.353)	5.16^{b} (.983)	0.32
Chroma	8.20 (1.516)	8.18 (1.149)	8.77 (1.539)	8.94 (1.621)	0.421
Hue	32.23^{a} (7.471)	36.75^{b} (3.396)	36.42^{b} (4.930)	35.52^{b} (4.676)	1.548
Shear force (g)	3320^{a} (1443)	5121^{b} (1092)	4660^{b} (1024)	5254^{b} (1187)	345.7
% Moisture	75.45^{a} (.367)	74.88^{b} (.476)	74.72^{b} (.375)	74.44^{c} (.353)	0.012
% Fat	0.91^{a} (.365)	0.57^{b} (.181)	0.73^{c} (.262)	0.94^{a} (.225)	0.008

As shown in Table 1 the pigs were drawn from each batch for slaughter when they had achieved approximately 100kg live weight and at 106.6, 106.9, 106.4 and 104.5 for lines H, E, F, and M respectively, there was no significant difference in final live weight between groups showing that the selection process had been successfully

applied. The H line was significantly younger than the E, F and M lines (P = <0.001; <0.001 and 0.014 respectively) at point of slaughter even though there was no significant difference in final live weight.

The killing out percentage for the E line sired slaughter animals was significantly higher than the H lines (P = 0.033) although there were no other differences between lines. The F line produced significantly darker meat then the M line (P = 0.02) although there were no other significant differences in L^* values between treatments. The H line produced a significantly yellower meat with the b^* value being significantly lower then the F and M lines (P = 0.006 and 0.02 respectively). Hue angle is significantly lower for the H line in comparison to the E, F and M lines (P = 0.004, 0.008 and 0.049 respectively). Shear force values for the E, F and M lines are significantly higher than the H line (P = <0.001 for all sires). Percentage moisture is significantly lower in M line progeny than the H, E and F lines (P = <0.001, <0.001 and 0.032 respectively) whilst the H line has significantly higher levels of moisture than the E, F and M lines (P = <0.001 for all sires). H and M lines have significantly higher levels of IMF than the E and F lines. The F line has significantly lower levels of IMF than the H, E and M lines (P = 0.030, 0.039 and 0.012 respectively). Although significantly higher then the F line the E line has significantly lower levels of IMF compared to the H and M lines (P = <0.001).

3.1. Analysis of data using date of slaughter as a factor

Table 2 shows the number of samples, adjusted means and sed for each sire line with date of slaughter used as a co-variate. There is no significant difference between sire line treatments for age at slaughter, killing out percentage, pH_{45}, percentage chill loss, $pH_{ultimate}$, $Temperature_{24}$, percentage drip, L^*, a^*, b^*, Chroma and Hue.

Table 2. Adjusted means of selected descriptive characteristics of the four different sire line progeny using day of slaughter as a factor.

Measurements	Sire line Mean				sed
	H	E	F	M	
No	24	24	24	19	
Age at Slaughter	149.29	153.24	152.9	149.78	2.18
Live Weight	106.6^{ab}	107.1^{ab}	109.7^{a}	105.5^{b}	1.328
Hot Carcass Weight (kg)	85.2^{ab}	85.8^{ab}	87.3^{a}	84.3^{b}	1.123
KO%	79.87	80.12	79.54	79.80	0.036
pH_{45}	6.28	6.43	6.46	6.39	0.085
$Temperature_{45}$ (°C)	36.7^{a}	35.6^{b}	35.9^{ab}	36.5^{a}	0.371
P2	12.4^{a}	12.7^{a}	13.4^{ab}	14.1^{b}	0.555
Cold Carcass Weight (kg)	82.9^{ab}	83.6^{ab}	85.0^{a}	82.0^{b}	1.105
% Chill Loss	2.69	2.62	2.69	2.65	0.063
$pH_{ultimate}$	5.41	5.44	5.42	5.44	0.016
$Temperature_{24}$ (°C)	6.6	7.0	6.8	7.3	0.169
% Drip	4.20	3.04	3.38	3.68	0.573
*L**	53.0	52.9	53.4	51.6	0.774
*a**	6.88	6.44	6.93	7.22	0.352
*b**	4.35	4.38	4.90	4.62	0.294
Chroma	8.20	7.82	8.53	8.61	0.420
Hue	32.23	34.14	34.66	32.43	1.313
Shear force (g)	3320^{a}	5182^{c}	4269^{b}	5147^{c}	325
% Moisture	75.45^{a}	74.87^{b}	74.82^{b}	74.40^{c}	0.11
% Fat	0.91^{ab}	0.65^{c}	0.75^{cb}	1.06^{a}	0.07

Live weight of the F line is significantly higher than the M line (P = 0.009). This significant difference also occurs for the hot carcass weight (P = 0.021) and cold carcass weight (P = 0.024). The $temperature_{45}$ of the E line is significantly lower then the H and M lines (P = 0.01 and 0.04 respectively). The adjusted means show the backfat for the M line as significantly thinner than the H line (1.7mm, P = 0.012) and the E line (1.4mm, P = 0.030). The H line is significantly more tender then the E, F and M lines (P = <0.001, 0.015 and <0.001 respectively). Although not as tender as the H line the F line has significantly lower shear force compared to the E and M lines (P = 0.015 and 0.022 respectively).

Percentage moisture is significantly lower in the M line then the H, E and F lines (P = <0.001, <0.001 and 0.001 respectively). The H line has significantly more moisture

than the E, F and M lines (P = <0.001 for all sires). There is no significant difference in moisture between the E and F lines.

3.2. Analysis of age at slaughter and hot carcass weight as covariates:

Table 3 shows the estimates of covariate. From looking at the data we can see that age at slaughter significantly affects percentage chill loss, percentage moisture and percentage fat whilst hot carcass weight significantly affects P2, *a**, Chroma, shear force and percentage moisture, when used as covariates.

Table 3: Estimates of Covariate

	Estimate of Covariate	
Measurements	Age at slaughter	Hot carcass weight
pH45	-0.00229^{NS}	-0.01132^{NS}
Temp45	0.0061^{NS}	0.0168^{NS}
P2	-0.0053^{NS}	0.1909***
pH24	-0.001550^{NS}	-0.00166^{NS}
% Chill Loss	-0.00639*	0.01168^{NS}
% Drip	0.0346^{NS}	0.1103^{NS}
*L**	-0.0474^{NS}	0.1016^{NS}
*a**	0.0036^{NS}	0.0775*
*b**	0.0022^{NS}	0.0539^{NS}
Chroma	0.0036^{NS}	0.0922*
Hue	-0.0086^{NS}	-0.057^{NS}
Shear Force	-9.0^{NS}	-103.6***
% Moisture	-0.01660**	-0.0240*
% Fat	0.00726*	0.00811^{NS}
% Fat inc P2 as Factor	0.00747*	0.00098^{NS}

Table 3 shows that the age at slaughter has significant effects on percentage moisture (P = 0.003) and percentage fat (P = 0.044) within a carcass. The estimate of the covariate shows that as the age of slaughter increases the percentage moisture decreases (-0.01660) and the percentage fat increases (0.00726). Percentage chill loss significantly decreases as age at slaughter increases (P = 0.047). No other meat quality attributes were significantly affected by age at slaughter.

When hot carcass weight is included in the statistical model the estimate of the covariate (Table 3) has a significant affect on P2, *a**, chroma, shear force and percentage moisture. The estimate of the covariate shows as hot carcass weight increases it has a significant ($P < 0.001$) additive affect (0.1909) on the P2 of the animal. As hot carcass weight increases *a** and chroma also significantly ($P < 0.05$) increase (0.0775 and 0.0922 respectively). For every kilogram (kg) hot carcass weight increases there is a significant ($P < 0.001$) decrease in shear force by 103.6g. A decrease in percentage moisture of 0.0240% is also significantly ($P < 0.05$) associated with hot carcass weight increase.

3.3. Differences in meat quality attributes between sire lines when age at slaughter is a covariate.

As shown in table 4 there was no significant difference between pH_{45} minutes, percentage drip, *a**, *b**, Chroma or Hue when age at slaughter is used as a covariate. Although there is no significant difference in pH_{45} when investigating pH_{24} only the H and E lines were significantly different to each other ($P = 0.032$) with the H line having more acidic meat. $Temp_{45}$ of the E line is significantly cooler then the H ($P = 0.010$) and M lines ($P = 0.039$). The P2 measure for the M line, whilst not significantly different to the F line, was significantly fatter than both H ($P = 0.012$) and E ($P = 0.035$) line animals with the adjusted mean P2 being 1.66mm and 1.32mm thicker respectively.

None of the bloomed colour breakdown (*a**, *b**, Hue and Chroma) are significantly different between groups. However, *L** is significantly different between the F and M lines ($P = 0.038$) but not the two other lines, with the M line having significantly darker meat. The adjusted means for shear force show the M line as being the most tender and the H line being significantly tougher then the other 3 lines. When age is not used as a covariate the H line is the most tender of all 3 lines. Shear force is therefore a function of age. The H line had a significantly higher percentage moisture ($P = <0.001$ for all lines) whilst the M line had a significantly lower percentage moisture in comparison to the E and F lines ($P < 0.001$ for all lines). However, both the H and M lines had significantly more percentage fat in comparison to the E and F lines, even when P2 was fitted as an additional covariate.

Table 4: Adjusted mean meat quality attributes using age at slaughter as a covariate and the fixed effect of day of slaughter (i.e. all animals 149.29 days at slaughter)

Measurements	Sire Line				
	H	E	F	M	sed
Number	24	24	24	19	
Age at Slaughter	149.29	160.25	160.67	156.89	
% Chill Loss	2.71	2.67	2.73	2.68	0.062
% Moisture	74.44[a]	73.93[b]	73.87[b]	73.40[c]	0.01047
% Fat	0.91[a]	0.62[b]	0.72[b]	1.05[a]	0.07
% Fat inc P2 as Factor	0.91[a]	0.60[b]	0.69[b]	0.99[a]	0.07

3.3. Differences in meat quality attributes between sire lines when hot carcass weight is a covariate.

Table 5 shows the adjusted means for when hot carcass weight is used as a covariate. There are no significant differences between lines for pH ultimate, % Chill Loss, % Drip, *L**, *b** or Hue. pH_{45} of the H line is significantly more acidic ($P = 0.046$) then the F line. The H and M lines were both significantly warmer 45 minutes post slaughter then the E line ($P = 0.010$ & 0.037 respectively). The M line is significantly fatter at the P2 point than any other lines. Although there is no significant difference in bloomed colour for *L**, *b** or hue; *a** and chroma were significantly different between breed lines with the M line having a richer chroma and redder tones then the E line ($P = 0.048$ chroma, $P = 0.024$ *a**). Meat from the E line has the highest shear force and is significantly tougher compared to both the H and F lines ($P = <0.001$ & 0.031 respectively). The H line has the most tender meat and is significantly different to the E ($P = <0.001$), F ($P = 0.002$) and M lines ($P = <0.001$).

Percentage moisture is not significantly different between the E line and the F line. However, the H line is significantly more moist in comparison to the E, F and M lines ($P < 0.001$ for all lines) in addition the M line is significantly dryer in comparison to the H, E and F lines ($P < 0.001$ for all lines). Between treatment groups the percentage fat content of the *LD* is not significantly different between the H and M lines but these have significantly higher levels of IMF than the E and F lines even when P2 is a factor.

Table 5: Adjusted mean meat quality attributes using hot carcass weight as a covariate. (i.e. All carcass taken to be 85.18kg)

Measurements	Sire Line				
	H	E	F	M	sed
Number	24	24	24	19	
Hot Carcass Weight	85.18kg	86.26kg	85.42kg	83.68kg	
P2	12.38[a]	12.52[a]	12.96[a]	14.22[b]	0.516
*a**	6.88[ab]	6.39[a]	6.77[ab]	7.29[b]	0.343
Chroma	8.20[ab]	7.76[a]	8.33[ab]	8.70[b]	0.410
Shear Force (g)	3320[a]	5248[b]	4487[c]	5048[bc]	305
% Moisture	74.44[a]	73.88[b]	73.86[b]	73.37[c]	0.011

DISCUSSION

The analysis of the raw data, with non adjusted means, is important since this is an assessment of the meat quality as the potential consumer would have received it. The only traits which are seen to be different between treatment groups are age at slaughter, killing out percentage, *L**, *b**, hue, shear force, percentage moisture and percentage fat. The UK pig production industry sends animals to slaughter when a contractually agreed weight is reached. As a result, data analysis where hot carcass weight is a covariate, is extremely relevant to processors and retailers. However, when considering meat quality and analysing the results obtained it is important to use the maturity of an animal as a covariate since age at slaughter is known to affect levels of connective tissue and therefore shear force and levels of IMF (Purslow, 2005; Bailey & Shimokomaki, 1971). In addition the age at slaughter is significantly different between treatment groups, using age as a covariate accounts for the effects caused by difference in age.

4.1. Age at slaughter and Killing out percentage

The H line reached slaughter weight 7.6 days earlier then the next fastest line (M). Because the weight at slaughter was not significantly different to other lines but the age at slaughter was, it is possible to deduce that the H line also has a higher DLWG than the other lines which is in agreement with studies by Enfält *et al* (1997).

The killing out percentage (KO%) is significantly different between the H and E lines with the H line having a significantly lower killing out percentage. The main factors that contribute to differences in KO% are those that affect the live weight of the animal at the point of slaughter i.e. Housing, system, transport stress, food withdrawal, dietary regime, gender, body weight and breed (BPEX, 2009). For all animals the factors were the same except the breed. Therefore it must be the difference in breed that has created the difference in KO%. This is in agreement with Monin & Sellier (1985) who also found RN⁻Hampshire sire animals to have a lower technological yield.

4.2. P2, percentage moisture and percentage fat

As the age of an animal increases its live weight also increases, however, the composition within the animal is not constant. The ratio of fat:lean increases throughout the life of the animal (Whittemore, 1993). The age at which it begins to lay down more fat relative to lean depends upon the age at which an animal approaches its mature body weight, with older animals tending to be fatter as subcutaneous fat is the last tissue to mature (Warriss, 2000). As a result the older an animal is, the more fat it will have in comparison to lean. Hence, two animals of the same weight could have different lean to fat ratios due to difference in age. The M line is significantly fatter (>1.3mm) at P2 then the other lines when means are adjusted for hot carcass weight, which suggests that it has a lower mature carcass weight. The results from this study show a positive correlation between percentage fat and age at slaughter (0.00726) as well as a negative correlation in percentage moisture and age at slaughter (-0.01660) which is in agreement with Whittemore (1993).

The H and M lines had the highest ratio of muscle lipid to subcutaneous fat thickness. Wood *et al* (2004) also found that animals with Duroc genetics had the highest ratio of muscle lipid to subcutaneous fat thickness. The RN⁻ Hampshire is associated with a leaner carcass (Enfalt *et al*, 1997) however, although the heritability of IMF percentage and fat tissue is high (0.50 and 0.69 respectively) there is a low genetic correlation between the two suggesting that it is possible to select for carcasses that have a lean P2 and also have high IMF (Rosenvold & Anderson, 2003).

The moisture within meat comes from the lean matter and as a result a decrease in moisture content represents a decrease in lean meat within a set volume. These results are in agreement with previous studies (Whittemore, 1993). The E, F and M lines all follow this relationship, however, when age at slaughter is used as a covariate the H line does not agree with the common preconception since as its % moisture increases its % fat ratio also increases. The increased marbling shown in the M line would be expected from an animal with 25% Duroc genetics (Blanchard *et al.*, 1999b).

4.3. pH_{45} minutes and $pH_{ultimate}$

Looking at the non adjusted means for pH_{45} the E and F lines both produced pork with a slower rate of pH fall than the others. However, the $pH_{ultimate}$ shows that we can eliminate DFD as being responsible. None of the treatment groups had a pH approaching PSE levels at either pH_{45} or $pH_{ultimate}$. Even though the RN- genotype is associated with "acid meat" and lower pH_{45} and $pH_{ultimate}$ the H line progeny did not have a significantly lower pH at either test point. This is not in agreement with results from previous studies (Lundstrom *et al*, 1995; Lundstrom *et al*, 1997; Bertram *et al*, 2000; Josell *et al* 2003, Lindahl *et al*, 2006).

4.4. Bloomed colour

The M line produced the darkest meat (L^* = 53.90, non adjusted) of the 3 lines. An increase in L^*, a^*, b^*, Chroma and Hue are all associated with the higher levels of pigmentation in meat. The M line progeny contain 25% Duroc genetics, the Duroc produces significantly darker meat (Blanchard *et al.*, 1999b). However, the F line progeny also contain 25% Duroc genetics, yet their meat is significantly lighter then the other lines, the difference in darkness could be due to the inclusion of the NN Pietrain in the M line. Although Fabrega *et a*l (2002) found the NN Pietrain to have darker meat then Nn Pietrains and white breeds.

The RN^- Hampshire breed is known to have a higher concentration of the muscle pigment, myoglobin, which results in a darker, redder colour in fresh meat (Monin & Sellier, 1985; Bertram *et al*, 2000) although Lindahl *et al* (2006) found RN^- meat to be lighter and more red and yellow than rn^+ meat. The results from this study are in agreement with previous research by Lindahl *et al* (2006) since the RN^- sired animals produced meat that had a b^* which was significantly yellower than the F and M lines

although not significantly darker or lighter then the other treatments. This is reiterated when looking at Hue. The RN^- sired animals have a colour angle closer to yellow than the other 3 lines as in agreement with Lindahl *et al* (2006).

4.5. Shear force

Conditioning of pork meat by storage increases its tenderness on cooking, with 80% of tenderising being achieved in five days (Etherington, Taylor & Dransfield, 1987). Wood *et al* (1996) found that aging pork for 10 days post-mortem had a greater effect than genotype in improving tenderness. The significant differences in tenderness, for both statistical models is not due to the 10 day aging process since all lines were aged for the same length of time. In addition there is no significance between lines for the standard deviation of shear force, meaning that the level of consistency in tenderness is the same between lines. However, the lower shear force value demonstrated by the H line is also seen in studies by Lundstrom, Andresson & Hansson (1996) and Lundstrom *et al* (1998). The lower shear force of the H line may not be due to the younger age at slaughter because the estimate of covariate is not significant. However, the H line had a faster growth rate and in another large study at Bristol (Richardson, personal communication), meat from faster growing pigs was more tender than that from slower growing pigs or those observed to have had a growth check. Younger animals have less stable collagen fibres (Bailey & Shimokomaki, 1971) and older animals have increased collagen fibre diameter and mature crosslinks (Purslow, 2005). In addition, Blanchard *et al* (1999a) showed that pigs which are growing lean tissue rapidly, particularly in the later stages of the growing period, produce more tender meat. The H line was over 7 days younger at slaughter then the other breed groups yet had the same slaughter weight and was not significantly different at the P2 level, thereby the H line had a faster lean tissue growth rate which may also account for its improved tenderness.

4.7. Percentage drip and chill loss

Neither age at slaughter or hot carcass weight had a significant effect on drip loss. Age at slaughter had a significant effect ($P < 0.05$) on percentage chill loss whereas hot carcass weight did not. There was no significant difference seen between genotypes for either percentage drip loss or chill loss. This is not in agreement with other studies where the RN^- genotype expressed significantly lower water holding

capacity than non-carriers (Lundstrom *et al*, 1995; Lundstrom *et al*, 1997; Bertram *et al*, 2000; Josell *et al* 2003).

CONCLUSIONS

Of the 4 lines the RN^- Hampshire meets the requirements of both the pig production industry and the retail industry the best. It has a higher DLWG than the other lines and produces meat that is significantly more tender than the other sire lines. This is unlike the other 3 lines has significantly higher % moisture whilst maintaining significantly higher levels of IMF which results in pork which is more acceptable to the consumer (Bryhni *et al* 2002; Fortin, Robertson & Tong, 2005). In addition it does not demonstrate the higher levels of chill loss or drip as expected from the RN^- gene.

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Assessment of Novel Sire Lines for Meat Quality Traits

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A dissertation submitted to the University of Bristol in accordance with the requirements of the degree of MSc Meat Science and Technology in the Faculty of Medical and Veterinary Sciences.

AUTHOR'S DECLARATION

I declare that the work in this dissertation was carried out in accordance with the regulations of the University of Bristol. The work is original except where indicated by special reference in the text and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the University of Bristol.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

Signed Date 8th September 2010

CONTENTS:

1. INTRODUCTION:

There are many factors to consider when analysing pork meat quality. It is necessary to test pig lines to ensure that they produce the growth rates, productivity and economy of production required by the pig production industry, whilst ensuring that it is also visually and organoleptically acceptable to the consumer without loosing technological yield or being microbially hazardous. All these areas are encapsulated by the term meat quality.

Meat quality can be divided into technological quality and quality attributes both depend on animal-related and environmental factors (Lammens *et al*, 2007). Quality assessment looks at the inherent properties of meat such as water-holding capacity, tenderness, colour, fat content and composition, oxidative stability and uniformity (Rosenvold *et al,* 2003), as well as suitability for further processing, storage and retail. Animal-related and environmental factors include, breed, genotype, nutrition, pre-slaughter handling, stunning, slaughter method and post-slaughter handling. All these factors can affect muscle metabolism and therefore affect the development of PSE (pale, soft, exudative) and DFD (dark, firm, dry) meat. Both PSE and DFD meat are a major problem for the pork industry (Lammens *et al*, 2007). All the levels of quality are mainly affected by whether the meat is PSE (Pale, Soft, Exudative), DFD (Dark, Firm, Dry) or acid meat (Hampshire Effect).

1.1 PSE AND DFD MEAT

Both PSE & DFD meat are a direct result of the levels of stress received by the animal:

- PSE – *Acute stress*, lasting hours, minutes prior to slaughter
- DFD – *Chronic stress*, lasting hours, day, weeks etc prior to slaughter

(Warriss, 2000)

PSE, DFD and Acid meat are all caused by changes in pH fall that are different to the normal, see Figure 1. The result is that meat has a colour difference to normal and produces more/less exudate, as shown in Figure 2.

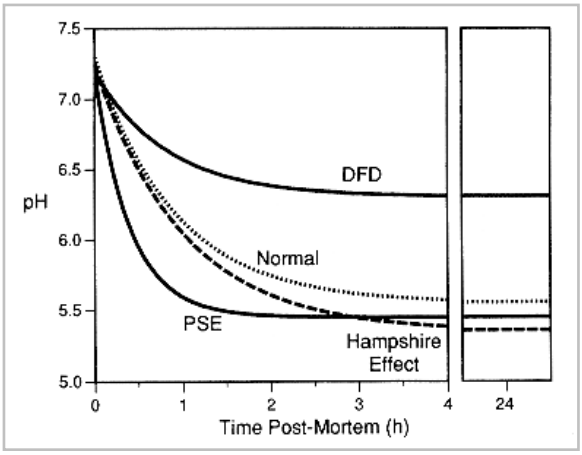
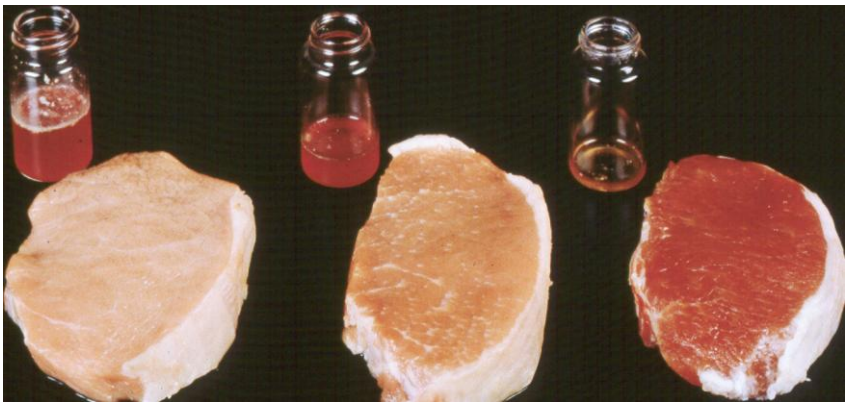


Figure 1: pH fall over time of Normal, PSE, DFD and Acid Meat.
Taken from http://www.nsif.com/conferences/1996/gariepy.htm
Last accessed, 12/8/2010

In meat that is PSE there is extensive protein denaturation due to low pH & high temperature in combination at early post mortem. This results in a meat of pale colour that exudes higher levels of drip than normal. On the other hand, DFD meat does not undergo sufficient protein breakdown, leaving the meat dry to the touch and dark in colour. DFD meat has a higher level of available water a_w and in conjunction with the higher pH allows spoilage organisms to colonise the meat thereby reducing the shelf life and potentially making the meat a public health hazard (Newton & Gill, 1981).

The extent of the pH fall is determined by the amount of glycogen present in the muscles at death. Little or no glycogen results in DFD meat, whereas an excessive level of glycogen causes PSE meat (Warriss, 2000). The accepted pH values for Normal, PSE and DFD meat are shown below:

	Standard pH Plot	
	pH45	**pH24**
PSE	<6	5.30
Normal	6.40	5.50
DFD	6.40	≥6



PSE **Normal** **DFD**

Figure 2: Colour and exudate differences between meat types.

Taken from: http://labs.ansci.illinois.edu/ellislab/images/pork%20color%20PSE%20to%20DFD.jpg Accessed November 2009.

The level of drip produced from a carcass directly influences yield. In PSE meat you can expect to see a technological yield reduction of 2-3% as a minimum (Rosenvold, 2003). This is in addition to the levels of drip expected during processing.

The increased drip loss will be demonstrated during the first 24 hours of chilling due to the air circulation systems causing increased evaporative loss. But this will not be the main area of loss since at this point carcasses are only split, resulting in a low surface to volume ratio. The main area of drip loss will be seen upon butchery where the breaking of cell membranes during cutting and the increase in surface area during the splitting of muscles will allow the drip to be more readily released.

DFD meat, whilst not affecting the yield of a carcass negatively, has a reduced shelf life and will become spoiled by pathogens faster than normal meat due to a greater a_w value. The a_w of meat determines what spoilage organisms will flourish and will directly affect the safety of the final product. DFD meat also has poor processing characteristics with slow/uneven formation of cured meat pigments. Flavour development is poor in both processed and cooked fresh DFD meat. If DFD meat is vacuum-packed a green colouration may develop due to sulphmyoglobin.

There is also evidence that stress pre-slaughter may predispose animals to showing blood splash in their muscles and other tissues which results in yield loss (Channon *et al*, 2002). Due to PSE & DFD meat being the result of stressors there are many areas to investigate.

1.2 TENDERNESS OF MEAT

The major factor influencing the tenderness of meat is the quality of the intermolecular cross-links in collagen, rather then the quantity (Fortin *et al*, 2005). It has been shown that the initial breakdown of meat occurs between the fibre bundles in the connective tissue of the perimysium. Intramuscular fat is primarily located in the perimysium although can be found, to a lesser extent, in the endomysium (Purslow, 1985; Wood, 1990). Figure 3 shows the structure of skeletal muscle.

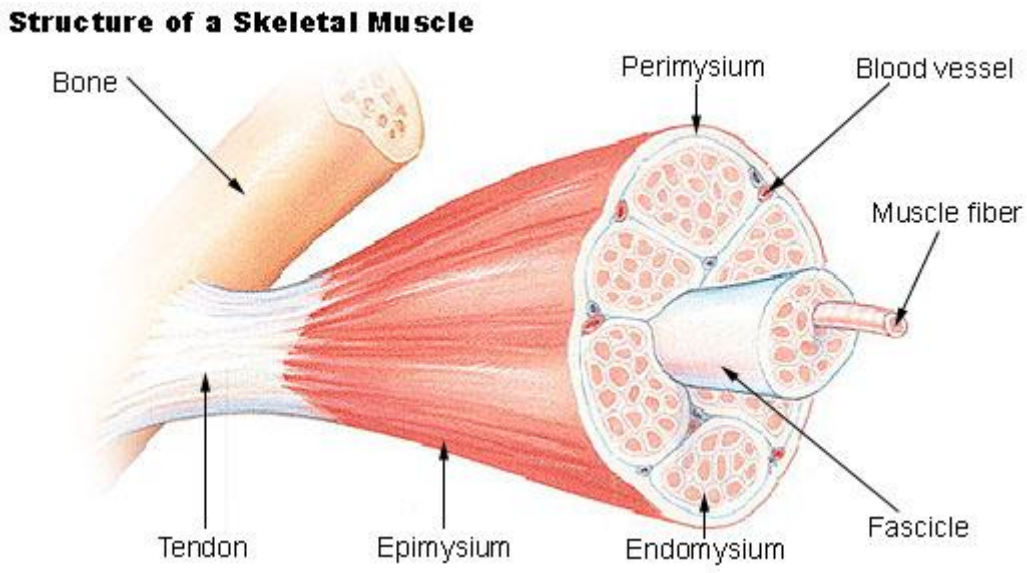


Figure 3: structure of skeletal muscle
http://upload.wikimedia.org/wikipedia/commons/8/89/Illu_muscle_structure.jpg

It is thought that IMF in the perimysium connective tissue causes the cross links between collagen fibres to become weakened, thereby reducing the force needed to breakdown connective tissue (Essén-Gustavsson *et al*, 1994). The structure is further weakened by the expansion of fat cells in the perimysium which forces the muscle bundles apart (Wood, 1990). The relationship between IMF and tenderness is further demonstrated in Figure 4 and Figure 5 from research done by Fortin *et al* (2005). The diagrams clearly demonstrate that as IMF percentage increases the meat becomes more tender.

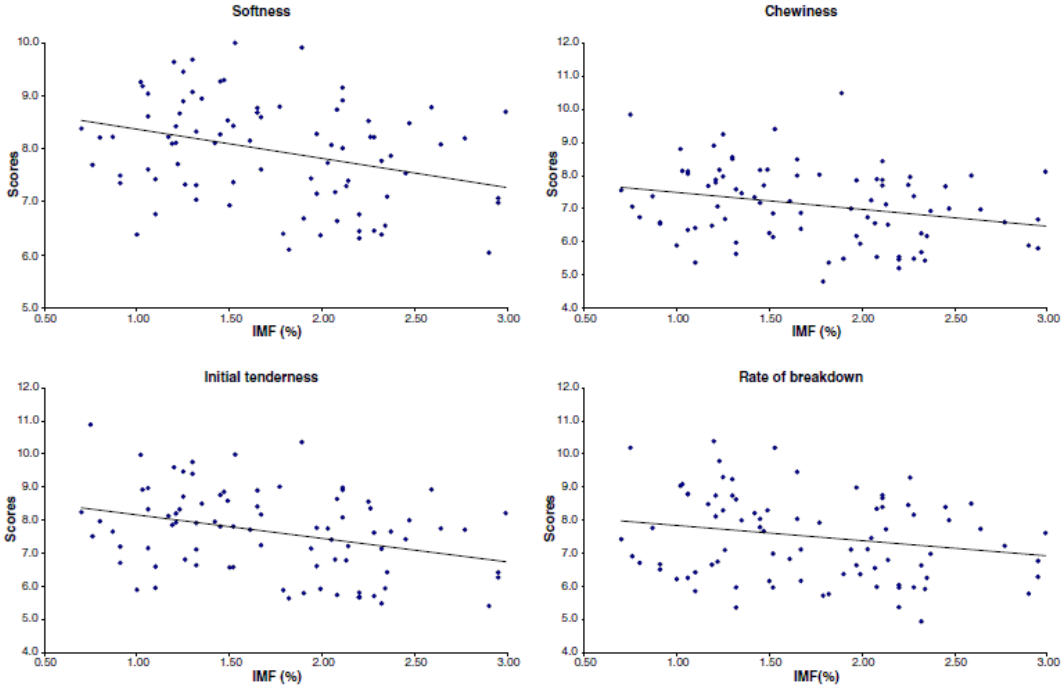


Figure 4: Relationship between sensory attributes describing tenderness in pork loin and IMF. Fortin *et al* (2005)

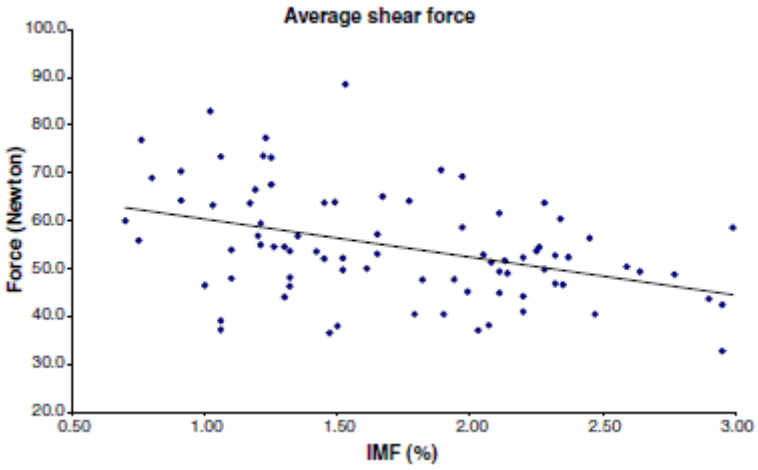


Figure 5: Relationship between average shear force in pork loin and IMF.

Fortin *et al* (2005)

As discussed by Fortin *et al* (2005) it is widely accepted that the perceived juiciness of meat is dependant on both the amount of saliva released during mastication and the amount of moisture within the meat. Furthermore moisture and IMF levels have a synergistic affect on perceived juiciness because the levels of IMF within the meat stimulate saliva production. The link between IMF, flavour and juiciness means that pork producers are required to balance levels of visible fat so that the consumer purchases product based on observation and then is satisfied at point of consumption by the eating experience provided by the product. Wood (1990) recommends a minimum of 1% IMF in UK pork, to ensure a satisfactory eating experience.

This literature review will investigate areas that affect pork meat quality.

2. BREEDING STOCK:

Pork meat comes from the progeny that result from using Sire Line genetics on a commercial crossbred sow. In the UK pig industry indoor pig production systems favour a Large White x Landrace sow. The sows have been bred for their mothering abilities, prolificacy, longevity and the production system that they will be in. Sire animals are selected based on what is desired from the final commercial progeny e.g. large loin eye area, large ham muscle or further processing ability. The inclusion of at least 50% Duroc genetics, whilst having no effect on daily live weight gain or lean tissue conversion ratio (Blanchard *et al,*. 1999) results in significantly darker meat, firmer fat and increased marbling (Blanchard *et al.*, 1999). The MLC (1992) Blueprint recommends a 50-75% Duroc inclusion for improved pork tenderness and juiciness. However, other commercially used sire lines are known to have meat quality advantages.

Pig producers aim to produce slaughter animals that have an efficient conversion of feed into good-quality lean meat, since consumers demand lean meat at the lowest possible cost (Aumaitre *et al*, 1982). Commercially the halothane gene is of interest since its presence is associated with an increased content of lean meat in the carcass (Fisher *et al*, 2000). However, the gene is also linked to porcine stress syndrome in pigs (PSS) which results in increased levels of PSE in meat (Fisher *et al*, 2000; Oliver *et al*, 1993).

Different sire lines have been bred and improved by different genetics companies to meet the specific remit of processors and retailers. However, consumer acceptability is only just becoming a key factor of influence when selecting sire lines for commercial progeny.

2.1 SELECTING THE DAM LINE:

The choice of dam line is affected by the production system to be used. However, it should be considered that some dam lines contain Duroc in their genetics that will improve the eating quality of the offspring if used with a Duroc sire line (Channon *et*

al 2004). However, if both sire and dam contain genetics for colour the progeny are likely to also show colour as shown in table 1. The gene responsible for the red coat colour in Durocs is generally thought to be recessive to the gene for white coat colour and if the Duroc is restricted to one side of the pedigree and crossed with white breed few problems with deep seated hairs are likely (Rempel & Marshall, 1990). Incidence of colour and deep seated hairs occurs when Duroc genetics are present in both the sire and the dam lines.

Table 1: Incidence of colour based on parenting.
Designed and used by JSR Genetics Ltd based on genetic marker technology.

Gilts		Hampshire	Pietrain	Duroc	White Pietrain	Large White
White Parent	Spots/Patches	10%	1%	10%	0.3%	0.3%
	Full Colour	0%	0%	0%	0%	0%
12% White Duroc	Spots/Patches	10%	1.6%	10%	0.4%	0.4%
	Full Colour	0.6% White Belt	0.6%	0.6%	<0.1%	<0.1%
25% Red Duroc	Spots/Patches	7.5%	2.4%	7.5%	1.4%	1.4%
	Full Colour	25% White Belt	25%	25%	1.3%	1.3%
50% Red Duroc	Spots/Patches	5%	2.8%	5%	3.4%	3.4%
	Full Colour	50% White Belt	50.0%	50%	2.5%	2.5%

When choosing the dam line it is important to consider that consistency in the birth weight of piglets and length of gestation will affect final meat quality of the slaughter animal. Since the number and size of the myofibres are the main determinants of muscle mass and both the number and size are established following a complex sequence of pre- and postnatal events (Oksbjerg *et al*, 2004). Myoblasts proliferate and differentiate into myotubes and myofibres during embryonic and foetal development. (Oksbjerg *et al*, 2004). This agrees with studies of cattle which have shown that within the first two months post-conception the primary muscle fibres form and during secondary myogenesis the majority of the muscle fibres are formed (Russell & Oteruelo, 1981).

2.2 SELECTING THE SIRE LINE:

Sire line is often chosen based on hybrid vigour, disease resistance and conformation. However, a sire line boar with good conformation does not mean the progeny will have good meat eating quality. Carcass quality and Meat quality are only weakly related, if at all.

There are only two sire line breeds (Duroc and Hampshire) that have been proven to produce consistently high eating quality meat. However, when using good eating quality sire lines the genetics of these lines also need to be considered. To achieve the best eating quality possible the following criteria need to be met:

- Progeny must have ≥ 50% Duroc Genetics (Blanchard *et al,* 1999)
- Hampshire Sires used need to be either RN^-/RN^- or rn^+/ RN^- (Huiid, 2002; Lindahl *et al* 2001)
- The sire lines need to be Halothane negative (Fàbrega et al, 2002)

2.2.1 DUROC SIRE LINES:

To ensure worthwhile improvement in eating quality it has been recommended that there is at least a 50% inclusion of Duroc in the slaughter generation (MLC, 1992; Blanchard *et al.*, 1999). There is no significant difference in daily live weight gain to white sire line genotypes, whilst the lean tissue and subcutaneous fat growth rates are higher ($P<0.05$) in 50% Duroc progeny (Blanchard *et al*., 1999). However, whilst there is no significant difference in lean tissue food conversion ration, the FCR in 50% Duroc progeny is lower than that seen in 25% or 0% progeny (Blanchard *et al*., 1999). In addition as the inclusion level of Duroc increased the killing out percentage was positively affected and the P2 fat thickness also increased (See Table 2). In addition 50% Duroc animals have higher fat firmness scores and higher penetrometer values compared to the 25% and 0% inclusion animals (Blanchard *et al*., 1999).

Table 2: Taken from Blanchard *et al.* (1999)

	0% Duroc	**25% Duroc**	**50% Duroc**	**s.e.**
Killing Out %	75.5^{a}	75.8^{b}	76.1^{c}	0.0014**
P2 (mm)	10.6^{a}	11.6^{b}	12.7^{c}	0.14**

^{a,b,c} means values in a row with different superscripts differ significantly (P<0.05)

As the percentage content of Duroc increases from 0% to 25% and 50% the *Longissimus Dorsi* (LD) becomes significantly darker (P<0.05). The darker colour of the muscle is related to an increased muscle haem (red pigment) concentration for the Duroc suggesting more red oxidative fibres (Warriss *et al*, 1990a, Channon *et al* 2004). There is no significant difference in drip loss, rind side blemish, or deep-seated hairs between different percentages of Duroc (Blanchard *et al*., 1999). D'Souza and Mullan (2002) reported higher pH24 in a 50% Duroc line compared with a <25% Duroc line, although WHC was lower in the former.

2.2.2 HAMPSHIRE SIRE LINES:

The Hampshire breed is a known carrier of the Rendement Napole (RN^{-}) gene and as a result slaughter progeny carrying the gene are associated with acid meat (Fenandez *et al*, 1992; Bertram, Petersen & Andersen, 2000). Carriers of the RN^{-} gene have a high glycogen content in the muscles which makes a lower ultimate pH possible (Bertram, Petersen & Andersen, 2000). A low ultimate pH in meat is also associated with a reduced water holding capacity (Bendall and Swatland, 1988). However, the Hampshire breed is used in the production of slaughter progeny because it has a superior performance on farm, with a higher daily gain and produces a carcass with a higher lean meat content and a larger proportion ham (Enfält *et al*, 1997). The study by Enfält *et al* (1997) also showed that RN^{-} carriers have a larger ham then non-carriers. In addition muscles from the Hampshire breed have been shown to have a darker redder colour, which is due to having higher concentrations of myoglobin the pigment in muscle (Monin & Sellier, 1985; Warriss, 2000).

2.3 Genetics Affecting Pork Quality:

2.3.1 Halothane Gene:

The halothane gene (nn) is also known as the porcine stress syndrome gene (PSS). It is triggered by stress and causes malignant hyperthermia, which is associated with the development of PSE (Pale, Soft, Exudative) meat. PSE meat is caused by extensive protein denaturation that results from low pH and high temperature, in combination, shortly after post-mortem (usually 45minutes post mortem) as shown in Graph 1.

Carriers of the halothane gene, both homozygous and heterozygous, are highly susceptible to stress. Even when careful handling has been used, pre-slaughter stress is often sufficient to cause a high rate of post-mortem glycolysis in pigs resulting in low pH_{45} values in combination with higher temperatures leading to protein denaturation and PSE meat. The effect of stress is more severe in homozygous animals.

When present in pigs as either a homozygous or heterozygous form the halothane gene results in the animals having higher carcass yields and higher lean meat percentages. The benefits the halothane gene has on the carcass characteristics of the pigs are, however, cancelled by the negative effect on both the colour and water holding capacity (WHC) of the meat (see Picture 1). As discussed by Rosenvold *et al*, (2003) the technological yield is reduced by 2 to 3 percentage points in meat from carriers of the Halothane gene compared with non carriers.

2.3.2 The RN^- Gene:

The Rendement Napole gene (RN^-) is associated with a reduced technological yield. The RN^- gene is only found in Hampshire pigs and is thought to cause high muscle glycogen stores and an extended pH decline post-mortem (Rosenvold *et al*, 2003). The glycogen content increases is thought to be especially prevalent in muscles with high levels of white glycolytic fibres with redder muscles being little affected (Warriss, Chapter 6, 2000). The presence of the RN^- gene results in a low pHu, it does not affect the pH_{45} of the meat. The low pHu that results has caused meat from RN^- carriers to be known as acid meat and is associated with meat being lighter (higher

reflectance) having a greater drip and cooking loss due to reduced water holding capacity. Due to the low technical yields that result from carcasses of RN^- carriers the processing industry have a preference for animals that are non carriers. This is because while the presence of the Halothane gene has a dramatic effect on WHC, the RN^- gene only increases drip loss by approximately 1 percentage point. In contrast, the technological yield is reduced by 5 to 6 percentage points (Rosenvold et al, 2003) although Warriss (2000) found an 8% technological decrease.

2.3.3 POLYGENIC EFFECTS:

Not including the RN^- or Halothane genes, attributes that are known to affect the quality of pork show a low to moderate (0.15 – 0.30) heritability (Rosenvold *et al* 2003), with the exception of the inheritance of intramuscular fat content which has a heritability of 0.40-0.50 (Sellier & Monin, 1994). Although the heritability of intramuscular fat percentage and fat tissue is high (0.50 and 0.69, respectively) the genetic correlation between them is very low (0.11) Rosenvold et al 2003, Wood, 1990). This suggests that selection for high intramuscular fat in a lean carcasses should be possible. The heritability of pH_{24} has been shown to be approximately 0.21 (range of 0.07-0.39). However, as discussed by Rosenvold & Andersen (2003) it has been shown that pH_{24} in populations free of the Halothane gene and the RN^- gene may not be the ideal indicator of meat quality. Rosenvold *et al*, 2003).

3. FEEDING:

Meat Quality of monogastric animals, such as pigs, can be influenced both positively and negatively by altering the composition of pig feed and using additional supplementation. Pigs are able to transfer the nutrients directly to the muscle and tissue thereby altering the composition of the meat. Both the fat and lean tissue can be altered by feeding and it has been shown that glycogen levels at the time of slaughter, and therefore rate of pH decline, can also be manipulated.

3.1 LIFETIME FEEDING:

By ensuring the pigs receive *Ad libitum* lifetime feed the meat quality is improved since there is no stress during their time on the farm as a result of prolonged feed withdrawal – a factor that is known to be linked to DFD meat.

Blanchard *et al.* 1999 suggested that the diet should ideally consist of:
High energy (14.7 v 14.2 MJ/kg)
Low lysine (7.0 v 10 g/kg)

Table 3: effect on low energy v's high energy diet on meat quality

	Low Energy Diet	**High Energy Diet**	**s.e.**
Shear Force	327.4	303.5	6.09
Cooking Loss	277	286	3.8
Juiciness	4.897	5.217	0.059
Tenderness	5.130	5.470	0.072
Acceptability	4.731	5.063	0.058

3.2 MAGNESIUM SUPPLEMENTATION:

It has been shown that magnesium is integral to muscle metabolism which would suggest its ability to both positively and negatively affect the final quality of the meat. It has been hoped that by including Magnesium in feed pre-slaughter stress effects can be reduced, thereby decreasing the incidence of pale, soft, exudative (PSE) carcasses. Magnesium is already commonly used in Horse supplement to reduce stress, however, the practice hasn't transferred to the pig industry.

In some studies dietary magnesium supplementation in pigs has resulted in improved meat quality.

- Long term – slight improvement in colour and initial pH
- Short term – reduced initial pH and % drip loss

The most common forms of supplementation are:

- Magnesium Oxide (MgO)
- Magnesium Carbonate ($MgCO_3$)
- Magnesium Sulphate ($MgSO_4$) a.k.a. Epsom Salts
- Magnesium Chloride ($MgCl_2$)
- Magnesium-L-aspertate (MgAsp)

Magnesium-L-aspertate is considered to be the better of the supplements listed above. It is the magnesium salt of aspartic acid and is highly water soluble. When dissolved, it is readily absorbed through the intestinal wall as a result it has a higher biological uptake then the other listed supplements (D'Souza, 1999). However, it is often more expensive then the other supplements. Organic magnesium compounds such as magnesium aspartate and Bioplex Magnesium have a greater influence on meat quality because of the increased bioavailability of elemental magnesium, when compared with inorganic magnesium supplements such as magnesium sulphate and magnesium chloride (D'Souza, 1999).

- 900mg of $MgSO_4$ per litre of water for 2days prior to slaughter has been proven to be effective. (Frederick *et al*, 2006)

Supplementation of 3.2g elemental Mg for 5 days pre-slaughter significantly improves pork quality in pigs by reducing drip loss and improving pork colour and muscle pH as well as reducing catecholamine levels. Such were the benefits that there where no PSE carcasses in the magnesium supplementation treatment groups, irrespective of handling pre-slaughter. (D'Souza et al, 1998)

In two experiments D'Souza (1999, 2000) and his team showed that 5 days of pre-slaughter dietary supplementation of magnesium can improve pork quality by significantly reducing the incidence of PSE meat. However, other research has been less positive, often showing little or no improvement in pork quality. The most recent study by Humphreys *et al* (2009) also found no significant benefit to using magnesium, however, he did hypothesise that there may be no visible effect due to the high welfare standards of pigs used in the trial. This, therefore, suggests that higher welfare systems, such as those used in the UK, do not warrant a Magnesium additive and if indeed there is a prevalence of PSE it is the production system itself that should be investigated, not the feed ration.

3.3 Selenium Supplementation (Sel-Plex or Organic Selenium):

Organic selenium significantly improves meat quality by decreasing cell membrane oxidation leading to reduced muscle drip loss (Close *et al*, 2008). Sodium selenite, which is often found in feed, can increase drip loss, however, organic selenium (Selenomethionine at 0.3ppm) reduces drip loss(Close *et al*, 2008). When organic selenium is included in the finisher diet the average yield increases for loin is 1.5% (Zhan et al, 2007). In addition when organic selenium is used in conjunction with Vitamin E (200ppm) there is increased colour stability, therefore prolonging shelf life.

Sel-Plex supplementation results in higher selenium levels in the loin muscle at both 0.1 and 0.3ppm in the future Selenium rich foods may be well placed as functional foods (Close *et al*, 2008).

3.4 Vitamin D Supplementation:

In situ tenderisation of meat is due to the free activate-calpain which is controlled by calcium ion concentration (Dransfield, 1993).Vitamin D has been show to increase the

amount of free calcium (Swigert *et al*, 2004). Vit D_3 supplementation could improve the tenderness of meat by increasing meat calcium levels thereby activating the calpain systems during the aging process In steers Vit D_3 supplementation for 7 and 10days pre-slaughter resulted in increased plasma and muscle calcium levels and improve tenderness (Swantek *et al*, 1999). However, Vit D_3 failed to show consistent benefits when used on its own, however, when used in conjunction with magnesium pork quality was significantly improved (Swantek *et al*, 1999)

3.5 VITAMIN E SUPPLEMENTATION:

Vitamin can not be synthesised by animals, as a result levels found in fat and muscle are a reflection of dietary inclusion (Jensen *et al*, 1998). Vitamin E supplementation improves meat quality by reducing lipid oxidation in fresh meat and meat products. Meat quality is improved by reduction of thiobarbituric acid reactive substances (TBARS – markers for rancidity and off-flavours) to scores below 0.50mg malondialdehyde equivalents (MDA eq.) which is the borderline level for detection of rancidity and off-flavours by trained sensory panellists.

Supplementing 200mg/kg synthetic vitamin E decreased pork lipid oxidation, however, discolouration still occurred (Boler *et al*, 2009). Guo et al, (2006) also observed an improvement in lipid stability but no benefit to colour. When 200mg/kg of feed was added by Hoving-Bolink *et al*, (1998) they did see a change in meat colour. Vitamin E supplementation on muscle colour is perhaps more evident in species that have higher levels of myoglobin. Therefore minimal effect in pork.

4. BOAR TAINT:

4.1 INTRODUCTION:

Boar taint is an unpleasant odour that is associated with the fatty tissue and, more precisely with the nonsaponifiable fraction (Bonneau, 1982) of boar meat. In 1959 Craig and Pearson carried out the first attempts to identify the compound(s) responsible (Bonneau, 1982) for the taint. However, it was suggested by Sink (1967) that steroids which have a musk-like odour could be responsible for boar taint.

Two main compounds were identified as being the cause of boar taint. Androstenone was isolated in 1966 as being a sex odour in the fat of the entire male. Skatole was also identified as being a prime cause of boar taint. However, skatole is not unique to the pig and can be found in all mammals. There are many other compounds that may contribute to the odour and flavour of meat however, it is the levels of androstenone and skatole that are the main contributing factors towards boar taint.

Androstenone is fat-soluble and can be used to predict the presence of boar taint in backfat. Skatole is useful for determining levels of boar taint in both fat and lean meat since it is both fat and water soluble (Lundström *et al*, 1988) (see Figure 6)

Lundström *et al*, 1988

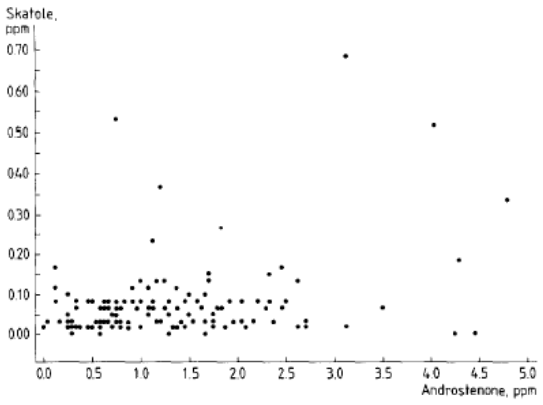


Figure 6a): The relationship between androstenone and skatole concentrations in backfat. Lundström *et al*, 1988

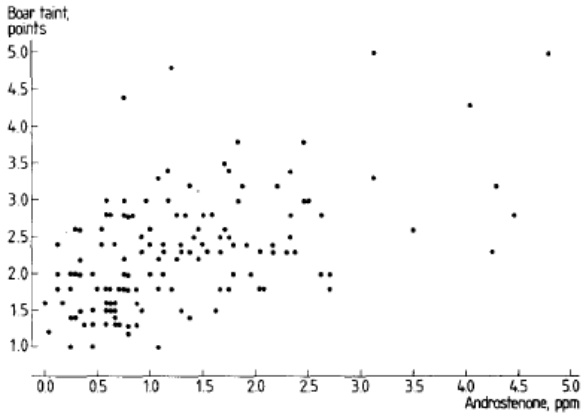


Figure 6b): The relationship between boar taint intensity and androstenone concentration in backfat. Lundström *et al*, 1988

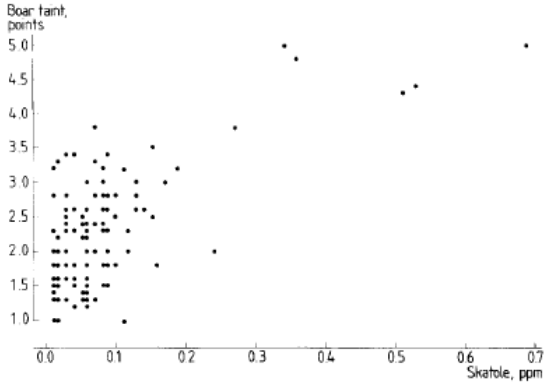


Figure 6c): The relationship between boar taint intensity and skatole concentration in backfat. Lundström *et al*, 1988

4.2 ANDROSTENONE:

Androstenone (5α-androst-16-en-3one) (see Figure 7) is a pheromone, used to stimulate a sow to mate, which is found in the entire adult male pig. It is produced in the testis and transported by the blood stream to the salivary glands, where it is found in high concentrations. The high levels found in the salivary glands are due to pheromaxein a binding protein which converts 5α-androstenone into 5α-androsten-3α-ol. Androstenone is hydrophobic and as a result is concentrated in the fat where it contributes to boar taint when the fat is heated (Squires).

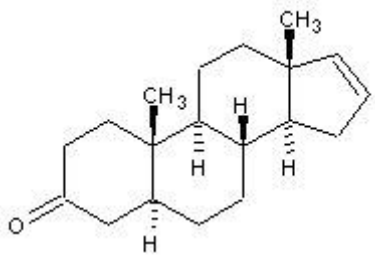


Figure 7: From (http://pherolibrary.com/images/androstenone.jpg)

Testicular production of androstenone is stimulated by increased levels of gonadotropins in the blood (Squires). The hypothalamus releases gonadotropin-releasing hormones which regulate the levels of gonadotropins produced by the pituitary gland. In the entire male pig there are two peaks of steroid levels in the blood (Squires). The first peak occurs at about one month old and the second peak occurs as the animal becomes sexually mature at about five months old. However, the timing of the second peak differs between pig breeds due to the variation in the age when sexual maturity is reached. As the boar becomes more sexually mature the bulbourethral gland and the submaxillary salivary glands increase in size. The growth of the glands is correlated with the increased levels (Squires) of androstenone.

Sensitivity to boar taint, due to levels of androstenone, differs between men and women. Generally women are found to be more sensitive to the compound then men (Warriss, 2000) and find the odour more offensive.

4.3 SKATOLE:

Skatole (3-methyl-indole) leads to an unpleasant faecal odour in meat when combined with other compounds. Specialized bacteria found in the colon convert L-tryptophan into Skatole (see Figure 8). Due to the lipophilic properties, and the ease with which it is absorbed by the gut, skatole that is not metabolised in the liver (Lösel and Claus, 2005), is able to accumulate in the adipose tissue (Lösel and Claus, 2005).

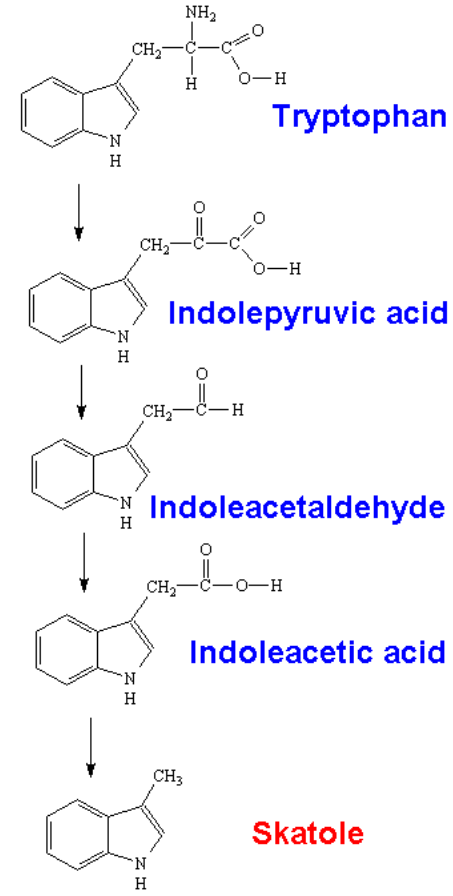


Figure 8: From (http://www.chm.bris.ac.uk/motm/skatole/mechanism.gif)

The production of tryptophan for the microbial formation of skatole is the result of gut mucosa cell debris from the distal part of the gastrointestinal tract (Lösel and Claus, 2005). This was confirmed in 1998 by Raab *et al* who conclusively proved that by altering the rate of cell turnover, and therefore the rate of cell debris production, the levels of skatole found can be altered. The rate of cell turnover is regulated by stem cell mitosis and apoptosis. By altering the mitotic rate in the mucosa of the small intestine (Lösel and Claus, 2005) the rate of skatole production is also altered. High energy content diets, especially diets that have high levels of carbohydrate with high pre-caecal digestibility (Lösel and Claus, 2005), will increase the mitotic rate of the small intestine mucosa and therefore increase the production of cell debris. The increased production of cell debris results in increased production of skatole. However, apoptosis is inhibited by butyrate, which means that by increasing levels of butyrate the production of skatole is decreased.

4.4 LEVELS OF TOLERANCE:

It has been suggested that there may be an interaction between the effects of skatole and androstenone so that the levels of one compound may determine the importance of levels of the other (Warriss, 2000). Although it has been observed that sensitivity to androstenone varies between men and women there is thought to be no variation between sexes for skatole sensitivity. Due to the national variation in sensitivity it has been suggested that, for meat acceptability, the maximum concentrations in fat should be Androstenone: 0.5 – 1.0 μg g^{-1} and Skatole 0.20 – 0.25 μg g^{-1} (Warriss, 2000).

4.5 FEEDING AND BOAR TAINT:

Androstenone which is enhanced by Skatole concentrations above 0.15μg/g (Godt *et al*, 1996) can be affected through diet, by controlling Skatole levels. Since, Carbohydrates which have a lower pre-caecal digestibility and favour butyrate formation in the colon decrease skatole synthesis (Lösel and Claus, 2005), thereby reducing the affect of androstenone. As a result by modifying the diet it is possible to improve the sensorial quality of pork. Neupert *et al*, (1995) demonstrated that the amount and type of energy in the diet has a considerable effect on the skatole concentration in adipose tissue of pigs, so that the differences in feeding may exceed sex-dependent effects (Lösel and Claus, 2005).

Stem-cell mitosis in the small intestine is regulated by the formation of insulin-like growth factor-1 (IGF-1). Glucose formation from easily digestible starch stimulates the formation of IGF-1 which in turn leads to higher rates of apoptosis and therefore, higher levels of skatole.

Potato Starch:

In 2005 both Lösel and Claus and Zamaratskaia *et al* used potato starch in the diet to alter the intestinal skatole formation and adipose tissue accumulation in the pig. Lösel and Claus (2005) used barrows (castrated males) and gilts in equal numbers and reared them to a live weight of 105kg (castrates) or 115kg (gilts). When the pigs weighed approximately 98kg live weight they were split into 4 groups, 3 were fed a diet with varying levels of raw potato starch and the 4^{th} group was fed a diet containing pre-gelatinised potato starch. Due to the transformation of raw potato

starch to volatile fatty acids energy is lost, Lösel and Claus compensated for this by increasing the kg/day of feed based on the levels of potato starch in the diet.

Lösel and Claus (2005) found that skatole levels decreased continuously with increasing amounts of potato starch in the diet. The trial further confirmed that raw potato starch reduces the intestinal formation and adipose tissue storage of skatole in the pig in a dose-dependant manner.

Further on from their study in 2005 Lösel and Claus with Lacorn and Büttner looked at the flavour improvement of pork from barrows and gilts (Lösel *et al*, 2006). They found that 300g of raw potato starch/ kg of body weight significantly ($P < 0.001$) reduced concentration of skatole in back fat from 25 to 1.4 ng/g in barrows and from 40 to 9ng/g in gilts. Lösel *et al* (2006) also used a trained taste panel, rating from 1-5 (very unpleasant to very pleasant) to look at the odour of the cooked pork. Pork with low skatole levels was rated at 3.07 and meat with both medium and high levels of skatole was rated at 2.66 ($P < 0.05$). Thereby proving that the eating quality of pork can be improved by the addition of raw potato starch to the diet of the pigs.

Zamaratskaia *et al* (2005) also looked at the effect of potato starch on levels of skatole, however they also looked at the effects potato starch had on the levels of Androstenone in the entire male pig. The study used 111 pigs, which were housed in pens of 7-9 animals either mixed or single sex. The animals were "all fed the same commercial diet until an average pen weight of 100kg was reached" (Zamaratskaia *et al* (2005)). For two weeks prior to slaughter 33 of the animals were then fed 0.6kg/pig/day of raw potato starch. Zamaratskaia *et al* (2005) found that entire males from the higher weight groups (115kg) that were not fed the potato starch had significantly higher levels of skatole and testicular steroids then the pigs from the lower and middle weight range (90kg and 100kg). However, there was no significant difference in levels of skatole and testicular steroids between the lower and middle weight groups. Zamaratskaia *et al* (2005) concluded that the diet with raw potato starch induced a decline in skatole levels in plasma and fat ($P < 0.001$), but not plasma levels of testicular steroids and fat levels of androstenone ($P > 0.05$). As a result it is possible to deduce that slaughter at a lower weight or dietary supplement of

raw potato starch can be used to manipulate skatole levels in entire male pigs and avoid boar taint due to skatole (Zamaratskaia *et al* (2005)).

Chicory roots (and Jerusalem artichoke):

Feeding Chicory roots to pigs is based on the theory that by changing the composition of the odour active compounds…would then be to increase the amount of less odour offensive compounds (from carbohydrate degradation) on the expense of more odour active compounds (from protein degradation). If the odour active compounds also include synthesis of esters, the odour quality would be improved further (Jensen and Hansen, 2006). Chicory roots and Jerusalem artichoke contain high levels of inulin. Composed of a mixture of fructopolysaccharides, fructoogiosaccharides and glucose inulin is a fermentable carbohydrate which is expected to reduce the levels of skatole in the animal.

Analysis of meat taken from pigs that have been fed chicory showed an overall improved eating quality (Jensen and Hansen, 2006) and a significant reduction in the levels of skatole. Hansen *et al* (2006) confirmed the effect chicory has on the diet. Using three separate trials, where pigs (entire males and females) were all slaughtered once they had achieved sexual maturity, Hansen *et al* (2006) observed that skatole concentrations in blood plasma and backfat at slaughter were reduced to almost zero levels by including crude or dried chicory or inulin in the diet (see figure 4).

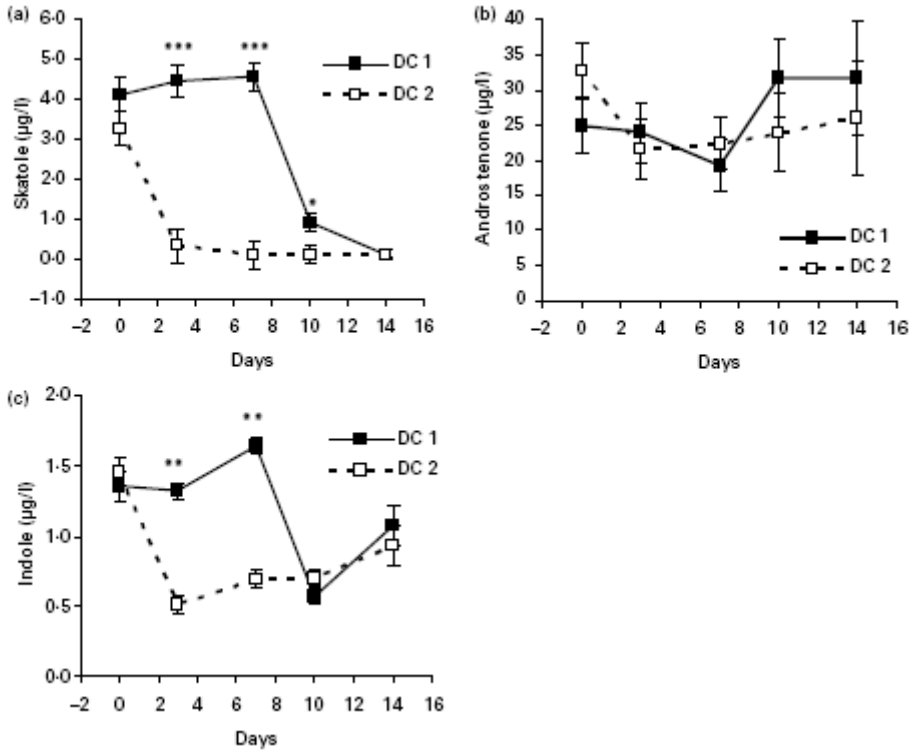


Figure 9: Hansen *et al* (2006).

Levels of (a) Skatole, (b) Androstenone and (c) Indole in blood of entire males given a concentrate with dried chicory from days 7 to 14 (DC1) and from day 0 to 14 (DC2).

The results observed by Hansen were not affected by the weight at slaughter or the length of feeding period. However, androstenone levels were only reduced in pigs which were fed crude chicory for nine weeks (see figure 9).

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Dietary supplementation can be highly effective in reducing the levels of skatole found in pig meat. By adding potato starch or chicory roots to the diet of pigs the production of skatole is reduced. However, the effect of dietary supplementation on the levels of androstenone found in the adipose tissue is varied.

Chicory is an ideal supplement for reducing boar taint because it does not effect the production or proportion of lean mean in the animal and consistently reduced skatole without reducing performance (Hansen *et al*, 2006) and when fed for extended periods of time a significant reduction in androstenone levels was also observed. Feeding crude or dried chicory roots with a high content of inulin, or purified inulin strongly

reduces the boar-taint compound skatole (Hansen *et al*, 2006). Moreover, skatole is known to enhance the off-odour and off-flavour of androstenone (Hansen *et al*, 2006; Godt *et al*, 1996) as a result of reducing skatole levels in pigs the effects of androstenone on the meat quality is also reduced, thereby producing a pig that is more commercially acceptable.

5. TRANSPORT

5.1 The effect of transport on the welfare of pigs:

To be able to understand the effect transport has on the welfare of an animal the definition of welfare needs to be understood, as well as how welfare is assessed. To measure welfare several areas are studied:

- Environment and facilities available
- Overall animal condition
- Animal behaviour and response
- Experimental measures of physiology, biochemical and neurophysical condition
- Retrospective assessments based on outcomes (Wilkins, 2008)

As explained by Warriss (1996) there are two main welfare indicators used in the assessment of welfare during transport. These are indicators which reflect an animal's ability to cope with environmental stresses and those which reflect the amount of effort required to cope. For example by looking at the rate of mortality during transportation it is possible to see how many animals were exposed to conditions that they were unable to cope with. As the rate of mortality increases the standard of welfare can be assumed to have decreased. Traumatic injuries gained during transportation are also indicators of reduced welfare since injuries are associated with unnecessary pain.

When studying the amount of effort required by an animal to cope with transportation physiological and behavioural responses are observed. The more effort that is required, the less acceptable is the animal's welfare (Warriss, 1996). It is possible to identify the type, and to a point, severity of the stressor by taking blood and tissue samples. For example reduced liver glycogen, increased levels of free fatty acids and increased ketones in the blood is indicative of prolonged food deprivation. If an animal is dehydrated it will have increased blood osmolarity and higher levels of blood plasma proteins. To study the extent of muscle fatigue or exposure to exercise

the blood activity of creatine phosphokinase (CPK) is looked at. The higher the levels of CPK, the greater the fatigue and therefore, the greater the stress. Warriss (1996) observed that psychological stresses such as fear produce elevations in the blood concentrations of hormones such as adrenaline, cortisol and corticosterone.

Once the areas of assessment, and methods to be used, have been identified the definition of welfare needs to be considered. There are three main definitions for welfare:

- Mental status
- Physical status
- "Naturalness"

Welfare with regards to mental status looks at how the animal feels opposed to the health status or fitness of the animal. Physical status with regards to welfare considers how an animal copes with its environment and the environmental effects on the animal. Naturalness considers the ability of an animal to express behaviours which would be observed in the natural, non-managed environment. In combination the three welfare definitions have created the five freedoms:

1. Freedom from Hunger and Thirst - by ready access to fresh water and a diet to maintain full health and vigour.
2. Freedom from Discomfort - by providing an appropriate environment including shelter and a comfortable resting area.
3. Freedom from Pain, Injury or Disease - by prevention or rapid diagnosis and treatment.
4. Freedom to Express Normal Behaviour - by providing sufficient space, proper facilities and company of the animal's own kind.
5. Freedom from Fear and Distress - by ensuring conditions and treatment which avoid mental suffering.
(As defined by: FAWC, Accessed 2008)

An animal treated in such a way that it does not have these freedoms may be looked upon as being subjected to experiences associated with varying degrees of stress

(Warriss, 1996) and therefore, has been exposed to reduced welfare. The transport of animals is inherently stressful as a result of handling during loading and unloading, change of environment and separation from social groupings. During the transportation process the pigs are exposed to noise, unfamiliar smells, vibration, extremes of temperature (Warriss, 1996) the pigs will also be exposed to food and water deprivation as well as close confinement and crowded conditions.

The EC and United Kingdom Government Legislation have specific guidelines for the transportation of animals' off-farm. The guidelines are designed to protect animals from compromises to welfare. As a result, within the UK, all animals being transported are done so by the standards set out in The Welfare of Animals (Transport) Order 1997 (S.I. 1997 No. 1480). Within the EU pigs can often be exposed to long journey times due to the possibility of movement between member states. Even though there are regulations in place in both the EC council directive (1991) and government legislation that are designed to protect pigs during transportation the associated handling and transportation process will always adversely affects the welfare of pigs. The loading and unloading stages of transportation are regulated by The Welfare of Farm Animals (England) Regulations 2000 (S.I. 2000 No.1870). It should be noted that Wales and Scotland have their own versions of The Welfare of Farm Animals (England) Regulations 2000.

There are many transport methods that are available to the pig industry, i.e., Air, Rail, and Road. However, in the United Kingdom the most common method of transportation is by road. There are approximately 13 million pigs sent to slaughter in the UK every year (Warriss, 1996). The transport times and distances are increasing due to the closure of smaller, local, family owned abattoirs in favour of large automated abattoirs with an annual throughput in excess of 100,000 pigs per year, such as those owned by Vion and Tulip.

The pigs are often transported to slaughter in lorries that are able to hold in excess of 200 commercial slaughter animals. However, there are several stages in the life cycle of a commercial pig during which such transportation may be used. It is not uncommon for farms to have a grow out unit where pigs are transported from the breeding farm at about 35kg to the grow out. The animals will then stay on the unit

until they reach slaughter weight, approximately 90kg, before being transported to the abattoir.

During the transportation period the welfare of the pigs is determined by the length of the journey and the conditions under which the animals are transported (Warriss, 1996). As journey time increases the importance of the conditions of transportation also increase. It has been mentioned that the factors which affect the suitability of the conditions of transport are stocking density, ventilation, temperature and humidity, noise and vibration (Warriss, 1996).

5.2 Stocking Density, Temperature and Ventilation:

It has often been thought that during transportation the ideal is probably a density at which all animals can just lie down together (Collins, 1993). For this to occur an area of between $0.41m^2$ and $1.09m^2$ per 100kg is required. It is thought that lower densities will allow more space for lying down and greater opportunity for the pigs to regulate their body temperatures by behavioural adaptations (Warriss *et al*, 1998) whereas higher densities may reduce the risk of pigs being thrown around (Warriss *et al*, 1998). However, as discussed by Guise *et al* (1998) the predominant behaviour during short journeys (3hours or less) is for most pigs to stand whilst the vehicle is moving. However, on long journeys in excess of 24hrs lying becomes the predominant behaviour within 2 to 5 hours of the journey commencing.

In order to be able to recommend a stocking density to reduce stress levels and increase welfare during short journey transit ($\leq$ 3hrs) Guise *et al* (1998) looked at the effects of four different stocking densities on the carcass measurements of pigs. The maximum stocking density, as set out by Directive 95/29 of the EU legislation, is $235kg/m^2$ however, during their study Guise *et al* (1998) looked at densities both above and below the maximum and found that overall, the measurements made produced no evidence that transport stocking density had an effect on the carcass quality or welfare on short journeys. However, during a further study by Warriss *et al* (1998), which looked at the physiological response of the pigs during transit, they found that increasing stocking densities during transit were associated with increased circulating CPK levels. As already discussed, increased levels of CPK reflect

increasing physical stress, since the enzyme is released from the muscle fibres under the influence of intense muscular exertion (Warriss *et al*, 1998). The increased levels of CPK suggest that at higher stocking densities the pigs were not able to settle down and tended to be jostled more (Warriss *et al*, 1998) which over extended periods of time would lead to fatigue. The difference in the results, between the two studies, shows the importance of considering both the mental and physical welfare of an animal. Therefore, with regards to stocking density it can be concluded that when looking at physiological responses higher stocking densities result in more physical stress, even if carcass measurements remain unchanged.

However, stocking density does have a direct effect on the temperatures and humidity of the conditions the animals are transported under. By influencing the rate at which heat can be dissipated from animals' bodies, stocking density affects mortality attributed to hyperthermia (Warriss, 1996). It has been shown that mortality rate within the transportation lorry is affected by the location of the pig within the penned areas. The area with the highest rate of mortality is directly behind the cab on the lower deck (Warriss, 2008 *Personal Communication*) this area has been shown to have the least effective ventilation and therefore pigs kept in this pen are exposed to heat stress. As a result pigs which have been transported on the lower deck are often associated with Pale Soft Exudative (PSE) meat and have been shown to have increased levels of cortisol. The presence of PSE meat is a form of retrospective assessment of the welfare of the pigs since PSE is know to be caused by acute stress.

Moreover, certain breeds of pigs, such as the Pietrain and Landrace, have a genetic tendency to suffer from Porcine Stress Syndrome (PSS). The gene is associated with acute stress, as well as sudden death as a result of malignant hyperthermia. The malignant hyperthermia, and often resultant death, is exasperated by temperature increases and poor ventilation. The ventilation within the lorry is maintained by the air flowing through as the vehicle moves forward, however, when the vehicle stops the temperature rises. The relationship between temperature and mortality is curvilinear with temperature increases above 15°C having more deleterious effect (Warriss, 1996). The relationship between temperature increases and mortality means that there is often seasonal effect, with the largest frequency of deaths occurring during the summer months. Warriss (1996) estimates that 10500 pigs die during

transportation every year, however, the number of pigs exposed to poor welfare is much greater than that and it is only the few animals that have been exposed to conditions beyond their coping ability that die.

5.3 Journey Time and Associated Stressors:

Legislation sets maximum journey times for pigs based on the type of transportation used. A standard vehicle has a maximum journey time of 8hrs whereas a vehicle that meets the additional specifications can carry pigs for 24hours as long as continuous access to water is available. If there are extenuating circumstances the journey time can be increased to 26hours. If the journey time is expected to take longer then the specified allowance then a 24 hour resting period is required before the journey can commence.

Due to the extended periods of time spent on the transportation lorry pigs are exposed to long periods of time where they are deprived of food. In addition, pigs are often not fed prior to loading when being sent to slaughter, since a full gut during evisceration has the possibility of contaminating the carcass. In addition pigs are monogastric, and do not have a rumen, therefore, the deprivation of food becomes a stressor earlier than in Cattle and Sheep which use the rumen as food/water reservoir. However, feed deprivation can also be seen as improving welfare since pigs are thought to suffer from motion sickness with symptoms being more acute in recently fed animals and as mentioned by Warriss (1996) recently fed pigs have a slightly higher risk of dying during transport.

In addition during transportation pigs are often removed from their social groupings and mixed at the point of loading. Mixing in itself is inheritantly stressful due to pigs being naturally antagonistic. Having established dominance hierarchies throughout their time on farm they have been removed from a stable social grouping and will fight upon mixing to re-establish a hierarchy. However, whilst the vehicle is moving the animals are unable to interact and fight, according to Warriss (1996) the problems arise when the vehicle stops allowing the pigs to fight causing additional stress, increasing body temperature and possibly resulting in physical trauma and injury. However, the increase in body temperature becomes difficult to manage in a stopped

vehicle since the ventilation is compromised, thereby increasing the risk of death due to hyperthermia. As a result it is recommended that stops during journey periods are reduced in length and frequency.

5.4 HANDLING:

It is generally accepted that the largest stressor during the transportation of pigs is during loading and unloading. Pigs are mixed into unfamiliar groups, loaded into an unfamiliar environment and exposed to human contact. With regards to welfare it is accepted that pigs loaded using less stressful systems may endure the rigours of the journey better and so loading systems could considerably influence the overall welfare of the transported animals (Brown *et al*, 2005)

The loading mechanism is often not ideal for the movement of pigs. The tailgate of lorries often lays an angles in excess of 29° (Brown *et al*, 2005) which animals find difficult to negotiate. Brown *et al* (2005) looked at three different loading systems that are commercially available, the experimental results suggest that ramps of 18° or the use of hydraulic tail-lifts are preferable with the animals showing no significant increases in cortisol levels. The lack of cortisol increase is a good indicator that the animals were not unduly stressed by the handling process.

The human interaction with the animals can be more stressful during the loading since the pigs will often have had very limited human contact whilst on the farm, yet at point of loading the stockman will remove pigs from their penned groups and using pig boards and goading methods herd the animals towards the transportation. When observing the loading process it can often be fairly noisy with stockman vocalising in an attempt to encourage the animals to load quickly. This period of human interaction will be mentally stressful if not physically so.

5.5 CONCLUSIONS:

The reason behind the transportation of animals over long periods of time is often due to economical reasons as well as the location of facilities. Welfare concerns with

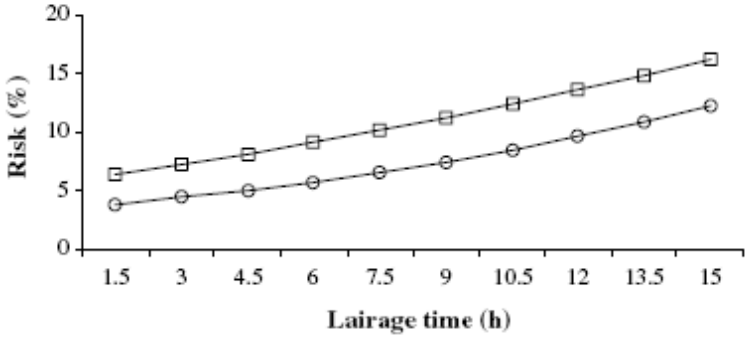
regards to animals for meat are relatively new and are often only found in Western Countries which have a secure food supply chain.

The improvement of welfare is often directly associated with improved stockmanship since the most stressful stage of the transportation is often regarded as being at the points of loading and unloading. By training people that come into contact with pigs during the transportation process to handle the animals in an empathic way welfare is automatically improved. By ensuring that stops during journey periods are reduced in length and frequency fighting during transportation is reduced and temperature increases are minimised. With regards to stocking density if can be concluded that when looking at physiological responses higher stocking densities result in more physical stress, even if carcass measurements remain unchanged.

6. LAIRAGE:

Lairage time has a direct correlation with stress levels in pigs. Optimal lairage time appears to be around 2-3hours (Santos *et al*, 1997; Van der Wal *et al*, 1999). The critical phase of aggression is around 40-60 minutes at entrance into lairage (Santos *et al*, 1997). Aggression decreases towards zero at about 2 hours in lairage (Fraqueza et al, 1998; Santos *et al*, 1997, Van der Wal *et al*, 1999), however, during extended lairage the proportion of skin damage and DFD meat due to fighting, and therefore muscle glycogen depletion, increases (Guardia *et al*, 2005). Guardia *et al* (2005) observed that after 3 hours in lairage the risk of DFD meat was 11.6%, after 9 hours 18.6% and when over night laired DFD incidence increased to 24.9% as shown in figure 10.

Figure 10: The effect of lairage time on DFD incidence (Guardia *et al*, 2005)



Optimum lairage time is therefore a compromise. The animals need time to recover from journey stress and therefore reduce DFD incidence but if they are held in lairage too long then DFD incidence will increase.

7. SLAUGHTER & REFRIGERATION:

7.1 SLAUGHTER METHOD:

It is a legal requirement (Council Directive 93/119/CEE, 1993) that all slaughter animals are rendered instantaneously insensible. They must remain in this state until there is a complete loss of brain response due to exsanguination. The two most widely used method in the UK are electrical stunning and killing by exposure to Carbon Dioxide (CO_2). To evaluate the slaughter methods the presence of haemorrhages, blood splash and bone fractures are considered.

In general although pH_{24} is not significantly affected, muscle from electrically stunned pigs have a more rapid early post-mortem pH decline and reduced WHC in comparison to meat from CO_2 stunned pigs (Channon, Payne & Warner, 2000; Channon, Payne & Warner, 2002). The rapid post-mortem pH decline and reduced WHC are caused by increased energy metabolism within the muscle (Josell, von Seth & Tornberg, 2003) which suggests that electrical stunning results in greater physiological stress than CO_2 killing. Channon, Payne & Warner (2000) also found a reduction in blood splash incidence when CO_2 stunning was used in comparison to Electrical stunning. However, not all research agrees that CO_2 is the most welfare friendly option. Becerril-Herrera *et al* (2009) found that CO2 stunning lead to major mineral imbalances, resulting in reduced pH hypercapnia, hypercalcemia and hyperglucemia, in comparison to electrical stunning. These metabolic imbalances may all possibly lead to compromised welfare.

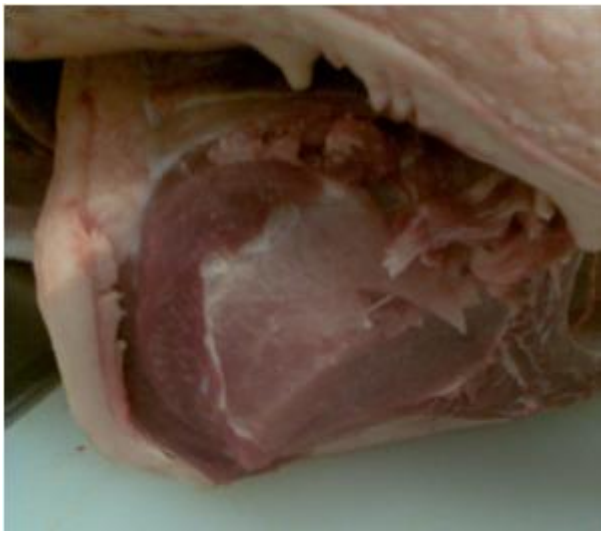
7.2 REFRIGERATION:

Chilling has serious effects on meat if it is carried out rapidly when the meat is still in a pre-rigor condition. Under normal conditions the onset of rigor-mortis occurs 6-8hrs post-slaughter (D'Souza *et al*, 1998). In pork the rate of breakdown of ATP is more rapid and under moderate chilling regimes, cold-shortening will not occur. However, in pork meat high muscle temperatures and low pH are known to cause PSE meat (Savell *et al*, 2005). To reduce PSE incidence it is recommended that an internal muscle temperature of 10ºC at 12 hours and 2-4ºC at 24 hours.

However, pig muscle can cold-shorten, and with fast chilling, for example using sub-zero air temperatures, cold shortening has been clearly demonstrated . In addition at an early stage, the surface of the carcass will reach the same temperature as that of the air. Since the air temperature used in chilling is commonly below 10°C, there exists the possibility that cold shortening may occur at the surface, even if it does not occur in the bulk of the meat. Cold shortening can be prevented by not cooling the carcass below 10°C until after rigor has set in. Rigor normally takes on average 6 hours to reach completion and will start approximately 15 min - 1hr post slaughter dependant on pre-slaughter handling (Savell *et al*, 2005, Etherington *et al*, 1987). As a result, if the carcass is not cooled to below 10°C until rigor has set in, then CS will not occur. If the pig has not been unduly stressed and rapid/blast chilling is not practiced, by the abattoir, then the likely hood of CS happening in pigs in minimal. The use of electrical stimulation to the carcass, immediately after slaughter, overcomes cold shortening by using up any remaining muscle energy stores (Taylor *et al*, 1995; Channon *et al*, 2003)

Rapid or blast chilling can be an effective method to reduce the incidence of PSE meat but extreme chilling systems may cause quality problems due to the difference between surface carcass temperature and deep muscle temperature (Savell *et al*, 2005). When this occurs two-toning can result, as shown in figure 11:

Figure 11: An example of two-toning. Picture taken by author.



During blast chilling it is also possible that the surface of the meat is becoming frozen. If this occurs the integrity of the muscle structure is compromised and upon thaw there are increased levels of drip shown.

8. CONSUMER ACCEPTABILITY:

Meat is often considered as being comprised of two main components the lean meat and the fat. Compounds found in both the lean and fat tissues lead to the overall meat flavour. Lean meat is approximately 75% water and is thought to give the meaty flavour that is associated with all species (Myers *et al*, 2009). The species-specific flavours comes from the fat (Myers *et al*, 2009), whether it is subcutaneous, inter or intra muscular fat. Boar taint, an abnormal flavour, is known to be deposited in the subcutaneous fat of male pigs and if levels are above the accepted threshold the final meat eating quality is negatively affected. Flavour is known to result from the degradation of soluble and lipid soluble components into aldehydes, alcohols and ketones (Wood *et al*, 1999). As a result the flavour of meat is affected by both the species and fat content (see Figure 12).

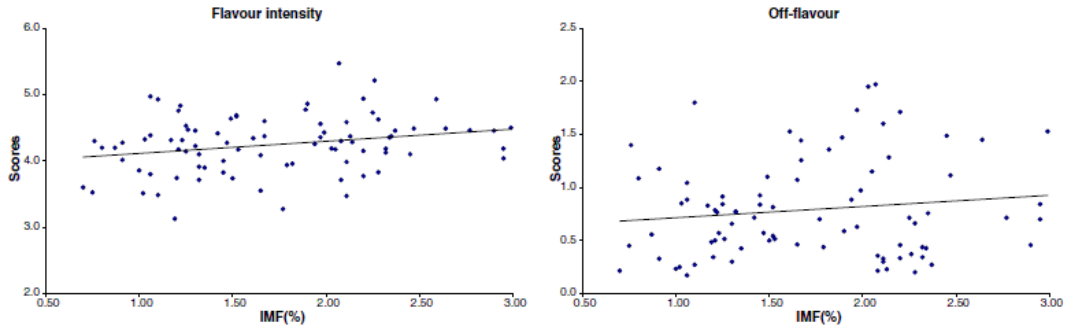


Figure 12: The relationship between flavour (flavour intensity and off-flavour) attributes in pork loin and IMF. Fortin *et al* (2005)

Studies such as those carried out by Brewer & McKeith (1999) and Brewer *et al* (2001) confirmed that at point of purchase the choice of product is most strongly affected by the amount of visible fat. They observed that the primary characteristic driving the consumer to purchase pork is the amount of marbling or intramuscular fat (IMF) in the loin. In both studies the conclusion was that loin chops with high marbling had lower acceptability and purchase intent scores than loin chops with low or medium levels of marbling. In a similar study Bryhni *et al* (2002) concluded that young consumers were more aware of fat content and showed a lower consumption

than older consumers but that flavour was still the single most important sensory characteristic.

The tenderness of meat has long been known to affect the acceptability of meat to the consumer. Tenderness can be improved by the aging of the meat. Carcasses or meat are aged by holding them at refrigeration temperatures for extended periods of time after slaughter and initial chill. Aging (or conditioning) improves the tenderness and flavour of meat. There are two methods for aging meat: wet aging and dry aging. Wood *et al* (1996) found that aging pork for 10 days post-mortem had a greater effect than genotype in improving tenderness. Aging has also been shown to improve sensory tenderness and overall liking scores of pork meat (Taylor *et al*, 1995). However, studies in beef by Huffman *et al* (1996) found that flavour had a stronger relationship ($R^2 = 0.67$) than any other factor when consumers prepared meat at home. A similar study by Sitz *et al* (2005) showed that flavour was the most important factor affecting meat buying habits and preferences when tenderness of beef was held constant.

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