Determining the variability in eating quality of Australian fresh pork
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Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

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Executive Summary

Consumer fail rates for eating quality of pork in Australia have been reported to be as high as 30%. As the Australian pork industry needs to limit these levels to below 10%, strategies to optimize eating quality need to be implemented by the whole supply chain. The large fail rates are likely due to variability in carcase characteristics; however, the exact cause(s) has not been identified. One likely factor is the variation in pH and pH decline between carcases. The pH and pH decline is primarily driven by the amount of stored energy in the form of glycogen that the animal has in its muscles at slaughter and this can be affected by a number of processing technologies. Furthermore, it has been noted that the ultimate pH (pHu; the pH reached once post mortem metabolism has ceased; measured at 72 hour post mortem in the current study) of Australian pork has declined to levels lower than what is considered "normal" (ie. < 5.5). It is not known what impact this observed decrease in ultimate pH may be having on consumer acceptability and eating quality. Thus, this study was designed to investigate the effect of a range of pHu (pHu 5.35-5.65), from low (5.35 to 5.5) to normal (5.5.1 to 5.65), on consumer sensory and meat quality attributes of loin (*M longissimus dorsi*) muscles sourced from female and entire male pigs from two Australian supply chains.

This study was a 2 (supply chains) x 2 (sex; female, entire male) x pHu category (low 5.35-5.5; normal 5.5-5.65) factorial study. The design allowed for the analysis of pHu as a covariate due to the range of pHu of muscles selected for use in the study. A total of 160 loins (80 per supply chain) from entire male and female carcases were selected on the basis of pHu. Loins were also tested for colour and drip loss as part of the selection procedure and any outliers were excluded. Four steaks from each loin were cut and aged for 7 days before being frozen and sent to SARDI for sensory analysis. A total of 160 consumers were used for the study, with 640 total evaluations of sensory meat quality being collected. Objective meat quality measures of colour, drip loss, cook loss, shear force and intramuscular fat (IMF) were also measured.

The key findings from this experiment were:

- Consumers preferred loin steaks with a higher pHu, favoring samples that were towards the higher end of the pH range. This preference increased linearly across the range of pHu sampled. The largest effect of pHu was observed for sensory tenderness in female carcases, with a 22% improvement in tenderness scores across the pHu range.
- Consumers discriminated against samples with poor objective meat quality measurements, particularly, shear force. Shear force correlated highly with tenderness thus highlighting the importance of tenderness in consumer acceptance. Strong correlations were also found between shear force and quality grade and re-purchase intention
- Shear force, drip loss, cook loss and L value (muscle lightness) were all positively influenced by pHu as well as pH measured at 24 hours post mortem (pH24). The fact that pH24 correlated with these measures reinforces the importance of the rate of pH decline on meat quality.
- Glycogen concentration at slaughter correlated strongly with pHu, however lactate concentration did not. This suggests that glycogen concentration at slaughter is a driver of pHu and pH decline and strategies to optimize muscle glycogen concentrations should be further considered

- Drip loss percentage from loin differed between supply chains. This may reflect differences in processing factors influencing early post mortem decline and/ or different rates of chilling.

The outcomes from this experiment indicate that strategies need to be developed to optimize the rate and extent of pH decline to improve consumer acceptability and reduce the variability in pork eating quality.

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1. Introduction

To ensure the maintenance and growth of domestic pork consumption, and growth of the export market for premium pork products, pork consumers must be confident they will have a positive eating quality experience when purchasing fresh pork. Thus, the availability of pork of variable eating quality needs to be minimized or completely eliminated from the supply chain . To accomplish this, it is important for the industry to be aware of the current fail rate levels and have an understanding of the basis of poor eating quality.

It is well documented that both production and processing factors contribute to pork quality and therefore subsequent eating quality. Production factors include genotype, sex, production system, nutrition and season, while processing factors include carcase chilling regime, moisture infusion and aging. Many of these factors have the ability to manipulate pH, which in turn can have a massive detrimental effect on meat quality. Pork with an increased ultimate pH (pHu; when a decline in pH has ceased; measured at 72 hours post mortem) of 5.8-6.0 tends to result in a higher rating for consumer overall liking with interactions between cooking temperature also identified (Bryhni *et al.*, 2003). Pork with a lower ultimate pH seems to be correlated with a negative sour/acidic flavour (Aaslyng *et al.*, 2007; Myers et al., 2009) as well as decreased juiciness and tenderness (Lonergan *et al.*, 2007), thus effecting the overall liking of the product.

Previous work carried to assess the benchmark of pork eating quality across Australia, identified a trend towards lower pHu meat, without being classed as pale soft and exudative (PSE) and separate to the RN- gene. The mean pHu from 8 farms across Australia ranged from pH 5.43 to 5.00 - levels that would traditionally fit well within typical PSE limits. There is also evidence that low pH pork was present in both Western Australia and Victoria (D'Souza and Moore, 2005). However, this work was performed over a decade ago and the present industry average pHu is currently unknown. Assuming the ultimate pH of pork across Australia has shown a trend to be reduced, and not being PSE, a more definitive understanding of the impact of low pH pork on both sensory and meat quality is required.

This study was conducted to quantify and redefine the inconsistencies in eating quality occurring in fresh Australian pork. The aim was to determine the current level of variability in eating quality in Australian fresh pork and identify reasons (consumer generated) why pork fails to meet consumer eating quality standards. The association of this fail rate in relation to pH was of particular interest. Profiles of eating quality variability were developed for two major supply chains identifying differences in genotype and sex. The effects of different production systems and carcass chilling regimes were not addressed, however the production system and chilling program for the locations where samples were collected were noted and variability minimised. Samples analysed in this study were not moisture infused.

The identification of any inconsistencies will allow interventions to be developed for different pork production systems. The interventions can then be used as tools to reduce the incidence of unacceptable product quality. This project will also provide essential information to assist in building a profile of current consumer expectations of fresh pork in Australia and provides further data/information to complement the CRC for High Integrity Australian Pork project 3A, developing predictive models for pork quality. By investigating the relationship between low ultimate pH and sensory eating quality, potential management strategies to improve the consistency of pork eating quality are likely to become evident.

2. Methodology

2.1. Experimental design

Samples were collected from finisher carcasses from two major Australian supply chains. Selected carcasses were categorised by sex (entire male or female) and ultimate pH (Low: 5.35-5.5; Normal: 5.5-5.65). There were a total of eight treatments (2 supply chains x 2 sexes x 2 pH_u categories) with 20 animals per treatment; a total of 160 animals.

2.2. Supply chain information

The two supply chains differed in geographical location. Carcases sampled came from two different genotypes and all pigs were commercial crosses (Landrace x Large White x Duroc).

Pigs sourced from Supply Chain 1 (SC1), were housed in ecoshelters and fed five different diets from weaning to slaughter. Diets were wheat/barley based rations, with lupins included in grower and finisher rations. The digestible energy content ranged from 15MJ to 13MJ. The farm was located 300km from the abattoir and pigs were transported in loads of approximately 240.

Pigs from supply chain 2 (SC2) were also housed in straw based ecoshelters and fed a wheat/barley plus pulse based diet. Pigs were fed seven different diets from weaning to slaughter and ranged in digestible energy from 16MJ to 13.8MJ. The farm was located 170km from the abattoir and pigs were transported in loads of 220-230.

Both supply chains used CO_2 stunning to anaesthetize pigs prior to exsanguination. For SC1, hair was removed from the carcase by scalding in water baths at a temperature of 61°C for 5 minutes. Time from stunning to entering the chiller was 35-45 minutes, and the chillers were set at 0°C. For SC2, hair was removed by steam at a temperature of 60.7-61.7°C and time from stunning to entering the chiller was also 45 minutes. Chillers were set at 1.5°C.

2.3. Sample collection

Samples were collected across the two supply chains from May to October 2012) over ten different sampling days (6 days for SC1 and 4 days for SC2). One hundred pigs were tested for pH at 24 hours per sampling day. Hot carcass weight and P2 backfat depth for selected carcasses were recorded. About 1 kg of loin muscle (*m.longissimus dorsi*) was removed from the right hand side of the carcase and transported to South Perth, Western Australia for further objective analysis.

At 48 hours post-slaughter, 4 2.5cm thick steaks were cut from each loin piece, vacuum packaged and labeled individually for sensory analysis, aged for 7 days at 2°C and then frozen at -20°C. These samples were sent to SARDI, Adelaide for sensory analysis. At the same time a 40±5g sample (weights recorded) was cut and used to measure drip loss and intramuscular fat (IMF) content. A final sample of 70±5g (weight recorded) was cut into a cube and vacuum packaged, aged for 7 days at 4°C and then frozen at -20°C. This sample was used for shear force and cook loss analysis.

For each loin, muscle pH at both 48 and 72 hours were measured and those samples that fitted into either of the pHu categories were selected for the experiment. Samples which

had PSE characteristics were eliminated from the experiment and drip loss and colour were also discriminated against (any outliers were removed).

2.4. Objective measures

Muscle pH was determined at 24, 48 and 72 hours post-slaughter in the loin. The pH was measured using a pH 300 hand-held pH/mV/temperature meter (Eutech instruments, Singapore) fitted with a temperature and IJ44C intermediate junction pH probe (Ionode, Tennyson). The pH meter was calibrated on two standards (pH 4.01 and 7.0) as per manufacturer's instructions. At 24 hours, the probe was inserted into the loin muscle on the right side of each carcass between the 3rd and 4th ribs 7.5 cm from the ventral edge of the split pork carcass (pH24 measurement). At 48 and 72 hours, the pH was measured directly into the removed piece of loin. The pH at 72 hours was considered the ultimate pH (pHu).

Loin colour was measured at 48 hours post slaughter. Muscle samples were cut and a surface was exposed to air at room temperature for 10 min. Meat colour was determined using a Minolta Chromameter Model CR-400 (calibrated on a white tile) set on the L*, a* and b* system where L* denotes relative lightness (higher L* values = paler meat), a* relative redness (higher a* values = more red) and b* relative yellowness (higher b* values = more yellow), using D65 illumination and a 2° standard observer.

Drip loss was determined using a modified method of Honikel (1998). A sample of pork loin was cut to a 40 g cube, weighed and weight recorded. The sample was then wrapped in a piece of square netting. The wrapped sample was then suspended in a 200 ml plastic container and left to stand in a 4°C chiller for 24 h, after which it was removed from the container, gently rolled in paper toweling and reweighed to determine percentage drip loss. The remaining sample was then frozen at -20ºC and used for IMF analysis.

Samples for intramuscular fat measurement were freighted to Silliker Australia, Regents Park, (Sydney) for analysis using the Ankom method (extraction of crude fat using petroleum ether).

Samples for WBSF were cooked from frozen state and dependent on internal temperature treatment, cooked in a water bath preheated to 70°C until an internal temperature of 70°C was attained. Each sample was suspended from a metal rack and cooked in a water bath. Samples were then cooled in iced water for 30 minutes. Samples were dried and weighed to determine cook loss (expressed as a percentage of weight lost due to cooking) and then stored at 4°C for 24 hours. From each sample, five 1 cm^2 replicate samples were cut parallel to the orientation of muscle fibres and WBSF was measured using a Warner Bratzler shear blade fitted to a Lloyd Texture Analyser (TA-2, United Kingdom).

Analysis of the muscle samples collected were chemically analysed for lactate and residual glycogen content at Murdoch University. The glycogen assay was based on the enzymatic method of Chan & Exton (1976) but excluding the filter paper step, and the lactate assays used the same homogenate. Briefly, 250 mg of frozen LD muscle samples were weighed out into test tubes and kept on ice. Next, 2.5 mL of 30 mM HCl was added to the test tubes and the sample was homogenized for 30 sec using a Polytron (Bosch GGS 27C Professional) and left to settle whilst on ice for 1-2 h. Sample liquid (not foam) was transferred to Eppendorf tubes and frozen at -20 °C until required. The auto-analyser (Olympus AU 400, Olympus Diagnostics, Tokyo, Japan) used for completing the analysis was calibrated using lactate and glucose standards according to the machine manual, then 60 µl of defrosted, vortex spun samples were pipetted into auto-analyser cups and analysed for lactate. Glycogen in each of

the remaining homogenate samples was then broken into glucose for analysis in the auto-analyser, by combining 125 µl of homogenate with 125 µl of distilled water and 1 mL of an enzyme and acetate buffer mixture (0.0128 mg amylase, 0.0128 mg amyloglucosidase in 80 mL of pH 4.8, 40 mM acetate buffer (0.41 g sodium acetate, 0.3g glacial acetic acid and distilled water)) and incubating in shaking water bath at 37 °C for 60 min. This mixture was then pipetted in 60 µl aliquots into auto analyser cups and analysed for glucose content to establish the amount of total residual glycogen in the muscle sample (number of moles of glucose reflects the number of moles of glycogen in the sample). Total glycogen was calculated by adding the number of moles of residual glycogen with half the number of moles of lactate (equivalent of two lactate molecules to every one glucose or glycogen) and converting to g per 100 g of muscle sample. This resulted in a value for total glycogen at slaughter, while lactate measures were what was present in the tissue at 72 post slaughter.

2.5. Sensory measurements

The study was designed with three factors (supply chain, sex and pH) with two levels within each factor giving eight treatments. The levels for each factor were:

- Supply Chain: SC1 and SC2
- Sex: Entire male and female
- pH: low and normal

One primal cut (loin) and one cooking method (grilling as steaks) were evaluated. One loin primal was obtained from each pig which was cut into four loin steaks of 2.5 cm thickness; a total of 640 loin steaks. Each loin steak was aged for seven days post-slaughter and cooked to a 70°C endpoint temperature. Panelists evaluated four loin steaks in each sensory session, requiring 160 consumers.

2.6. Sensory Evaluation

The consumer panel was designed to determine sensory attributes of aroma, tenderness, juiciness, flavour and overall liking for each pork loin steak sample assessed. Demographic information (gender, household size, age, current purchasing, cooking and consumption habits of fresh pork) was also captured for each consumer along with a quality grade and re-purchase intention score for each pork sample evaluated.

The consumer sensory sessions were conducted at one central location at the University of South Australia (UniSA) sensory facilities based at the city centre campus in Adelaide.

2.6.1 *Consumer Recruitment*

Consumers were recruited by an independent recruitment company (Intuito Market Research) by emailing their extensive database of consumers willing to participate in taste testing.

All participants needed to be consumers who had eaten fresh pork (not bacon or ham) in the past month and aged between 18 and 65 years. Butchers and other people working with meat production and sales were excluded. Individuals (n=160) were asked to join a panel of eight consumers for approximately 40 minutes at session times of 10.00 am, 11.30 am, 1 pm, 2.30 pm and 4.00 pm on four pre-determined days from Monday to Thursday in November 2012.

Potential participants registered with Intuito, either online or over the telephone, and were contacted by a recruiter to arrange a time that would suit them to attend. Participants who

cancelled their appointments were replaced using the database of over 1,000 consumers. Participants were given an honorarium for their participation in the study and were used only once.

2.6.2 *Allocation of Frozen Samples into Sensory Sessions*

The pork loin steak samples, prepared at SC2 by Dr Cameron Jose, were individually vacuum packed at the SARDI Waite campus, stored in a cool room (4°C) for a seven day ageing period and then frozen to -18°C. Samples from SC1 were supplied to the SARDI Waite campus in a frozen format and stored at -18°C until required for the sensory sessions. The samples were prepared and frozen during the period July – September 2012. Loin steak samples were sorted into the individual sensory sessions in the product development kitchen at the SARDI Waite campus.

Copies of a one page session labeling document were prepared in advance for every session to indicate which loin steaks (n=32) were required for the sessions. The document showed the session number and a list of the 3 digit codes for each loin steak required along with details of the supply chain, sex and pH. The 32 loin steaks required for each session were located using the session labeling document, checked off the list and put into a plastic bag. Once all samples had been located, the session labeling document was also placed inside the plastic bag; the bag was sealed and returned to the freezer at SARDI Waite. Once this was completed, five sessions required for each day were then collated into one carton and labeled with the session numbers.

2.6.3 *Thawing and Preparation Protocols*

The carton required for each day of sensory sessions was removed from the -18°C freezer and placed into the 4°C constant temperature room for 48 hours. Samples were prepared for the sensory sessions between one and seven hours after removal from the 4°C room.

On each day of the sensory sessions the carton was collected from SARDI Waite campus (at 8 am) and transported to the central testing location at UniSA by car. The carton was transported in the boot of the car and the journey was approximately 15 minutes. The sensory sessions were undertaken in November 2012. The average minimum temperature in Adelaide in November was 15.1°C (Australian Government Bureau of Meteorology, Accessed 12 Feb 2013)}. The samples were not transported under refrigerated conditions due to the short transport time and low ambient temperature.

On arrival at the test location, the samples were removed from the carton. Samples for Sessions 2 - 5 were placed on separate shelves in a holding chiller (5°C) and preparation commenced with samples for Session 1.

On removal from the carton, the 32 individual loin steak samples were checked against the session labeling document to ensure the session contained the correct samples. The 3 digit number was used as the primary identification tool. Each sample was identified by its unique 3 digit number and this ID followed the sample from removal from its vacuum packaging to presentation to the sensory panelist for evaluation.

2.6.4 *Grilling Protocol*

The loin steaks were removed from the vacuum packaging, labeled with their 3 digit number, placed onto a tray and stored at 5°C until required. The temperature of the loin steaks was 5-7°C before cooking commenced. The four samples to be evaluated by each

consumer were in a randomised tasting order so the cooking of samples (n=32) could not be done to order. The loin steaks were grilled in groups of four loin steaks with eight grilling batches required for each session.

The grill used for this study was a Silex Grill Model GTTPowersave 10.10-30 (Silex Elektrogerate GmbH, 22143 Hamburg, Germany). The grilling protocol was that previously developed and utilised in Pork CRC project 3A-103 to produce grilled steaks cooked to an end point temperature of 70°C after a two minute resting period. The grilling started approximately 40 minutes before the start of each session.

For every group of loin steaks grilled, the internal take-off and resting temperature was measured for one steak cooked to ensure the equipment was functioning as expected and the required end point temperature of 70°C was achieved. The grilling and resting times were measured with digital timers.

Once the steaks had been grilled for the required amount of time, they were removed from the grill and placed next to their ID label on the cutting board for resting. This process was repeated until all 32 steaks had been cooked for the session. In between each sensory session the grill was switched off and the plates thoroughly cleaned with hot water and detergent.

2.6.5 *Presentation Protocol*

The preparation room was maintained at a temperature of 23°C during the sensory sessions. In each session, the samples (n=4) evaluated by each consumer (n=8) were in a randomised tasting order so all samples (n=32) needed to be prepared and ready to serve for the start of the sample evaluation section of the sensory session; approximately 10 minutes after the start of the session. The samples could not be prepared to order. Some samples were stored in the containers for up to 45 minutes prior to consumer evaluation.

To keep the prepared samples warm during the evaluation and prevent moisture loss they were stored in sealed and labelled glass Pyrex containers (World Kitchen, Rosemont, Illinois, USA) on top of heated warming plates (n=4) from Cuisinart Model CWT-240A (Cuisinart Australia, 24, Salisbury Road, Asquith, NSW, Aus.). At the start of the day, the warming plates were preheated to the 65°C setting and the Pyrex containers (n=16) placed on top. A duplicate set of Pyrex containers was available so these could be placed on the warming trays to pre-heat for the next sensory session whilst the soiled ones were cleaned.

After two minutes resting on the cutting board, four steaks (grilled at the same time) were trimmed on all four sides to remove the fat and edges and the centre pieces used for consumer evaluation. These were transferred with their labels to sealed Pyrex holding containers. Two steak pieces were placed at each end of an individual container. This process was repeated for the 32 steaks required for each sensory session.

2.6.6 *Serving of Samples to Consumers*

A one page serving order document was prepared for each of the 160 consumers in the study. This document contained the order in which the four samples were to be tasted (identified by order, sample description and 3 digit identification number) by each panelist in each session. Before the start of each session, the page corresponding to the correct session and panelist was secured above the booth for each consumer in the preparation room. The four sample plates were also pre-labeled with the 3 digit sample numbers and stacked in the correct tasting order by the booth.

The consumers were instructed to switch on a light in their booth once they were ready to evaluate a sample of pork. This action illuminated a duplicate light in the preparation room which served as a signal to commence the serving process to that consumer. Two people undertook the serving of samples in a sensory session; one person responsible for serving Panelists 1-4 and the other for Panelists 5-8.

When a consumer was ready for a sample and the light was illuminated, the server would identify the panelist and sample number required. They would:

1. collect pre-labeled sample plate from beside the tasting booth;
2. locate the correct sample in the Pyrex container;
3. undertake a number identification check between plate and Pyrex container;
4. place sample onto plate;
5. open the serving hatch and present the sample to the consumer;
6. switch off the light beside the tasting booth; and
7. cross out the sample ID number on the serving order document.

This process was repeated for all four samples and the protocol followed for all sensory sessions. The serving operation was completed in approximately 20 to 25 minutes per session.

2.6.7 *Consumer Evaluation*

In each sensory session (n=20), eight consumers evaluated four pork samples (32 tastings). The eight consumers registered at the start of each session were given a short briefing on the sensory evaluation process and then taken to the sensory evaluation room and placed in the eight individual tasting booths to start the session. Panelists recorded assessments by touch screen through the use of a computerised sensory evaluation program, Compusense Five version 5.2 (6/9 Southgate Drive, Guelph, Ontario, Canada).

The session commenced with consumers answering a number of questions presented on the screen to capture individual demographic information which included: gender, household size, age, current purchasing, cooking and consumption habits of fresh pork. Consumers were then presented with each pork sample for evaluation on a numbered plastic plate as per the serving protocol described above. They were first asked to enter the 3 digit identification number for the sample, smell it and rate the sample for aroma. They were then asked to eat most of the sample before scoring for tenderness, juiciness, flavour and overall liking.

Consumers assessed the eating quality attributes of the pork samples using a continuous line scale as per Australian Standard for Sensory Analysis (AS 2542, 2007). This method provided panelists with an opportunity to express small differences in judgment as they marked the line in the position corresponding to perceived intensity for that attribute. Although potentially a more difficult task for the consumer than using a category scale, the line scale permits unlimited fineness of differentiation among consumer assessments. To ensure that the scale was easily understood by panelists, word anchors were carefully selected for each attribute and prior to the evaluation of pork samples, consumers completed a number of line scale practice assessments.

The continuous line scales used for the five quality attributes were anchored at each end with words with left hand side equivalent to 0 and right hand side equivalent to 100.

Numerical intensity values were not shown to the consumers:

1. Aroma liking: Dislike extremely to Like extremely.
2. Tenderness: Not tender to Very tender
3. Juiciness: Not juicy to Very juicy
4. Flavour liking: Dislike extremely to Like extremely
5. Overall liking: Dislike extremely to Like extremely

Each consumer also graded the samples for quality into one of the following categories:

1. Unsatisfactory (this was terrible, I did not enjoy it all)
2. Below average (this was not nice, I did not enjoy it)
3. Average (this pork was nice, I somewhat enjoyed it)
4. Above average (this pork was really nice, I enjoyed it)
5. Excellent (this pork was excellent, I really enjoyed it)

Each sample was also rated for repurchase intention into one of the following categories:

1. I definitely would not buy it
2. I would probably not buy it
3. I might buy it
4. I would probably buy it
5. I would definitely buy it

Consumer assessment progress was monitored remotely on the laptop running the computerised program and assistance was provided when required. Consumers could not move onto the next question or assessment until the previous answer or assessment was completed. The session was completed once all consumers had assessed and rated their seven samples.

2.7. Data analysis

The software package SAS® was used for all statistical analyses (SAS Institute, 2001). Sensory data was analysed in a two-step process. Each sample was scored by 4 different consumers and thus had 4 scores per question. The means of these scores for a sample were adjusted for by the consumer, outputted so there is one score per sample, and included in the master data set.

Data were analysed using a linear mixed effects model, using sex, supply chain and pHu category as fixed effects, with day of sampling within supply chain as the random term. First order interactions as well as all two way and three way interactions were tested. In a separate analysis, pHu and pH24 were used as covariates, with sex and supply chain as fixed effects and day of sampling within supply chain as the random term. Linearity and curve-linearity were tested for pHu and pH24 as well as all two and three way interactions. Interactions with non-significant ($P>0.05$) interactions were removed in a step wise regression process. A similar model was used to test interactions of objective measures and sensory scores.

3. Outcomes

3.1. Objective and carcase measurements

The raw means data for pH category are described in Table 1. Briefly, the low pH category ranged from pHu 5.31-5.49 with a mean of 5.42 ± 0.005, while the normal category ranged from 5.49-5.69 with a mean of 5.56 ± 0.006. The raw means data for SC1 by sex is shown in Table 2 and SC2 by sex in Table 3. The statistical outputs for the main fixed effects (sex, supply chain and pHu category) and treatment interactions are described in Table 4. The modeled mean values for statistically significant outputs are described in Tables 5 and 6.

Ultimate lactate, glycogen at slaughter and residual glucose levels were higher ($P<0.05$) in loins with a low pHu. Furthermore, lactate levels were higher in males from SC1 across all pHu levels. Lactate levels in males from SC2 were lower ($P<0.001$), whilst females from both supply chains had the similar lactate levels. Glycogen levels at slaughter were lowest in SC1 females across all pHu levels ($P<0.01$). These interactions are possibly due to the biased selection for pHu when collecting samples. The mean pH24 differed between pHu categories with the "low" pHu group being about 0.03 pH units lower than the "normal" pHu group at 24 hours post mortem ($P<0.05$).

There was no difference in hot carcase weight (HCW) between any main fixed effects, although normal pHu carcases were heavier from SC2 ($P<0.001$). Female carcases from SC2 had a higher P2 fat depth measurement ($P<0.05$), while females had more IMF than males ($P<0.01$), however this level of IMF is still considered low.

Percentage drip loss, cook loss and shear force were all higher in the lower pHu treatment ($P<0.05$). SC2 samples lost about 0.8% more weight through drip loss in 24 hours than SC1 samples ($P<0.05$). There was a significant effect of sex on cook loss, which was driven by an increased loss in males from SC2 worth about 3% in weight lost ($P<0.01$).

An effect of sex and pH category existed for L value; generally males samples with a normal pH were slightly darker ($P<0.01$). L value differed further with interactions on pH by supply chain and pH by sex. It seemed that low pH females, and samples from SC2 with low pH were the lightest ($P<0.05$) in these interactions. No effects on a or b values were observed.

There were significant correlations (data not shown) between cook loss and drip loss (0.37), shear force (0.2) and L value (0.31). L value further correlated with drip loss (0.25) and a and b values (-0.33 and 0.48, respectively).

Table 1 Descriptive statistical data for carcase and loin objective measures for the two pHu categories

	pH low					pH normal				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
pHu	80	5.42	0.045	5.31	5.49	80	5.56	0.055	5.49	5.69
pH48	80	5.44	0.062	5.31	5.67	80	5.58	0.080	5.43	5.75
pH24	80	5.66	0.081	5.45	5.80	80	5.70	0.072	5.55	5.93
Lactate (u mole)	80	101.14	17.864	25.53	153.22	80	96.75	15.873	47.06	133.51
Glycogen (u mole)	80	66.71	9.857	36.44	96.13	80	57.50	10.216	29.36	81.37
Glucose (u mole)	80	16.13	8.825	0.00	43.45	80	9.12	7.251	0.00	26.29
HCW (kg)	80	66.79	5.812	50.90	84.30	80	67.83	6.970	50.00	81.70
P2 Fat Depth (mm)	80	9.51	2.025	5.00	16.00	80	10.03	2.181	6.00	16.00
IMF (g/100g)	80	0.86	0.540	0.10	2.90	80	0.86	0.536	0.10	2.30
Drip loss (% wt.)	80	4.81	0.983	1.72	6.28	80	4.01	1.220	1.28	6.12
Cook loss (% wt.)	80	25.05	3.016	18.33	31.40	80	23.04	2.724	14.61	29.19
Shear force (N)	80	39.70	12.043	18.93	69.37	80	36.43	9.778	18.68	63.63
L	80	51.39	3.267	44.23	58.36	80	49.52	2.701	43.17	55.48
a	80	6.47	1.503	3.49	10.33	80	6.21	1.383	2.69	9.14
b	80	3.21	1.265	0.00	6.37	80	2.81	1.389	0.20	7.71

Table 2. Descriptive statistical data for carcase and loin objective measures for SC1 by sex

	Female					Male				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
pHu	40	5.49	0.084	5.34	5.67	40	5.49	0.075	5.31	5.65
pH24	40	5.68	0.075	5.52	5.93	40	5.68	0.084	5.48	5.87
Lactate (u mole)	40	100.65	15.175	55.00	126.76	40	110.25	16.104	72.60	153.22
Glycogen (u mole)	40	58.54	8.246	38.82	74.88	40	64.74	10.696	41.09	96.13
Glucose (u mole)	40	8.22	5.812	0.00	27.45	40	9.61	5.570	0.00	23.27
HCW (kg)	40	64.24	6.806	50.00	84.30	40	64.35	5.613	50.90	77.30
P2 Fat Depth (mm)	40	9.48	2.050	5.00	15.00	40	9.40	2.251	7.00	16.00
IMF (g/100g)	40	0.75	0.521	0.10	2.50	40	0.51	0.272	0.10	1.30
Drip loss (% wt.)	40	4.04	1.051	2.14	5.75	40	3.97	1.217	1.28	5.88
Cook loss (% wt.)	40	22.78	3.514	14.61	31.40	40	23.40	2.626	18.62	29.61
Shear force (N)	40	37.68	11.375	21.64	69.37	40	39.23	11.353	18.93	63.63
L	40	50.94	3.288	43.17	58.36	40	49.14	2.774	44.23	55.48
a	40	6.04	1.637	2.69	9.95	40	6.58	1.507	3.83	10.33
b	40	3.07	1.134	0.20	6.01	40	2.78	1.561	0.00	7.71

Table 3. Descriptive statistical data for carcase and loin objective measures for SC2 by sex

	Female					Male				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
pHu	40	5.50	0.093	5.33	5.68	40	5.49	0.091	5.35	5.69
pH24	40	5.68	0.069	5.52	5.81	40	5.68	0.090	5.45	5.85
Lactate (u mole)	40	95.46	8.778	79.02	117.50	40	89.43	19.252	25.53	124.23
Glycogen (u mole)	40	64.40	10.657	42.05	93.46	40	60.73	13.110	29.36	82.68
Glucose (u mole)	40	16.67	10.670	0.00	43.45	40	16.02	8.849	0.00	33.11
HCW (kg)	40	69.68	5.102	60.20	79.50	40	70.97	5.089	60.30	81.70
P2 Fat Depth (mm)	40	10.80	1.682	8.00	14.00	40	9.40	2.158	6.00	15.00
IMF (g/100g)	40	1.19	0.506	0.20	2.90	40	1.00	0.547	0.20	2.50
Drip loss (% wt.)	40	4.70	1.336	1.30	6.12	40	4.93	0.742	3.87	6.28
Cook loss (% wt.)	40	23.58	2.203	18.84	30.11	40	26.42	2.321	21.61	30.63
Shear force (N)	40	36.75	11.908	18.68	68.01	40	38.60	9.733	21.49	65.37
L	40	51.13	3.181	44.07	56.52	40	50.61	2.971	43.34	57.91
a	40	6.22	1.201	4.01	9.16	40	6.52	1.388	3.49	9.38
b	40	3.13	1.465	0.26	6.37	40	3.05	1.168	0.66	5.93

Table 4. Statistical outputs for objective and carcase measures against fixed effects and interactions. Only significant interactions are provided

	Supply chain			sex			pH category		
	*NDF;DDF**	*F value*	*P value*	*NDF;DDF*	*F value*	*P value*	*NDF;DDF*	*F value*	*P value*
pH24	1;8	0.10	0.76	1;148	0.14	0.71	1;148	5.08	0.026
Lactate	1;8	0.92	0.37	1;147	0.14	0.71	1;147	5.41	0.021
Glycogen	1;8	0.17	0.69	1;147	0.64	0.42	1;147	19.34	<0.0001
Residual glucose	1;8	2.7	0.14	1;148	0.62	0.43	1;148	12.04	0.0007
HCW	1;8	1.44	0.27	1;147	1.77	0.19	1;147	0.85	0.36
P2 Fat depth	1;8	0.96	0.36	1;147	5.67	0.019	1;147	2.62	0.11
IMF	1;8	3.09	0.12	1;148	7.77	0.006	1;148	1.27	0.26
Drip loss	1;8	6.73	0.032	1;148	0.21	0.64	1;148	22.41	<0.0001
Cook loss	1;8	3.65	0.093	1;147	18.09	<0.0001	1;147	20.05	<0.0001
Shear force	1;8	0.12	0.74	1;148	1.48	0.22	1;148	4.09	0.045
L	1;8	0.96	0.36	1;146	8.77	0.004	1;146	8.54	0.004
a	1;8	0.17	0.69	1;148	3.55	0.061	1;148	1.83	0.17
b	1;8	0.11	0.75	1;148	0.97	0.33	1;148	0.62	0.43
	Supply chain x sex			pH x supply chain			pH x sex		
	NDF;DDF	*F value*	*P value*	*NDF;DDF*	*F value*	*P value*	*NDF;DDF*	*F value*	*P value*
Lactate	1;147	11.66	0.001						
Glycogen	1;147	8.44	0.004						
HCW				1;147	11.34	0.001			
P2 Fat depth	1;147	4.77	0.031						
Cook loss	1;147	6.76	0.010						
Shear force									
L				1;146	4.43	0.037	1;146	4.45	0.037

*Numerator degrees of freedom (NDF); Denominator degrees of freedom (DDF).

Table 5 Modeled means data (± standard error of the mean, sem) of objective measures against significant fixed effects

	pH				sex				Supply chain			
	low		normal		Female		Male		SC1		SC2	
	mean	*sem*	*mean*	*sem*	*mean*	*sem*	*mean*	*sem*	*mean*	*sem*	*mean*	*sem*
Drip loss (% wt.)	4.87	0.175	4.06	0.176					4.07	0.214	4.86	0.220
L	51.27	0.625	49.92	0.625	51.24	0.617	49.95	0.623				
P2 Fat depth (mm)					10.22	0.280	9.44	0.281				
IMF (g/100g)					1.01	0.103	0.80	0.104				
Cook loss (%wt.)	24.95	0.507	23.07	0.507	23.17	0.501	24.85	0.505				
Shear force (N)	38.09	2.361	34.74	2.354								
Lactate (umole)	96.61	3.880	91.12	3.860								
Glycogen (umole)	65.00	1.876	57.84	1.877								
Residual glucose (umole)	15.94	1.784	12.21	1.777								

Table 6 Modeled means (± standard error of the mean, sem) data of objective measures for significant (P<0.05) fixed effect interactions

	Supply chain x sex							
	Female				Male			
	SC1		SC2		SC1		SC2	
	mean	*sem*	*mean*	*sem*	*mean*	*sem*	*mean*	*sem*
P2 Fat depth (mm)	9.64	0.391	10.79	0.401	9.57	0.400	9.31	0.395
Cook loss (%wt.)	22.80	0.676	23.53	0.738	23.45	0.699	26.25	0.729
Lactate (umole)	93.20	5.053	93.72	5.768	101.61	5.189	86.96	5.728
Glycogen (umole)	57.85	2.513	63.74	2.719	63.58	2.596	60.49	2.684
	pH x supply chain							
	Low pH				Normal pH			
	SC1		SC2		SC1		SC2	
L	50.21	0.850	52.33	0.919	49.84	0.838	50.00	0.927
HCW (kg)	67.58	2.289	68.69	2.617	65.46	2.258	72.41	2.626
	pH x sex							
	Low pH				Normal pH			
	Female		Male		Female		Male	
L	52.37	0.691	50.17	0.697	50.10	0.698	49.73	0.700

3.2. Sensory measurements

3.2.1 *Demographics*

Of the 160 consumer involved in this study, 56% were female and 44% were male, with 98% of these consumers responsible for the cooking in the household. The average household size was 2.8 persons and the age distribution of the consumers is shown in Figure 1. The consumption frequency of meat meals in these households is detailed in Table 7.

In general, 71% of consumers involved in the study consumed a pork meal at least once a week and 93% at least every fortnight (Figure 2). The level of appeal of pork is shown to be consistent with other forms of meat (Table 8). Chops/cutlets were the preferred purchased cut of pork next to roast, while schnitzels and steaks were the least preferred (Figure 3), with consumers preferring to grill/BBQ/pan-fry and roast/bake pork (Figure 4). The majority of consumers (80%) preferred pork cooked medium to medium well done, with less than 5% preferring it medium rare (Figure 5).

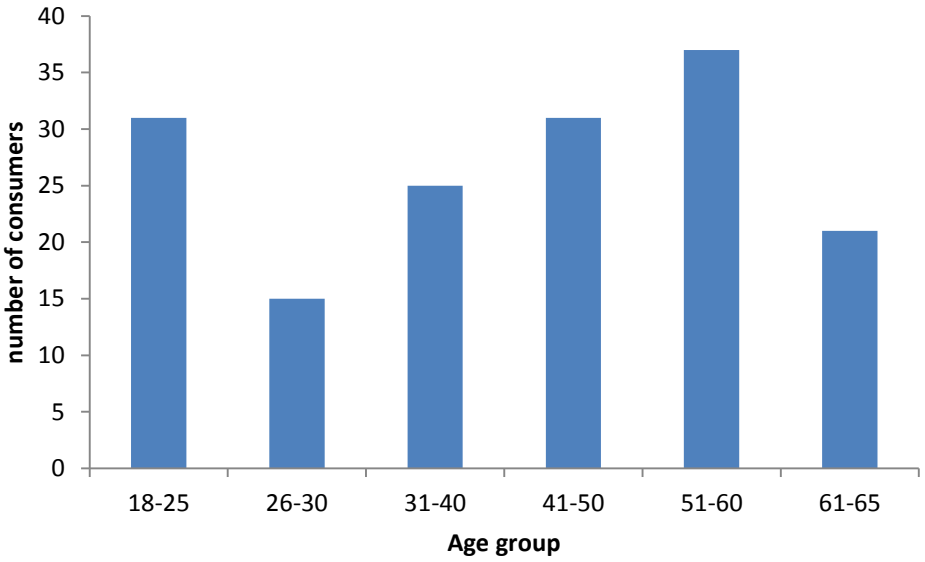

Figure 1: Age distribution of consumers involved in the sensory study (n-160)

Table 7 Frequency of consumption by consumers involved in this study of pork, lamb, beef, chicken and fish meals in the last week

	Number of meals in the last week			
	1	2	3	4
Pork	50.0	24.4	12.5	3.1
Lamb	48.1	21.3	3.1	0.0
Beef	37.5	29.4	15.6	1.9
Chicken	32.5	38.1	17.5	4.4
Fish	38.8	18.8	3.1	1.3

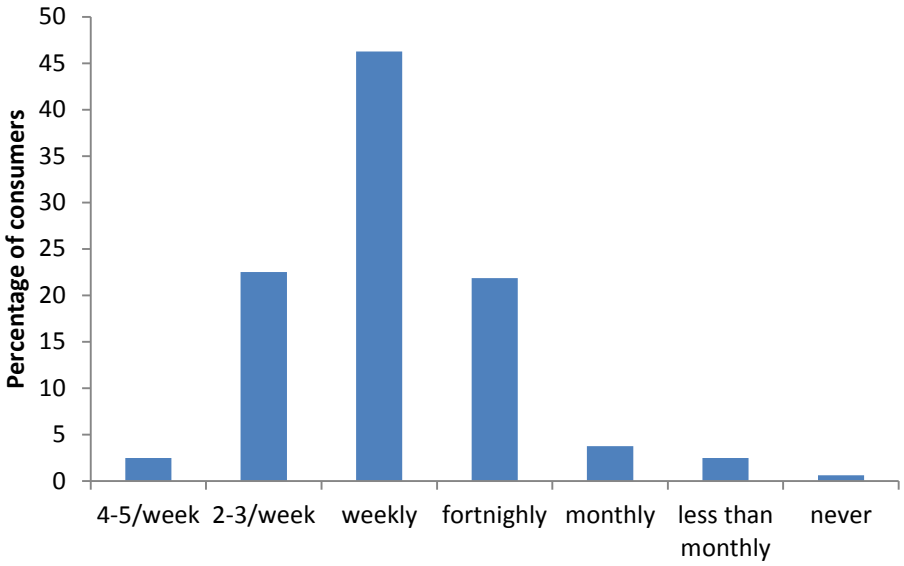

Figure 2. The frequency that consumers eat a pork meal

Table 8. Consumer ratings of level of appeal* (expressed as a percentage of consumers, n=160) of different meat species -

	Level of appeal				
	0-4	**5-6**	**7-8**	**9-10**	**Average**
Pork	6	26	52	16	7.03
Lamb	19	24	40	18	6.47
Beef	15	26	46	13	6.51
Chicken	7	18	48	27	7.33
Fish	26	24	33	18	6.02

* 0= not appealing to 10 highly appealing

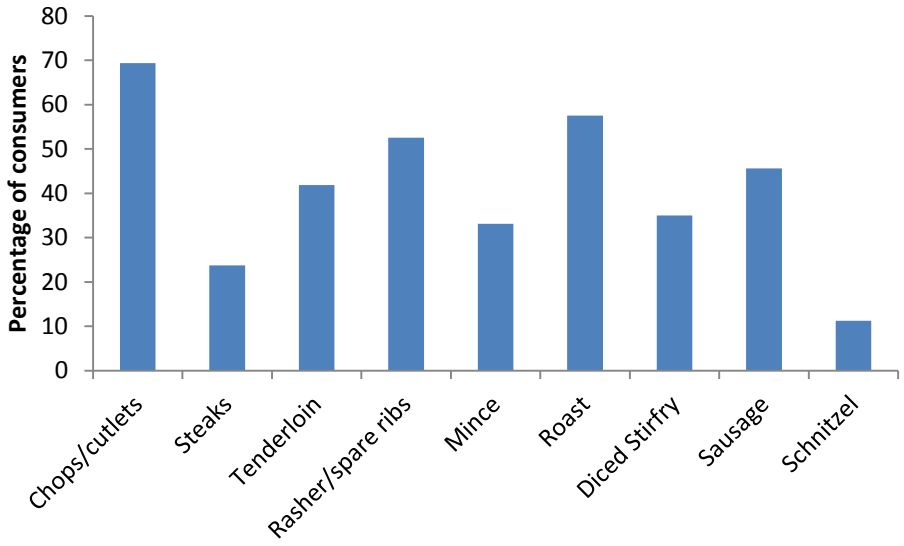

Figure3. Preferred cuts of pork by consumers involved in this study.

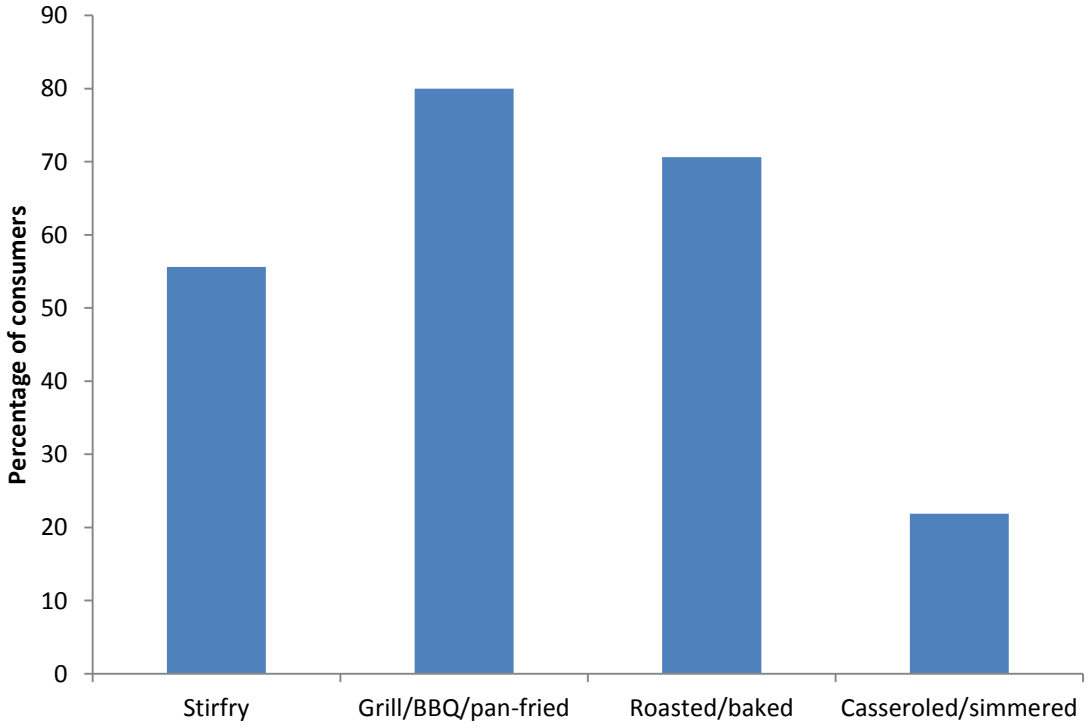

Figure 4. Preferred cooking method of pork by consumers involved in this study

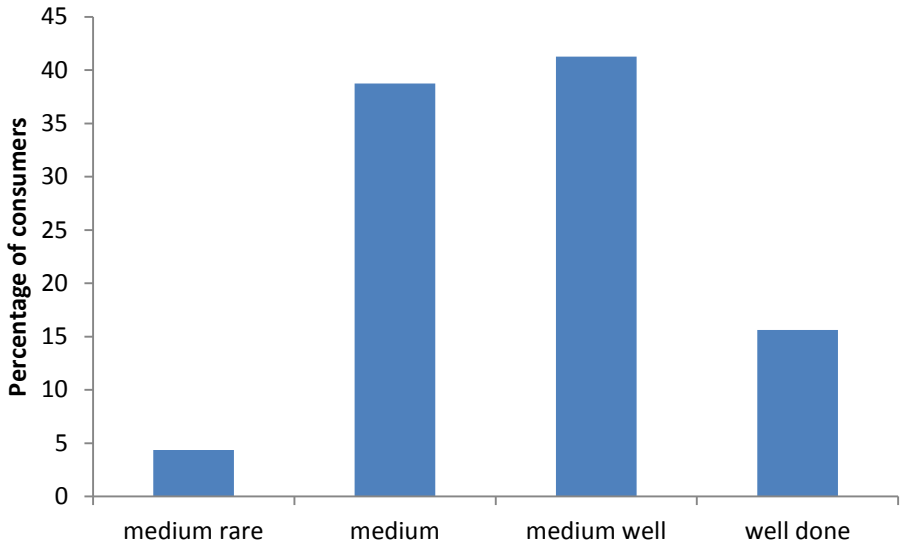

Figure 5. Preferred level of cooking for pork by consumers involved in this study

3.2.2 *Sensory results*

The summary of the consumer adjusted means data is presented in Table 9 for supply chain by sex and in Table 10 for pH category. The statistical outputs for the fixed effects model are shown in Table 11, while significantly different means are shown in Table 12.

Supply chain and sex alone did not significantly influence any sensory traits evaluated. Only pH category influenced overall liking ($P<0.05$); steaks from loins categorized as low pHu had a lower average overall liking score of 53.54±1.712 compared to normal pHu at 58.23±1.744.

Significant interactions between pH category and supply chain were found for quality grade ($P=0.027$), re-purchase intention ($P=0.045$) and aroma ($P=0.012$). Loin samples from SC1 with a normal pHu had higher quality grade and re-purchase intention scores, while the aroma from low pHu SC1 samples was the least preferred by consumers.

Table 9: Descriptive statistics for consumer adjusted sensory scores for each supply chain by sex.

	SC1									
	Female					*Male*				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
Overall liking	40	56.44	12.358	27.56	77.39	40	57.30	14.311	26.85	90.32
Tenderness	40	52.71	14.262	11.94	84.44	40	52.87	15.625	28.54	82.01
Juiciness	40	53.31	11.163	34.45	80.08	40	55.03	16.192	16.20	89.84
Flavour	40	57.54	10.901	29.67	76.47	40	58.95	12.045	34.48	87.52
Quality grade	40	3.27	0.499	2.17	4.17	40	3.28	0.591	2.22	5.12
Re-purchase intention	40	3.31	0.660	1.47	4.59	40	3.31	0.751	1.76	5.14
Aroma	40	61.07	11.650	29.76	79.21	40	61.81	10.278	35.97	80.16
	SC2									
	Female					*Male*				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
Overall liking	40	55.71	13.947	24.98	83.72	40	52.83	11.718	25.62	77.26
Tenderness	40	47.56	19.000	16.50	86.49	40	46.11	14.583	13.84	73.00
Juiciness	40	55.50	15.492	22.31	88.52	40	55.13	12.888	13.44	78.75
Flavour	40	59.68	11.157	27.60	81.26	40	55.41	11.152	25.09	76.42
Quality grade	40	3.19	0.558	2.13	4.29	40	3.07	0.492	1.96	4.00
Re-purchase intention	40	3.18	0.719	1.80	4.64	40	3.00	0.601	1.40	4.23
Aroma	40	65.56	11.650	30.04	81.46	40	65.20	10.450	45.05	84.52

Table 10 Descriptive statistics for consumer adjusted sensory scores against pHu category

	pH low					pH normal				
Variable	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
Overall liking	80	53.23	12.911	24.98	83.72	80	57.91	12.972	31.89	90.32
Tenderness	80	47.13	15.750	11.94	84.44	80	52.50	16.124	17.86	86.49
Juiciness	80	53.45	14.246	13.44	81.37	80	56.04	13.657	26.46	89.84
Flavour	80	56.43	11.632	25.09	81.26	80	59.36	10.903	33.50	87.52
Quality grade	80	3.12	0.510	1.96	4.29	80	3.29	0.555	2.13	5.12
Re-purchase intention	80	3.11	0.686	1.40	4.64	80	3.29	0.688	1.80	5.14
Aroma	80	61.84	11.451	29.76	80.47	80	64.98	10.582	30.04	84.52

Table 11. Statistical output for the fixed effects analysis for consumer adjusted sensory scores.

	supply chain			sex			pH Category			pH x supply chain		
	**NDF; DDF*	*F Value*	*P value*	*NDF;DDF*	*F Value*	*P value*	*NDF; DDF*	*F Value*	*P value*	*NDF; DDF*	*F Value*	*P value*
Overall liking	1;8	4.22	0.074	1;148	0.14	0.71	1;148	3.66	0.058			
Tenderness	1;8	1.76	0.22	1;148	0.23	0.63	1;148	4.93	0.028			
Juiciness	1;8	0.27	0.62	1;148	0.09	0.76	1;148	1.36	0.24			
Flavour	1;8	0.41	0.54	1;148	0.54	0.46	1;148	2.85	0.093			
Quality grade	1;8	2.14	0.18	1;147	0.57	0.45	1;147	2.63	0.11	1;147	5.31	0.023
Re-purchase intention	1;8	2.96	0.12	1;147	0.76	0.39	1;147	1.22	0.271	1;147	4.09	0.045
Aroma	1;8	4.37	0.070	1;147	0.02	0.88	1;147	3.4	0.0674	1;147	6.49	0.012

*Numerator degrees of freedom (NDF); Denominator degrees of freedom (DDF).

Table 12. Means (± standard error of the mean, sem) for consumer adjusted sensory scores for significant interactions only.

	pH x supply chain							
	Low pH				*Normal pH*			
	SC1		*SC2*		*SC1*		*SC2*	
	mean	*sem*	*mean*	*sem*	*mean*	*sem*	*mean*	*sem*
Quality grade	3.14	0.109	3.14	0.111	3.48	0.11	3.09	0.113
Re-purchase intention	3.22	0.156	3.11	0.160	3.57	0.156	3.01	0.163
Aroma	57.84	1.753	65.97	1.753	65.35	1.762	64.77	1.766

	pH			
	Low		*Normal*	
	mean	*sem*	*mean*	*sem*
Overall liking	53.54	1.717	58.23	1.744

The correlation coefficients between sensory attributes for all consumer tastings are shown in Table 13. Flavour and overall liking were most highly correlated and aroma least correlated with the other four attributes.

Table 13: Correlation coefficients between sensory attributes for all consumer tastings (n=600)

	Aroma	Tenderness	Juiciness	Flavour	Overall liking
Aroma	1.000				
Tenderness	0.241	1.000			
Juiciness	0.317	0.694	1.000		
Flavour	0.448	0.615	0.680	1.000	
Overall liking	0.368	0.799	0.753	0.847	1.000

Across all treatments, overall liking of pork was influenced, in order of importance, by flavour, tenderness and juiciness.

Overall liking= 0.64 + 0.550xFlavour + 0.331xTenderness+ 0.120xJuiciness (R^2=0.847, se 8.94). All coefficients were statistically significant (P<0.001), except aroma (P=0.966)

3.2.3 *Sensory fail and premium rates*

The percentage of samples that scored either 1 or 2 (fail) or 4 or 5 (premium) on both quality grade and re-purchase intention are presented in Table 14. The overall score matrix are presented in Tables 15 and 16. Steaks obtaining scores of 1 or 2 are considered to fail in eating quality. Of all the steaks tasted, 21% were considered to have poor eating quality and 29% of consumers would not re-purchase a loin steak that they tasted. Loin steaks from females in a normal pHu range performed the best with the lowest fail rates, while males from SC2 consistently had the highest fail rate despite the pH category.

Overall, 29.7% of samples were graded as above average (4) and 7.8% as excellent (5). These were also reflected in the re-purchasing decisions of consumers, with 24.2% of steaks obtaining a rating of probably would buy (4) 24.2% and 16.3% of steaks were rated as definitely would buy (5). Of all these, normal pH steaks from SC1 seemed to perform the best, with a greater number of steaks performing at a premium level compared to the other treatments.

Table 14. Percentages of consumer scoring a sample as premium (score of 4 or 5) eating quality and will re-purchase, and fail rates (scores 1 and 2) for supply chain by sex by pHu category.

	SC1				SC2			
	Female		Male		Female		Male	
	low	normal	low	normal	low	normal	low	normal
Premium								
Quality grade	30	47.5	37.5	47.5	31.3	40	32.5	33.8
Re-purchase intention	38.8	48.8	37.5	51.3	35	45	32.5	35
Fail								
Quality grade	22.5	10	25	18.8	21.3	23.8	26.3	25
Re-purchase intention	28.8	22.5	32.5	23.8	31.3	27.5	30	37.5

Table 15. Effect of supply chain, sex and pH category on percentage of consumer scores rated unsatisfactory (1) to excellent (5) for quality grade

	SC1				SC2				Total
	Female		Male		Female		Male		
	low	normal	low	normal	low	normal	low	normal	
Unsatisfactory (1)	5.0	0.0	3.8	1.3	2.5	3.8	7.5	3.8	3.4
Below average (2)	17.5	10.0	21.3	17.5	18.8	20.0	18.8	21.3	18.1
Average (3)	47.5	42.5	37.5	33.8	47.5	36.3	41.3	41.3	40.9
Above average (4)	27.5	38.8	23.8	38.8	21.3	28.8	28.8	30.0	29.7
Excellent (5)	2.5	8.8	13.8	8.8	10.0	11.3	3.8	3.8	7.8

Table 16. Effect of supply chain, sex and pH category on percentage of consumer scores rated from 1 (I definitely would not buy it) to 5 (I would definitely buy it) for re-purchase intention

	SC1				SC2				Total
	Female		Male		Female		Male		
	low	normal	low	normal	low	normal	low	normal	
I definitely would not buy it	7.5	0.0	7.5	5.0	6.3	10.0	16.3	7.5	7.5
I would probably not buy it	21.3	22.5	25.0	18.8	25.0	17.5	13.8	30.0	21.7
I might buy it	32.5	28.8	30.0	25.0	33.8	27.5	37.5	27.5	30.3
I would probably buy it	22.5	33.8	18.8	25.0	21.3	26.3	21.3	25.0	24.2
I would definitely buy it	16.3	15.0	18.8	26.3	13.8	18.8	11.3	10.0	16.3

3.3. pH analysis

Whilst an analysis of pHu category as a fixed effect and the treatment interactions involved offer an insight into the relationships of pHu, objective measures and sensory scores, the true relationship against a continuous range of pHu may provide a better understanding of these effects. This section presents data from an analysis using pH as a continuous variable against consumer sensory scores and meat quality objective measurements.

3.3.1 *Effect of pHu on consumer sensory scores*

The correlation coefficients for pHu and pH24 with the consumer sensory scores are shown in Table 17. All sensory scores correlated significantly with pHu except juiciness and aroma. Although these correlations were relatively weak, no correlations between pH24 and sensory scores existed. There was a stronger correlation between pHu and pH24; however this correlation was not as strong as expected since pH24 is often used as an indicator of ultimate pH.

Table 17. Correlation coefficients for pHu and pH24 between consumer adjusted sensory scores

	pHu	pH24
pHu	1.000	
pH24	0.357***	1.000
Overall liking	0.204**	-0.079
Tenderness	0.190*	-0.115
Juiciness	0.120	-0.024
Flavour	0.173*	-0.069
Quality grade	0.196*	-0.051
Re-purchase intention	0.165*	-0.045
Aroma	0.147	0.016

*** P<0.001; ** P<0.01; * P<0.05.

The statistical outputs for the analysis of pHu and pH24 as a continuous variable are shown in Tables 18 and 19. There was a positive effect of pHu on overall liking (P<0.01), tenderness (P<0.05), flavour (P<0.05) and quality grade (P<0.05) and an increase in pHu was associated with better consumer scores. Across the range of pHu, overall liking scores increased by 10 percent (Figure 6) and flavour increased by about 8 percent (Figure 7). A significant pHu by sex effect was observed for both tenderness and quality grade (P<0.05), with consumer scores for steaks from females only increasing by 22% for tenderness (Figure 8) and quality grade scores increasing by 14% (Figure 9) across the range of pHu tested.

No significant relationships of consumer sensory scores with pH24 as a continuous variable were observed.

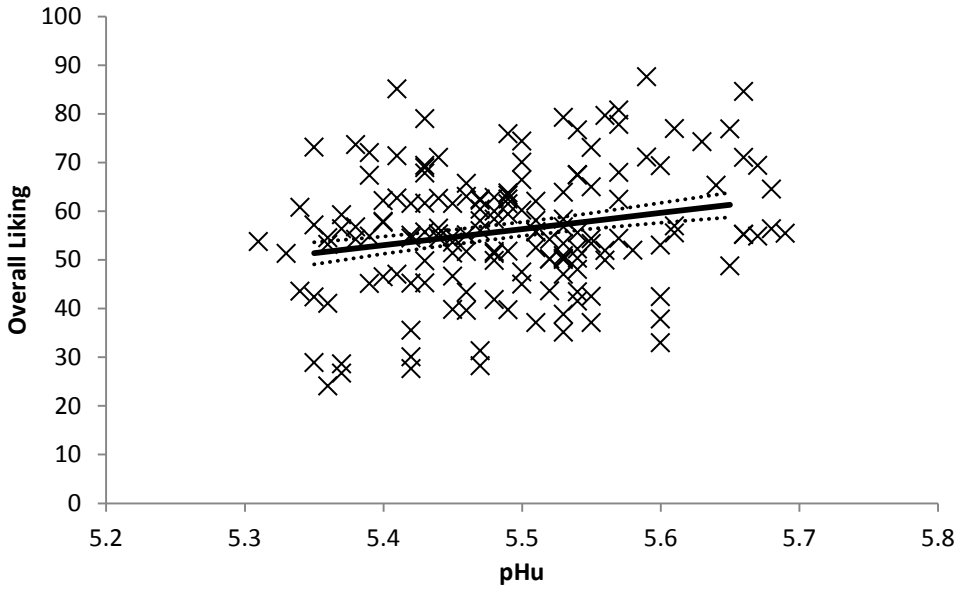

Figure 6. Relationship between pHu and overall liking for all samples from both supply chains and sexes.

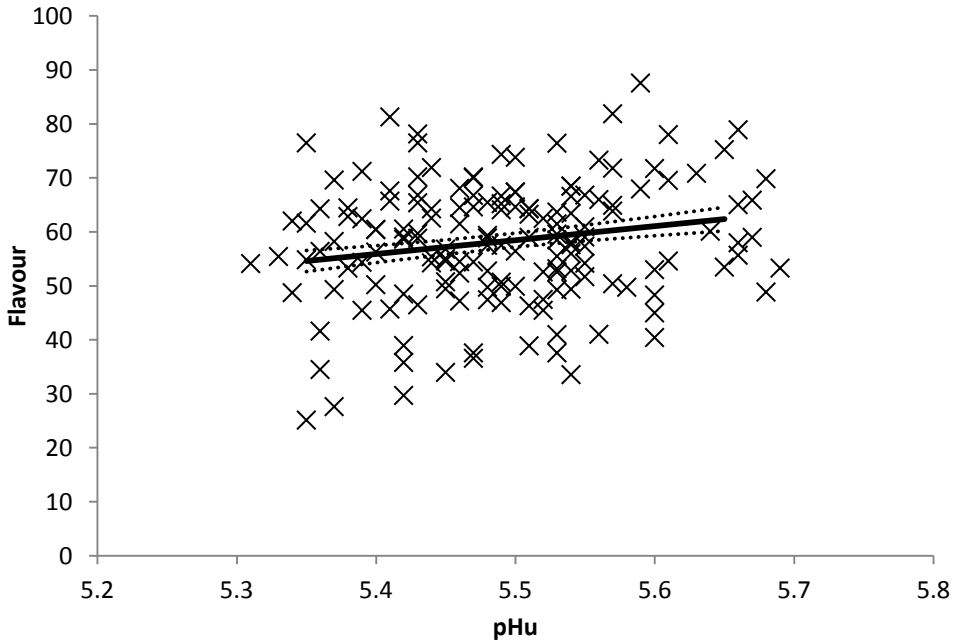

Figure 7. Relationship between pHu and flavour scores for all samples from both supply chains and sexes.

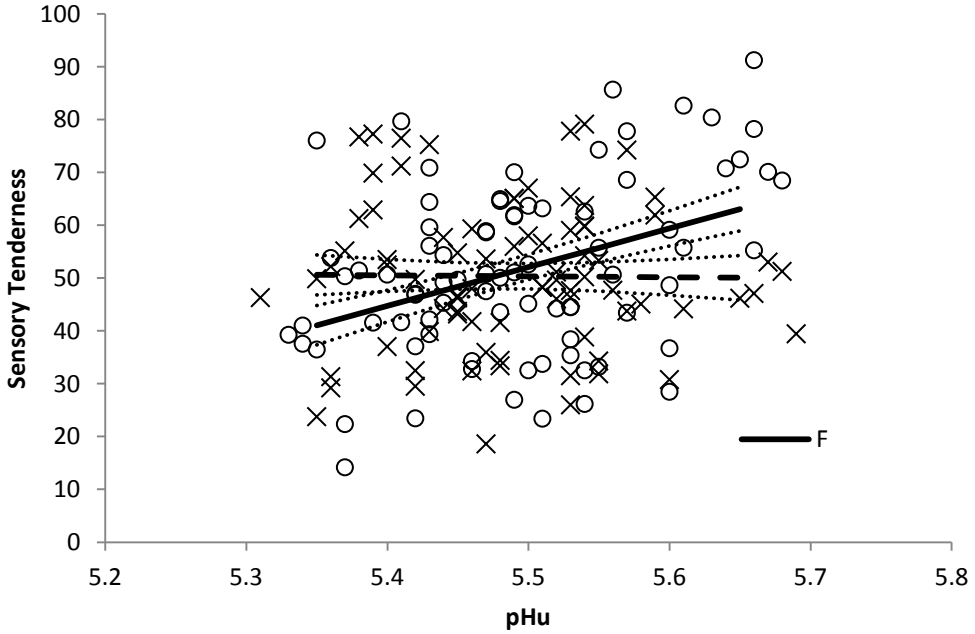

Figure 8. Relationship between pHu and consumer tenderness scores for loin steaks from males and females across both supply chains. Raw data for females are represented by “o” and raw data for males by “x”.

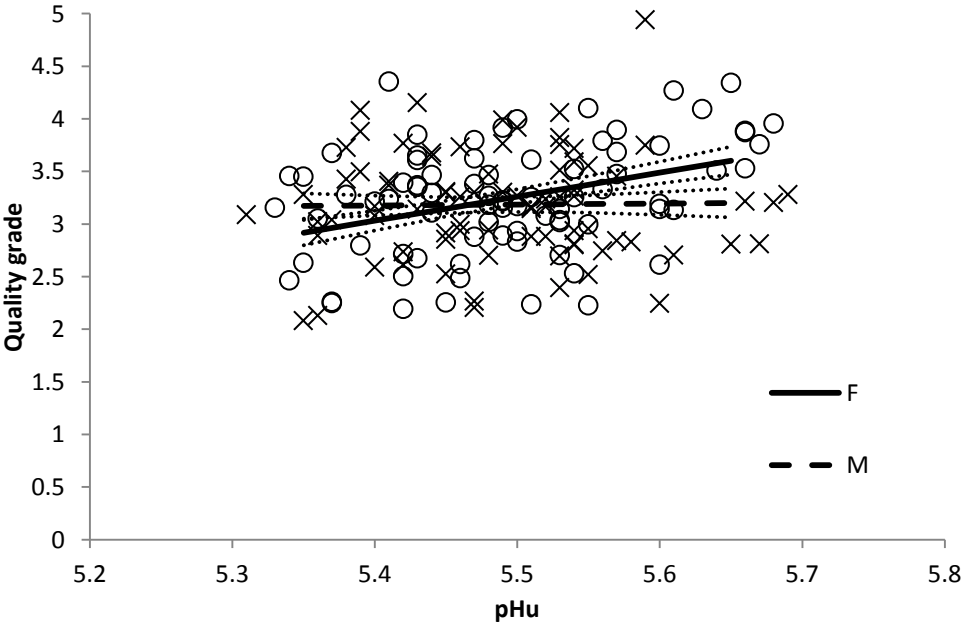

Figure 9. Relationship between pHu and quality grade scores for loin steaks from males and females across both supply chains. Raw data for females are represented by “o” and raw data for males by “x”.

Table 18. Statistical outputs for the linear mixed effects model for consumer adjusted sensory scores and pHu

	Supply chain			Sex			pHu			pHu x Sex		
	*NDF;DDF	F Value	P value	NDF;DDF	F Value	P value	NDF;DDF	F Value	P value	NDF;DDF	F Value	P value
Tenderness	1;8	2.07	0.1879	1;148	0.21	0.6485	1;148	6.73	0.0105			
Overall liking	1;8	4.11	0.0772	1;147	6.95	0.0093	1;147	5.19	0.0241	1;147	6.99	0.0091
Juiciness	1;8	0.18	0.6855	1;148	0.12	0.725	1;148	2.29	0.1319			
Flavour	1;8	0.57	0.4715	1;148	0.51	0.4784	1;148	5.38	0.0218			
Quality grade	1;8	2.84	0.1304	1;147	5.09	0.0255	1;147	5.31	0.0226	1;147	5.14	0.0248
Re-purchase intention	1;8	3.67	0.0916	1;148	0.6	0.4382	1;148	2.94	0.0886			
Aroma	1;8	4.66	0.0629	1;148	0.03	0.8666	1;148	3.42	0.0663			

*Numerator degrees of freedom (NDF); Denominator degrees of freedom (DDF).

Table 19. Statistical outputs for the linear mixed effects model for consumer adjusted sensory scores and pH24

	Supply chain			Sex			pH24		
	*NDF;DDF	F Value	P value	NDF;DDF	F Value	P value	NDF;DDF	F Value	P value
Tenderness	1;8	1.67	0.2324	1;148	0.25	0.6149	1;148	0.58	0.4457
Overall liking	1;8	3.72	0.0898	1;148	0.17	0.6782	1;148	1.33	0.2506
Juiciness	1;8	0.26	0.6231	1;148	0.09	0.7663	1;148	0.09	0.7613
Flavour	1;8	0.38	0.5547	1;148	0.57	0.4502	1;148	0.39	0.5334
Quality grade	1;8	2.2	0.176	1;148	0.48	0.4881	1;148	0.21	0.6508
Re-purchase intention	1;8	3.08	0.1175	1;148	0.65	0.4217	1;148	0.08	0.772
Aroma	1;8	5.11	0.0537	1;148	0.01	0.9126	1;148	0.04	0.8457

*Numerator degrees of freedom (NDF); Denominator degrees of freedom (DDF).

3.3.2 *Effect of pH on objective measures*

The correlation coefficients for pHu and pH24 with the objective meat quality measurements are shown in Table 20. All objective measures correlated significantly with pHu and pH24 except for a* value and shear force for pHu and a value only for pH24. For those measures that correlated with both pHu and pH24, generally the correlation was strongest with pHu, except for b value.

Table 20. Correlation coefficients for pHu and pH24 between objective measures

	pHu	pH24
pHu	1.000	
pH24	0.357***	1.000
Cook loss	-0.341***	-0.238**
Drip loss	-0.395***	-0.259***
L	-0.400***	-0.245**
a	-0.064	-0.155
b	-0.257**	-0.262***
Shear Force	-0.127	0.230**

*** P<0.001; ** P<0.01; * P<0.05.

The statistical outputs for the analysis of pHu and pH24 as a continuous variable against objective meat quality measurements are provided in Table 21. A decrease in pHu increased drip loss, cook loss, shear force and L values. Loin samples from SC2 lost more weight through drip over a 24 hour period than those from SC1 (P<0.05).Drip loss percentage decreased at the same rate as pHu was increased. Drip loss decreased by 1.7% across the range of pHu tested (Figure 10).

Similar to the fixed effect analysis, SC2 males had the highest cook loss percentage being about 3 percentage units higher than other treatments across the range of pH (P<0.05; 27.8-24.5%), however all treatments decreased linearly in percentage weight lost during cooking and this was worth about 3.3 percentage units across the range of pHu. A similar effect was observed for cook loss with pH24, however this effect was not present across the range of pH24. Shear force was significantly decreased as pHu and pH24 increased (Figure 11; pHu only), and across this range of pHu and pH24 was worth a decrease in shear force of 7 N (18%) and 6.3 N (16%), respectively.

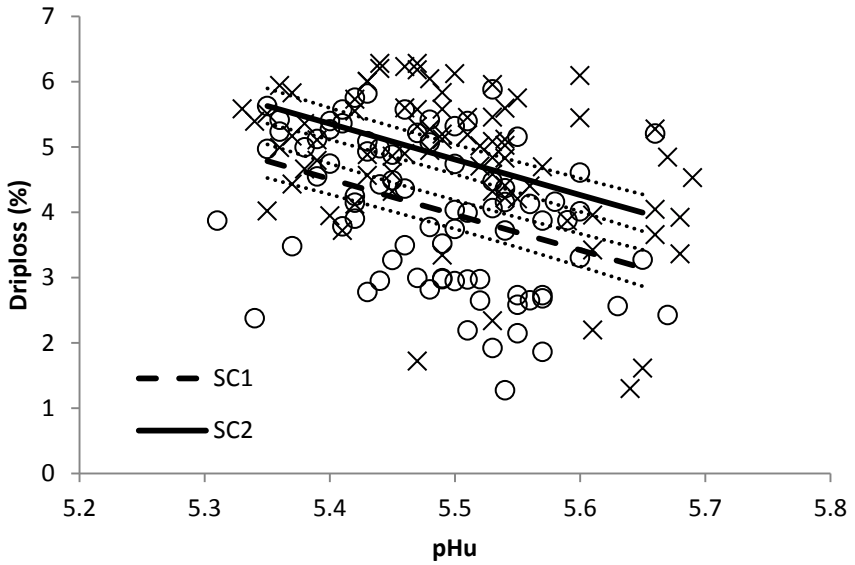

Figure 10. The relationship between pHu and drip loss percentage for Supply chain 1 (SC1) and 2 (SC2). Raw data for SC1 are presented as “o” and SC2 as “x”.

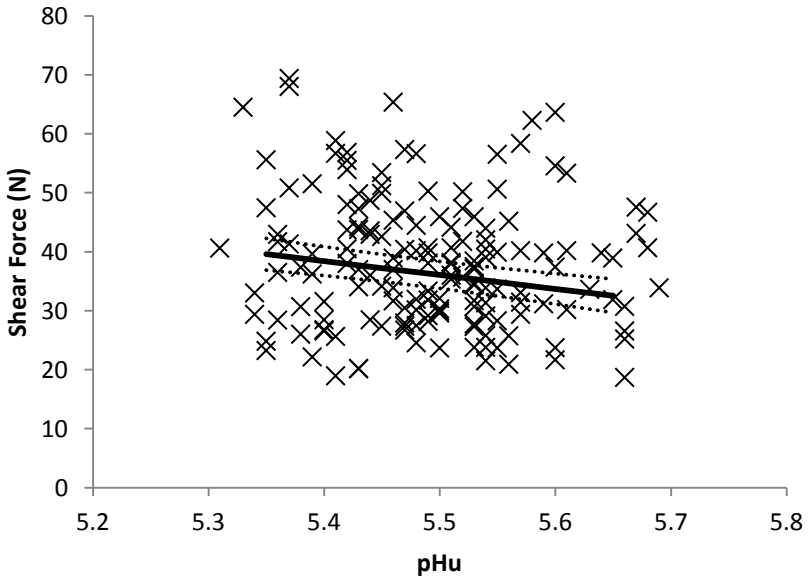

Figure 11. Relationship between pHu and shear force of loin.

As pHu declined, the L value (muscle lightness) of the loin increased (P<0.001). This increased lightness was worth 3.3 units of L (52.07 to 48.9 ±0.6) across the range of pHu. Loin muscles from males were darker than females (P<0.01). There was no effect of pH24 on L values, however other colour measurements of a value (P=0.05) and b value (P<0.05) both decreased when pH24 was higher, but this effect was not observed with pHu. Across the range of pH24, a value changed by 0.9 units and the b value by 1.2 units.

Table 21. The statistical outputs for the linear mixed effects model of objective score for ultimate pH and pH24

	Supply chain			Sex			pH			Supply chain x sex		
	*NDF;DDF	F Value	P value	NDF;DDF	F Value	P value	NDF;DDF	F Value	P value	NDF;DDF	F Value	P value
pH ultimate												
Drip loss	1;8	7.24	0.028	1;148	0.27	0.60	1;148	27.09	<0.0001			
Shear Force	1;8	0.14	0.72	1;148	1.63	0.20	1;148	5.13	0.025			
Cook loss	1;8	3.77	0.088	1;147	18.63	<0.0001	1;147	16.8	<0.0001	1;147	6.85	0.0098
L	1;8	1.63	0.24	1;148	8.15	0.005	1;148	13.34	0.0004			
a	1;8	0.11	0.74	1;148	3.53	0.062	1;148	0.93	0.33			
b	1;8	0.21	0.66	1;148	1.01	0.31	1;148	3.47	0.064			
pH at 24 hours												
Drip loss	1;8	8.71	0.018	1;148	0.31	0.58	1;148	7.29	0.008			
Shear Force	1;8	0.12	0.74	1;148	1.5	0.22	1;148	3.94	0.049			
Cook loss	1;8	3.26	0.11	1;147	17.77	<0.0001	1;147	2.41	0.12	1;147	7.2	0.0081
L	1;148	3.4	0.067	1;148	7.34	0.008	1;8	1.29	0.29			
a	1;8	0.06	0.82	1;148	3.64	0.059	1;148	3.85	0.052			
b	1;8	0.22	0.65	1;148	0.9	0.34	1;148	8.4	0.004			

*Numerator degrees of freedom (NDF); Denominator degrees of freedom (DDF).

3.4. Correlations between sensory and objective measures

Shear force correlated strongly with all consumer sensory scores, except aroma ($P<0.01$; Table 22). Cook loss had weak, but significant, correlations with all consumer sensory scores except like flavor and aroma ($P<0.05$), while drip loss was negatively ($P<0.05$) correlated with tenderness . There were no other significant correlations.

Table 22. Correlation coefficient matrix for objective measures and consumer sensory scores

	Overall liking	Tenderness	Juiciness	Flavour	Quality grade	Re-purchase intention	Aroma
Cook loss	-0.177*	-0.173*	-0.164*	-0.139	-0.157*	-0.182*	-0.084
Drip loss	-0.135	-0.176*	-0.138	-0.100	-0.122	-0.089	-0.093
L	-0.127	-0.107	-0.112	-0.101	-0.094	-0.052	-0.028
a	0.134	0.130	0.150	0.109	0.095	0.147	0.023
b	0.008	0.052	0.043	0.001	-0.030	0.050	-0.046
Shear Force	-0.310***	-0.416***	-0.225**	-0.261***	-0.276***	-0.297***	-0.120

*** $P<0.001$; $^{**}P<0.01$; $^{*}P<0.05$.

The statistical outputs for drip loss, cook loss and shear force against sensory scores are presented in Table 23. No outputs are provided for colour data as no interactions between colour and consumer sensory scores were significant. As drip loss decreased, overall liking increased. This increase was 7.7 % across the range of drip loss and worth about a 2% increase in overall liking for every 1% decrease in drip loss (Table 23). Sensory tenderness was also improved as drip loss decreased, but only in females ($P<0.05$). Across the range of drip loss, a 21% improvement in tenderness was observed in loins from females (Table 24).

A decrease in cook loss resulted in increased overall liking, tenderness and juiciness scores, by 11%, 13% and 10%, respectively, across the range of cook loss. Quality grade and re-purchase intention scores were also improved as cook loss decreased ($P<0.05$) by 8% and 12%, respectively, across the range of cook loss. Furthermore, across the range of shear force, overall liking, tenderness, juiciness and flavour scores were higher as shear force declined ($P<0.05$). The corresponding improvements were worth 14.7, 23.9, 11.4 and 10.7 % for overall liking, tenderness, juiciness and flavour, respectively, across the range of shear force. Loin cuts from SC1 were judged to be overall more tender than those from SC2 ($P<0.05$). Quality grade and re-purchase intention was also improved when shear force was lower by 10 and 14%, respectively, across the range of shear force.

Table 23. Statistical output for the linear mixed effects model for consumer sensory scores against drip loss, cook loss and shear force.

	supply chain			sex			Objective measure			Drip loss x sex		
	*NDF; DDF	F Value	P value	NDF;DDF	F Value	P value	NDF;DDF	F Value	P value	NDF;DDF	F Value	P value
					Drip loss							
Tenderness	1;8	0.6	0.45	1;148	0.19	0.66	1;148	4.02	0.047			
Overall liking	1;8	2.11	0.18	1;147	5.82	0.017	1;147	6.01	0.015	1;147	5.75	0.012
Juiciness	1;8	1.19	0.31	1;148	0.14	0.71	1;148	3.04	0.083			
Flavour	1;8	0.06	0.81	1;148	0.48	0.49	1;148	2.42	0.12			
Quality grade	1;8	0.97	0.35	1;148	0.4	0.53	1;148	3.34	0.070			
Re-purchase intention	1;8	2.02	0.19	1;148	0.57	0.45	1;148	2.02	0.16			
Aroma	1;8	6.41	0.035	1;148	0.02	0.88	1;148	1.36	0.25			
					Cook Loss							
Tenderness	1;8	0.58	0.47	1;148	0.05	0.82	1;148	5.79	0.017			
Overall liking	1;8	2.1	0.19	1;148	0.09	0.77	1;148	5.82	0.017			
Juiciness	1;8	1.38	0.27	1;148	0.84	0.36	1;148	4.29	0.040			
Flavour	1;8	0.04	0.84	1;148	0.03	0.87	1;148	3.6	0.060			
Quality grade	1;8	1.01	0.34	1;148	0	0.96	1;148	4.42	0.037			
Re-purchase intention	1;8	1.73	0.23	1;148	0	0.96	1;148	6.01	0.015			
Aroma	1;8	6.17	0.038	1;148	0.18	0.68	1;148	1.1	0.30			
					Shear Force							
Tenderness	1;8	2.13	0.18	1;148	0.04	0.85	1;148	16.63	<0.0001			
Overall liking	1;8	7.79	0.024	1;148	0.02	0.87	1;148	32.59	<0.0001			
Juiciness	1;8	0.18	0.68	1;148	0.28	0.60	1;148	8.33	0.005			
Flavour	1;8	0.28	0.61	1;148	0.31	0.58	1;148	11.22	0.001			
Quality grade	1;8	3.28	0.11	1;148	0.17	0.68	1;148	11.97	0.0007			
Re-purchase intention	1;8	4.32	0.071	1;148	0.29	0.59	1;148	11.94	0.0007			
Aroma	1;8	4.93	0.057	1;148	0.05	0.82	1;148	2.3	0.13			

*Numerator degrees of freedom (NDF); Denominator degrees of freedom (DDF).

Table 24. Effect of range in drip loss, cook loss and shear force on sensory scores (significant interactions only) - range differences and effect expressed per unit of each objective measure.

Drip Loss						
			min^	*max*	*range difference*	*per objective unit*
		Drip loss range(%)	1.5	5.5	4.0	
Overall liking		*Sensory score*	61.6	53.9	7.7	1.925
Tenderness	*Female**		66.9	45.6	21.3	5.325
	Male		51.3	50.5	0.8	0.200
		Cook loss				
			min^	*max*	*range difference*	*per objective unit*
		Cook loss range(%)	18	30	12	
Overall liking		*Sensory score*	61.4	50.5	10.9	0.908
Tenderness			57.4	44.1	13.3	1.108
Juiciness			59.8	49.8	10	0.833
Quality grade			3.4	3.0	0.4	0.033
Re-purchase intention			3.5	2.9	0.6	0.050
		Shear Force				
			min^	*max*	*range difference*	*per objective unit*
		Shear force range (N)	20	60	40	
Overall liking		*Sensory score*	62.2	47.5	14.7	0.368
Tenderness	*SC1*		63.8	39.9	23.9	-0.598
	SC2		57.4	33.5	23.9	-0.598
Juiciness			59.9	48.5	11.4	0.285
Flavour			62.7	52.0	10.7	0.268
Quality grade			3.4	2.9	0.5	0.013
Re-purchase intention			3.5	2.8	0.7	0.018

*Differences due to sex; ^ min and max relates to the min and max of the objective measure, sensory scores listed correspond to the min and max of the objective measurement

3.5. **Glycogen utilization**

Correlations of pHu and pH24 for lactate (measured at 72 h post-slaughter), residual glucose and total glycogen measured at slaughter are shown in Table 25. No pH category correlated with the amount of lactate measured at 72 hours. There was a strong negative correlation with pHu and residual glucose and total glycogen at slaughter (P<0.001), with a weaker correlation for both residual glucose and total glycogen with pH24 (P<0.01).

Table 25. Correlation coefficients for pHu and pH24 against IMF and glycolytic potential measures.

	pHu	pH24
IMF	0.047	0.062
Lactate	-0.126	-0.105
Residual Glucose	-0.554***	-0.235**
Glycogen	-0.490***	-0.245**

*** P<0.001; ** P<0.01; * P<0.05.

When statistically modeled, glycogen, lactate and residual glucose concentrations significantly altered pHu, however, only glycogen influenced pH24 (P<0.05; Figure 12). When glycogen levels in the loin were higher at slaughter, the pHu was more likely to be low (P<0.05) with concentrations above 60 µ moles at slaughter likely to result in a pHu below 5.5. This relationship was also observed in pH24 (P<0.05) but was to a much lesser extent. Although the correlation of lactate and pHu was very weak, a relationship between lactate and pHu was observed (Figure 13). When more lactate is produced at 72 hours the pHu will be lower (P<0.05), however, across the range of lactate in these samples a decrease of only 0.07 pH units was observed. Higher residual glucose at 72 hours will likely result in a lower pHu (P<0.05; Figure 14), and when no residual glucose is present, the pHu will likely be above 5.5.

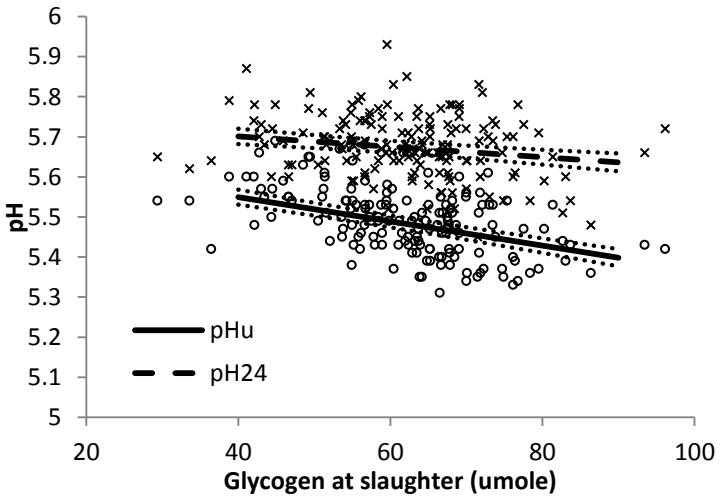

Figure 12. Relationship between glycogen at slaughter and pHu and pH24.

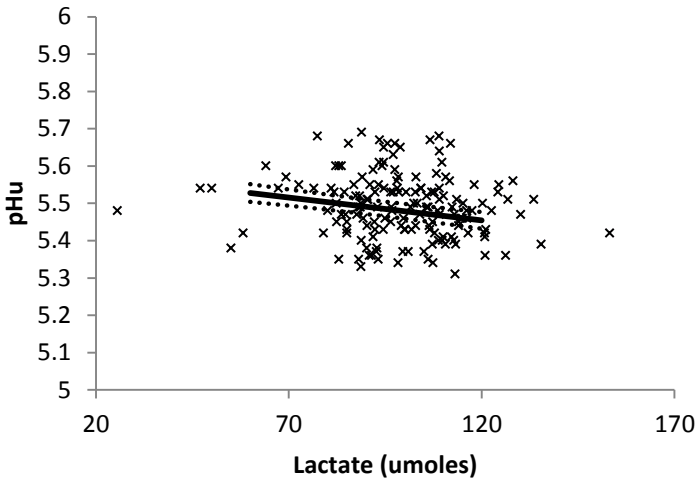

Figure 13. Relationship between lactate and pHu.

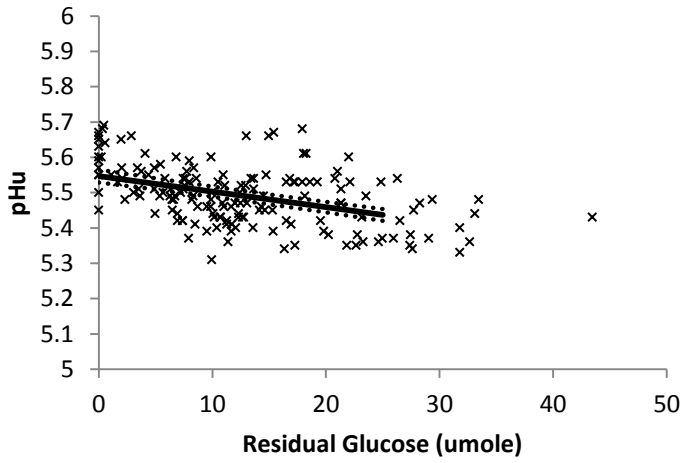

Figure 14. Relationship between residual glycogen and pHu.

The correlation between pH24 and pHu was significant ($P<0.05$) but considered weak ($r=0.35$). As a higher pH24 typically would result in a higher pHu (Figure 15), it was considered that using pH24 to predict pHu was unreliable due to the large variation in pH24.

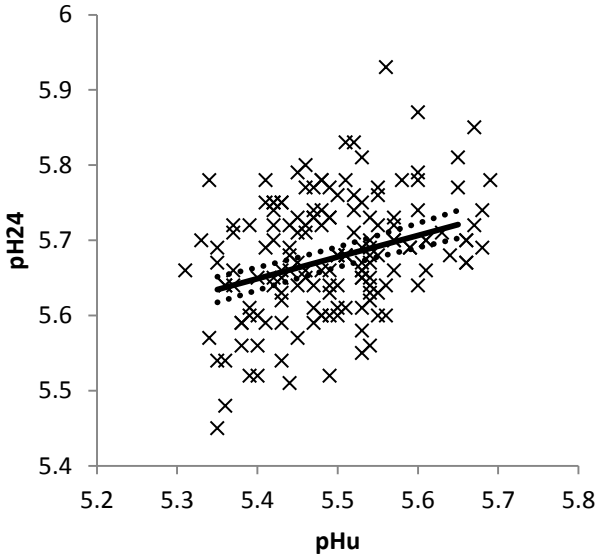

Figure 15. Relationship between pH24 and pHu.

No significant interactions of glycogen concentration at slaughter, lactate concentration and residual glycogen on any consumer sensory scores were found. There was also no effect of glycogen concentration at slaughter, lactate concentration and residual glycogen on objective meat quality measurements, except for drip loss, where the amount of glycogen at slaughter influenced percentage lost through drip ($P<0.05$; Figure 16). At lower levels of glycogen, less drip was recorded.

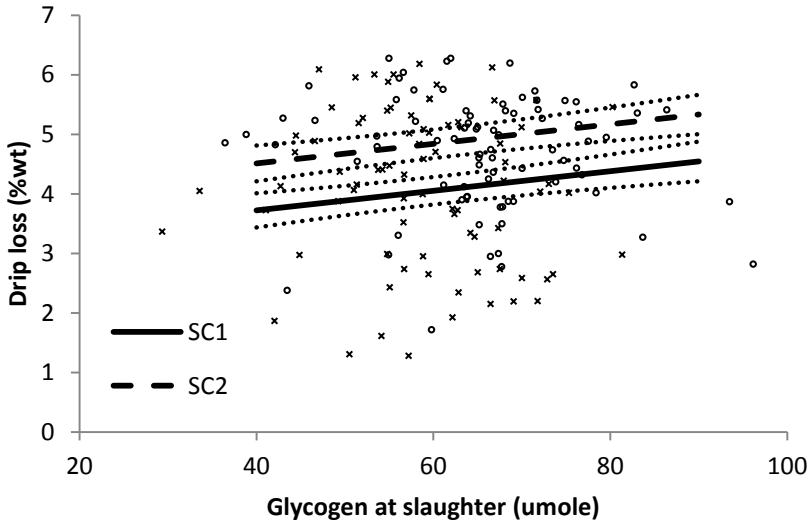

Figure 16. Relationship between glycogen at slaughter and drip loss for supply chain 1 (SC1) and supply chain 2 (SC2). Raw data for SC1 are presented as "x" and SC2 as "o".

3.6. **Intramuscular fat content**

There were no significant interactions with treatment and or any measures or sensory scores with IMF content, except b value ($P<0.05$). As IMF increased, steaks would be more yellow in colour (data not shown). Additionally, there was a sex effect of IMF with P2 fat depth ($P<0.05$). An increased P2 fat depth score increased the level of IMF in females, however, increased P2 fat depth of male carcases led to a decrease in IMF in the loin.

4. Application of Research

4.1. Sensory and objective eating quality in relation to ultimate pH

With the large fail rates observed in this study, it is important that the pork industry understands both the causes of product failure and what is different about those products that obtain a premium score. Most sensory scores are highly correlated and this is also true for the current study. However, some scoring categories are more likely to define overall eating quality, such as quality grade and overall liking. These two categories were the most influenced by the pHu range evaluated, and along with tenderness and flavour, improved as pHu increased. Any improvement in quality grade will reduce fail rates and place the product in a more premium category.

Consumer scores, in general, increased linearly from a pHu of 5.35 to 5.65 and it may be postulated that further improvement may be observed as the pHu increases beyond 5.65. Previous studies have shown that consumers prefer pork with a pHu closer towards 5.8 than that of 5.5 (Bryhni *et al.,* 2003), and thus it is likely that a further increase in sensory scores could be observed. However, the flavour and shelf life of fresh pork has been shown to be compromised when pHu exceeds 6.1 (Holmer *et al.,* 2009; Klont et al., 1998) and off flavours have also been noted to occur when the pHu drops below 5.2 (Bidner *et al.,* 2004). Thus the industry should keep in mind that an increase in pHu should be targeted for consumer sensory preference but only within a certain range.

The impact that pHu had on consumer sensory scores in the pHu range of 5.35-5.65 was relatively small (8-10% increase) compared to the influence of shear force, cook loss and to a lesser extent drip loss. Shear force was a good indicator of consumer sensory scores, correlating strongly with consumer tenderness scores, with lower shear force values improving overall liking by nearly 15%, quality grade by 10% and re-purchase intention by 14%. Because of the strong association of tenderness and shear force, and the large influence shear force has on sensory scores, improving tenderness is likely to be an important driver for improving eating quality and overall consumer acceptability. Many studies have shown that consumers value tenderness as an important meat quality attribute (Bouton *et al.,* 1975; Channon et al., 2003; Nam *et al.*, 2009; Poste *et al.*, 1993; Rees et al., 2003) and thus a focus on ways to optimize tenderness of pork is required.

Water holding capacity (WHC) of pork can have a large impact on overall meat quality as it is associated with sensory aspects (Huff-Lonergan *et al.,* 2002; Nam *et al.*, 2009) and with PSE meat (Barbut *et al.*, 2008; Torley *et al.,* 2000; Van Oeckel & Warnants, 2003). Although cook loss had a larger impact on consumer sensory scores than drip loss, an increased overall WHC improved overall liking scores of the pork steaks. Nam *et al.*(2009) found that there was no correlation of overall consumer acceptability of samples with decreased drip loss and or cook loss, however, as both cook loss and drip loss were found to correlate with tenderness in this current study as well as previous studies (eg. Huff-Lonergan *et al.*, 2002), it is not surprising that these two measures would influence overall liking.

Tenderness was an important driver of overall liking in this study. The likely driver of this outcome may bethe impact that pHu and pH decline had on tenderness and shear force is. Ultimate pH is known to influence sensory scores (Huff-Lonergan *et al.*, 2002; Nam *et al.*, 2009). Whilst pH24 may be a poor indicator of consumer sensory quality, both are likely to play a role in the development of tenderness profiles and moisture retention (Bendall & Swatland, 1988; Lindahl *et al.,* 2006; Rees *et al.*, 2003; Van Oeckel *et al.*, 2003).This

suggests that the influence that pH has on overall consumer sensory quality is due to the development of tenderness (perhaps through increased proteolytic enzyme activity) and improved moisture retention, but also possibly affecting the flavour of the product that the consumers are eating. Consumers have been known to describe low pH pork as having a sour flavor and it has been labeled as "acid meat" (Aaslyng *et al.*, 2007). Hence, pH may after all be the most important driver of consumer sensory preference due to its impact on sensory scores alone and the role that it plays in the development of important meat quality traits.

4.2. Effect of supply chain and sex on sensory and eating quality

There were several interactions of sex with both sensory and objective measures, typically with females performing better than males. These differences could be associated with the difference in metabolites and fat profiles between sexes. Females produced carcases with a higher P2 fat depth and this was also associated with an increased level of intramuscular fat (IMF). Although there was no benefit of IMF in the current study, likely due to IMF being too low, increased IMF has been shown to correlate with improved tenderness, drip loss and cook loss (Huff-Lonergan *et al.*, 2002).

Drip loss between supply chains was different with SC2 losing a greater percentage of weight through drip over 24 hours. Drip loss has been shown to be a factor of pH decline and can be influenced by chilling regimes (Lindahl *et al.*, 2006; Rees *et al.*, 2003) and increased early post mortem metabolism (Rosenvold et al., 2003); which may explain the difference between supply chains. This effect of supply chain was also observed when sensory tenderness scores were adjusted for shear force; pork steaks from SC1 achieved higher tenderness scores than SC2, despite no difference in shear force measures. Unfortunately, the early post mortem pH declines were not monitored in this study, thus an indepth explanation of the differences cannot be offered. However, it is plausible that there were differences in rates of pH decline both pre and post 24 hours post mortem. The mean pH for the two pHu categories differed by about 0.14 pH units at both 72 and 48 hours, however at 24 hours the pH differed by only 0.04 pH units. Although this might be explained by the relationship with glycogen at slaughter, a further understanding of the possible different late and early post mortem pH declines is needed.

4.3. Management of pH and meat quality

The decline in pH post mortem is primarily due to the utilization of muscle glycogen stores at slaughter to produce lactate, which in turn forms lactic acid and accumulates in the muscle post mortem. This accumulation of lactic acid coincides with an increase in H^+ and thus a drop in pH. This decline will typically stop once substrate (glycogen) has been exhausted or the activity of glycolytic enzymes is compromised. However the cessation of post mortem glycolysis in pork meat is a controversial topic. Unlike red meat, pork can reach a pH close to 5 and the fact that the post mortem metabolism continues at a pH this low has been the focus of many discussions (Hudson, 2012; Scheffler & Gerrard, 2007; Scheffler *et al.*, 2011). Thus the extent of pH decline is difficult to predict in pork and may not just be related directly to glycolytic potential, in the form of glycogen, pre-slaughter. Besides the continued pH decline, the rate of pH decline is an issue that needs to be optimized for meat quality. The following section will discuss the issues established in the current study of two supply chains in the Australian herd and possible scenarios to manage these meat quality issues.

Within the past two decades, breeding programs in the pork industry have focused on eliminating the Halothane and RN^- genes which have been responsible for poor meat quality (Barbut *et al.*, 2008; Rosenvold & Andersen, 2003). Currently, breeding programs are based around growth and increasing yield which may have an impact on meat quality traits. It has been shown that pork with more type I and IIA muscle fibers will likely have decreased drip loss, improved shear force and a higher early post mortem pH (Ryu & Kim, 2005), while pork with a high content of type IIB fiber had low tenderness (Karlsson et al., 1993). However, differences in fibre types do not necessarily influence sensory scores (Nam *et al.*, 2009). The differences observed in meat quality between type I/IIA and type IIB is likely due to the size of fibers (Ryu *et al.*, 2005) and the potential to store glycogen (Karlsson et al., 1999). Type IIB fibers have fast twitch, glycolytic metabolic characteristics and a high glycogen content, while type I has slow twitch, oxidative metabolic characteristics with low glycogen content (Karlsson *et al.*, 1999). Type IIA is an intermediate fast oxidative-glycolytic fiber. The difference in meat quality attributes between these fibre types is a direct result of the differing ability to store muscle glycogen.

In the current data set, larger pools of muscle glycogen at slaughter resulted in a lower pHu and pH24. These findings are supported by Choe *et al.*(2008). They found that higher glycogen stores are associated with faster early pH decline and lower pH24. Their findings were also associated with increased percentage of type IIB fibers. The current status of fibre type composition in the Australian herd is unknown, however the loin muscle is more glycolytic than oxidative and theoretically could have lower meat quality than muscles with a more oxidative potential. An investigation into optimizing the composition of fiber types for meat quality while maintaining good yield is essential. This work must also extend beyond the loin muscle.

High glycogen levels are likely to impact on pH decline and meat quality and many studies have investigated nutritional means to lower glycogen at slaughter to improve meat quality. Strategic finishing diets have been shown to reduce muscle glycogen and improve meat quality, namely WHC (Rosenvold et al., 2001; Rosenvold et al., 2002). Diets containing high fat (17-18%) and protein (22-24%) with low contents of digestible carbohydrate (<5%) were required to reduce muscle glycogen stores in the loin muscle without affecting performance (Rosenvold *et al.*, 2001; Rosenvold *et al.*, 2002). The high ratio of fat to carbohydrate is essential in replicating this effect on muscle glycogen stores (Rosenvold *et al.*, 2003). It was also found that this improvement in meat quality was due to a higher pH at 45 minutes post slaughter and not an increase in pH24 (Rosenvold *et al.*, 2001; Rosenvold *et al.*, 2002; Tikk, *et al.*, 2006). Although the true ultimate pH was not measured, it seems likely, due to the current data and the relationship of glycogen and pH, that pHu could be increased with strategic feeding. It has been shown that magnesium supplementation prior to slaughter improves pork quality by improving WHC (D'Souza *et al.*, 1999; D'Souza *et al.*, 2000) and these differences are likely due to increased lactate production immediately post slaughter (D'Souza *et al.*, 1999). The increased early metabolism could be explained by the discovery of two different pools of glycogen. Firstly, a smaller pool, named proglycogen is degraded in favour of the larger pool, macroglycogen (Rosenvold *et al.*, 2003), and the rate that proglycogen is metabolized will drive early post mortem glycolysis. Additionally, when glycogen-reducing feeding strategies are implemented, a reduction in macroglycogen pools and not proglycogen are observed, however, this interaction leads to a decreased rate of proglycogen metabolism (Rosenvold *et al.*, 2003). Thus, differences in drip loss between supply chains could be a result of early post mortem metabolism and this may need to be investigated in order to optimize early pH declines and WHC.

Processing techniques have been extensively studied in order to improve pork meat quality. These technologies include, but are not limited to, chilling rates and electrical stimulation. Each technology offers a significant benefit by altering pH declines and or the development of tenderness. However, the timing post mortem and the pH-temperature dependence is likely to be a large determinant of the meat quality outcomes (Rosenvold *et al.*, 2003). Channon *et al.*(2003) found that an accelerated pH decline as a consequence of electrical stimulation at 2 minutes post slaughter resulted in lower shear force and higher sensory tenderness scores, but did not affect on drip loss. The lack of effect of drip loss maybe due to the timing of stimulation early post mortem, influencing the early pH decline which has been shown to influence WHC (Rosenvold *et al.*, 2003). Coincidently, Rees *et al.*,(2003) found that early post mortem electrical stimulation increased drip loss. This resulted in a faster pH decline and shear force was decreased and tenderness scores improved. Thus implementing electrical stimulation is likely to improve tenderness development through an increased pH decline, resulting in a lower pH at higher temperatures.

Conversely, rapid chilling has been shown to improve WHC (Juárez *et al.,* 2009; Kerth *et al.*, 2001) but typically can result in tougher meat to conventionally chilled meat (van der Wal *et al.,* 1995), possibly due to slower pH declines (Tomović *et al.,* 2008). Thus, it is of significant importance for meat quality to optimize the pH-temperature window in which chilling should commence for the development of tenderness and improved WHC. Furthermore, this should also be adjusted for the different segments of pH decline (ie. early post slaughter, pH24, and beyond pH24) and this requires further investigation.

5. Conclusion

The effect of ultimate pH on consumer sensory scores for pork steaks has not been widely investigated. Although high fail rates were found in this study, it was found that a large proportion of steaks obtained high scores (4 or 5) for quality grade by consumers. It is these steaks that industry needs to try to replicate in order to produce a consistently premium eating quality product. It was established that low pHu has a negative impact on sensory and overall eating quality. Consumers preferred pork loin steaks towards the higher end of the pHu range and also steaks with lower drip loss, cook loss and shear force. Furthermore, the impact that tenderness has on overall liking , across a range of pHu, suggested that it is the primary determinant of eating quality and it can influence consumer re-purchasing decisions.

Objective measures were also highly influenced by pHu and pH24 (or rate of pH decline). The pHu and the rate of pH decline is influenced by the total glycogen available at slaughter and it is recognized that breeding programs, nutritional strategies and processing technologies can be manipulated to optimize pHu and pH declines. There are no current estimates of the normal pHu range in the current Australian herd, but it is suggested that the pHu is consistently low (below 5.5). Because of the large influence that pHu has on sensory and eating quality, it is of great importance that the Australian pork industry implements a strategy to improve the pHu and the consistency of pH declines to optimize meat quality.

6. Limitations/Risks

It is not considered that there is risk associated with these outcomes.

7. Implications

The results of this study have considerable implications to the Australian pork industry. Firstly, the low ultimate pH which occurs in the Australian industry contributes to a decrease in consumer eating quality, thus it is imperative that the industry addresses the low pH issue and its associated variability. If the industry continues to produce pork with a low pH, then it is likely that the eating quality of pork will continue to perform poorly against consumer taste panels, despite other attempts to improve eating quality. However, it is not only the ultimate pH that will influence the eating quality, but also the rate of the pH decline. It has been well noted in this report that pH declines are influenced by many factors, and thus all these factors must be monitored and technologies incorporated to lessen the variation in pH declines. It is likely that a combination of technologies is the best solution for decreasing the variability in pork eating quality, and these must be interacted and optimized to ultimately improve the eating quality which is driven by pH.

The Australian pork industry is now set with the task to investigate the variation of pH to a higher extent, in order to provide consumers with a high quality product. The first area of focus should be on the fibre typing of the current Australian herd. It is very likely that the industry's focus on feed conversion and lean yield has changed the fibre type composition to favour pigs with higher glycogen stores. This could be considered similar to the Hampshire effect which the industry breeding program focused on removing. By altering the fibre type composition to favour lower glycogen stores it is more likely that this will impact on overall pHu and pH declines, and as shown will improve eating quality. It is important to note that glycogen can be manipulated via nutrition, however to control the variation between animals will prove to be difficult. Thus by minimizing the variation in the animal's ability to accumulate glycogen stores may be the key to limiting eating quality variations. The current herd fibre type composition could also be responsible for diminished iron content in pork meat. Thus, the next step in this process would be to apply for an innovation project focused on fibre typing pork from different supply chains around Australia as well as monitoring pH and pH declines and implying technologies to optimize pH through the different stages of pH decline.

In the Australian industry there is no indication of what "normal" ultimate pH is, due to the continued pH decline beyond 24 hours post mortem, and it is difficult to audit this due to the unavailability of samples beyond 24 hours in an abattoir. However, having knowledge of the occurrence of low pHu in Australian pork is a necessity when considering the consequences of low pHu pork on eating quality. The authors can only speculate, but the likelihood of the pork having an ultimate pH below 5.5 is expected to far outnumber the occurrence of those above 5.5. Thus the product, more often than not, will perform poorly in sensory analysis and express poor meat quality.

8. Recommendations

Based on these implications, the following recommendations for the Australian pork industry are given below:

- Ultimate pH must be increased. This will coincide with improved tenderness, WHC and increased consumer liking. The occurrence of low pHu must be quantified, as well as the fibre type content of the current Australian herd. Fibre type compositions have the greatest ability to control variations in glycogen stores and should be studied and adjusted to benefit product consistency. These studies need to be performed on multiple muscle types and not just the loin.
- Technologies need to be implemented to slow early post mortem pH declines. Early post mortem declines are likely to have the greatest impact on WHC, thus efforts must be made to slow the metabolism early post mortem. Ways to accomplish this may be through minimizing stress at slaughter, lowering glycogen content, and investigating the influence of early post mortem processing factors such as scalding baths.
- The rate of pH decline during chilling is likely to be a large driver of tenderness and thus having a large impact on consumer overall liking. Variations in chilling regimes are likely to have the most influence in this and the carcases will not reach a pH temperature window that is ideal for the development of tenderness. This may also mean the incorporation of electrical stimulation units before chilling.
- An understanding of the different stages of pH decline is an absolute requirement in order to minimize carcase variation. Early declines are highly correlated with WHC, and pre-24 declines tend to alter tenderness profiles, while the influence of late pH decline (post 24 hours) to pHu affects overall acceptability - this needs further investigation. Any strategies incorporated to improve pork quality must take these three stages of pH decline into account.
- If fibre types are not the cause of changes in pH declines and glycogen content, then cost-effective nutritional regimes should be implemented to lower glycogen at slaughter. However, consistency between animals will be difficult to accomplish.
- For overall eating quality, increasing IMF is essential. The current levels of IMF are much lower than the acceptable level for increasing consumer like. Will IMF play a bigger role in sensory scores and increasing other objective measures known to influence consumer liking? Would this be a benefit of larger carcase sizes?

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