3A:116 – DEVELOPMENT OF A GENERIC PORK EATING QUALITY MODEL AND INTERACTIVE TOOL

Report prepared for the
Co-operative Research Centre for High Integrity Australian Pork

By

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June 2018

Pork CRC

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Programme

1 Executive Summary

A number of meat science research projects, funded by the Pork CRC (Sub-Program 3A: Optimal Pork Quality for Multiple Markets) and Australian Pork Limited, have been undertaken to determine the effects of key factors on eating quality attributes of fresh pork. Factors investigated include gender, cut type, cooking method, ageing period, endpoint temperature, diet supplementation and carcase weight, hanging method, electrical stimulation, moisture infusion and ultimate pH.

The aim of this project was to utilize all relevant Pork CRC data to develop an eating quality predictive model for Australian fresh pork, based on an overall quality score, as part of a non-prescriptive eating quality system. The adoption of such a system by industry could be beneficial to position Australian pork as a premium product in new and expanding markets and to differentiate it from competitors on the basis of consistent eating quality.

Sensory data were used from Pork CRC projects conducted within Subprogram 3A: Optional Pork Quality for Multiple Markets and included consumer scores for the sensory attributes of aroma/smell, tenderness, juiciness, flavour, overall liking as well as quality grade and re-purchae intention, in addition to objective variables including ultimate pH, hot carcase weight and intramuscular fat content. A total of 3,564 muscle samples from 626 pigs and 14,208 individual consumer responses were collated for analysis and included four different muscles, loin, silverside, chuck tender and bolar blade by three different cooking methods.

From the multinomial regression of quality grade results against the recorded sensory attributes of aroma, tenderness, juiciness, flavour and overall liking, a model for the composite pork quality score (PQS) was developed.

PQS = 0.82*Overall Liking + 0.14*Flavour + 0.07*Tenderness + 0.02*Juiciness – 0.05*Aroma

The PQS was also classified into four quality grade categories: unsatisfactory/below average, average, above average and excellent with the cut-off values of ≤35 (unsatisfactory/below average), 36-65 (average), 66-87 (above average) and ≥88 (excellent). These cutoffs were determined by requiring that the classification using PQS delivered the same proportions of samples in each category as the original quality grade results; 67.2% of the samples were correctly allocated when compared to the opinion score originally given by the consumer.

The additive terms in the eating quality model were gender, ageing period, cut type x cooking method, endpoint temperature, moisture infusion, electrical stimulation, hanging method and ultimate pH. Significant interactions were found between endpoint temperature and gender, ageing period and cut type x cooking method. The key additive factors shown to have the largest influence on the PQS were moisture infusion (with larger effects of moisture infusion identified for loin roast and loin stir fry, compared with the other five evaluated cuts), hanging method and electrical stimulation (where the effect change was highest for roasts compared to the other cuts). The predicted values from the model for the range of samples tested in the various studies ranged from 46.2 to 78.2 (Figure 1), indicating that all samples would have been graded as either average (category 3; 36-65) or above average (category 4; 66-87).

From the predictive model, an interactive spreadsheet tool has been developed which predicts the PQSs for 70°C and 75°C, based on the input parameters of gender, ageing period, cut, cooking method, electrical stimulation, moisture infusion, ultimate pH and hanging method.

This project has delivered a solid framework for an eating quality predictive model that needs to continue to be built on to ensure the model is and remains reliable for different cut types x cooking methods and when different combinations of factors are used. The recommendation for more samples will assist in strengthening the estimates of the model and investigating combinations of factors that may result in increasing the quality scores for pork cuts and further assist processors in producing high quality and consistent pork.

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1. Introduction

The eating quality of pork has been a focus area for the High Integrity Australian Pork Co-operative Research Centre (Pork CRC) and more broadly, the Australian pork industry. The primary aim is to develop and implement systems that can reliably deliver consistently high quality fresh Australian pork cuts to our markets.

Channon et al. (2017a) notes that the Australian pork industry is strongly focused on being able to differentiate Australian pork from other meat proteins, both locally produced and those from imported sources. The implementation of an eating quality system for pork, that provides clearly defined, integrated pathway options from production through to consumption for supply chain partners, has strong industry support to enable Australia's domestic and export customers to be supplied with consistently high quality pork. The adoption of such a system by industry could be beneficial to position Australian pork as a premium product in new and expanding markets and to differentiate it from competitors on the basis of consistent eating quality.

A number of meat science research projects, funded by the Pork CRC (Sub-Program 3A: Optimal Pork Quality for Multiple Markets) and Australian Pork Limited, have been undertaken to determine the effects of key factors on eating quality attributes of fresh pork. These studies, involving consumer sensory evaluations, have identified important pre- and post- slaughter management factors on pork eating quality. Factors investigated include gender, cut type, cooking method, ageing period, endpoint temperature, diet supplementation and carcase weight, hanging method, electrical stimulation, moisture infusion and ultimate pH. However, this information was not collated and integrated into a non-prescriptive pathway-based eating quality grading system for pork, until now.

The effect on sensory quality between different muscle and cooking method combinations has been demonstrated in beef (Watson et al. 2008a, 2008b) and sheep meat (Young et al. 2005), but not in pork. The Meat Standards Australia (MSA) system developed for beef and sheep meat grades individual cuts for eating quality based on cooking method (Watson et al. 2008a; Young et al. 2005). Watson et al. (2008a) described the complex MSA grading model that was initially developed, using meta-analysis techniques to use the extensive dataset (32,237 muscle samples) collected largely from unrelated experiments involving MSA consumer panels, to estimate meat quality scores for forty different individual beef muscles that had been aged for specified periods and cooked using up to five different methods. A protocol for consumer evaluation of beef was also developed (Watson et al. 2008b). Both the beef and sheep meat MSA systems use an aggregated eating quality score based on the sum of weighted scores for tenderness, juiciness, flavour and overall liking and from here, use this aggregated score, together with quality grade outcomes, to determine cut off scores. This methodology provides a strong basis and sound framework for the analysis of pork eating quality data to derive a predictive eating quality model. The Australian pork industry recognizes that such an approach is needed to ensure their customers are consistently supplied with assured high quality pork.

The aim of this project is to utilize all relevant Pork CRC data to develop an eating quality predictive model for Australian fresh pork, based on an overall quality score, as part of a non-prescriptive eating quality system.

2. Methodology

Data collation

Sensory data were used from Pork CRC projects conducted within Subprogram 3A: Optional Pork Quality for Multiple Markets:

- 3A-101: Body composition and physiological changes associated with immunocastration at two different live weights (Karen Moore) (Moore et al. 2017)
- 3A-103: Effects of various eating quality pathway factors on pork quality (Frank Dunshea) (Channon et al. 2016)
- 3A-105: Verification of eating quality pathways to produce consistently high quality pork (Frank Dunshea) (Channon et al. 2018a)
- 3A-106: Determining the effect of ageing period, cut type, cooking method and internal temperature on sensory and technological quality of pork from entire male and immunocastrated pigs (Frank Dunshea) (Channon et al. 2018b)
- 3B-101: Determining the variability in the eating quality of Australian fresh pork (Cameron Jose) (Jose et al. 2013)
- 3A-109: Validation of pork eating quality pathways in three commercial supply chains (Frank Dunshea) (Channon et al. 2015a; Channon et al. 2015b; Channon et al. 2015c)

The data included consumer scores for the sensory attributes of aroma/smell, tenderness, juiciness, flavour, overall liking as well as quality grade and re-purchase intention, in addition to objective variables including ultimate pH, hot carcase weight and intramuscular fat content. A total of 3,564 muscle samples from 626 pigs and 14,208 individual consumer responses were collated for analysis. These included four different muscles, loin, silverside, chuck tender and bolar blade by three different cooking methods (Table 1). The individual Pork CRC project reports provide further details on the number of samples and consumers, treatment variables/factors and the cooking methodology within each sensory experiment.

Table 1: Number of pork muscles evaluated by consumers for each muscle type, cut type and cooking method.

Muscle type	Stirfry	Roast	Grill	Total
Loin	500	500	1,044	2,014
Silverside	500	620		1,150
Chuck tender	200			200
Bolar blade		200		200
Total				3,564

Data structure

Across all studies, a number of 'Packs' (between 1 and 14 in the different studies) were obtained from each 'Pig'. These Packs were from either the left or right side and represented different cuts of meat. Each Pack was cut into several (between two and five in the different studies) samples which were then presented to consumers. A total of eight consumers were typically involved in each sensory session, each tasting between four and seven samples from different Packs. It followed that the samples for each Pack were tasted by between two and five different consumers.

Statistical modelling

All statistical analyses were performed in R (R version 3.4.3, http://www.r-project.org).

Pork Quality Score

The purpose of this analysis was to obtain a predictive equation which would predict Quality Grade using the measurements provided by the tasting panel. The full data set of 14,208 readings was used in this analysis. Watson et al. (2008a) measured a total of 13 variables on each sample and undertook a preliminary analysis to reduce this list down to just four: tenderness, juiciness, flavour and overall liking. In this study, five variables were measured on a 0-100 point scale, namely, Aroma, Tenderness, Juiciness, Flavour and Overall Liking and these were used to predict Quality Grade, which was assessed by the consumers on a 1-5 scale.

Watson et al. (2008a) used a linear discriminant analysis to determine their predictive equation. This method involves a response variable (y) which takes the value either 0 or 1, and so in this case, it was necessary that the analysis be performed several times, once for each star category. It appears that Watson et al. (2008a) obtained their overall equation MQ4 by astute averaging and testing of the individual equations thus obtained. By contrast, in this paper, the ordered categorical variable Quality Grade (on a 1-5) scale is subjected to a multinomial regression model, whereby the cumulative probabilities of the different star categories are modelled using a logit link function and a single linear function of the explanatory variables with different intercepts for each category. In particular, if p_k is the probability of a sample being scored k or above (k=2,...,5), then the model says that the Quality Score y_i for the ith observation (i=1,...,14208) is multinomial with probabilities (q_1,q_2,q_3,q_4,q_5) of obtaining scores 105, respectively, so that $p_5=q_5$, $p_4=q_4+q_5$, $p_3=q_3+q_4+q_5$ and $p_2=q_2+q_3+q_4+q_5$, where

$$\log\{ p_j/(1-p_j) \} = a_k + b_1x_{i1}+b_2x_{i2}+b_3x_{i3}+b_4x_{i4}+b_5x_{i5}.$$

Here a_k (k=2,...,5) and b_j (j=1,...,5) are parameters to be estimated, and x_{i1}, x_{i2}, ..., x_{i5} are the values of Aroma, Tenderness, Juiciness, Flavour and Overall Liking for the ith sample. This model was fitted using the 'polr' function (Agresti, 2002) in R and provided the combined pork quality score (PQS) across all consumer evaluations. Results were compared with those obtained using the method described by Watson et al. (2008a).

Predictive Eating Quality Model

Before moving to the predictive eating quality model, Watson et al. (2008a) considered the fact that each pack of meat had been subdivided into ten samples which had been assessed by ten different consumers. For the next stage, a summary value for each pack of meat was required, so the question was how best to summarise the ten values. They argued that the best summary was obtained using a "trimmed mean" given by excluding the two largest and two smallest of the ten values and averaging the remaining six. In our case, pigs being rather smaller than beef cattle, each pack of meat was only divided into four samples in most of the experiments, and the exclusion of (for example) the smallest and largest led to a loss of accuracy. As a result, each pack was summarised by the mean score of the consumer evaluations for that Pack.

This reduced the data set from 14,208 samples to 3,564 Packs, taken from 626 different Pigs across 10 different studies. To manage the complexity and non-orthogonality of the dataset, reflecting that it has been generated from a combination of multiple individual studies, ASREML (VSN International, https://www.vsni.co.uk/; Butler, Cullis, Gilmour & Gogel, 2009) was applied to the dataset using R. Linear mixed models using restricted maximum likelihood were fitted to combine the estimates of treatments across the three strata of 'Study', 'Pig' and 'Pack', with estimated random effects for each stratum used to obtain the predicted means.

This approach took into account that there were inherent differences between the studies (for example, different sources for the pigs, different research groups in different locations undertaking the studies, different diets given to the pigs in each study) that would not be well modelled by the other factors involved. In addition, it had already been established in the individual studies that there was significant variation between Pigs, over and above the variation due to differences between Packs. Hence, variance components corresponding to between studies, between pigs and within pigs were included in the ASREML analysis and estimates for these components obtained. Initially, a full model involving the major factors and all their interactions was fitted and it was then reduced down by including all the main effects and sets of interactions between them that were seen as having an impact. As a result, the fixed terms included in the final model were gender, endpoint temperature, ageing period, cut type by cooking method, moisture infusion, electrical stimulation, hanging method and ultimate pH as well as interactions between endpoint temperature and gender, ageing period and cut type x cooking method. These terms were significant and included in the final ASREML model.

3. Outcomes

Pork Quality Score

Multiple sensory attributes were assessed for each sample, but a single score would be more useful as a basis for describing pork eating quality at an industry level. From the multinomial regression of Quality Grade results against the recorded sensory attributes of aroma, tenderness, juiciness, flavour and overall liking, a model for the composite pork quality score (PQS) was developed.

PQS = 0.82*Overall Liking + 0.14*Flavour + 0.07*Tenderness + 0.02*Juiciness – 0.05*Aroma

This equation identified the eating quality factors which account for the variation in consumer satisfaction, in decreasing order, to be overall liking, flavour, tenderness, juiciness and aroma. Appendix 1 [Ed: Removed] shows that there are high correlations between these variables so that, while each of these terms showed statistical significance in the final model, there remain quite high correlations between the coefficients. The implication of this, as was found by Watson et al. (2008a), is that there are a variety of equations available all of which give similar performance in terms of predicting the Quality Grade.

In contrast, this equation differs from the revised MSA formula for determining the meat quality score (MQ4) for beef and the consumer eating quality (CEQ) score for sheepmeat (Meat and Livestock Australia, 2017):

MQ4 = 0.3*Overall Liking + 0.3*Flavour+0.3*Tenderness + 0.1*Juiciness
CEQ = 0.4*Overall Liking + 0.3*Flavour + 0.2*Tenderness + 0.1*Juiciness.

Based on the sensory data, the PQS was also classified into four quality grade categories: unsatisfactory/below average, average, above average and excellent with the cut-off values of ≤35 (unsatisfactory/below average), 36-65 (average), 66-87 (above average) and ≥88 (excellent). These cutoffs were determined by requiring that the classification using PQS delivered the same proportions of samples in each category as the original quality grade results. In comparison, sheepmeat cuts that obtain a CEQ score of <50 cannot be included in the MSA system for sheepmeat, whilst for beef, the cut-off MQ4 score is <46.

From this equation, a pork quality score was predicted for every sample in the sensory database and 67.2% of the samples were correctly allocated when compared to the opinion score originally given by the consumer. Table 2 shows the proportion of individual consumer responses that were correctly allocated to each PQS category.

Table 2: Percentage of samples correctly allocated to each opinion category (as assessed by consumers) based on predicted pork quality score.

Opinion category	Pork Quality Score (predicted)			
	Unsatisfactory (≤ 35)	Average (36-65)	Above Average (66-87)	Excellent (≥ 88)
Unsatisfactory/Below average	74.3	12.7	0.3	0.0
Average	25.1	68.4	23.4	2.2
Above Average	0.5	18.4	62.4	33.5
Excellent	0.1	0.5	13.8	64.3

*due to rounding, these percentages do not add up to 100.

From Watson et al. (2008a), the percentage of correct classifications between the predicted and true quality scores was 68.4% for their best four-discriminant model but 66.1% for the model MQ4 which they finally adopted for beef quality, so the outcome is very similar between beef and pork.

Predictive Eating Quality Model

Table 3 details the analysis of variance output for the model used from the ASREML analysis. The additive terms in the model were gender, ageing period, cut type x cooking method, endpoint temperature, moisture infusion, electrical stimulation, hanging method and ultimate pH. Significant interactions were found between endpoint temperature and gender, ageing period and cut type x cooking method.

It should be noted that the significance of factors depends somewhat on the order of fitting and here the significance of each term is obtained having fitted all terms above it but omitting all terms below it. The denominator degrees of freedom provide a good indicator of where the term is estimated and how accurately it is estimated. The intercept (the overall mean) and the Ageing contrast of 1 and 5 days vs the rest are terms that essentially vary between studies. These have less than 10 degrees of freedom for error and are very poorly estimated. Gender, electrical stimulation and hanging method are specific to a Pig, so these terms are tested against a residual variance largely based on variation between Pigs, about 330 degrees of freedom, while all other factors are largely estimated using variation between Packs within Pigs and have around 3100 degrees of freedom for error and are estimated with much better accuracy.

Table 3: Summary ASREML output for main effects and interactions in eating quality model to indicate significance of pathway factors.

Term	Df	Denominator df	F-value	P-value
Intercept	1	7.5	2713	<0.001
Gender	3	337.0	3.30	0.021
Ageing for 14 and 28 days vs. other days	1	2833.7	1.12	0.289
Ageing for 1 and 5 days vs. other days	1	8.5	2.09	0.184
Ageing for 7 days vs. 2 days	1	3441.4	1.39	0.238
Cut type x cooking method	6	3067.0	113.70	<0.001
Endpoint temperature	1	3526.3	4.49	0.034
Moisture infusion	1	3258.5	95.41	<0.001
Electrical stimulation	1	337.2	7.35	0.007
Hanging method	1	322.4	6.54	0.011
pH	1	1153.0	4.35	0.037
Gender:Temperature	3	3400.8	5.32	0.001
Ageing for 14 and 28 days vs. other days:Temperature	1	3097.2	10.52	0.001
Ageing for 7 days vs. 2 days:Temperature	1	3499.2	6.21	0.013
Cut type x cooking method:Temperature	6	3076.8	5.35	<0.001
Moisture infusion: loin roast/stir fry vs. other cuts	1	3077.7	12.43	0.001
Electrical stimulation:roast vs. other cuts	1	3093.6	9.54	0.002

When included in the ASREML model, hot carcase weight did not have an effect on PQS and although intramuscular fat content did have an effect, it was so small to not be practically important; an increase in intramuscular fat content of one unit reduced PQS by 0.7 units. Intramuscular fat content also appeared to be closely correlated to gender, with surgically castrated pigs having higher intramuscular fat content results on average than the other gender categories.

The effects for each pathway factor, together with interactions where relevant, are presented in Table 4. These estimates are based on the base value of 52.1 for a non-moisture infused loin roast sample from a non-electrically stimulated, Achilles hung entire male carcase aged for two days with pH of <5.5 cooked to an endpoint temperature of 70°C. The prediction for other combinations is obtained by adding the relevant amounts to the base value of 52.1. For example, for a shoulder stir fry at 75°C, the base value of 52.1 is increased by 1.0 (because it is at 75°C, not 70°C) and then a further 17.5 because it is a shoulder stir fry at 75°C, giving a predicted value of 52.1+1.0+17.5 = 70.6.

Table 4: Estimated effect changes for pathway variables within those pathway factors included in the pork eating quality model.

Pathway factor	Pathway variable	Base value*	Effect change	Effect change due to interactions		
				70˚C	75˚C	Cut type x cooking method
		52.1				
Endpoint temperature	70˚C		0.0			
	75˚C		1.0			
Gender	Entire male			0.0	0.0	
	Female			2.0	-2.2	
	Physical castrate			3.5	3.3	
	Immunocastrated male			2.4	0.7	
Ageing period	1 day			-0.1	N.A.	
	2 days			0.0	0.0	
	5 days			-0.1	N.A.	
	7 days			1.7	-0.5	
	14 days			3.6	-2.6	
	28 days			3.6	-2.6	
Cut type x cooking method	Loin roast			0.0	0.0	
	Loin stir fry			2.8	1.5	
	Loin steak (grilled)			-3.2	-8.5	
	Shoulder roast			7.4	10.9	
	Shoulder stir fry			15.0	17.5	
	Silverside roast			-9.1	-3.2	
	Silverside stir fry			-3.4	-2.9	
Moisture infusion	Moisture infused		7.7			All cuts except loin roast or stir fry
	Moisture infused		13.3			Loin roast or stir fry
	None		0.0			
Electrical stimulation	Yes – 150mA for 30 sec		1.8			All cuts except roasts
	Yes – 150mA for 30 sec		6.1			Roasts only
	None		0.0			
Hanging method	Achilles		0.0			
	Aitchbone		4.4			
Ultimate pH (72 hours)	5.5-5.7		4.3			
	<5.5*		0.0			

*refers to a non-moisture infused loin roast sample from a non-electrically stimulated, Achilles hung entire male carcase aged for two days with pH < 5.5 cooked to an endpoint temperature of 70˚C.

Whilst, to the authors' knowledge, the size of this dataset is the largest compiled for Australian pork, it is still limited. For example, whilst a pH of 5.5-5.7 was determined to increase PQS by 4.3 units (SE=2.1, t=2.1, P=0.037), the analysis was only informed by one study conducted using loin steaks (Jose et al., 2013). The application of these effect changes (Table 4) for different combinations of pathway factors needs to be done with care as not all combinations of the factors included in the model occur in the compiled dataset. This fact is included in the interactive spreadsheet tool in the form of a colour indicator which is green if a particular combination of factors has been tested by the Pork CRC sensory trials or red if it has not.

In the light of the interpretive limitations, the key additive factors shown to have the largest influence on the PQS were moisture infusion (with larger effects of moisture infusion identified for loin roast and loin stir fry, compared with the other five evaluated cuts), hanging method and electrical stimulation (where the effect change was highest for roasts compared to the other cuts).

The predicted values from the model ranged from 46.2 to 78.2 (Figure 1), indicating that all samples would have been graded as either average (category 3; 36-65) or above average (category 4; 66-87). It may be that as part of an eating quality system for pork, the industry may decide that only cuts predicted to achieve PQS that meet a category 4 or more would be eligible for inclusion for grading as being "eating quality assured".

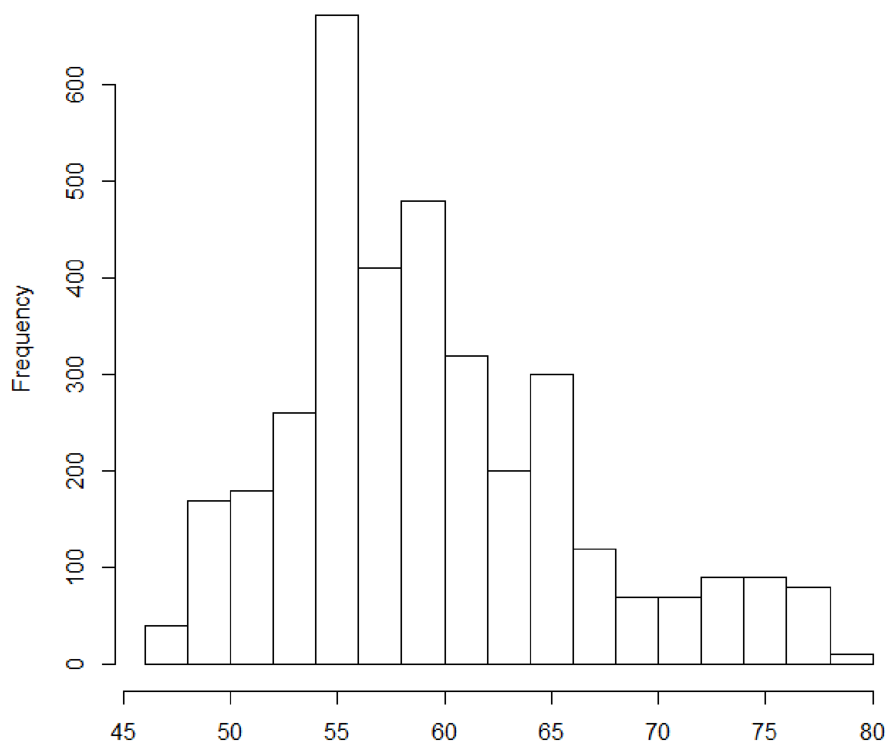

Figure 1: Distribution of estimated values of pork quality score (PQS) determined from the eating quality predictive model.

Note: A document with the workings, preliminary analyses and investigations and R code and output undertaken by Dr Richard Jarrett is attached in Appendix 1 [Ed:Removed]. A manuscript has also be submitted to and accepted by Meat Science

(Appendix 2) [Ed:Removed] and will be presented at the 64th International Congress of Meat Science and Technology (August 2018, Melbourne). The predictive model given in the manuscript is a slightly earlier version of the model adopted for this report.

Model predictions for Cut type x Cooking Method combinations

Generally, across all cuts of meat and cooking methods, Surgically Castrated and Immunocastrates score slightly higher than Females which scored slightly higher than Entire Males.

The following tables and comments summarise the results for each of the seven combinations of Cut type x Cooking Method. In each case, four standard methods, the combinations of Ageing=2 days and 7 days, and Cooking Temperature = 70 degrees and 75 degrees, were used. Each of these involved the Achilles hanging method. Then for most of the cuts, a number of additional tests were done involving a different Hanging method (Aitchbone instead of Achilles), Moisture Infusion and Electrostimulation.

Loin Roasts have scores ranging from 71-52. Under standard conditions, Ageing=7 days, Temperature=70 degrees offers the best score of 58-62 across the Sex levels. Moisture Infusion improves these scores by about ten points, while both Aitchbone and Electrostimulation also offer significant improvements.

Loin Stirfry has scores 56-75. While Ageing=7 days, Temperature=70 degrees provides the best results under standard conditions, Moisture Infusion at 70 degrees for 2 days improves these scores by over ten points with top scores of 75. Aitchbone hanging and Electrostimulaton (particularly at Ageing=14 days) also provide improvements in score.

Loin Steaks have predicted scores range from 46-63. All of these would be graded as a "3". Under standard conditions, Ageing=7 days, Temperature=70 degrees provides the best results. However, Moisture Infusion lifts these results well above 60, and Aitchbone hanging and Electrostimulation also lift the scores substantially. The most striking effect is that 70 degrees should be used, as all the scores below 52 are either at 75 degrees or are Entire Males. This combination is where the pH was at the "Low" level and the scores are lower by approximately four points compared to the same combination at pH="Normal".

Shoulder Roasts are in a narrow band from 64-72. There is particularly low replication here, with only ten packs for most of the combinations here and correspondingly high standard errors. Furthermore, not many alternatives have been tried – Moisture Infusion, Electrostimulation, pH and Hanging are all constant, and only Sex, Ageing and Temperature change. From the table below, the recommendation would be to use Ageing=2 days and Temperature=75 degrees. This would ensure that these were graded as "4".

Shoulder Stirfry again has relatively few combinations tested, with only Sex, Ageing and Temperature changing. The values vary between 71-78 so these are all graded as "4". Generally, Ageing=2 days and Temperature=75 degrees appears to be the best option, with all samples graded well into the "4" category.

Silverside Roast has values ranging 47-63. All are graded as "3". For standard conditions, Ageing=2 days and Temperature=75 degrees provides the best values for all Sex levels, with scores ranging from 52-58. Moisture Infusion raises the scores by approximately 8 points, while Aitchbone hanging and Electrostimulation, especially at shorter Ageing times, also offer improvements. However, they do not succeed in getting the grading up from "3" to "4".

Silverside Stirfy has scores ranging 52-63. For the standard conditions, Ageing=7 days and Temperature=70 degrees appears to be the best for all Sex levels. Moisture Infusion at 70 degrees for 2 days raises the scores by approximately 6 points, while Aitchbone hanging and Electrostimulation, particularly at longer Ageing times, improve the results. Again, all samples are graded as a "3".

Table 5: Model predictions for each cut type x cooking method combination covered in the sensory trials.

	(Ageing,Temp)				Aitch	Aitch	MI	ES	ES	ES
Loin Roast	2,70	7,70	2,75	7,75	2,75	7,75	2,75	2,75	7,75	14,75
SurgCas	60.0	61.6	60.7	60.1						
Immuno	58.8	60.4	58.0	57.5	62.4	61.9	71.4	64.1	63.6	61.5
Female	58.4	60.1	55.2	54.7	59.6	59.1	68.5	61.2	60.7	58.6
Entire	56.1	58.1	57.4	56.8						
Loin Stirfry	2,70	7,70	2,75	7,75	2,70	7,70	2,70	2,70	7,70	14,70
SurgCas	62.7	64.4	62.2	61.6						
Immuno	61.6	63.3	59.5	59.0	66.0	67.7	75.0	63.4	65.0	67.0
Female	61.3	63.0	56.7	56.2	65.7	67.3	74.6	63.0	64.7	66.7
Entire	59.3	60.9	58.9	58.3						
Loin Steak	2,70	7,70	2,75	7,75	2,70	7,70	2,70	2,70	7,70	14,70
SurgCas	56.7	58.4	52.2	51.0						
Immuno	55.6	57.3	49.5	49.0	60.0	61.7	63.3	57.4	59.0	61.0
Female	55.3	57.0	46.7	46.2	59.7	61.3	63.0	57.0	58.7	60.7
Entire	53.3	54.9	48.9	48.3						
Shoulder Roast	2,70	7,70	2,75	7,75						
SurgCas	67.3	69.0	71.6	71.1						
Immuno	66.2	67.8	69.0	68.4						
Female	65.8	67.5	66.1	65.6						
Entire	63.8	65.5	68.3	67.7						
Shoulder Stirfry	2,70	7,70	2,75	7,75						
SurgCas	74.9	76.6	78.2	77.6						
Immuno	73.8	75.5	75.6	75.0						
Female	73.5	75.1	72.7	72.2						
Entire	71.4	73.1	74.9	74.3						
Silverside Roast	2,70	7,70	2,75	7,75	2,75	7,75	2,75	2,75	7,75	14,75
SurgCas	50.8	52.4	57.5	56.9						
Immuno	49.6	51.3	54.8	54.3	59.2	58.7	62.6	60.9	60.3	58.3
Female	49.3	51.0	52.0	51.5	56.4	55.8	59.7	58.0	57.5	55.4
Entire	47.3	49.0	54.2	53.6						
Silverside Stirfry	2,70	7,70	2,75	7,75	2,70	7,70	2,70	2,70	7,70	14,70
SurgCas	56.5	58.1	57.7	57.2						
Immuno	55.3	57.0	55.1	54.6	59.7	61.4	63.1	57.1	58.8	60.7
Female	55.0	56.7	52.3	51.7	59.4	61.1	62.8	56.8	58.4	60.4
Entire	53.0	54.7	54.4	53.9						

Interactive Spreadsheet Tool

An interactive spreadsheet tool has been developed which has the following input parameters (Figure 2):

- Gender – entire/surgical castrate/immunocastrated male or female
- Ageing period - 2 days/7 days/other
- Cut – loin/shoulder/silverside

- Cooking method – roast/steak/stir fry
- Electrical stimulation – yes/no
- Moisture infusion – yes/no
- Ultimate pH – normal/low
- Hanging method – Achilles/Aitchbone

	A	B
1	**PREDICTED PORK QUALITY SCORE (PQS)**	
6		
7	Sex	Immuno
8		
9	Ageing (d)	1
10		
11	Cut	Loin
12		
13	Cooking	Steak
14		
15	ES	No
16		
17	MI	No
18		
19	pH	Normal
20		
21	Hanging	Achilles
22		
23	Temp	70
24		
25	Score:	55.51
26	Category:	**Average**
32		
33	Note: The predictions that can be obtained here range outside the parameters that were tested in the 10 studies.	
34	As a result, although the predictions for the combinations in the study only range from 45.3 to 77.4, there are combinations	
35	we can enter here that will give MQ scores as high as 91. Some assessment needs to be done of whether such combinations are feasible.	
36	Combinations that were not observed result in a prediction that is highlighted in red.	

Figure 2: Screenshot of the interactive spreadsheet tool, based on the predictive eating quality model.

Information is contained in the interactive spreadsheet tool on the effects of each of the treatment factors (based on the eating quality model) and the output is the predicted PQSs for two endpoint temperatures, 70°C and 75°C.

4. Application of Research

The engagement of all pork supply chain participants, including producers, processors, wholesalers, retailers, food service businesses and consumers, will now be needed to enable and support the commercial implementation of an eating quality system for pork. This represents the next phase of activity to ensure that its adoption is successful.

The management systems that support the MSA system, whilst functional, are extensive and require considerable industry investment in grading of carcases and cuts, verification of compliance of licensees with MSA Standards through independent third-party auditing managed through AUS-MEAT and education and training programs for all licensees and reporting to producers. It is acknowledged that this comes at a considerable cost to the red meat sector, so management processes to support the commercialization of a national system by all sectors of the pork supply chain will need to be carefully considered to ensure that such initiatives are supported by industry, are cost-effective and functional and maximize return on investment.

5. Conclusion

This analysis has enabled the key outcomes arising from the complex multi-factorial studies conducted with Pork CRC support to be modelled and more simply communicated. An interactive spreadsheet tool has also been developed from which the effect of different pathway factors can be estimated. The Australian pork industry now has tools to assist processors in producing high quality and consistent pork.

This project has delivered a solid framework for an eating quality predictive model that needs to continue to be built on to ensure the model is and remains reliable for different cut types x cooking methods and when different combinations of factors are used (see Limitations/Risks). The recommendation for more samples will assist in strengthening the estimates of the model and investigating combinations of factors that may result in increasing the quality scores for pork cuts.

6. Limitations/Risks

The pork studies were undertaken on a project-by-project basis, rather than with a design to specifically investigate all different possibilities or an overall view of an integrated model. This has resulted in imbalance in the number of results for different treatment factors and reduced rigour in the estimation of the effects.

It is important to note that in comparison to the pork studies, where the combined total number of consumer evaluations to date was 14,208 (representing 3564 individual samples), the Meat Standards Australia model for beef has now involved over 800,000 consumer evaluations by >114,000 consumers from 11 countries. The MSA program has developed over time to include more consumers and a similar approach could be applied to pork in order to collect more data and improve the model.

Not all combinations of treatment factors were evaluated by the Pork CRC consumer studies and so predictions from the model and spreadsheet tool can range outside the evaluated parameters. As a result, although the predictions for the combinations in the studies only range from 46.2 to 78.2, there are combinations which can be entered into the spreadsheet tool that will give PQS scores as high as 91 (highlighted in the spreadsheet). Some assessment needs to be completed of whether such combinations are feasible and whether they give such high pork quality scores in reality; this assessment could form part of a prospective validation study.

7. Recommendations

In light of the limitations outlined in the preceding section, further work is still needed to strengthen the predictive algorithms and more accurately determine the effect size of the many pathway interventions experienced by pigs, carcases and pork that can influence the eating quality of pork. It is foreseen that other sensory studies will need to be conducted to provide additional data for other pathway parameters that were either not investigated (e.g. retail ready packaging systems, alternative cooking methods) or investigated here only in small studies (such as pH, electrical stimulation and moisture infusion) and to accommodate new developments adopted by supply chain partners to improve production, processing and post-slaughter practices.

For example, an observation is that the majority of the 'above average' pork quality scores were attained by the shoulder cuts and the 'average' scores were attributed to the loin and leg cuts. Further research and development could be invested into potential pathway interventions which would increase the pork quality score for loin and leg cuts to fall into the 'above average' category (> 66) and for shoulder cuts to be graded as 'excellent'.

Further work is also required to address the inconsistent effects of interventions on all sensory traits across the different cut type x cooking method combinations investigated and identify alternative methods to increase pork quality scores. Additional sensory studies would continue to investigate the extent to which eating quality can be shifted by implementation of particular pathway interventions and determine if these need to be incorporated into the predictive algorithms.

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