Verification of eating quality pathways to produce consistently high quality pork

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High Integrity Australian Pork

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Executive Summary

Improving the positioning of Australian pork through differentiation is required for the development of new export and domestic market opportunities, particularly with the increasing threat of fresh pork imports into Australia. Consistent availability of pork that meets eating quality expectations is required to drive consumer demand and increase purchasing frequency. Rather than importing pork into Australia from our major competitors, in North America and Denmark, the approach taken in this study was to undertake a simulation study involving Australian pigs, using feed ingredients typically used in US and Danish diets and slaughtering animals at heavier average liveweights than Australian pigs and comparing pork and eating quality attributes with that of typical Australian pork. The hypothesis of this study is that the effect of increased age at slaughter will result in increased intramuscular fat of pork and together with ageing of pork for 28 d, rather than 7d, will reduce the fail rate of pork to less than 10%.

This study aimed to evaluate whether nutritional management/age at slaughter and ageing period can influence pork eating quality of loin and silverside muscles and to quantify Australia's competitive position on an eating quality basis.

This study was designed as a 3 (dietary treatment/slaughter age) x 2 (ageing period) x 2 (cuts) factorial study. A total of 75 crossbred female pigs (25 per dietary treatment/slaughter age group) were randomly allocated at 16 weeks of age to one of three nutritional treatments matched for digestible energy (13.6 MJ DE/kg) and total lysine (0.93-0.95%) fed for either 4, 5 or 8 weeks prior to slaughter. After slaughter, the median 20 animals per treatment were selected and the loin and silverside muscles were obtained from the left side of each carcase at boning. Loin and silversides were prepared into steaks and roasts, respectively, with ageing treatment of 7 or 28 d post-slaughter allocated within muscle. Steaks were cooked to achieve an endpoint temperature of 70°C and roasts were cooked to a 75°C internal temperature. A total of 240 consumers were involved in this study, each tasting five samples within a session (total evaluations = 1200).

The key findings from this study were:

- Dietary treatment/age at slaughter did not influence sensory attributes of pork. This suggests that relatively small differences in pork sensory quality due to slaughter weight/dietary treatment do not necessarily discount the inclusion of heavier carcases in an eating quality system for Australian pork.
- Extended ageing for 28 d did not result in additional improvements in pork sensory quality compared with ageing for 7 d for both the loin and silverside.
- The overall fail rate (quality grade score) of pork loin steaks was 11.5% - almost meeting the target cut off of <10%. In contrast, the fail rate of the silverside was 22.6% for quality grade score.
- Further research to reduce the fail rate of the silverside primal to less than 10% is required.
- Intramuscular fat levels were very low in the loin muscle, averaging 0.47±0.31% and for the silverside 2.03±1.23%.
- Overall liking of pork was influenced, in order, by flavour, juiciness and tenderness.

The outcomes of this study indicated that further work is still required to optimise eating quality pathways to deliver different pork cuts to our consumers with fail rates of <10%.

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1 Introduction

Eating quality variability of Australian pork remains a significant issue that needs to be overcome for ongoing industry sustainability. Both Australian Pork Limited and the Pork CRC are contributing significant funding to determine the impact of key factors on eating quality attributes of fresh pork for the development of a predictive model to enable the industry to produce pork that consistently meets consumer expectations for high quality. Channon, D'Souza, Hamilton, & Dunshea, (2013) determined the effect of sex (entire male, female and surgical castrate), ageing period (2 or 7 d post-slaughter), cut type (loin, , cooking method (roast, stir fry, grill) and endpoint temperature (70 or 75°C) on eating quality parameters using pigs from one major supply chain as well as the effect of soy lecithin supplementation on eating quality attributes of pork. The influence of other factors, including age at slaughter and extended ageing, still need to be quantified as well as the need to obtain information on the eating quality performance of pork from other genotypes.

The need to differentiate Australian pork has increased given the New Zealand Ministry of Primary Industries decision to lift restrictions on the importation of fresh pork cuts in packs of 3kg or less from countries where Porcine Reproductive and Respiratory Syndrome is present. This threat to the Australian pork industry is largely considered to be second only to bio-security in terms of level of threat to the Australian pork industry. As studies have not been conducted comparing Australian pork with pork from different countries on eating quality performance, our ability to differentiate Australian pork from pork from other sources on an eating quality basis is not known.

Improving the positioning of Australian pork through differentiation is required for the development of new export and domestic market opportunities, particularly with the increasing threat of fresh pork imports into Australia. Consistent availability of pork that meets eating quality expectations is required to drive consumer demand and increase purchasing frequency. Rather than importing pork into Australia from our major competitors, in North America and Denmark, the approach taken in this study was to undertake a simulation study involving Australian pigs, using feed ingredients typically used in US and Danish diets and slaughtering animals at heavier average live weights than Australian pigs and comparing pork and eating quality attributes with that of typical Australian pork. The hypothesis of this study was that the effect of increased age at slaughter will result in increased intramuscular fat of pork and together with ageing of pork for 28 d, rather than 7d, will reduce the fail rate of pork to less than 10%.

This study aimed to:

- evaluate whether nutritional management, age at slaughter and ageing period can influence pork eating quality of loin and silverside muscles
- quantify Australia's competitive position on an eating quality basis.

2 Methodology

A total of 75 crossbred female pigs (25 per dietary treatment/slaughter age group), from a piggery located in South East Queensland, were randomly allocated at 16 weeks of age to one of three nutritional treatments matched for digestible energy (13.6 MJ DE/kg) and total lysine (0.93-0.95%) (Table 1). These were Diet A: 77% corn and 16% soybean meal (14.9% crude protein (CP)), slaughtered at 24 weeks of age (168 d); Diet B: 71% wheat and

10% canola meal (16.3% CP, restricted animal material (RAM) free) slaughtered at 21 weeks (147 d) and Diet C: 46% wheat and 30% sorghum (16.0% CP) slaughtered at 20 weeks (140 d). Pigs in Diet A group also received a second pre-sale diet from 21 weeks: 81% corn and 12% soybean meal (13.4 MJ DE/kg, 0.76% total lysine, 13.0% CP).

Table 1: Diet composition and specifications used to simulate in this study fed to pigs from 16 weeks of age until slaughter

Treatment	A		B	C
Duration of feeding (weeks)	16-21	21-24	16-21	16-20
Sorghum				30.0
Wheat			71.44	45.83
Maize	77.35	~~80.6~~		
Millrun			10.0	10.73
Canola meal			7.53	5.0
Soybean meal	16.2	11.5	7.47	1.6
Blood meal				2.1
Meat meal				2.8
Limestone	1.31	1.09	1.65	1.0
Dicalphos	1.2	2.0	0.53	0.067
Salt	0.3	0.2	0.2	0.2
Choline chloride	0.027	0.07		0.03
M.H.A. calcium	0.02		0.027	0.047
Lysine HCL	0.28	0.23	0.3	0.3
Threonine			0.013	0.02
Phytase	0.01	0.01	0.01	0.01
Deodorase	0.1	0.1	0.1	0.1
BN Grower premix	0.2	0.2	0.2	0.2
Stockfeed blended oil			0.53	
Bentonite	3.0	4.0		
DE (MJ/kg)	13.60	13.40	13.60	13.60
Crude protein (%)	14.93	12.95	16.31	15.96
Crude fibre (%)	2.91	2.71	3.87	3.41
Lysine (%)	0.93	0.76	0.95	0.95

The intention of this study was to produce pigs of targeted liveweight specifications: Diet A 130±5 kg, Diet B 100±5 kg and Diet C 90±5 kg, respectively. Animals allocated to the dietary treatments A, B and C were fed for a total of 8, 5 and 4 weeks, respectively. Feeding of pigs in Diet A commenced in early November 2012, for slaughter scheduled for 15 January 2013. Pigs in each nutritional/slaughter age treatment were housed in one group throughout the feeding period, with the exception of pigs fed Diet A, where they were held in one group until 21 weeks of age and then split into two pens, for space allocation reasons. On the day prior to slaughter, each animal was weighed and individually tattooed to allow carcases to be identified in the chiller.

Animals were removed from feed, loaded and penned by nutritional treatment on the truck to avoid mixing and then transported for 2:50 hours to a large commercial abattoir, located 170 km from the piggery. Pigs were group housed according to treatment in lairage in solid concrete walled pens fitted with open steel gates, with *ad libitum* access to water via nipple drinkers. Following overnight lairage for 17 hours, all animals were slaughtered the following morning at the commencement of production. Pigs in each treatment were moved separately to the point of stunning with minimal handling and stunned using 95% carbon dioxide (Butina, Denmark). Carcases were scalded in a scald tank set at 62°C for 6.25 min, dehaired for 2 min in a tumbler, brushed for 30 sec, flamed prior to evisceration and dressing. The stun to scale time was 29 min and stun to chill time was 50 min post-slaughter.

Hot carcase weight (Trim 1, AUS-MEAT Ltd., Brisbane) and fat depth at the P2 site, using PorkScan (PorkScan Pty Ltd, Canberra, Australia) was measured and recorded for all carcases. Carcases were then further trimmed to Trim 18 (AUS-MEAT Ltd., Brisbane) and split prior to chilling. Carcases were placed in the same chiller, fitted with overhead fans, and conventionally chilled according to standard commercial practice for 24 hours, until a deep butt temperature of 4°C was attained. Hot carcase weight and P2 fat depth were used to select the median 20 pigs from each treatment for further meat and eating quality assessment. Carcases were then labelled with the carcase number using a crayon on the skin overlying the loin (*M. longissimus thoracis et lumborum*) and silverside (BF; *M. biceps femoris*) on the left side only.

Measurements of muscle pH and temperature decline post-slaughter were made in the loin from the left side of each carcase, adjacent to the P2 site at 45 min, 90 min, 3 h and 6 h post-slaughter using a portable pH meter fitted with a polypropylene spear-type gel electrode and a separate temperature probe. Meat colour of the flank muscle was also measured using a Minolta Chromameter CR-400 at 90 min, 3 h, 6 h and 24 h post-slaughter.

At 24 h post-slaughter, cold carcase weight was obtained and carcases were boned. Estimated chill loss was determined by estimating AUS-MEAT Trim 18 for all carcases and expressing the difference (resulting from chilling) between estimated Trim 18 hot carcase weight and cold carcase weight as a percentage. Outcomes from Channon et al. (2013) were used to select cuts and endpoint temperatures in this study. Boneless, rind-on loin and silverside primals were collected from the left side of each carcase. These primals were then prepared into the required cuts for both sensory and meat quality assessment by experienced boning room personnel.

Ageing period (7 or 28 days) for each loin steak and silverside roast piece was allocated on each primal. For the loin, a 2-3 cm slice was firstly removed from the caudal end and a total of ten 2.5 cm thick steaks were then sliced, de-rinded and denuded of subcutaneous fat, labelled and individually vacuum packaged. The loin was regarded as five sections, with each section containing two steaks, to enable ageing period to be allocated along the length of the loin as well as to allow steak position to be assessed. For odd numbered carcases, the first slice from each cut was allocated to 7 d ageing, with the next piece allocated to 28 d ageing, with this ordering continuing for all 10 steaks. For even numbered carcases, the first slice from each cut was allocated to 28 d ageing and the second to 7 d ageing, with this ordering continuing for all 10 loin steaks. The remaining loin piece was used for objective meat quality measurements. For the silverside, two 7 cm

pieces, for roasting, with rind and subcutaneous fat remaining, were then cut, labelled and individually packaged, with the remaining muscle used for objective meat quality measurements. All steaks and roast pieces were individually labelled, vacuum packaged, boxed within cut and ageing period and held at 2-4°C prior to and during transport. This experiment was therefore a 3 (country group) x 2 (ageing period) x 2 (cuts) factorial designed study. .

Samples for sensory analysis were sent via refrigerated transport from the abattoir to SARDI, Waite Campus, Urrbrae, South Australia where they were placed in chillers running at 0.5-0.6°C until frozen at either 7 or 28d post-slaughter.

2.1 Objective measurements

Muscle pH, temperature and meat colour was determined at 1, 7 and 28 days post-slaughter. Muscle samples from all muscles were 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.

At 7d post-slaughter, the vacuum packaged samples allocated to objective measurements from the loin and silverside was removed from the bag and purge loss determined. Each loin was then divided into a total of four sections – two for Warner-Bratzler shear force (WBSF) and two for drip loss, colour and muscle pH, with ageing treatment allocated based on carcass number as previously described for sensory samples. With cutting commencing from the caudal end, the first two sections were prepared into 70±5 g blocks for Warner-Bratzler shear force (WBSF) assessment. Samples were then bagged, labelled and either frozen at -20°C until required for analysis (7d aged samples) or held at 0-2C for an additional 21d and then frozen (28d aged samples). The next two sections were used for drip loss, colour and muscle pH. For the sample allocated to 7d ageing, a 40 g block for drip loss assessment was prepared, once colour and muscle pH was assessed. The sample allocated to 28 d ageing was weighed, labelled and vacuum packaged and stored at 0-2C for an additional 21d, upon which drip loss, colour and muscle pH was assessed. Due to lack of muscle, the objective sample from each silverside was allocated to one ageing period only based on carcase number – silverside muscles from odd numbered carcases were aged for 7d post-slaughter and those from even numbered carcases were aged for 28d post-slaughter. Muscle pH and colour were measured on all silversides at both 7 and 28d post-slaughter.

Drip loss was determined using a modified method of Rasmussen and Andersson (1995). A sample of pork loin was cut to a 40 g cube, weighed and weight recorded. The sample was then wrapped in 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 towelling and reweighed to determine percentage drip loss.

Samples for intramuscular fat measurement were obtained from loin and silverside from the left side of each carcase, labelled, individually vacuum packaged, frozen and

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 either 70 or 75°C until an internal temperature of 70 or 75°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 cooking 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).

2.2 Sensory assessment

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

Protocols for the preparation and cooking of pork loin steaks and silverside roasts were as detailed by Channon et al. (2013) as part of a previous pork CRC funded project (3A-103 1112). Loin steaks and silverside roasts were cooked to achieve an endpoint temperature of 70 and 75°C, respectively. The consumer sensory sessions were conducted at one central location at the University of South Australia (UniSA) sensory facilities based at the City East campus in Adelaide.

2.2.1 Consumer Recruitment

Consumers were recruited by an independent recruitment company (Intuito Market Research). The early process for recruitment included emailing their extensive database of consumers willing to participate in taste testing as well as running advertisements in local Adelaide newspapers (The Advertiser and Sunday Mail).

The specifications for recruitment were that all participants needed to be consumers who had eaten fresh pork (not bacon or ham) in the past month and who were aged between 18 and 65 years. Butchers and other people working with meat production and sales were excluded. Individuals (n=240) were asked to join a panel of eight consumers for approximately one hour at varying times of the day from 10.00 am to 6.00 pm with three sessions per day on three pre-determined days per week.

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 generated of over 1,000 consumers. Participants were given an honorarium for their participation in the study and were used only once.

2.2.2 Allocation of Frozen Samples into Sensory Sessions

The pork samples were transported to SARDI Waite campus and arrived on 21 January 2013. The cartons containing the samples were stored in a 0.5°C chiller for 7 or 28 d and

then placed in a freezer at -18°C until required for sensory analysis. At this time, the samples were removed from the cartons and sorted into their pre-allocated sensory sessions.

The sorting was undertaken in a controlled temperature room at SARDI. For each sensory session involving eight consumers each, 20 loin steaks and 4 silverside roasts from two sides were used.

Duplicate copies of a one page session labelling document were prepared in advance for every session to indicate which samples were required for the sessions. The document showed the session number, carcase number, ageing period and a list of the 4 digit codes for each sample required for each steak or roast. Outer labels were also prepared for the labelling of cartons for each session; with the sensory session number.

2.2.3 Thawing and preparation protocols

The thawing protocol reported in Channon et al. (2013) was used to thaw samples required per testing day (three sensory sessions per day; total number of sessions = 30) to ensure samples of varying sizes/dimensions would be defrosted to the same temperature prior to being prepared and cooked. This protocol also determined the thawing schedule based on the dates of the sessions to ensure all samples undertook the same thawing time prior to use. Samples were thawed in their sealed cartons of individual sensory sessions to ensure no confusion or mix up of samples when multiple sessions were required to be thawed at the same time.

On each day of the sensory sessions, the three cartons of samples required were collected from SARDI Waite campus (at 8 am) and transported to the central testing location at UniSA. On arrival at the test location, the samples were removed from the carton. Samples for Sessions 2 and 3 were placed on separate shelves in a domestic fridge (5°C) and preparation commenced with samples for Session 1.

On removal from the carton, the 24 individual samples were checked against the session labelling document to ensure the session contained the correct samples. The 4 digit number was used as the primary identification tool. Each sample was identified by its unique 4 digit number and this ID followed the sample from removal from its vacuum packaging to presentation to the sensory panellist for evaluation.

As the five samples to be evaluated by each consumer were in a randomised tasting order, the cooking of samples could not be done to order.

Roasting was undertaken on the silverside only. Four samples were roasted in each session, two from each ageing period. The roast pieces were removed from vacuum packaging and labelled with their 4 digit number. Four roast pieces were placed onto a greaseproof paper lined roasting tray (with removable drip tray) and an oven proof label attached to the tray to identify each piece.

Oven trials were completed at a test day at UniSA prior to the start of the study to determine the optimum oven heat and thermometer settings to produce pork roasts cooked to the required degrees of doneness for the study of 75°C after a five minute resting period. The roast cooking times were variable (approximately 10 minutes) even with relatively consistent dimensions and weights and regardless of location in the oven.

The results of this trial indicated a convection oven setting of 175°C and thermometer settings of 73°C (to signal removal of roasts from the oven) would achieve a medium/well done degree of doneness (75°C) after a five minute resting period.

A stainless steel probe with a 1m lead connected to a digital thermometer on the outside of the oven was inserted into the centre of each roast and used to monitor the internal temperature of the roast pieces throughout cooking. Each thermometer was also labelled with the matching 4 digit number for the roast. The thermometer alarm preset function was used and set to 73°C. The temperature of the roasts was 1-3°C before cooking commenced. The oven utilised at the UniSA facilities was a Fagor single electric oven Model Visual VE101 (Fagor, Mondreagon, Spain). At the start of each day the oven was set to convection mode and pre-heated to the required temperature.

Roasts were cooked in a fan forced oven set at 175°C to achieve the required endpoint temperature of 75°C after a five minute resting period. The tray of four roasts was placed on the top shelf in the pre-heated oven approximately 75 minutes before the start of each sensory session. The temperatures of the roasts were monitored throughout the cooking period. Once a roast had reached the required temperature and the thermometer alarm sounded, the roast and its ID label were removed and placed on a wire rack located on the bench next to the oven for the resting period. At the start of each day, the roasts were monitored for temperature during the resting period to ensure the equipment was functioning as expected. After this confirmation, further resting period temperatures were not monitored.

The grill used for this study was a Silex Grill Model GTT Powersave 10.10-30 (Silex Elektrogerate GmbH, 22143 Hamburg, Germany). A total of twenty steaks were required for each session. The steaks were removed from the vacuum packaging and labelled with their 4 digit number. They were measured for length, graded into large and small sizes, placed onto a tray and stored at 5°C until required. The steaks were sorted into small and large sizes based on the revised grilling protocols (refer to Channon et al. 2013). The temperature of the loin steaks was 5-7°C before cooking commenced. A grill temperature of 160°C was used to achieve an endpoint temperature of 70°C after a rest period of 2 minutes.

In the sample preparation in the boning room, ten steaks were cut from the loin primal from one carcase side and their relative position on the loin (paired samples allocated to an ageing period of either 7 or 28 d with position numbers of 1 (caudal end) to 5(cranial end) was recorded. A maximum of four steaks were grilled at one time to ensure that no confusion or mix up of the loin steak IDs during the grilling and serving procedures would occur.

Approximately 40 minutes before the start of the sensory session, the grill was pre-heated to 160°C and cooking commenced. The loin steaks were brushed on each side with rice bran oil before being placed onto the grill plate and the lid lowered. For each batch of steaks, the internal take-off and resting temperatures was measured for one of the steaks cooked to ensure the equipment was functioning as expected. The grilling and resting times were measured with digital timers. To maintain sample identification once the steaks were placed on the grill, their corresponding labels were secured on the grill stand. Duplicate labels were also placed on the cutting board next to the grill. 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 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.

The grilling and roasting was undertaken by two people in parallel to minimise the holding time of samples prior to consumer evaluation.

2.2.4 Presentation Protocols

The kitchen/preparation room was maintained at a temperature of 23°C during the sensory sessions. In each session, the samples (n=5) evaluated by each consumer (n=8) were in a randomised tasting order so the samples (n=40) needed to be prepared and ready to serve for the start of the sample evaluation section of the sensory session; approximately 15 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 30 minutes prior to consumer evaluation.

To keep the cooked samples warm during the evaluation as well as to prevent moisture loss, samples 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). At the start of the day, the warming plates were preheated to the 65°C setting and the Pyrex containers (n=24) 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.

The silverside roast and its ID label were transferred from the bench next to the oven to a cutting board and the temperature probe removed after an identification check between the label on the roasting tray and digital thermometer. After cooking, the roast pieces were prepared as follows:

1) the rind and all visible fat were removed;
2) the pieces were cut into 6mm ±1 mm thick slices across the grain; and
3) all slices were placed into a Pyrex holding container and labeled.

Approximately 7 slices were obtained from each roast piece with 5 slices required for each sensory session.

After two minutes resting on the cutting board, up to four steaks (grilled at the same time) were trimmed on all four sides to remove fat and edges and the centre piece used for consumer evaluation. This was transferred with its label to a Pyrex holding container. One steak piece was placed in an individual container. This process was repeated for the twenty steaks required for each sensory session.

2.2.5 Serving of Samples to Consumers

A one page serving order document was prepared for all 240 consumers in the study. This document contained the order in which the five samples were to be tasted (identified by order, sample description and 4 digit identification number) by each panellist in each session. Before the start of each session, the page corresponding to the correct session and panellist was secured above the booth for each consumer in the kitchen/preparation

room. The five sample plates were also pre-labelled with the 4 digit sample numbers and stacked in the correct tasting order by the booth.

The consumers were instructed to switch on a light once they were ready to evaluate a sample of pork. This action illuminated a duplicate light in the kitchen/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) switch off the light to indicate the sample was being prepared;
2) collect the pre-labeled sample plate from beside the tasting booth
3) locate the correct sample in the Pyrex container;
4) undertake a number identification check between plate and Pyrex container;
5) place sample onto the plate;
6) open the serving hatch and present the sample to the consumer; and
7) cross out the sample ID number on the serving order document.

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

The serving sizes for each cooking method were:

1) Roast: one slice
2) Grill: steak centre piece

2.2.6 Consumer Evaluation

In each sensory session (n=30), eight consumers evaluated five pork samples (40 tastings). Within a session, consumers evaluated either 2 loin steaks and 3 silverside roast samples or 3 loin steaks and 2 silverside roast samples. Only five of the treatment combinations, from a total of 12, were evaluated by each consumer. 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 to capture individual demographic information which included: gender, household size, age, current purchasing, cooking and consumption habits of fresh pork (Appendix 1). 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 4 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 (2007). This method provided panellists 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, the 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 right hand side equivalent to 100 and left hand side equivalent to 0. 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 was also asked to rate each sample for quality grade score:

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 five samples.

2.3 Statistical analysis

2.3.1 Animal performance and objective meat quality analysis

An analysis of variance was conducted using Genstat 15 (VSN International, 2013) to determine the effect of dietary treatment/age at slaughter on growth performance and carcase attributes, the effect of ageing period and interactions with dietary treatment/age at slaughter on objective meat quality attributes. Due to heterogeneity in variances, the IMF data were log-transformed for analyses.

2.3.2 Sensory analysis

An analysis of variance was conducted to determine the effect of treatment factors and their interactions on sensory attributes of pork using R (R version 2.14.0, http://www.r-project.org). The analysis used accounted for variation between pigs, packs within pigs (4 per pig for each cut x ageing period combination), tasting sessions, consumers and samples within packs.

The different components of the analysis of variance are shown below – degrees of freedom with efficiency for treatments (in brackets). There was a total of eight stratum in the analysis – one stratum for sessions, three for consumers and four for samples:

	Sessions		Consumers		Samples		Total
Dietary treatment	2	(0.25)	2	(0.03)	2	(0.72)	
Residual	27	(0.25)	28	(0.03)	28	(0.72)	
Pigs	29		30		30		
Ageing period			1	(0.04)	1	(0.96)	
Dietary treatment x ageing period			2	(0.04)	2	(0.96)	
Residual			57	(0.04)	57	(0.96)	
Packs within pigs	0		60		60		
Cut			1	(0.12)	1	(0.88)	
Dietary treatment x Cut			2	(0.12)	2	(0.88)	
Ageing period x Cut			1	(0.12)	1	(0.88)	
Dietary treatment x ageing period x Cut			2	(0.12)	2	(0.88)	
Residual			114	(0.12)	114	(0.88)	
Packs within pigs	0		120		120		
Samples within packs	0		0		750		
Total	29		210		960		1199

There were three treatment factors in this factorial designed study: dietary treatment/slaughter age (3 levels), ageing period (2 levels) and cut (2 levels); a total of 12 combinations. Each consumer tasted 5 samples in a session, so 240 consumers (1200 samples/5 assessments =240 consumers) were required. There were 30 sessions each involving eight consumers.

Regression analysis was used to predict overall liking of pork based on the four attributes of tenderness, aroma, juiciness and flavour. Regression analysis was also used to determine whether quality grading score and re-purchase intention could be predicted from sensory variables assessed in this study. Correlation coefficients were determined using sensory data averaged for each pig for each cut. Chi-square analysis was conducted to determine treatment effects on fail rate for both quality grade and re-purchase intention.

3 Outcomes

3.1 Animal performance

The average liveweight at 16 weeks for animals allocated to treatments A, B and C were 61.4, 62.4 and 62.3 kg, respectively, whilst the average growth rate from 16 weeks of age until slaughter was 0.859, 0.749 and 0.667 kg/day, respectively.

Pigs allocated to treatment A were heavier at slaughter (P<0.001), produced heavier (P<0.001), fatter (P<0.001) carcases with higher dressing percentages (P<0.001) compared with pigs allocated to the treatments B and C (Table 2). Carcases in treatment C had a higher estimated chill loss (P=0.019) than carcases in treatments A and B.

Table 2: Predicted means and standard error of the difference (s.e.d.) for effect of effect of dietary treatment/age at slaughter (A: corn/soy; B: Restricted animal material-free wheat; C: wheat/sorghum) on final liveweight, hot carcase weight, fat depth at the P2 site (mm) and carcase parameters

Dietary treatment Age at slaughter	Diet A, 24 weeks	Diet B, 21 weeks	Diet C, 20 weeks	s.e.d.	P value
Final liveweight	110.7	89.1	86.2	1.59	<0.001
Hot carcase weight (kg)	88.2	70.0	67.8	1.25	<0.001
P2 fat depth (mm)	13.40	9.40	9.60	0.668	<0.001
Dressing percentage	79.70	78.56	78.72	0.30	<0.001
Cold carcase weight (kg)	80.8	64.1	61.9	1.15	<0.001
Estimated Trim 18 weight (kg)	82.8	65.7	63.6	1.17	<0.001
Estimated chill loss (%)	2.30	2.44	2.71	0.140	0.019

3.2 Objective measurements

At 24 h, loin muscle pH was lower in carcases from treatment C than those from treatments A and B (Table 3). From 90 min to 6 hours post-slaughter, muscle temperature of the loin from carcases in treatment A were higher (P<0.001) compared to the treatments B and C pigs, which may reflect differences in both hot carcase weight and fat depth.

Table 3: Predicted means and standard error of the difference (s.e.d) for effect of dietary treatment/age at slaughter (A: Corn/soy; B:, RAM-free wheat; C: Wheat/sorghum) on muscle pH and temperature measured in the loin muscle at the P2 site (*M. longissimus thoracis et lumborum*) from 45 min to 24 h post-slaughter

Dietary treatment Age at slaughter	Diet A, 24 weeks	Diet B, 21 weeks	Diet C, 20 weeks	s.e.d.	P value	P value co-variate
Muscle pH						
45 min	6.06	6.00	6.00	0.079	0.702	
90 min	5.87	5.85	5.83	0.094	0.911	
3 hours	5.74	5.79	5.79	0.103	0.849	
6 hours	5.48	5.54	5.54	0.073	0.620	
24 hours	5.55	5.53	5.43	0.019	<0.001	
Temperature						
45 min	37.8	37.2	38.1	0.33	0.019	
90 min	31.9	29.1	30.1	0.48	<0.001	
3 hours	22.8	19.7	19.7	0.35	<0.001	
6 hours	13.5	11.9	11.8	0.25	<0.001	
24 hours	4.80	5.06	4.89	0.024	<0.001	
Means adjusted to a HCW of 75.4 kg						
Temperature						
45 min	38.0	37.1	38.0	0.64	0.018	0.632
90 min	29.7	30.0	31.3	0.85	0.011	<0.001
3 hours	21.4	20.3	20.5	0.65	0.300	0.003
6 hours	12.7	12.3	12.3	0.47	0.726	0.011
24 hours	4.81	5.05	4.88	0.047	<0.001	0.605
Means adjusted to a P2 fat depth of 10.8 mm						
Temperature						
45 min	37.5	37.3	38.3	0.38	0.014	0.070
90 min	31.5	29.3	30.3	0.56	0.002	0.091
3 hours	22.2	20.1	20.0	0.38	<0.001	<0.001
6 hours	13.1	12.2	12.0	0.26	0.002	<0.001
24 hours	4.79	5.06	4.89	0.028	<0.001	0.634

Although muscle lightness (L* value) of the flank muscle was lighter (P<0.05) in carcases from treatment C when measured at 90 min and 3 h post-slaughter, no difference between treatments for muscle lightness was found at 24 h post-slaughter (Table 4). The percentage of carcases with muscle lightness values for the flank muscle of >42% was higher for carcases from treatment C (60%) and B (45%) treatments than pigs in treatment A (20%) (Figure 1).

Flank muscles from carcases in treatment A were redder (higher a* value) than those from the treatment B at 24 hours post-slaughter, with those from treatment C intermediate for this trait. For the b* value (or yellowness), treatment differences were only observed at 24 h post-slaughter with flank muscles from carcases from treatment A compared with treatments B and C.

Table 4: Predicted means and standard error of the difference (s.e.d) for effect of dietary treatment/age at slaughter (A: Corn/soy; B:, RAM-free wheat; C: Wheat/sorghum) on colour of the flank muscle from 90 min to 24 h post-slaughter

Dietary treatment Age at slaughter	Diet A, 24 weeks	Diet B, 21 weeks	Diet C, 20 weeks	s.e.d.	P value
L* value – flank					
90 min	36.28	37.26	37.92	0.638	0.042
3 hours	36.05	36.30	37.70	0.705	0.049
6 hours	36.00	36.85	37.72	0.696	0.055
24 hours	40.79	40.70	41.38	0.937	0.735
a* value – flank					
90 min	11.03	10.75	12.12	0.456	0.009
3 hours	12.20	11.68	12.81	0.467	0.061
6 hours	13.73	12.78	13.49	0.537	0.194
24 hours	15.85	12.51	14.77	0.645	<0.001
b* value – flank					
90 min	0.41	0.74	0.82	0.397	0.564
3 hours	1.39	1.57	1.53	0.362	0.869
6 hours	2.77	2.76	2.53	0.408	0.806
24 hours	8.65	5.11	6.19	0.674	<0.001

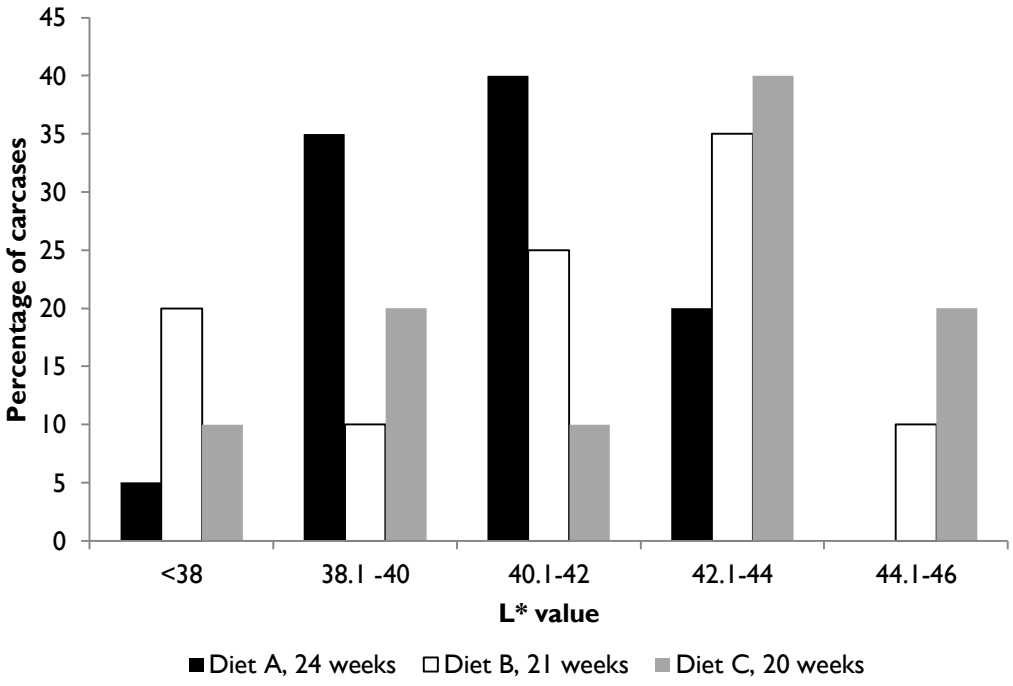

Figure 1: Distribution of muscle lightness, measured at 24 h post-slaughter, of the flank muscle due to dietary treatment/age at slaughter (A: Corn/soy; B:, RAM-free wheat; C: Wheat/sorghum)

At 24 h post-slaughter, average muscle pH of the loins from treatment A and B were higher ($P<0.001$) than those from treatment C (5.55, 5.53 and 5.43, respectively (s.e.d. 0.019). At both 7 d and 28 d post-slaughter, muscle pH of loins from pigs in treatment C were higher than those from treatments A and B (Table 5). At 7 d across all treatments, muscle pH ranged from 5.17 to 5.47 in the loin and 5.08 to 5.49 in the silverside. In contrast, muscle pH at 28 d post-slaughter ranged from 5.38 to 5.77 in the loin and 5.34 to 5.71 in the silverside. Overall, muscle pH were ~0.2 pH units lower at 7 d than when measured at both 24 h and 28 d for the loin and at 28 d for the silverside.

Meat colour of the loin was not influenced by experimental treatment at 7 d post-slaughter, whilst at 28 d post-slaughter, loin muscles from carcases in treatment A were yellower than those from treatment C, with those from treatment B intermediate for this attribute. Drip loss levels were reduced ($P=0.026$) in the loin following ageing for 28 d compared with 7 d, however, a concomitant increase in purge loss ($P=0.002$) was observed for treatments A and C, but not treatment B. For the silverside, both drip loss ($P<0.001$) and purge ($P<0.001$) were reduced following ageing for 28 d, rather than 7d.

Neither dietary treatment/age at slaughter nor ageing for 28 d influenced muscle lightness (L* value) of the loin. However, muscle lightness was paler ($P=0.048$) in 28 d aged silversides compared to 7 d post-slaughter. Ageing for 28 d increased a* value of both the loin ($P<0.001$) and silverside ($P=0.006$) compared with 7 d ageing. Similar observations were found for b* value, with 28 d aged loin ($P<0.001$) and silverside ($P<0.001$) found to be yellower than 7 d aged product. Drip loss and purge loss was higher for pork loins ($P<0.001$ and $P=0.004$, respectively) and silversides ($P<0.001$ and $P<0.001$, respectively) aged for 28 d rather than for 7 d.

Diet/age at slaughter influenced intramuscular fat levels (log transformed data) in both the loin ($P=0.017$) and silverside ($P=0.045$); muscles from pigs slaughtered at an older age of 24 weeks (Treatment A) higher than those from Treatment C slaughtered at 20 weeks, with Treatment B intermediate. Regression analysis of log transformed intramuscular fat data with both dietary treatment/age at slaughter and muscle in the model was significant ($P<0.001$) and accounted 48.1% of the variance (se 0.366) in intramuscular fat levels. The interaction between dietary treatment/age at slaughter and muscle was not significant.

IMF-Log% (Loin) = -0.6588 + 0.211 (0.116) x Treatment B ($P=0.07$) + 0.354 (0.116) x Treatment C ($P=0.003$) + 0.699 (0.116) (Silverside) ($P<0.001$)

Only 10% of loins from the Treatment A had intramuscular fat levels of greater than 1% compared with 0 and 5% for loins from treatments B and C, respectively.

Ageing vacuum packaged silverside muscles for 28 d post-slaughter reduced ($P=0.021$) WBSF values compared to those aged for 7 d. However, neither WBSF of the loin muscle nor cooking loss from either muscle was influenced by treatments imposed in this study.

Table 5: Predicted means and standard error of the difference (s.e.d) for effect of dietary treatment/age at slaughter (A: Corn/soy; B:, RAM-free wheat; C: Wheat/sorghum) age at slaughter and ageing period (7 or 28 d)), on muscle pH (24 hours), meat colour (L*, a*, b*), muscle pH, drip loss, purge, total water loss measured at 7 and 28 d post-slaughter and intramuscular fat content of the loin (*M. longissimus thoracis*) and silverside (*M. gbiceps femoris*). Values for IMF in parentheses are back-transformed means.

	A, 24 weeks		B, 21 weeks		C, 20 weeks		s.e.d.	P value		
	7 d	28 d	7 d	28 d	7 d	28 d		D	A	DxA
Loin										
L* value	54.77	57.30	56.18	56.87	56.32	55.19	0.985	0.633	0.129	0.006
a * value	8.08	9.40	7.39	9.37	7.55	8.58	0.512	0.181	<0.001	0.400
b* value	4.80	7.28	4.30	6.70	4.70	5.89	0.432	0.046	<0.001	0.064
pH	5.32	5.48	5.30	5.50	5.36	5.55	0.021	<0.001	<0.001	0.305
Drip loss (%)	2.60	0.84	2.08	1.18	2.03	1.18	0.227	0.471	<0.001	0.026
Purge (%)	2.21	3.54	3.87	3.22	2.40	4.40	0.528	0.175	0.004	0.002
Total water loss	4.81	4.38	5.96	4.40	4.47	5.59	1.885	0.523	0.296	0.765
WBSF (N)	29.43	31.32	31.99	31.36	29.30	29.07	1.848	0.17	0.75	0.58
Cooking loss (%)	25.77	25.92	26.22	26.91	25.53	26.75	1.705	0.84	0.49	0.91
Log IMF (%)	-0.304 (0.50)[a]		-0.447 (0.36)[ab]		-0.659 (0.21)[b]		0.1210	0.017		
% > 1% IMF	10		0		5					
Silverside										
L* value	50.46	54.39	54.44	55.35	53.30	52.90	1.271	0.021	0.048	0.052
a * value	11.10	11.99	10.47	11.99	10.32	11.42	0.711	0.408	0.006	0.819
b* value	5.64	7.81	6.43	8.01	5.59	6.98	0.513	0.040	<0.001	0.537
pH	5.28	5.47	5.27	5.47	5.32	5.55	0.026	0.001	<0.001	0.566
Drip loss (%)	1.82	1.10	2.25	0.94	1.88	0.79	0.117	0.012	<0.001	0.003
Purge (%)	2.02	1.84	3.00	2.06	3.74	1.19	0.391	0.053	<0.001	<0.001
Total water loss	3.97	2.94	5.42	3.00	5.89	1.98	0.964	0.003	0.096	0.009
WBSF (N)	41.35	37.80	41.67	35.94	39.87	35.62	3.297	0.73	0.021	0.89
Cooking loss (%)	29.54	29.83	30.59	32.34	31.10	30.45	1.093	0.076	0.47	0.30
Log IMF (%)	0.314 (2.06)[a]		0.237 (1.73)[ab]		0.040 (1.09)[b]		0.1103	0.045		
% > 1% IMF	85		85		70					

3.3 Demographic details

Of the 240 consumers involved in this study, 57.5% were female and 42.5% were males, with 60% of consumers aged mainly between 31 to 60 years of age. The average household size was 2.7±1.29 persons. The consumption frequency of meat meals, including pork, is detailed in Table 6. Overall, 42.9% of consumers in this study responded that they ate fresh pork (not including ham, bacon or salami) at least weekly, with an additional 28% of consumers stating that they consumed pork at least twice a week.

Table 6: Frequency of consumption of pork, beef, lamb, chicken and fish (other than mince or sausages) in the last week by consumers who participated in this study

	Number of meals in the last week				
	1	2	3	4	5 or more
Pork	42.5	25.0	12.1	3.8	1.7
Beef	41.3	34.6	10.0	1.7	1.7
Lamb	40.8	25.0	2.9	0.4	0.4
Chicken	24.6	39.2	17.5	5.8	3.3
Fish	44.6	18.8	6.7	0.8	0

The major cuts of pork purchased by consumers involved in the sensory panels were pork loin chops/cutlets, roasting cuts, followed by rashers/spare ribs and fillets (Figure 2). Consumer preference for cooking pork to 'medium rare, pink', 'medium, hint of pink', 'medium/ well done, white' and 'well done' was 5.8%, 35.0%, 46.3% and 12.9%, respectively. Grilling/BBQ/pan frying was the most popular cooking method used by consumers involved in this study (81.3%), followed by roasting (72.4%), stir frying (51.3%) and casserole/simmer (15.8%).

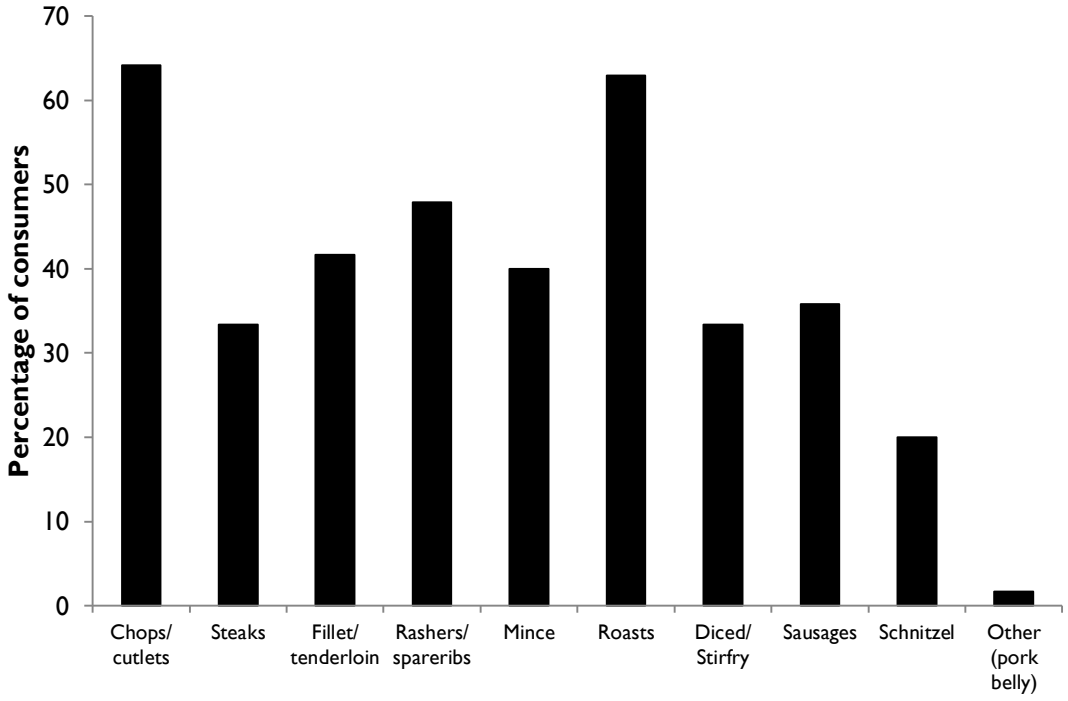

Figure 2: Major cuts of meat purchased by consumers evaluating eating quality attributes of pork

Consumer responses in relation to rating of their cooking skills and attitudes are presented in Table 7.

Table 7: How would you rate your meat cooking skills and attitudes over an entire week (0=strongly disagree to 10 – strongly agree)

	Rating of cooking skills and attitudes				
	0-4	5-6	7-8	9-10	Average
I am an excellent cook	19.2	37.5	37.1	6.3	5.97±1.74
I am a very creative cook	32.0	37.5	25.4	5.0	5.36±2.06
I have lots of time for cooking	48.3	31.7	15.4	4.58	4.69±2.12
I cook by feel, I use the recipe as a guide	29.1	31.3	31.7	7.9	5.45±2.45
I love to cook	19.6	32.5	32.9	15.0	6.17±2.19
I am always looking for new food ideas	13.3	26.7	44.2	15.8	6.62±1.97

Consumer attitudes to fresh meat are presented in Table 8.

Table 8: Thinking about fresh meat, not including fish, which of these statements do you agree with? (0=strongly disagree to 10 – strongly agree)

	Rating of cooking skills and attitudes				
	0-4	5-6	7-8	9-10	Average
I love meat	6.7	18.8	44.6	30.0	7.41±1.69
I buy organic/free range meat	52.9	27.1	15.4	4.6	3.95±2.73
I don't like the fat on meat	29.6	17.1	25.8	27.5	6.15±2.76
I look for the cheapest cuts of meat	48.8	33.8	15.0	2.5	4.24±2.33
I look for the cheapest price in a range of cuts I like	25.0	32.1	35.8	7.1	5.73±2.24
Meat is expensive	15.0	26.3	41.3	17.5	6.60±1.89
Meat is hard to prepare	81.7	11.7	5.8	0.8	2.78±2.00
Meat is important for nutrition	3.8	12.9	50.4	32.9	7.74±1.50
I believe you should eat meat two or three times a week	5.4	15.0	43.3	36.3	7.65±1.64
Red meat is not good for you	78.8	9.2	7.5	4.9	2.50±2.65

Pork was favourably rated in terms of its appeal to consumers, rating second to chicken (Table 9).

Table 9: How appealing to you are these different types of meat/fish? (0=not at all appealing to 10 – extremely appealing)

	Rating of cooking skills and attitudes				
	0-4	5-6	7-8	9-10	Average
Chicken	3.8	13.3	45.8	37.1	7.80±1.50
Pork	4.2	17.1	52.5	26.3	7.46±1.49
Beef	9.6	23.8	46.7	20.0	6.96±1.83
Lamb	14.2	23.3	40.8	21.7	6.70±2.24
Fish	19.2	25.4	35.8	19.6	6.39±2.38

3.4 Sensory results

The summary statistics for sensory attributes of pork across all treatments are presented in Table 10.

Table 10: Summary data for sensory attributes of cooked pork aroma, tenderness, juiciness, flavour and overall liking of pork (n=1200)

	Minimum	1st quartile	Median	Mean	SD	3rd quartile	Maximum
Aroma	0.0	47.0	63.75	61.36	21.44	78.50	100
Tenderness	0.0	40.0	61.00	57.95	24.49	77.12	100
Juiciness	0.0	42.50	62.50	59.58	23.73	77.50	100
Flavour	0.0	45.5	63.50	60.77	21.65	77.00	100
Overall liking	0.0	45.0	63.50	60.39	22.72	78.00	100
Quality grade	1.0	3.0	3.00	3.38	0.94	4.00	5
Re-purchase intention	1.0	3.0	4.00	3.41	1.14	4.00	5

The correlation coefficients between sensory attributes for all evaluations is shown in Table 11 Flavour and overall liking were most highly correlated and aroma least correlated with the other four attributes.

Table 11: Correlation coefficients between sensory attributes for all evaluations (n=1200)

	Aroma	Tenderness	Juiciness	Flavour	Overall liking
Aroma	1.000				
Tenderness	0.474	1.000			
Juiciness	0.477	0.784	1.000		
Flavour	0.597	0.742	0.755	1.000	
Overall liking	0.568	0.826	0.832	0.911	1.000

The correlations for all consumers involved in this study, as shown in Table 12, are higher than those presented in Table 11 for all evaluations, indicating that consumers tend to be

'high scorers' or 'low scorers'. These correlations were determined from mean consumer responses and the highest correlation was found between flavour and overall liking.

Table 12: Correlation coefficients between sensory attributes for all consumers (n=240)

	Aroma	Tenderness	Juiciness	Flavour	Overall liking
Aroma	1.000				
Tenderness	0.666	1.000			
Juiciness	0.623	0.822	1.000		
Flavour	0.733	0.795	0.829	1.000	
Overall liking	0.706	0.848	0.853	0.937	1.000

A strong relationship between tenderness, juiciness, flavour and overall liking was observed as the prediction equation for overall liking included these key variables (across all treatments):

Overall liking= -1.584 + 0.208 x Tenderness + 0.209 x Juiciness + 0.597 x Flavour (R2=0.90)

All coefficients were statistically significant (P<0.0001; SE 7.5).

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

Across all 1200 samples assessed in this study, consumer responses for quality grade score and re-purchase intention are shown in Table 13. Similar mean scores for both attributes were found, however, the variance in quality grade scores were lower than for re-purchase intention. A lower percentage of scores were at the extreme ends for quality grade (with 155 out of 1200 scored as either 1 or 5 compared with 298 out of 1200 for re-purchase intention).

Table 13: Matrix of panelist scores received for quality grade and re-purchase intention

Quality grade score	Re-purchase intention				
	1	2	3	4	5
1	23	0	0	0	0
2	43	133	6	0	0
3	1	67	290	92	2
4	2	2	29	273	95
5	0	0	0	10	132

Linear regression analysis of quality grade score with the five sensory attributes assessed in this study identified that overall liking was the most important variable influencing quality grade score, followed by flavour. Tenderness, juiciness and aroma were not significant terms in the model. The equation was:

Quality grade score = 1.258 + 0.006 x Flavour + 0.030 x Overall liking

As the coefficient for overall liking was larger than for flavour, a regression analysis was then conducted, with only overall liking included in the analysis:

Quality grade score = 1.28 + 0.0348 x Overall liking (SD 0.52, prediction accuracy 66%)

The relationship between re-purchase intention and the sensory attributes assessed was:

Re-purchase intention = 0.932 + 0.0063 x Flavour + 0.0331 x Overall liking

As the coefficient for overall liking was larger than flavour, a regression analysis was then conducted including only overall liking in the analysis:

Re-purchase intention = 0.956 + 0.0407 x Overall liking (SD 0.67, prediction accuracy 57%)

3.4.1 Sensory results

Across both muscles evaluated in this study, dietary treatment/age at slaughter influenced juiciness - pork from Treatment A, from animals slaughtered at 24 weeks of age, tended to be less juicy (P=0.087) than pork from pigs in Treatments B and C (Table 14). Sensory results for the main effect of dietary treatment/age at slaughter were similar for pork produced from pigs in treatments B and C compared with treatment A.

Table 14: Effect of dietary treatment/age at slaughter on pork sensory quality

Dietary treatment Age at slaughter	Diet A, 24 weeks	Diet B, 21 weeks	Diet C, 20 weeks	s.e.d.	P value
Aroma	62.65	60.07	61.36	1.752	0.35
Tenderness	56.75	58.61	58.48	2.478	0.71
Juiciness	56.57	61.45	60.72	2.276	0.087
Flavour	60.14	61.21	60.96	1.837	0.83
Overall liking	59.08	60.81	61.29	2.045	0.53
Quality grade	3.32	3.41	3.40	0.085	0.52
Re-purchase intention	3.34	3.47	3.42	0.109	0.49

Ageing pork loin and silversides for 28 d compared with 7 d post-slaughter did not affect eating quality attributes of pork (Table 15).

Table 15: Effect of ageing period (7 and 28 d post-slaughter) on pork sensory quality

	7 d	28 d	s.e.d.	P value
Aroma	61.55	61.17	0.894	0.67
Tenderness	57.32	58.58	1.303	0.34
Juiciness	60.23	58.93	1.460	0.37
Flavour	60.69	60.85	1.175	0.89
Overall liking	60.36	60.42	1.364	0.97
Quality grade	3.38	3.39	0.063	0.87
Re-purchase intention	3.41	3.41	0.073	1.00

Loin steaks obtained higher scores for all sensory attributes evaluated in this study compared with silverside roasts (Table 16).

Table 16: Effect of cut (loin (*M. longissimus thoracis et lumborum)* and silverside (*M. biceps femoris*) on pork sensory quality

	Loin	Silverside	s.e.d.	P value
Aroma	67.36	55.35	1.062	<0.001
Tenderness	64.28	51.62	1.294	<0.001
Juiciness	65.84	53.32	1.318	<0.001
Flavour	65.40	56.14	1.082	<0.001
Overall liking	66.28	54.51	1.249	<0.001
Quality grade	3.62	3.14	0.054	<0.001
Re-purchase intention	3.71	3.11	0.068	<0.001

No interactions between dietary treatment/age at slaughter, ageing period and cut type were found for tenderness, juiciness, flavour, aroma, overall liking, quality grade or re-purchase intention (Table 17). The effect of dietary treatment on pork sensory quality from pigs fed Diet B and C were similar. When analysed as a contrast of Diet A compared with the average of Diets B and C, pork from pigs allocated to Diet A was less juicy than the average juiciness score of pork from pigs in Diets B and C (58.08 vs. 60.33, respectively; P=0.03). This effect was largely due to the juiciness scores from 7d aged loins from Diet A being 7.46 units lower than the averaged juiciness score for pork from pigs fed Diets B and C (60.86 vs. 68.32, respectively; P<0.001). Furthermore, 7 d aged loin steaks from pigs fed Diet A obtained lower overall liking (61.97 vs. 68.43, respectively ; P=0.021) and flavour (62.17 vs. 67.01, respectively P=0.047) than the average scores for Diets B and C. No differences for the other three combinations of ageing period and cut were found for juiciness, . The interaction between contrast of Diet A compared with the average of Diets B and C and cut was significant for aroma (P=0.010), with aroma scores for silverside roasts from pigs fed diet A shown to be 6.33 units higher than the average scores for Diets B and C. Although re-purchase intention scores for loin steaks from pigs fed diet A were lower (P=0.054) than the average score for pigs fed Diets B & C, this was not observed for the silverside.

Overall, the fail rates of pork loin steaks was lower compared with silverside roasts, for both quality grade (11.5 and 22.6%, respectively) and re-purchase intention (15.6 and 29.5%, respectively). In terms of effect of dietary treatment/age at slaughter, the fail rates for quality grade of pork from pigs in treatments A, B and C were 18.3, 16.8 and 16.3%, respectively, across both cuts. Fail rates due to ageing period did not markedly differ for both quality grade score and re-purchase intention.

Table 17 Effect of dietary treatment/age at slaughter (D), ageing period (A) and cut (C) on consumer scores for tenderness, juiciness, flavour, odour, overall liking, quality grade and repurchase intention and fail rates[†] for both the loin (*M. longissimus thoracis et lumborum)* and silverside (BF; *M. biceps femoris*)

Treatment	Diet A, 24 weeks				Diet B, 21 weeks				Diet C, 20 weeks				s.e.d.	P value
Ageing period	7 d		28 d		7 d		28 d		7 d		28 d			
Cut	Loin	BF	Loin	BF	Loin	BF	Loin	BF	Loin	BF	Loin	BF		
Tenderness[a]	59.86	50.11	64.94	52.10	65.66	49.37	66.30	53.11	64.47	54.45	64.43	50.59	4.100	C <0.0001
Juiciness[b]	62.07	50.47	61.56	52.18	69.17	54.31	68.72	53.60	68.75	56.61	64.75	52.75	4.059	C <0.0001
Flavour[c]	62.16	55.83	64.32	58.24	67.67	55.12	66.10	55.95	66.89	56.49	65.25	55.23	3.287	C <0.0001
Odour[c]	66.30	57.27	67.11	59.92	67.17	55.24	66.13	51.73	68.35	54.94	69.13	53.01	2.990	C <0.0001, DxC 0.033
Overall liking[c]	62.51	53.33	65.55	56.73	68.25	53.38	65.81	54.02	68.23	57.03	66.69	53.20	3.738	C <0.0001
Quality grade[d]	3.46	3.08	3.55	3.21	3.79	3.08	3.56	3.23	3.66	3.19	3.69	3.08	0.161	C <0.0001
Re-purchase intention[e]	3.54	3.10	3.56	3.16	3.92	3.03	3.77	3.15	3.79	3.11	3.71	3.09	0.199	C <0.0001
Fail rate														
Quality grade	*14*	*27*	*13*	*19*	*9*	*25*	*13*	*20*	*9*	*19*	*11*	*26*		*C <0.05*
Re-purchase intention	*18*	*30*	*18*	*26*	*13*	*31*	*13*	*28*	*16*	*29*	*16*	*33*		*C <0.05*

a 0 = very tough to 100 = very tender;
b 0 = very dry to 100 = very juicy;
c 0 = dislike extremely to 100 = like extremely
d 0 = unsatisfactory to 5 = excellent;
e 0= definitely would not purchase to 5 = would definitely purchase
† Percentage of consumer evaluations of half loin steaks and silverside roast slices with scores of <3for quality grade and re-purchase intention

Correlation coefficients between aroma, tenderness, juiciness, flavour and overall liking with objective measurements were low (Table 18).

Table 18 Correlation matrix between sensory attributes of loin (*M. longissimus thoracis et lumborum*) and silverside (*M. biceps femoris*) and objective measurements of ultimate pH, L*, a* and b* values, intramuscular fat, drip loss, purge, WB shear force (WBSF) and cooking loss (n=60).

	Aroma	Tenderness	Juiciness	Flavour	Overall liking
Loin					
Ultimate pH	-0.032	-0.005	-0.192	-0.099	-0.125
L* value	-0.030	-0.027	0.064	-0.025	-0.038
a* value	0.018	0.108	0.051	0.088	-0.159
b* value	-0.013	0.082	-0.001	0.022	0.383
Intramuscular fat (%)	-0.104	-0.125	-0.009	-0.146	-0.145
Drip loss (%)	-0.011	-0.037	0.045	-0.014	-0.039
Purge (%)	-0.071	0.040	0.042	-0.044	0.068
WBSF (N)	-0.060	-0.203	-0.040	-0.079	-0.073
Cooking loss (%)	-0.065	-0.011	0.093	0.029	0.040
Silverside					
Ultimate pH	0.031	-0.049	-0.071	-0.016	-0.024
L* value	0.031	0.074	0.138	0.124	0.119
a* value	0.023	-0.220	-0.217	-0.156	-0.158
b* value	-0.007	-0.153	-0.120	-0.091	-0.105
Intramuscular fat (%)	0.157	-0.047	-0.044	-0.023	-0.046
Drip loss (%)	0.150	0.105	0.141	0.133	0.113
Purge (%)	0.228	0.114	0.261	0.270	0.237
WBSF (N)	-0.122	-0.179	0.003	-0.113	-0.137
Cooking loss (%)	-0.239	-0.217	0 005	-0.204	-0.170

4 Application of research

4.1 Effects of age at slaughter/dietary treatments on pork quality

Levels of intramuscular fat, particularly in the loin muscle, were very low in this study – averaging 0.47±0.31% for the loin and 2.03±1.23% for the silverside. It is suggested that the response to dietary treatments and/or the increased slaughter age of animals on intramuscular fat content in this study may have been influenced by the genotype of pigs used. Although animals slaughtered at 24 weeks of age (168 days) were 4 mm fatter at the P2 site than those slaughtered at 21 and 20 weeks (147 and 140 days, respectively), this was not enough to result in a large shift in intramuscular fat deposition. This indicates that, at least for the genetic line of pigs used in this study, that selection for increased lean deposition, in response to consumer demand for lean pork, has reduced intramuscular fat deposition at heavier liveweights. Low levels of intramuscular fat in Australian pork loins of 0.98 ± 0.50% from carcases ranging in hot carcase weight from 60-75 kg (Trim 1) with fat depth at the P2 site of 8-13 mm were also reported by Channon et al. (2001) - in pigs from eastern Australia. Intramuscular fat levels reported in this study were markedly lower than these. In contrast, female pigs (averaging 75.8±5.8 kg HCW, 10.3±2.1 mm P2) sourced from another Australian commercial genotype averaged

intramuscular fat levels of 2.95±1.46% in the loin and 2.20±1.33% in silversides (Channon et al. 2013). Many studies have reported positive effects of intramuscular fat content on sensory attributes of pork when levels of intramuscular fat in the loin are in excess of 2%, but not exceeding 3.5%, including Alonso et al. (2010) Bejerholm and Barton Gade (1986), DeVol, McKeith, Bechtel, Novakofski, Shanks, and Carr (1988), Fernandez, Monin, Talmant, Mourot, and Lebret (1999) and Touraille, Monin, and Legault (1989).

Bosch, Tor, Reixach, and Estany, (2012) compared the effect of age (from 160 to 220 days) on the content of both intramuscular fat and subcutaneous backfat in the loin of purebred Duroc surgically castrated males and showed that the intramuscular fat content of the loin increased linearly with age. This relationship, although small in magnitude, was also observed from 140 to 168 d of age in both the loin and silverside in this study, once intramuscular fat data had been log transformed. Candek-Potokar, Zlender, and Bonneau (1996) found that carcases of up to 130 kg had higher intramuscular fat levels compared with 100 kg pigs. Weatherup, Beattie, Moss, Kilpatrick, and Walker, (1998) showed that as carcase weight increased from 80 to 100 kg, intramuscular fat content increased in individually housed animals, although the effect was small; data for group housed animals was not presented. However, other studies have reported that intramuscular fat content remained constant as age at slaughter increased from 16 to 25 weeks (D'Souza, Pethick, Dunshea, Suster, Pluske, & Mullan, 2004) and as liveweight increased from 80 to 120 kg (Ellis, Webb, Avery, & Brown, 1996), This led to D'Souza et al. (2004) suggesting that focusing on the grower phase, rather than the finisher phase, to increase intramuscular fat levels may offer more potential without significantly impacting upon growth performance or carcase fatness.

In this study, dietary lysine to energy ratios were kept relatively similar between dietary treatments in an effort to simulate the use of different dietary ingredients fed to pigs in different regions of the world, namely North America and Northern Europe and quantify these effects on pork eating quality when compared to pigs fed a diet typical of north-eastern Australia. This may have accounted for the small differences observed between treatments in intramuscular fat content, particularly in the loin.

Whilst considerable research effort has been directed toward dietary manipulation of intramuscular fat in an effort to improve eating quality of pork, the relationship between intramuscular fat content and sensory attributes of pork remains equivocal. In this study, the main effect of dietary treatment/age at slaughter did not influence the eating quality attributes or WBSF of either the loin or silverside. It was not surprising that little difference was observed in eating quality attributes of pork from pigs allocated to dietary treatments B and C and slaughtered at 21 and 20 weeks, respectively, given that the 7 d difference in average age between groups resulted in a 3 kg average difference in liveweight. It is also noteworthy that dietary treatment B contained dietary ingredients commonly fed to pigs in South Eastern Australia (with the exception of meat and bone meal) whilst treatment C, with its higher sorghum component, was more typical of diets fed to pigs in Queensland.

Sensory analyses were therefore conducted to determine whether differences existed between treatment A and pooled scores for treatments B and C. For pork loins aged for 7 d, lower juiciness, flavour and overall liking scores were found were comparisons were

made between treatment A and treatments B+C. This finding was perplexing given the higher levels of intramuscular fat in loins from Treatment A as well as this diet/age x ageing period interaction not being observed after 28 d ageing for the loin or for the silverside.

Intramuscular fat content was poorly correlated with sensory attributes for both the loin and silverside in this study. Previous studies have also reported low correlations between intramuscular fat content and eating quality of pork (Channon, Kerr, & Walker, 2004; Channon, Taverner, D'Souza, & Warner, submitted; Lonergan, Stalder, Huff-Lonergan, Knight, Goodwin, Prusa, & Beitz, 2007; Rincker, Killefer, Ellis, Brewer, & McKeith, 2008; van Laack, Stevens, & Stalder, 2001; Wood, Jones, Francombe, & Whelehan, 1986). Peinado, Serrano, Medel, Fuentetaja, and Mateos, (2011), using female pigs slaughtered at either 106 or 122 kg liveweight, showed that sensory attributes of pork were not influenced by liveweight at slaughter even though intramuscular fat content increased as liveweight increased. Correa, Faucitano, Laforest, Rivest, Marcoux, and Gariépy (2006) also concluded that carcase and meat quality traits were not affected by finishing female and surgically castrated pigs to average liveweights of 107, 115 and 125 kg. Correa et al. (2006) also reported that soluble collagen levels in the loin muscle was lower in animals slaughtered at 115 and 125 kg compared with 107 kg; suggesting that tenderness of pork could be reduced in heavier animals. Although collagen content, collagen solubility and compression measurements were not determined in this study, the lack of effect of dietary treatment/age at slaughter on eating quality attributes in this study suggests that collagen solubility was not influenced by age at slaughter/carcase weight of animals. If this was considered an issue, as average Australian slaughter weights are increasing, the supplementation of finisher diets with soy lecithin may be worthy of inclusion, particularly as Akit, Fahri, Leury, & Dunshea, (2011) have shown that feeding soy lecithin to pigs slaughtered at 22 weeks of age of ~78 kg HCW reduced the expression of genes responsible for collagen synthesis (Type I and Type III procollagen, MMP-1and prolyl-4-hydroxylase), reduced hydroxyproline levels in loin connective tissue as well as reduced chewiness and cohesiveness of cooked pork, when the contribution of connective tissue to pork tenderness was measured objectively. Although eating quality attributes of pork were not influenced by soy lecithin supplementation (Channon et al., 2013), the effect of feeding soy lecithin to heavier, older pigs on connective tissue solubility has not been investigated.

Despite low levels of intramuscular fat present in loin muscle in this study across all dietary treatment/age at slaughter groups and ageing treatments, the fail rate for quality grade score was only 11.5%. In contrast, Channon et al. (2013) found that even with higher levels of intramuscular fat content present in the loin and silverside muscle of female pigs, after ageing for 7 d, the fail rate of loin steaks (cooked to 70°C endpoint temperature) and silverside roasts (cooked to 75°C endpoint temperature) was 27.5% and 35%, respectively. This emphasizes that other interventions need to be in place, as reliance on a higher intramuscular fat content alone will not necessarily deliver pork of consistently high quality to consumers. These differences between these studies in fail rates may be due to genetic differences and/or other pathway effects and it is anticipated that these will be further elucidated in the proposed eating quality validation study to be supported by the Pork CRC in 2013/14.

The final live weights of animals in this study were lower than what was intended. It was unfortunate that animals experienced extremely hot ambient temperatures in early January 2013 at the end of the finisher phase which may have impacted on growth rates. Although it may have been logistically possible to extend the experiment by postponing the slaughter for an additional week, continuing hot temperatures were forecasted, negating any resultant benefits on liveweight gain.

The production of heavier carcases presents some challenges for producers, particularly in relation to management of subcutaneous fat deposition. Carcases with excessive fat levels (in excess of 12 mm) are penalised through the carcase pricing systems currently in place in Australia.

4.2 Effects of ageing period

As no differences in pork eating quality were found due to ageing period in this study, it may be concluded that the improvements in tenderness resulting from proteolytic breakdown of the myofibrillar lattice, resulting from ageing, had plateaued before 7 d post-slaughter. This concurs with Dransfield, Jones, and MacFie, (1980-81) who concluded that improvements in tenderness of pork are rapid in the first 1-2 days post-slaughter, slows down and then plateaus at around 6 days post-slaughter. Other studies have also reported positive benefits on pork eating quality following ageing for 7-12 d post-slaughter (Channon, Baud, Kerr, & Walker, 2003; Channon et al., 2004; Channon et al., submitted; Moore, Mullan, & D'Souza, 2012; Taylor, Nute, & Warkup, 1995; Wood, Brown, Nute, Whittington, Perry, Johnson, & Enser, 1996) An extended ageing period of 43 d post-slaughter has also been shown to improve consumer scores for tenderness, juiciness, flavour liking and overall acceptability than pork aged for 5 d post-slaughter (Ngapo, Riendeau, Laberge, & Fortin, 2012). Our current findings, however, are in contrast to Channon et al. (2013) who found that post-slaughter ageing for 7 d did not improve eating quality of pork loin steaks or silverside roasts compared to 2 d ageing. Differences in genetic backgrounds of pigs used, other environmental effects, on-farm and/or at the abattoir, as well as differences in the rate of muscle pH decline post-slaughter may have contributed to these differences.

Although silversides from pigs slaughtered at 24 weeks of age at 7 d post-slaughter had lower L* values, the effect of age at slaughter was inconsistent with ageing period as at 28 d post-slaughter, silverside muscles from 20 week old animals were darker in colour. As pork was relatively pale in this study, it was not considered that consumers would be able to discern between pork produced from pigs differing in age based on its appearance. Weatherup et al. (1998) also reported no effect of increasing slaughter weight from 80 to 100 kg on meat colour. Overall, pork muscle colour produced at either 7 or 28 d post-slaughter would be considered acceptable by Australian consumers due to their preference for pale pork (Ngapo, Martin, & Dransfield, 2007).

In the loin, the initial rate of muscle pH decline was rapid, given that it had attained a pH of 6.00 at 45 min post-slaughter whilst the muscle temperature was still high at ~38°C. A final pH appeared to have been reached by 6 hours post-slaughter, as there was very little change in pH when assessed at 24 hours. This may have impacted on drip loss and purge when assessed at both 7 d and 28 d post-slaughter. Based on these parameters, pork in this study may have been affected by rapid rates of muscle pH decline post-slaughter

resulting in pale pork, with relatively high total water loss. It was also noted that the chillers did not commence the chill stage of the cycle until after 3 h post-slaughter which may have impacted on rate of muscle temperature decline and chill loss. These conditions are similar to those reported for pigs carrying the RN^- (Hampshire gene) which causes high muscle glycogen levels of live pigs resulting in lower ultimate pH post-slaughter. It has also been reported that heterozygous RN pigs have lower intramuscular fat levels, whilst sensory tenderness and juiciness scores are also higher in pork from pigs carrying the RN- gene. Although the Hampshire gene is not considered to be present in Australia, the findings from this study, together with those reported by Jose et al. (2013), suggest that there may be some other underlying mechanism influencing pork quality. Despite this, it may be suggested that eating quality performance, at least for the pork loin (in terms of fail rates), was reasonable. Reasons for the lower pH values obtained for pork at 7d post-slaughter compared to those measured at both 24 h (loin only) and at 28 d (for both muscles) are not clear.

The importance of flavour to overall liking was again confirmed, with the coefficient for flavour three times as large as for juiciness and tenderness. Channon et al. (2013) in a study investigating the effect of sex, ageing period, cut type, cooking method and endpoint temperature, found that overall liking was influenced firstly by flavour, followed by tenderness, juiciness and aroma. Aroma was not a significant term in this study and it may be that this may be due to only female pigs being involved.

Microbiological quality was not assessed in this study, however, all product was stored at 0.5°C for up to 28 d to ensure that the product would be suitable for sensory evaluation.

5 Conclusions and recommendations

Based on the outcomes of this study:

- There was little difference in sensory quality of pork resulting from finishing female pigs, of the genotype used in this study, to 24 weeks of age compared with pigs of 21 or 20 weeks of age. This suggests that relatively small differences in pork sensory quality due to slaughter weight/dietary treatment do not necessarily discount the inclusion of heavier carcases in an eating quality system for Australian pork.
- Despite a rapid rate of muscle pH decline post-slaughter in the loin, the overall fail rate (quality grade score) of pork loin steaks was 11.5% - almost meeting the target cut off of <10%.
- Extended ageing for 28 d did not result in additional improvements in pork sensory quality compared with ageing for 7 d for both the loin and silverside. Based on this, it is recommended that further validation work will include an ageing period of 7 d.
    - It is important to note that if longer ageing periods are required in excess of 7 d to maximize pork quality, this may have significant commercial implications associated with stock on hold, management and logistics.
- Further research to reduce the fail rate of the silverside primal to less than 10% is required. These conditions can then be applied to similar cuts (eg. rump, topside) to maximize their quality as part of an eating quality program.

- Ageing period had inconsistent effects on fail rate (for quality grade score) for silversides; 7 d aged silversides from Treatment C had a lower fail rate compared with Treatments A and B and higher fail rates after 28 d ageing.

- Fail rates for re-purchase intention were higher than those for quality grade score for both the silverside and loin.
- Overall liking of pork was influenced, in order, by flavour, juiciness and tenderness.
- Overall, the experimental treatments imposed in this study did not allow pork from pigs slaughtered at 20 weeks to be positively differentiated on an eating quality basis from those slaughtered at 21 or 24 weeks of age. This suggests that the 4-5 week increase in animal age is unlikely to result in a negative sensory experience for consumers. These findings also suggest that feeding finisher pigs isoenergetic and isonitrogenous diets, formulated using dietary ingredients typically used in North America and Northern Europe, did not result in markedly different eating quality performance.
- Continued work to optimise eating quality pathway parameters is necessary to achieve fail rates of less than 10% for different pork cuts. This will be addressed in the validation study, involving three supply chains, to evaluate the incorporation of a number of processing interventions to improve the eating quality performance of pork derived from immunocastrated and female pigs.

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