# IDENTIFYING PRE- AND POST-SLAUGHTER FACTORS THAT IMPACT FINAL MEAT QUALITY IN HEAVY AND LIGHT CARCASSES REARED IN CONVENTIONAL AND DEEP LITTER FARM SYSTEMS

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# Executive Summary


The Australian pork industry is progressing towards an eating quality pathway that ensures pork is produced of the highest quality and consistency for consumers. Previous research has focused on individual pre-slaughter and post-slaughter effects that can influence meat quality without always considering multiple interacting factors. The project aim was to establish a benchmark dataset that compares multiple pre-slaughter factors of housing (conventional vs deep-litter ecoshelters), carcass weight (light (66 kg HSCW) supermarket carcasses through to heavy carcasses (84 kg HSCW), and sex (females vs immunocastrates) within the same genotype, nutritional regimen, slaughter day and post-slaughter conditions.

The study was conducted over eight slaughter replicates between June 2015 and May 20116. A total of 5120 pigs were reared under normal commercial conditions at two farm sites of equal travel distance (4h) to the Corowa abattoir. One farm was a conventional wean to finish site with pigs housed on concrete slatted floors in groups of 10-60 at 0.65 m2/pig during the finisher phase. The second farm housed pigs in deep litter ecoshelters with pigs housed in groups of 400 at 1 m2/pig. Pigs were commercially transported to the abattoir at the same age (22 weeks) and market date, separated into subgroups from the market sale load and slaughtered in a randomised sequence. A total of 384 carcasses were selected for objective meat quality assessment over the eight replicates. Within each slaughter replicate, 48 carcasses were allocated to a 2 x 2 x 3 factorial (Housing x Sex x Weight). After carcass measures for HSCW, P2 backfat and pH were taken, the carcasses were boned on-site at 24h post-slaughter and meat quality measures were recorded on the loin (m. longissimus), the rump (m. gluteus medius) and silverside (m. biceps femoris).

There were significant effects of Housing, Weight and Sex on different measures of the carcass prior to boning. Housing differences between pigs reared on deep litter in ecoshelters compared to conventional housed pigs on slatted flooring had the biggest impact on carcass and meat quality. Carcasses from Deep litter housing were 1 mm fatter within each weight cohort and sex group when slaughtered at the same age. Whilst this has an economic penalty that pig producers have to account for, there were advantages in carcass quality of Deep litter carcasses such as a more rapid pH decline. In terms of boned meat quality 24 h after slaughter, meat cuts from Deep litter carcasses were more tender (lower shear force), were darker in the loin but paler in the rump and silverside, and redder and more yellow in all three cuts. On the downside, meat from Deep litter carcasses had a higher drip loss.

Weight was also a significant contributor to carcass and meat quality. The heavier the carcass within Housing and Sex cohort, the slower the pH decline and rate of carcass chill. For objective meat quality measures, Weight was inversely related to shear force, so as carcass weight increased, so did tenderness.

Sex had no effect on carcass quality measures within 24 h post slaughter. However, meat cuts from Castrates had a lower drip loss and were less red in colour. There was a tendency (P<0.06) for Castrates to have a higher shear force value (less tender) than Females.

Several interactions between Housing x Weight x Sex were recorded, and this may be exploited by supply chain mangers to select which type of carcasses delivers the “best” overall meat quality outcome.

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# 1. Introduction

As consumer's expectation of meat quality grows, there is an obligation for suppliers to implement quality control pathways throughout the supply chain that consistently delivers high quality pork. The Australian pig industry has focused on the implementation of an eating quality pathway to improve quality and consistency of pork. In order to consistently produce high quality meat, previous research has focused on individual pre-slaughter and post-slaughter effects that can influence meat quality both negatively and positively without always taking into account the multiple interacting factors. Factors that cause quality to vary include breed and genotype; feeding; pre-slaughter handling; final carcass weight; and slaughter procedures, such as stunning method and chilling conditions. Warner *et al.* (2010) stated that supply of meat which is wholesome, safe, nutritious, and of high quality to the consumer will ensure continued consumption of meat. Identifying and implementing a pathway standard that takes into account the multiple factors would minimize the quality variation and overall improve consumers experience in regards to pork consumption.

With an increased focus on housing, there has been greater use of deep-litter systems to grow out pigs to slaughter weight. Many Australian pig producers are also following overseas trends for heavier carcass production to minimise overhead production costs. However, there is conflicting research concerning the impact of housing and a heavier carcass on meat quality. Cisneros *et al.* (1996); Latorre *et al.* (2004) found poorer meat quality associated with heavier carcasses whereas Correa *et al.* (2006) found no effect on meat quality. Gender has also been identified as a factor that affects meat quality. However again there are contradicting results. D'Souza and Mullan (2002) found females had a lower ultimate pH compared to surgical castrates and immunocastrates whereas Nold *et al.* (1999) found no difference in pH between entire males, surgical castrates and females.

The cause of inconsistent and inferior pork quality is often attributed to the genetic pressure to select on production attributes such as a decreased fat depth, better feed efficiency and high lean carcass percentage due to high economic weightings of these heritable traits on profitability. This study aimed to determine the effect of housing, carcass weight and sex on objective pork quality measurements in the

carcass and specific meat cuts from pigs of the same genotype, offered the same dietary regimen, and slaughtered and processed under identical conditions.

# 2. Methodology

## 2.1 Animals, housing and feed

The study was carried out between June 2015 and May 2016, with a total of eight replicates taking place. A total of 384 (192 female and 192 immunocastrated) Large White x Landrace commercial pigs (PrimeGro Genetics™, Corowa, NSW) were sourced from two separate housing systems within gender. All male pigs were immunised against gonadotropin releasing factor (GnRF) using Improvac® (Zoetis, Australia), with vaccinations administered at 15 weeks and 19 weeks of age (IM). Pigs were sourced from a conventional partially-slatted birth to bacon production system located in Huntly, Victoria and a grow-out deep-litter system using rice hull bedding located in Temora, New South Wales. Conventional housing represented one treatment and pigs were penned in groups of 10-60 pigs at 0.60-0.65 $m^2$/pig. Deep litter reared pigs represented the second Housing treatment and pigs were penned in groups of 400 (1.0 $m^2$/pig). Pigs could not be moved between the two housing treatments. A normal commercial finisher diet was supplied to both treatments with the diet containing 13.5 MJ DE/kg and 0.60 g available lysine/MJ DE. All diets were pelleted and fed *ad libitum* throughout the normal production period. All animals had *ad libitum* access to water via nipple drinkers for the entire experimental period.

## 2.2 Transport

At 22 weeks of age, pigs were transported from either Housing site in market groups of 320 per site, with each truck carrying 160 immunocastrates and 160 females on separate decks to a commercial abattoir (Corowa, New South Wales). The Housing treatments were not transported together on the same truck. Housing sites were equidistant and pigs were transported (approximately 4h) on the same day over the eight replicates. Pigs were moved onto trucks by the driver using best practice procedures with genders separated by on-board gates on the vehicle. Where necessary, pigs were moved with the assistance of hand-held paddles. Electric goads were not used in the loading of pigs. The same driver and trailer design was used to transport the Deep litter housing system pigs across the entire sampling period.

However for the Conventional housing system, the same trailer design was used for the entire sampling period with the driver alternating for the replicates. The time the truck left the site and the time the truck arrived at the commercial abattoir was recorded.

### 2.3 Lairage and slaughter

On arrival at the commercial abattoir, the first fifty of each gender from each housing treatment were counted, placed into separate pens and times of movements were recorded. The time it took for the selected pigs to settle was recorded. Remaining pigs (220 pigs per housing treatment) were placed into the separate pens and were not used in further measures. Pigs were held in lairage for an average of 17 hours prior to slaughter, with access to water. Each group of fifty pigs based on gender and each housing system was moved separately to the point of stunning with minimal handling and stunned using 90% carbon dioxide (Butina, Denmark). The stunning unit loaded from the rear of the holding cage. Where necessary pigs were moved with the assistance of hand-held paddles. Electric goads were not used. Following evisceration, hot carcass weight (AUS-MEAT Trim 1) and fat depth at the P2 site, using Hennessy Grading Probe (Hennessy Grading Systems Ltd, New Zealand) was measured and recorded for all carcasses. Out of each group of fifty carcasses within each Housing type and Sex, 12 carcasses were selected within three carcass Weight defined cohorts: Light (66.3 ± 0.3 kg, 10.1 ± 0.2 mm); Medium (75.1 ± 0.3 kg, 11.4 ± 0.2 mm); Heavy (83.9 ± 0.3; 12.7 ± 0.2 mm) for HSCW and backfat P2, respectively (mean ± SE). This created within each replicate a focus dataset of 48 carcasses in a 2 x 2 x 3 factorial design (Housing x Sex x Weight). Within each slaughter date, there were four carcasses per treatment.

Carcasses were stored in the same chiller fitted with overhead fans, and conventionally chilled according to standard commercial practice (1-2°C for 24 hours). The left side of each carcass was marked with an individual carcass identification number on the leg hind quarter and the loin primal using a food grade carcass marker crayon. A total of 48 carcasses were selected on each slaughter day replicate for subsequent meat quality assessment in the boning room that was located on-site.

### 2.4 Muscle Glycogen and Lactate, Carcass pH and temperature, and carcass score

A 50 g sample for muscle glycogen was removed from the *Musculus biceps femoris* and the *Musculus longissimus thoracis et lumborum* (LTL) at 40 min and 24 h post-slaughter. All fat and silver skin was removed and each muscle sample was allocated an identification tag, individually wrapped in foil and placed directly into a liquid nitrogen dewar (-80$^0$C). Measurements of muscle pH and temperature post-slaughter were made in the *Musculus longissimus thoracis* (LT) between the tenth and eleventh rib at 45 min, 90 min, 3 h, 6 h and 24 h post-slaughter in the left hand side of each carcass using a portable pH meter fitted with a polypropylene spear-type gel electrode (MPI, Kansas, USA) and a separate Noronix temperature probe. In the chiller, carcass scores were taken to measure the degree of bruising and lesions that covered the carcass to measure impact of fighting before slaughter as described by McCauley *et al.* (2001). Carcasses were scored on a 0 to 3 basis; a score of 0 was equivalent to a carcass without bruising or scratch marks: carcass score 1 for one or two bruises; score 2 if there was obvious bruising and minor damage to the carcass; and score 3 for severe bruising and significant amount of damage to the carcass.

### 2.5 Muscle Sample collection

Each carcass (both sides) was weighed on entry to the boning room (7$^o$C), the *Psoas major* (tenderloin) was removed, and the carcass side split by a revolving saw blade (minimal bone dust) into each shoulder, middle and leg. The left side of each carcass was followed through the boning process for further meat quality assessment. Each identified middle primal (excluding the *Psoas major*) was further processed to remove the chine bone (lumbar and thoracic vertebrae) by rib top saw and the belly split from the loin 30 mm ventral to the *m. longissimus*. The marked loin primal from each left carcass side was recovered from the line after boning (chine bone removed, plate boned ribs removed) and the main *m. longissimus* muscle (loin) was partially removed from the rind and subcutaneous fat layer allowing for identification. The loin primals were placed in a tub and when all the loin primals had been collected off the line (approximately within 30 mins from first to last loin primal) and the tubs transferred to a dissection table in the boning room. The marked leg primal (excluding the *Psoas major* head) was collected from the line after boning (trotter, tail bone, tibia, fibula, femur and aitch bone were removed) and the *Musculus vastus intermedius*, *Musculus vastus lateralis, Musculus vastus*

*medialis*, *Musculus gastrocnemius* and *Musculus semimembranosus* was removed leaving the rind with identification number on the *M. biceps femoris* and *Musculus gluteus medius* muscles. Rind on *M. biceps femoris* and *M. gluteus medius* were placed in a tub and when all the samples had been collected off the line, the tubs were transferred to a dissection table in the boning room. The muscle samples were then prepared into the required cuts for both sensory and objective quality assessment. Each loin primal was orientated on the bench caudal to cranial and the loin primal trimmed by removing and discarding 100 mm from the caudal end on each LTL primal. From the caudal end, a steak of 25 mm was cut for colour assessment. Another steak of 40 mm thickness was cut from the caudal end for drip loss assessment. A steak of 65 mm thickness was cut from the caudal end for shear force assessment. An additional steak of 100 mm thickness was cut from the caudal end identified, cryovaced and frozen for eating quality assessment at a later date. For the *M. biceps femoris* (silverside) and *M. gluteus medius* (rump) sample, the *M. gluteus medius* was seamed out from the fat and rind and orientated on the bench cranial to caudal and the *M. gluteus medius* trimmed by removing a 15 mm steak for colour assessment. The *M. gluteus medius* was then orientated ventral to dorsal and a 70 mm portion were removed, identified, cryovaced and frozen for eating quality assessment at a later date. The remaining *M. gluteus medius* (rump) sample was evenly split in half, with the most ventral piece for drip loss assessment and the remaining piece for shear force assessment. The *M. semitendinosus* was seamed out from the rind on *M. biceps femoris* and rind removed and the *M. biceps femoris* was then orientated on the bench cranial to caudal. The *M. biceps femoris* was further trimmed by removing and discarding 50 mm from the cranial end on each sample. From the cranial end, a steak of 40 mm was cut for drip loss assessment. Another steak of 40 mm was cut for shear force assessment and an additional steak of 10 mm was cut for the colour assessment. The remainder of the sample was identified, cryovaced and frozen for eating quality assessment at a later date.

## 2.6 Meat Quality Measures

For colour assessment, each *M. longissimus thoracis et lumborum, M. biceps femoris* and *M. gluteus medius* steak was placed with the anterior face upwards and allowed to bloom for 10 min on a bench and measured for colour using a Konica Minolta Colour Chromameter (CR-400 series v 1.10). The chromameter using D65 illumination and a 2° standard observer was calibrated on a white tile and set on

the L*, a* and b* system where L* is equal to relative lightness (higher L* values = paler meat), a* relative redness (higher a* values = more red) and b* relative yellowness (higher b* values = more yellow). The colour was recorded in triplicate on each sample from dorsal to ventral. Colour readings were averaged per sample for each measurement of L*, a* and b* reading. Following colour measurement, the *M. longissimus thoracis et lumborum, M. biceps femoris* and *M. gluteus medius* steak used for colour assessment had a 20 g sample removed and individually bagged, labelled and frozen for protein solubility assessment.

The steak cut for drip loss was trimmed of all fat and sinew and a cube of approximately 40 x 40 x 40 mm was prepared from the *M. longissimus thoracis et lumborum, M. biceps femoris* and *M. gluteus medius*. Each sample was weighed and if necessary further trimmed to fall within 60-65 g range. Final weights were recorded as Time 0 h. A sample identification number for each sample was placed at the bottom of a 500 mL polypropylene container fitted with a screw-top lid. The drip loss sample was then carefully placed in a nylon net (20 x 20 mm squares) and the lid secured such that the sample was free from all contact with the container and the netting suspended over the container and secured by the lid screwed over the netting. The container was then transferred from the boning room to the meat laboratory and stored in a temperature controlled cabinet (Thermoline Scientific, NSW) set at 2ºC for 24 h. The sample was removed from the container and netting and patted dry using absorbent paper then weighed (Time 24 h) and recorded. Drip loss was calculated as:

Drip loss % = (weight sample g Time 0 h – weight sample g Time 24 h)/weight sample g Time 0 h) x 100

A sample for shear force assessment was prepared (50 x 40 x 40 mm, approximately 75 g) and frozen (-20ºC) for subsequent cooking and shear force assessment. Shear force was prepared from frozen samples of *M. longissimus thoracis et lumborum, M. biceps femoris* and *M. gluteus medius* cut at the time of sample collection. Frozen samples were weighed in their bag; any air expelled and hung on a rack before immersion into the pre-heated water bath for 30 mins. Samples were checked for internal temperature of 70ºC and if necessary replaced into the water bath until the temperature was reached. Once cooked, samples were removed from

the water bath and placed in a mix of ice and cold water for 35 mins. Each meat sample were removed from the bag, placed on absorbent paper and patted dry, weighed and cooking loss calculated.

Cooking loss % = (weight sample g frozen – weight sample g cooked and cooled)/weight sample g frozen) x 100

The meat sample was placed on a tray which was wrapped in plastic film and refrigerated for 24 h at 2°C. Each sample was prepared with a clean cut face on each side then cut into 10 mm slices, the slice was then cut into 10 mm wide strips parallel with the muscle fibres. The meat sample was placed in a Warner-Bratzler attachment fitted to a force measurement machine (Mecmesin® BFG 500N, Slinfold, UK) and shear force determined as the amount of force required (kg) to shear the meat on the Warner-Bratzler attachment.

## **2.7** Chemical Analysis

### 2.7.1 Blood glucose and lactate

Blood samples were collected via the jugular (anterior vena cava) immediately after pigs were stuck into a 10mL lithium heparin Vacutainer® (BD medical, North Ryde, New South Wales, Australia). Samples were placed in an esky and plasma collected after centrifugation at 4000rpm for 5 min at 4°C then frozen at -40°C until subsequent analysis. Plasma glucose concentrations were measured using a glucose oxidase kit (Thermo Scientific, Scoresby, Victoria, Australia). Plasma lactate concentrations were measured using a lactate reagent kit (Immuno Pty Ltd, St Peters, New South Wales, Australia).

### 2.7.2 Muscle glycogen and lactate

Analysis of the muscle samples collected were chemically analysed for lactate and residual glycogen content. The enzymatic method described in Chan and Exton (1976) but not including the filter paper step was used in the muscle glycogen assay. The homogenate produced from the muscle glycogen assay was used in the muscle lactate assays. Briefly, 200mg of the LT muscle sample devoid of fat and connective tissue were weighed out into test tubes and kept on ice. Next, 1mL of 30mM hydrochloric acid was added to the test tubes and immediately placed on ice and

allowed to cool. The muscle sample was homogenised on ice using an Ultra Turrax® homogeniser (IKA T 18) for two 15 s pulses. After homogenising remove 1.5mL subsample and transfer 2mL into a labelled Eppendorf tubes. Centrifuge the subsample for 5 minutes at 11 000rpm. The supernatant was decanted into labelled Eppendorf tubes and frozen at -20°C until required. Muscle glycogen in the supernatant was converted to glucose by combining 50 µl of the supernatant with 500µl of amylogucosidase diluted in acetate buffer, vortexed then incubated for 90 minutes at 37°C. Acetate buffer consisted of 40 mM sodium acetate (0.82 g) and glacial acetic acid (0.6 mL) and distilled water added together until the pH adjusted to 4.8. Muscle glucose concentrations were measured using a glucose oxidase kit (Thermo Scientific, Scoresby, Victoria, Australia). Plate was incubated for 30mins at 37°C, cooled for 5 minutes and placed in the multiscan to establish the total residual glycogen content. Muscle lactate concentrations were measured using a lactate reagent kit (Immuno Pty Ltd, St Peters, New South Wales, Australia).

### 2.8 Statistical Analysis

The experiment was conducted in eight replicates, consisting of 48 animals each, on separate days of slaughter in a 2 x 2 x 3 factorial with a balanced randomised block design. The effect of Housing, Sex and Weight were analysed using the general ANOVA function in GenStat 16th edition. Data was blocked for replicate and kill order. Results are reported as means separated by least significant differences and pooled standard error and means were considered to differ significantly when $P \leq 0.001$, $P<0.01$ or $P \leq 0.05$. Trends are reported if $P<0.10$.

## 3. Outcomes

### 3.1 Effects of housing, carcass weight and sex on carcass objective measurements

Housing and Sex did not influence hot standard carcass weight (HSCW) nor cold carcass weight (Table 1). Carcass P2 was significantly different between Weight treatments with P2 increasing with weight as expected. Backfat P2 was also significantly affected by Housing such that carcasses sourced from deep-litter housing were fatter than Conventional housing, particularly at heavier weights (Table 1). Light weight carcasses and Medium carcasses were approximately 1 mm P2 fatter from Deep litter housing compared to Conventional housing, whilst at Heavy weights, the difference was closer to 2 mm ($P<0.05$). There was no significant

main effect or interaction of Housing, Weight or Sex on the Trim 1 to Trim 13 specification trimming and carcass chiller loss over 24 h (Table 1). The carcass score of fighting lesions was significant for Sex x Weight ($P<0.05$), such that there was more evidence of fighting in castrates (immunocastrates) compared to females, with a higher incidence of lesions in heavy female carcasses (Table 1).

Sex and carcass weight did not influence muscle pH of the loin measured from 45 min to 24 h post-slaughter. However, housing type did impact muscle pH at 45 min, 90 min, 3 h, 6 h post-slaughter, with pH values higher in carcasses sourced from Conventional compared to Deep litter housing (6.50 vs 6.39, SE 0.03, $P=0.001$), 90 min (6.28 vs 6.18, SE 0.04, $P=0.013$), 3 h (6.10 vs 6.00, SE 0.04, $P=0.014$) and 6 h post-slaughter (5.88 vs 5.80, SE 0.03, $P=0.006$, respectively). However there was no difference in 24 h carcass pH between the housing types (5.60 ± 0.01, $P=0.760$). In early chilling (45 min post slaughter), there was also a Housing x Sex interaction ($P<0.05$) but for the other times, Sex had no main effect or interaction.

Early rate of chilling was significantly slower in Heavy carcasses compared to Light carcasses (Table 3), with higher muscle temperature values associated with increasing carcass weight at 45 min (35.50°C vs 36.30°C vs 36.50°C, SE 0.23, $P<0.001$), 90 min (28.61°C vs 30.05°C vs 31.10°C, SE 0.25, $P<0.001$), 3 h (15.19°C vs 16.51°C vs 17.68°C, SE 0.28, $P<0.001$) and 6 h post-slaughter (7.60°C vs 8.25°C vs 9.12°C, SE 0.23, $P<0.001$, for Light, Medium and Heavy weight, respectively. However, by 24 h, there was no difference in deep muscle temperature between the different carcass weight treatment groups (2.59°C ± 0.03, $P=0.702$). Neither Housing treatment nor Sex significantly affected carcass chilling rates.

Table 1: Means and standard error of the difference (s.e.d.) for effect of housing (H), weight (W) and sex (S) on carcass parameters

| | | Housing type x Weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Conventional | | | Deep Litter | | | | |
| Objective Measurement | Sex | Light | Medium | Heavy | Light | Medium | Heavy | s.e.d | *P* value |
| HSCW kg | Castrate | 66.70 | 74.80 | 83.00 | 66.20 | 75.60 | 84.20 | 0.90 | W*** |
| | Female | 66.80 | 75.50 | 84.60 | 65.40 | 74.60 | 83.80 | | |
| P2 mm | Castrate | 10.00 | 11.20 | 11.30 | 10.00 | 11.50 | 13.10 | 0.51 | H**, W***, HxW* |
| | Female | 9.70 | 11.00 | 12.40 | 10.60 | 12.00 | 13.90 | | |
| Cold Weight kg | Castrate | 58.79 | 65.88 | 73.52 | 58.22 | 66.88 | 74.46 | 0.87 | W*** |
| | Female | 58.93 | 66.76 | 74.82 | 58.28 | 66.07 | 73.65 | | |
| Carcass Score | Castrate | 1.15 | 1.00 | 0.80 | 1.00 | 0.90 | 0.65 | 0.22 | SxW* |
| | Female | 0.90 | 0.60 | 0.85 | 0.60 | 0.55 | 0.80 | | |

Where *P<0.05, **P<0.01, ***P<0.001. n.s. Not significant

Table 2: Means and standard error of the difference (s.e.d) for effect of housing (H), weight (W) and sex (S) on muscle pH measured in the loin muscle at the P2 site (*M. longissimus thoracis et lumborum*) from 45 min to 24 h post-slaughter

| | | Housing type x Weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Conventional | | | Deep Litter | | | | |
| Objective Measurement | Sex | Light | Medium | Heavy | Light | Medium | Heavy | s.e.d | *P* value |
| 45 min pH | Castrate | 6.48 | 6.59 | 6.52 | 6.32 | 6.36 | 6.37 | 0.062 | H**, SxH* |
| | Female | 6.48 | 6.45 | 6.49 | 6.46 | 6.45 | 6.39 | | |
| 90 min pH | Castrate | 6.29 | 6.34 | 6.27 | 6.12 | 6.18 | 6.18 | 0.07 | H* |
| | Female | 6.25 | 6.25 | 6.26 | 6.25 | 6.20 | 6.19 | | |
| 3 h pH | Castrate | 6.12 | 6.18 | 6.10 | 5.98 | 5.97 | 5.95 | 0.079 | H* |
| | Female | 6.11 | 6.04 | 6.04 | 6.13 | 6.05 | 5.94 | | |
| 6 h pH | Castrate | 5.90 | 5.94 | 5.90 | 5.81 | 5.80 | 5.76 | 0.059 | H* |
| | Female | 5.88 | 5.80 | 5.81 | 5.88 | 5.79 | 5.74 | | |
| 24 h pH | Castrate | 5.60 | 5.59 | 5.60 | 5.61 | 5.62 | 5.59 | 0.024 | n.s. |
| | Female | 5.60 | 5.58 | 5.60 | 5.62 | 5.60 | 5.57 | | |

Where *P<0.05, **P<0.01, ***P<0.001. n.s. Not significant

Table 3: Means and standard error of the difference (s.e.d) for effect of housing (H), weight (W) and sex (S) on muscle temperature measured in the loin muscle at the P2 site (*M. longissimus thoracis et lumborum*) from 45 min to 24 h post-slaughter

| | | Housing type x Weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Conventional | | | Deep Litter | | | | |
| Objective Measurement | Sex | Light | Medium | Heavy | Light | Medium | Heavy | s.e.d | *P* value |
| 45 min temp, $^{o}$C | Castrate | 34.80 | 35.90 | 35.70 | 36.00 | 36.60 | 37.20 | 0.85 | W*** |
| | Female | 35.00 | 35.90 | 36.00 | 36.10 | 36.90 | 36.90 | | |
| 90 min temp, $^{o}$C | Castrate | 28.58 | 29.50 | 30.34 | 28.86 | 30.36 | 31.55 | 0.786 | W*** |
| | Female | 28.28 | 30.21 | 30.78 | 28.72 | 30.14 | 31.72 | | |
| 3 h temp, $^{o}$C | Castrate | 15.03 | 15.98 | 17.21 | 15.00 | 16.61 | 17.69 | 0.654 | W*** |
| | Female | 14.96 | 16.64 | 17.51 | 15.76 | 16.80 | 18.31 | | |
| 6 h temp, $^{o}$C | Castrate | 8.16 | 8.11 | 8.79 | 7.17 | 7.73 | 8.83 | 0.612 | W*** |
| | Female | 7.23 | 8.58 | 9.31 | 7.78 | 8.60 | 9.55 | | |
| 24 h temp, $^{o}$C | Castrate | 2.70 | 2.64 | 2.63 | 2.56 | 2.55 | 2.56 | 0.997 | n.s. |
| | Female | 2.56 | 2.58 | 2.59 | 2.58 | 2.57 | 2.54 | | |

Where *P<0.05, **P<0.01, ***P<0.001. n.s. Not significant

## 3.2 Effects of housing, carcass weight and sex on loin, silverside and rump objective measurements

### *3.2.1 Shear force*

Shear force values are inversely related to sensory tenderness, such that a lower shear force is associated with tenderness. There was a significant main effect of Housing on the shear force values, such that overall meat cuts from Deep litters were lower than meat cuts from Conventional pigs (4.43 kg vs 4.69 kg, SE 0.07, $P$=0.002). However, there were significant ($P$<0.01) Housing x Cut interactions (Table 4). Shear force was lower in carcasses from Deep litter housing compared to Conventional housing in the loin (4.69 kg v 5.08 kg, SE 0.18, $P$=0.048, respectively) and in the rump (3.94 kg v 4.21 kg, SE 0.12, $P$=0.035, respectively). In the loin and rump, this corresponded with an improvement in "tenderness" of 8% and 6%, respectively. By contrast, in the silverside there was no significant effect of Housing (P>0.10).

Weight treatment also was significantly related to shear force as an average across all meat cuts. As weight increased, shear force was reduced (4.65kg vs 4.55 kg vs 4.46 kg, SE 0.07, $P$=0.027, for Light, Medium and Heavy, respectively). There was a significant interaction between Cut and Weight (Table 4), with shear force being inversely related to Weight in the rump (4.22 kg vs 4.02 kg vs 3.97 kg, SE 0.09, $P$=0.012). However the shear force of the loin and silverside was unaffected by Weight.

There was a tendency for a Sex effect on shear force, with higher shear force values in Castrates than Females across all meat cuts ($P$=0.059). There were no significant Weight or Housing interactions with Sex ($P$>0.10).

### *3.2.2 Cooking loss*

There was no overall significant effect of Housing, Weight or Sex on cooking loss across the meat cuts, however there were trends for a Cut x Housing and Cut x Weight ($P$<0.10; Table 5). There was a trend for cooking loss to increase in Deep litter carcasses compared to Conventional carcasses in the silverside (P=0.062). However, there was no impact of Weight on cooking loss in the rump or silverside.

There was a significant decrease in cooking loss in the loin as carcass weight increased, 22.77%, 22.14%, 22.00% for Light, Medium and Heavy carcasses respectively (SED 0.01, *P*=0.021).

As main effects, Housing had no effect on cooking loss in the rump or silverside, Weight had no effect on cooking loss in the rump and silverside, whilst Sex had no effect on any of the three cuts (*P*>0.10). There was a trend for an interaction between Weight x Sex such that Heavy Castrates had a lower cook loss than Light Females (21.57% vs 23.88%, *P*=0.06). This Weight x Sex interaction was significant only in the loin cut (*P*=0.02).

### *3.2.3 Drip loss*

Drip loss as an average across all meat cuts was significantly different between Housing and Sex main effects (Table 6). For combined meat cuts, the drip loss was higher in Deep litter carcasses compared to Conventional carcasses (4.69% vs 4.26%, SE 0.152, *P*=0.01). There was a Cut x Housing interaction, such that the loin (6.70% vs 5.97%, *P*=0.023) and silverside (3.67% vs 3.16%, SE 0.01, *P*=0.013) from Deep litter carcasses recorded a higher drip loss than Conventional carcasses, respectively.

Although there was no main effect of Weight on drip loss on combined mean cuts, (Table 6) there were interactions. There was a Cut x Weight interaction for drip loss (Table 6), such that only the drip loss of the silverside was increased as Weight increased (3.19% vs 3.41% vs 3.64%, SE 0.002, *P*=0.024). However, in the rump and loin, there was no such effect of Weight on drip loss. There was a tendency for an interaction between Housing x Weight was such that Heavy carcasses from Deep litter housing recorded a higher drip loss in the silverside compared to Light Conventional carcasses (3.63% vs 3.12%, SE 0.265, P=0.06).

There was a significant main effect of Sex on drip loss on combined meat cuts, with Castrates recording a lower drip loss than Females (4.30% vs 4.65%, SE 0.073, *P*=0.033). This effect of Sex was most evident in the rump (3.46% vs 3.96%, *P*=0.025) and the silverside (3.12% vs 3.70, *P*=0.005) for Castrates and Females respectively. Drip loss in the rump was unaffected by Housing, Weight or Sex as main effects or interactions (Table 6).

### *3.2.4 Meat colour*

There were varying effects of Housing on colour measurements. As a main effect over all meat cuts, meat was darker (lower L* value), redder (higher a* value), and more yellow (higher b* value) in Deep litter carcasses compared with Conventional carcasses (Table 7). All these effects were highly significant (P<0.001). Within Cut, the loin showed Housing differences in a* value only between Deep litter and Conventional treatments (5.92 vs 5.51, SE 0.131, *P*<0.01). Whereas the rump (46.96 vs 47.75, *P*<0.01) and silverside (44.96 vs 46.40, *P*<0.001) had lower L* value and higher rump a* values (8.35 vs 7.23, *P*<0.001) and silverside a* values (11.5 vs 10.02, *P*<0.001) and rump b* values (2.89 vs 2.46, *P*=0.001) and silverside b* values (3.97 vs 3.64, *P*<0.001) for Deep litter vs Conventional, respectively. There was no effect of Housing on L* and b* value in the loin (L*:49.06 vs 49.45, 0.32, *P* value=0.226; b*: 2.01 vs 2.04, 0.12, *P* value=0.812; for Deep litter and Conventional housing respectively).

There was no main effect of Weight on colour measures on any of the meat cuts. However there were significant Housing x Weight interactions for L* value and b* value (Table 7). In Light carcasses from Deep litter, the L* value was lower than Light carcasses from Conventional housing (46.83 vs 48.2, P<0.05). This was most evident in the silverside cut. In the Heavy carcasses, Deep litter meat cuts recorded a lower b* value (5.44 vs 5.49, P<0.05). This pattern in yellowness, is in contrast to the higher b* value in Deep litter carcasses when all the meat cut results were combined.

The a* value as an indication of redness was significantly higher in Females compared to Castrates (8.18 vs 7.97, SE 0.089, *P*=0.027). This pattern was most evident in the rump and silverside cuts (*P*<0.05). Sex had no effect on L* value as a main effect. There was a Cut x Housing x Weight x Sex interaction that was significant for L* value (Table 7, *P*=0.036) such that Heavy Castrates from Deep litter housing were darker (46.88) compared with Light Females from Conventional housing (48.13).

### 3.2.5 Meat pH 24h

Meat cut pH was significantly affected by Housing with Deep litter carcasses recording a lower pH (5.45 vs 5.49, SE 0.007, $P<0.001$). The response was most evident in the rump (5.42 vs 5.49, SE 0.009, $P<0.001$) and the silverside (5.49 vs 5.53, SE 0.012, $P<0.0001$) for Deep litter and Conventional carcasses, respectively. Importantly, these Housing differences were not detected in the loin cut which is used mostly as the muscle for meat quality assessment.

There was no main effect of Weight on meat pH at 24h. The only significant interaction ($P=0.037$) was found in the silverside, where the pH decreased in heavier Conventional carcasses, whilst in contrast, silverside pH increased with weight in Deep litter carcasses.

Sex had a significant effect on meat pH (Table 8) with Females being lower in pH than castrates (5.46 vs 5.48, SE 0.007, $P<0.001$). This response was most evident in the rump ($P=0.005$) and silverside ($P=0.01$).

### 3.2.6 Meat quality assessment in different cuts

There were differences in the responses to Housing, Weight and Sex between cuts. The shear force, drip loss and colour a* value were significantly affected by Housing (Table 4, 6 and 7), but the other measures were similar between Deep litter and Conventional carcasses. The objective meat quality measures of the loin were unaffected by Weight differences, with the exception of cook loss (Table 5). The loin was also unresponsive to Sex effects in any of the meat quality measures recorded.

The silverside and rump were more responsive to the treatments of Housing, Weight and Sex in objective meat quality measures than the loin, although not all measures were similar in magnitude. Based on the significance of the probability outcomes for each objective quality measure, cooking loss was not a good indicator of variable pre-slaughter factors in any of the cuts.

Table 4: Means and standard error of the difference (s.e.d) for the effect of housing (H), weight (W) and sex (S) on shear force on the cut types (C) loin (*M. longissimus thoracis*), silverside (*M. biceps femoris*) and rump *(M. gluteus medius*).

| | | | Cut type x housing type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Loin | | Silverside | | Rump | | | |
| Objective Measurement | Carcass Weight | Sex | Conventional | Deep litter | Conventional | Deep litter | Conventional | Deep litter | s.e.d | P value |
| Shear force kg | Light | Castrate | 5.27 | 4.96 | 4.70 | 4.76 | 4.28 | 4.19 | 0.155 | H**, S*, C x H**, C x W* |
| | Medium | Castrate | 5.28 | 5.04 | 4.80 | 4.72 | 4.23 | 3.89 | | |
| | Heavy | Castrate | 5.19 | 4.49 | 4.65 | 4.66 | 4.18 | 4.02 | | |
| | Light | Female | 5.09 | 4.79 | 4.81 | 4.66 | 4.34 | 4.06 | | |
| | Medium | Female | 4.73 | 4.49 | 4.92 | 4.57 | 4.18 | 3.80 | | |
| | Heavy | Female | 4.91 | 4.37 | 4.80 | 4.54 | 4.03 | 3.67 | | |

Where *P<0.05, **P<0.01, ***P<0.001

Table 5: Means and standard error of the difference (s.e.d) for the effect of housing (H), weight (W) and sex (S) on cooking loss on the cut types (C) loin (*M. longissimus thoracis*), silverside (*M. biceps femoris*) and rump *(M. gluteus medius*).

| | | | Cut type x housing type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Loin | | Silverside | | Rump | | | |
| Objective Measurement | Carcass Weight | Sex | Conventional | Deep litter | Conventional | Deep litter | Conventional | Deep litter | s.e.d | P value |
| Cooking Loss | Light | Castrate | 22.92% | 24.85% | 22.92% | 24.55% | 21.99% | 20.35% | 0.65% | C x H#, C x W#, |
| | Medium | Castrate | 21.52% | 23.55% | 22.83% | 24.18% | 21.28% | 20.37% | | |
| | Heavy | Castrate | 21.86% | 22.98% | 23.19% | 24.36% | 22.09% | 19.90% | | |
| | Light | Female | 21.92% | 21.38% | 23.01% | 23.66% | 20.74% | 20.07% | | |
| | Medium | Female | 21.36% | 22.15% | 23.73% | 23.32% | 21.32% | 20.62% | | |
| | Heavy | Female | 21.22% | 21.92% | 23.21% | 24.45% | 20.97% | 21.16% | | |

Where #P<0.10, *P<0.05, **P<0.01, ***P<0.001

Table 6: Means and standard error of the difference (s.e.d) for the effect of housing (H), weight (W) and sex (S) on drip loss on the cut types (C) loin (*M. longissimus thoracis*), silverside (*M. biceps femoris*) and rump (*M. gluteus medius*).

| | | | Cut type x housing type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Loin | | Silverside | | Rump | | | |
| Objective Measurement | Carcass Weight | Sex | Conventional | Deep litter | Conventional | Deep litter | Conventional | Deep litter | s.e.d | P value |
| Drip Loss % | Light | Castrate | 5.93% | 6.87% | 2.81% | 3.20% | 3.87% | 3.58% | 0.31% | C x S*, C x H*, H x W# |
| | Medium | Castrate | 5.55% | 7.05% | 2.76% | 3.47% | 2.94% | 3.25% | | |
| | Heavy | Castrate | 5.81% | 6.81% | 2.85% | 3.65% | 3.56% | 3.54% | | |
| | Light | Female | 6.38% | 6.29% | 3.44% | 3.33% | 3.96% | 3.75% | | |
| | Medium | Female | 6.22% | 6.28% | 3.60% | 3.80% | 3.92% | 4.03% | | |
| | Heavy | Female | 5.92% | 6.66% | 3.52% | 4.54% | 3.80% | 4.28% | | |

Where #P<0.10, *P<0.05, **P<0.01, ***P<0.001

Table 7: Means and standard error of the difference (s.e.d) for the effect of housing (H), weight (W) and sex (S) on meat colour (L*, a*, b*) on the cut types (C) loin (*M. longissimus thoracis*), silverside (*M. biceps femoris*) and rump *(M. gluteus medius*).

| | | | Cut type x housing type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Loin | | Silverside | | Rump | | | |
| Objective Measurement | Carcass Weight | Sex | Conventional | Deep litter | Conventional | Deep litter | Conventional | Deep litter | s.e.d | P value |
| L* | Light | Castrate | 49.50 | 49.08 | 46.95 | 45.62 | 48.32 | 47.18 | 0.42 | H***, C x H***, H x W*, C x H x W*, C x S x H x W* |
| | Medium | Castrate | 49.44 | 49.21 | 45.92 | 45.30 | 47.64 | 47.06 | | |
| | Heavy | Castrate | 49.95 | 49.10 | 46.84 | 44.45 | 47.69 | 47.09 | | |
| | Light | Female | 49.28 | 48.59 | 47.15 | 44.37 | 47.90 | 46.16 | | |
| | Medium | Female | 49.89 | 49.25 | 45.74 | 44.86 | 47.51 | 47.13 | | |
| | Heavy | Female | 48.67 | 49.12 | 45.80 | 45.18 | 47.42 | 47.16 | | |
| a* | Light | Castrate | 5.58 | 5.90 | 9.87 | 11.40 | 7.10 | 8.12 | 0.22 | H***, C x S*, C x H*** |
| | Medium | Castrate | 5.42 | 5.78 | 9.96 | 11.16 | 7.00 | 8.40 | | |
| | Heavy | Castrate | 5.34 | 5.74 | 9.67 | 11.44 | 7.19 | 8.19 | | |
| | Light | Female | 5.28 | 6.19 | 9.84 | 11.67 | 7.37 | 8.60 | | |
| | Medium | Female | 5.74 | 6.00 | 10.35 | 11.83 | 7.59 | 8.40 | | |
| | Heavy | Female | 5.69 | 5.92 | 10.43 | 11.52 | 7.12 | 8.37 | | |
| b* | Light | Castrate | 2.00 | 1.91 | 3.87 | 4.16 | 2.68 | 3.02 | 0.15 | H***, C x H** |
| | Medium | Castrate | 2.06 | 1.96 | 3.48 | 3.86 | 2.21 | 2.93 | | |
| | Heavy | Castrate | 2.17 | 2.01 | 3.60 | 3.76 | 2.48 | 2.85 | | |
| | Light | Female | 1.85 | 1.94 | 3.75 | 3.94 | 2.60 | 2.47 | | |
| | Medium | Female | 2.19 | 2.18 | 3.54 | 4.10 | 2.49 | 3.04 | | |
| | Heavy | Female | 1.99 | 2.09 | 3.57 | 4.02 | 2.33 | 3.04 | | |

Where *P<0.05, **P<0.01, ***P<0.001

Table 8: Means and standard error of the difference (s.e.d) for the effect of housing (H), weight (W) and sex (S) on muscle pH on the cut types (C) loin (*M. longissimus thoracis*), silverside (*M. biceps femoris*) and rump *(M. gluteus medius*).

| | | | Cut type x housing type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Loin | | Silverside | | Rump | | | |
| Objective Measurement | Carcass Weight | Sex | Conventional | Deep litter | Conventional | Deep litter | Conventional | Deep litter | s.e.d | P value |
| pH | Light | Castrate | 5.45 | 5.45 | 5.54 | 5.50 | 5.48 | 5.43 | 0.03 | H***, S***, C x S***, C x H***, C x H x W* |
| | Medium | Castrate | 5.46 | 5.45 | 5.58 | 5.49 | 5.54 | 5.44 | | |
| | Heavy | Castrate | 5.46 | 5.43 | 5.55 | 5.50 | 5.50 | 5.42 | | |
| | Light | Female | 5.43 | 5.44 | 5.47 | 5.48 | 5.45 | 5.43 | | |
| | Medium | Female | 5.44 | 5.42 | 5.54 | 5.47 | 5.46 | 5.42 | | |
| | Heavy | Female | 5.43 | 5.43 | 5.53 | 5.48 | 5.48 | 5.40 | | |

Where *P<0.05, **P<0.01, ***P<0.001

# 4. Application of Research

## 4.1. Effects of housing, carcass weight and sex on carcass and meat cut objective measurements

Overall, of the three pre-slaughter factors studied, Housing had the biggest impact on carcass and the objective meat quality measurements across different meat cuts

### 4.1.1. Carcass P2

Deep litter carcasses were on average 1 mm fatter at the same equivalent carcass weight compared to conventional housed pigs ($P<0.002$, Table 1). The findings in this study is in agreement with Gentry *et al.* (2002) who reported an increased backfat level in deep litter housed compared to conventionally housed. However Morrison *et al.* (2007) found no impact of housing on carcass P2. Trezona *et al.* (2007) reported that although carcass backfat at the P2 was unaffected by housing system, there was a trend for pigs raised on deep litter straw to have different fat distribution measured in the belly and ham. There will likely be genetic differences which will impact on fatness and distribution of fat deposition. In our current study the increased backfat could be due to the fluctuations in ambient temperature conditions experienced by pigs in deep litter housing and increased energy requirements for thermoregulation. Previous research has found pigs raised in warm climates have less backfat (Lefaucher *et al.*, 1991) compared to pigs raised in colder climates (Campbell & Taverner, 1988).

There are potential advantages recognised by the industry in increasing final slaughter weight such as reduced overhead costs for producers, slaughterers and processors. Associated with the increase in heavier carcasses is an increase in carcass yield, improved meat to bone ratio and a reduction in chilling and production losses (Correa *et al.*, 2006).The findings from this study indicate increasing carcass weight resulted in an increase in carcass P2 fat depth in pigs of the same genotype and accounting for housing and sex difference are killed at the same age. This is a major limitation to increasing final slaughter weight due to carcasses not meeting customer specifications.

#### 4.1.2. Carcass pH decline

In the present study, Deep litter carcasses had a faster rate of muscle pH decline from 45 min to 6 h post slaughter compared to Conventional carcasses perhaps indicative of an increased glycolytic rate post slaughter as a consequence of increased pre-slaughter stress or higher glycogen stores. Hambrecht *et al.* (2005) found stress pre-slaughter decreased muscle glycogen potential, increased muscle temperature, rate of pH decline and ultimate pH. van Laack and Kauffman (1999) also reported that a higher glycogen potential resulted in a lower ultimate pH. Choe *et al.* (2008) found that higher glycogen stores are associated with faster early pH decline and lower pH 24. However, there was no housing effect on pH 24 h or carcass temperature decline. Muscle pH at 45 min post-slaughter was the only factor significantly influenced by the interaction between housing and sex. Both sexes in Deep litter housed had a lower 45 min post slaughter pH than Conventional carcasses but no differences at any other time points. The difference in the initial pH did not affect any other meat quality measurements.

#### 4.1.3. Carcass temperature decline

Heavy carcasses had a slower rate of chilling from 45 min to 6 h post slaughter compared to light and medium weight carcasses. The findings is in agreement with Cisneros *et al.* (1994) who also found that carcasses of heavier weight, larger muscle size and higher fat depth had a slower rate of chilling however in contrast the carcasses had a faster glycolysis and pH fall. Huff-Lonergan and Lonergan (2007) found that the rate of pH and temperature decline post-slaughter can have a significant impact on meat quality in relation to colour, water holding capacity and tenderness. Cisneros *et al.* (1996) and Latorre *et al.* (2004) found poorer meat quality associated with heavier carcasses whereas Correa *et al.* (2006) found no effect on meat quality. Piao *et al.* (2004) found pork quality in terms of juiciness, flavour and tenderness to be more highly rated at heavier carcass weights.

#### 4.1.4. Shear force

Deep litter carcasses had lower shear force values in the loin ($P<0.048$) and rump compared to conventional housed. These results are in contradiction to Morrison *et al.* (2007) who found no impact of housing on loin shear force, and Johnston *et al.* (2005) who found an improved shear force values for carcasses from conventionally

housed pigs. The improved shear force results in the loin could be attributed to the increase in intramuscular fat related to the increase in carcass P2 in deep litter housing; however this was not measured as part of this study. The lower shear force in the rump, which generally has a lower level of intramuscular fat, may however suggest other mechanisms, such as muscle fibre type (Gentry *et al.*, 2002), may be responsible for Housing effects on shear force. Whether the improved shear force values translate to an improved sensory value is unknown from our study. In studies where sensory evaluations have been conducted, there has been a high association between shear force and sensory tenderness. Tenderness was found to be the second most important factor in consumer overall liking (Channon *et al.*, 2016) behind flavour and ahead of juiciness and aroma.

The impact of weight on the meat quality measures varied between meat cuts. Of high importance was our finding that shear force values decreased (became more tender) as Weight increased, where it was significant in the rump. In the study by Channon *et al.* (2016), the rump was not included in the objective and sensory appraisal, but they concluded that the silverside was a muscle that contributed to higher fail rates amongst consumers.

#### 4.1.5. Drip loss

Drip loss increased in the silverside and loin cuts from Deep litter carcasses but there were significant differences in some objective meat quality measurements in the loin, silverside and rump which could be linked to the rate of pH decline. Johnston *et al.* (2005) found an improved loin drip loss in conventional housed pigs similar to the findings in this study. Bee (2002) found a higher glycogen potential is associated with paler colour and increased drip loss in the loin. The silverside was the only cut influenced by the interaction between Housing and Weight. Deep litter carcasses had higher drip loss values in the silverside than Conventional carcasses. Drip loss in the silverside increased with increased Weight. Cisneros *et al.* (1996) found loin drip loss increased at around 0.3% for a 10 kg increase in slaughter weight whereas the present data found silverside drip loss increased at over 6% for an increase in slaughter weight. A higher drip loss is associated with a higher increase in commercial loss at heavier weights. A possible explanation of increased drip loss levels is high pre-slaughter stress, although there was no significant housing effect

on carcass fighting lesion score recorded in our study. Hambrecht *et al.* (2005) found high stress pre-slaughter impaired water-holding properties.

Silverside and rump drip loss were influenced by Sex in this study. Castrates had a lower drip loss in both the silverside and rump compared to Females. However, there was no difference between Castrates or Females for loin drip loss. There are conflicting results of the influence of sex on drip loss. Unruh *et al.* (1996) reported less moisture exudate in the loin of barrows compared with females and D'Souza and Mullan (2002) reported a trend for females to have higher surface exudate compared to castrates, similar to the findings in this study in the silverside and rump. However Channon *et al.* (2016) found no significance of sex on silverside drip loss or loin drip loss. The conflicting results could be related to a difference in numbers of type I and type IIA muscle fibres in muscles by sex. Ryu and Kim (2005) found pork with more type I and type IIA muscle fibres had lower drip loss and higher early post mortem pH.

#### 4.1.6. Meat Colour

The perception of pork colour can influence a consumer's purchasing power. The L* value in the loin, rump and silverside has been found to be highly correlated with subjectively assessed colour (Brewer *et al.*, 2001). Ngapo *et al.* (2007) found Australian consumers preferred pale pork. A value of 47-52 for L* value is regarded as acceptable by Australian consumers (D'Souza pers comm.) though more recent sensory studies do not include colour as a factor contributing to consumer preference per se, but rather as an objective measure of overall meat quality (Channon *et al.*, 2016). The present study found meat from Deep litter housed was darker in the silverside and rump, redder in the loin, silverside and rump, and more yellow in the silverside and rump than Conventional carcasses. Morrison *et al.* (2007) found no significant differences in objective colour measurements L*, a* and b* between deep litter and conventional housing. Although there was an interaction in the present study between Housing and Weight on L* in the silverside, this was primarily due to the lower L* values recorded in the Deep litter carcasses compared to the Conventional carcasses. There was also a Housing x Weight interaction in meat colour b* when cut types were combined. The increase in carcass P2 in Deep litter housed combined with heavier weights could influence the b* value with a subsequent increase in intramuscular fat levels present in the silverside. Colour

could also differ as a result of differences in muscle fibre type between Housing due to different behavioural responses by pigs. Gentry *et al.* (2002) found that pigs born in the same environment but were outdoor reared had an alteration to muscle fibre composition from type IIb and IIx fibres to type IIa fibres compared to indoor reared and Morrison *et al.* (2007) found deep litter pigs more active and performed more exploratory behaviours than pigs in conventional housing. However Morrison *et al.* (2007) found no improvement in pork quality as a result of behavioural differences in the housing systems. Hambrecht *et al.* (2005) found L* and a* values unaffected by stress. In the present study carcass meat colour (L*, a* and b*) in any of the cut types were not influenced by Weight.

Silverside and rump a* value were influenced by Sex in this study. Castrates had a lower a* value in both the silverside and rump compared to Females. However, there was no difference between Castrates or Females in any of the meat quality measures recorded for the loin. The findings from this study are supported by previous studies. Unruh *et al.* (1996) and Nold *et al.* (1999) found similar a* value data in the loin muscle between sexes. Unruh *et al.* (1996) attributed the difference in a* value to castrates depositing more external and intramuscular fat resulting in less red meat. Nold *et al.* (1999) found no sex effect on L* value in the rump and silverside and no sex effect on L* and a* in the loin. D'Souza and Mullan (2002), Lampe *et al.* (2006) and Latorre *et al.* (2004) also found no sex effect on L* value in the loin. This study confirms that Sex affects some meat quality measures, but the response varies between meat cuts.

#### 4.1.7. Meat pH

Deep litter carcasses had a lower pH in the silverside and rump than carcasses from Conventional housing. But there was no significant difference for loin pH by housing. These results are in contradiction to Morrison *et al.* (2007) who found a lower loin pH in conventional housed pigs. The silverside was the only cut influenced by the interaction between Housing and Weight. Deep litter carcasses had higher pH in the silverside than Conventional carcasses for the medium and heavy carcass weights, however a lower silverside pH at light carcass weights. This could be attributed to the slower chilling rate associated with increased carcass weights. In the present study carcass muscle pH in any of the cut types were not influenced by Weight.

Silverside and rump pH were influenced by Sex in this study. Castrates had a higher pH in both the silverside and rump compared to Females. The loin pH was not impacted by by sex. There are conflicting results of the influence of sex on muscle pH. Unruh *et al.* (1996) reported an improved muscle pH in the loin of barrows compared with females and D'Souza and Mullan (2002) reported a trend for females to have lower pH compared to castrates, similar to the findings in this study in the silverside and rump. However Channon *et al.* (2016) found no significance of sex on silverside pH.

# 5. Conclusion

The results from this project have important industry outcomes. Firstly, this is one of the few experiments published where pre-slaughter factors are controlled under the same genetics, nutritional regimen and sale age, whilst keeping all lairage conditions, stunning and slaughter factors identical. Secondly, carcasses from variable pre-slaughter factors were assessed under identical post-slaughter conditions. Thirdly, objective meat quality was conducted on different meat cuts rather than the traditional practice of using the loin (*m. longissimus*) as the indicator of meat quality.

Housing differences between pigs reared on deep litter compared to conventional housed pigs on slatted flooring had the biggest impact on carcass and meat quality. Carcasses from Deep litter housed were 1 mm fatter within each weight cohort and sex group when slaughtered at the same age. Whilst this has an economic penalty that pig producers have to account for, there are advantages in carcass quality of Deep litter carcasses such as a more rapid pH decline. In terms of boned meat quality 24 h after slaughter, meat cuts from Deep litter carcasses were more tender (lower shear force), were darker in the loin but paler in the rump and silverside, and redder and more yellow in all three cuts. On the downside, meat from Deep litter carcasses had a higher drip loss.

Weight was also a significant contributor to carcass and meat quality. The heavier the carcass within Housing and Sex cohort, the slower the rates of carcass chill. For objective meat quality measures, Weight was inversely related to shear force, so as carcass weight increased, tenderness increased.

Sex had no effect on carcass quality measures within 24 h post slaughter. However, meat cuts from Castrates had a lower drip loss and were less red in colour. There was a tendency ($P<0.06$) for Castrates to have a higher shear force value (less tender) than Females.

Several interactions between Housing x Weight x Sex were reported, and this may be exploited by supply chain mangers to select which type of carcasses delivers the "best" overall meat quality outcome. Based on our results, Housing was a significant variable relating to shear force and carcass pH decline, which are major factors related to consumer preference of quality determined by Channon *et al.* (2016).

Finally, the inclusion of different meat cuts for objective quality testing showed that there are differences in measureable quality between cuts, and that the use of the loin as an indicator muscle for overall meat quality could be unreliable.

# 6. Limitations/Risks

This study was conducted on a single genotype under pre-determined management conditions. Post-slaughter factors were not investigated and these may have confounding effects on interpretation of these results in other processing facilities.

# 7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. Deep litter pigs need to be managed to overcome fatness at any given carcass weight.
2. Heavier carcasses do not contribute to poorer meat quality.
3. The timing of immunocastration needs to be managed so that fighting and possible stress related drip loss and higher shear force in cuts from Castrates could be minimised.
4. Further research is needed on the cause of meat quality differences due to Housing, Weight and Sex within different muscle groups.
5. Further research is warranted on benchmarking post-slaughter variables on carcass and meat quality, including electrical stimulation, chilling regimens, aging and moisture infusion.

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# Appendix 1 - Notes

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# Appendices

### *Appendix 1:*