THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION

VOLUME 62 2002

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Can Raman spectroscopy predict beef meat and eating quality traits?

SM Fowler, [1, 2*] H Schmidt[3] and DL Hopkins[1, 2]

[1]Centre for Sheep and Red Meat Development, NSW Department of Primary Industries, Cowra, Australia [2]Graham Centre for Agricultural Innovation, NSW Department of Primary Industries and Charles Sturt University, Wagga Wagga, Australia [3]Research Centre of Food Quality, University of Bayreuth, Kulmbach, Germany

**Corresponding author:* Email: steph.fowler@dpi.nsw.gov.au

Abstract

Quality assurance and guaranteeing meat and eating quality continues to be an ongoing challenge to red meat processors, as many measures of meat quality require resource intensive, destructive or subjective tests. Consequently, there is a need to develop rapid, non-invasive and non-destructive methods for meat quality assessment in commercial processing plants. Therefore, a preliminary investigation was conducted to determine the potential for a hand-held Raman spectroscopic device to predict meat quality and sensory traits measured by an untrained consumer panel. To this end, 45 beef loins (*m. longissimus thoracis*) were measured using a 671nm hand-held Raman spectroscopic device. Once spectra were collected, loins were frozen until sensory testing and shear force measurements. Further sub-samples were also collected to measure traits including sarcomere length, particle size, pH and colour. Derived models indicate that using Raman spectra it was possible to predict juiciness and tenderness, with cross validated correlations between the predicted and observed values (R^2_{cv}) of 0.42 (RMSEP = 11.29) and 0.47 (RMSEP = 10.52). A tentative band assignment suggests that these predictions may be based on changes to the biochemical characteristics of the muscle associated with hydrophobicity of proteins, fatty acid composition and the collagen matrix. However, further research is required to determine the repeatability and robustness of these models on a larger independent data set.

Keywords: eating quality, beef, Raman spectroscopy

Introduction

Quality assurance and guaranteeing meat and eating quality continues to be an ongoing challenge to red meat processors, as many measures of meat quality require resource intensive, destructive or subjective methods. Consequently, there is a need to develop rapid, robust and accurate measures of meat and eating quality traits which are suitable for measurement in commercial meat processing applications.

Of the spectroscopic technologies available, Raman spectroscopy (RS) is of particular interest to applications in meat quality assessment as it is based on scattering of light (Damez & Clerjon 2008). While several studies using a hand-held RS device have been conducted to investigate the prediction of meat quality traits in lamb (Fowler, Ponnampalam, Schmidt, Wynn & Hopkins 2015a, Fowler, Schmidt, Van de Ven & Hopkins 2015b) and pork (Scheier & Schmidt 2013, Scheier, Scheeder & Schmidt 2015, Bauer, Scheier, Eberle & Schmidt 2016), very little research has been conducted on beef (Bauer et al. 2016) and no studies have been conducted to investigate the potential to predict eating quality using RS.

Therefore, the aim of this research was to determine the potential for a Raman hand-held device to predict meat and eating quality traits of beef.

Materials and methods

Beef strip loins (*m. longissimus lumborum*) were collected at 24 h post-mortem (PM) from 45 carcases, which were randomly selected from carcases weighing between 250-450 kg with 0-4 teeth. The animals were of unknown background and sex from a commercial abattoir to represent prime cattle slaughtered in the southern states of Australia.

Measurements with the RS device were conducted perpendicular to the muscle fibre at 3 d PM after chilled storage at 1°C using a 671nM hand-held device (Schmidt, Sowoidnich, Maiwald, Sumpf & Kronfeldt 2009) set at an integration time of 3 s with five accumulations. After measurement, sections were vacuum packed and aged at 1°C for a further 18 days and at 21 d were cut into five slices and frozen for further sensory analysis (De Brito, McGrath, Holman, Friend, Fowler, van de Ven & Hopkins 2016). Further sub-samples were also collected to measure shear force, sarcomere length, particle size, pH, purge and colour as previously described by Fowler, Schmidt, van de Ven, Wynn & Hopkins (2015c).

Sensory analysis was conducted as previously described (Watson, Gee, Polkinghorne & Porter 2008, De Brito et al. 2016). In short, samples were eaten by 58 untrained consumer panellists, loins were allocated so that each loin was consumed by 10 different consumers. This was achieved by cutting each loin slice in half after thawing, grilling and resting.

Partial least squares (PLS) regression models cross validated with Leave One Out using the PLS toolbox with MatLab software (The Mathworks Inc. 2013) were produced to determine the potential to predict all meat and eating quality traits measured using the Raman spectra. Background correction of spectra was completed by fitting a order polynomial to further examine spectra and complete spectral band assignments.

Results

Analysis of spectra demonstrated that using RS to predict tenderness yielded a correlation between the observed and predicted values (R^2) equal to 0.60. However this was reduced when the model was cross validated (R^2_{cv}) 0.47. Using the spectra also reduced the error of the prediction by 12% compared to the prediction of tenderness using the average tenderness score (RMSEP = 10.52 and 11.93 for the Raman spectra and null models, respectively with three latent variables).

Furthermore, predicting juiciness scores using Raman spectra reduced the RMSEP from 12.11 for the null model to 11.29 using a model with five latent variables. This equates to a correlation between measured and predicted values of R^2 = 0.65 and a cross validated correlation between predicted and measured values of R^2_{cv} = 0.42.

As illustrated in Figure 1, the net intensity of the unprocessed spectra is higher for loins which had higher juiciness scores. When spectra were processed to remove the contribution from the non-Raman background, intensities at wavenumbers 826, 854, 936, 1031 – 1124, 1207, 1264, 1312, 1448, 1616 and 1660 cm^{-1} remained higher for loins that had higher juiciness scores.

There was a limited ability to predict pH at 72h PM using Raman spectra (R^2 = 0.12, R^2_{CV} = 0.09, RMSECV = 0.87). It was not possible to predict any of the other indicators of meat quality using Raman spectra measured at 3 days PM.

Part of the variation in sensory traits was explained by some indicators of meat quality (Table 2), however this study showed there was no correlation between sensory tenderness and shear force values (R^2 = 0.02).

Discussion

Summary statistics for the meat quality indicators measured in this study suggest that the loins collected in this study were affected by heat shortening. Heat shortening occurs when the temperature of the muscle is 20°C or above when the muscle enters into *rigor mortis* (Devine, Wells, Lowe & Waller 2014). This is particularly evident in the high percentage of fluid lost from the loins as purge. Indeed, Hopkins, Ponnampalam, van de Ven & Warner (2014) found that pH decline significantly affected purge, however loins in the current study had a mean purge of 7% indicating that they were more severely affected in comparison to those loins measured by Hopkins et

Figure 1 Background corrected Raman spectra (primary axis) and unprocessed Raman spectra (secondary axis) from beef *m. longissimus thoracis* with the highest average juiciness scores (66.2 – 82.5; grey line) and the lowest average juiciness scores (19.8 – 38.9; black line).

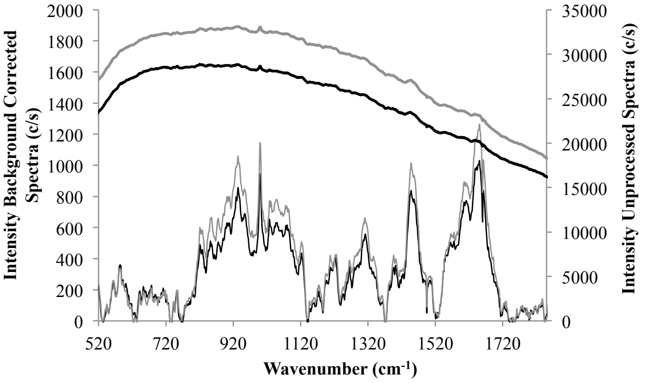

Table 1 Summary statistics of indicators of meat quality measured on the *longissimus lumborum* (LL) of 45 beef loins.

Trait		Mean (± s. d.)	Range (min, max)
pH	72 h (pH_{72})	5.8 (0.13)	5.5 – 6.1
	Ultimate (pHu)	5.7 (0.05)	5.6 – 5.8
L*	72 h	36.8 (2.59)	32.2 – 43.6
	21 d	38.1 (2.12)	34.0 – 43.4
*a**	72 h	19.1 (2.33)	14.6 – 22.9
	21 d	14.1 (2.34)	9.4 – 19.0
*b**	72 h	3.4 (1.53)	0.6 – 6.9
	21 d	3.9 (1.06)	6.3 – 1.9
Purge (%)		7.5 (2.6)	1.9 – 13.0
Cooking Loss (%)		24.5 (2.8)	20.0 – 32.0
Shear Force (N)		36.7 (11.4)	15.2 – 66.1
Sarcomere Length (μm)		1.74 (0.16)	1.40 – 2.19
Particle Size	72 h	181 (74.63)	84 – 339
	21 d	90 (33.39)	52 – 186
Tenderness		52.53 (1.76)	19.75 – 82.55
Juiciness		48.09 (1.79)	21.05 – 74.00
Flavour		50.81 (1.36)	24.10 – 71.70
Overall Liking		49.32 (1.44)	26.83 – 73.05
Quality Ranking		2 (0.059)	1 – 3

Table 2 Meat quality indicators of beef *m. longissimus lumborum* which explained variation in sensory traits, tenderness, juiciness, flavour and overall liking (regression coefficient, standard error and probability level).

Trait	Coefficient	Std Error	*P*-value
Tenderness			
Intercept	330.0	76.11	0.001
*b** value at 21d	2.36	1.16	0.05
*L** value at 21d	-2.04	0.61	0.002
pH_{72}	-37.4	10.90	0.001
Particle size at 3 d	-0.09	0.02	0.001
Sarcomere Length	14.74	7.50	0.05
Juiciness			
Intercept	234.8	74.31	0.003
Particle size at 3 d	-0.08	0.02	0.001
pH_{72}	-29.4	12.66	0.02
Flavour			
Intercept	188.9	58.20	0.002
pH_{72}	-21.84	9.91	0.03
Particle size at 3d	-0.06	0.02	0.001
Overall Liking			
Intercept	49.58	5.43	<0.00
*b** values at 21d	2.88	1.11	0.01
Particle size at 3d	-0.64	0.02	0.0004

al. (2014) who noted a mean purge of 2%. Furthermore, other characteristics including the significance of particle size, colour attributes and pH in determining shear force and sensory scores is consistent with the pale and watery characteristics of heat shortened beef (Warner, Dunshea, Gutzke, Lau & Kearney 2014).

Prediction of sensory traits using the hand held Raman device indicated that the accuracy of prediction for eating quality traits determined by an untrained consumer panel was comparable to that of Beattie, Bell, Farmer, Moss & Patterson (2004) for tenderness (R^2 = 0.65) and juiciness (R^2 = 0.62). However, unlike Beattie et al. (2004) it was not possible to predict overall acceptability. This may be the result of different experimental designs as a large untrained consumer panel was used in this study rather than a trained panel that was used by Beattie et al. (2004). Differences in the selection and training of panellists between studies may have affected the ability to predict sensory scores as measurements from trained panels have smaller variance compared to untrained panels (Thompson 2002).

Comparing the results of this research with previous research conducted by Bauer et al. (2016) to predict the shear force values of beef *m. gluteus medius* indicates that Raman spectroscopy may be a better predictor of sensory tenderness than shear force as demonstrated by the correlation between predicted and measured values (R^2_{val} = 0.23 and 0.33 for two models for shear force). This is plausible as sensory tenderness is associated with more than one biochemical characteristic. However, as shear force is a mechanical measurement it does not take into account the contributions of fat and water content to the perception of tenderness (Perry, Thompson, Hwang, Butchers & Egan 2001). This may explain the poor correlation found between tenderness and shear force values found in this study. As this research was conducted on a relatively small number of samples collected in one sampling, further research is warranted to determine whether the predictions are repeatable for independent data.

Raman spectra of intact beef muscles are complex and as such it is difficult to determine which biochemical characteristics are contributing to the reported predictions. Spectra which underlie the prediction for juiciness highlight this complexity, indicating that there are significant changes to the spectra from loins with the highest juiciness at multiple wavenumbers including 826, 854, 936, 1031 – 1124, 1207, 1264, 1312, 1448, 1616 and 1660 cm^{-1}. However, given the lack of scientific literature available, changes to the spectra are currently poorly defined.

Tentative band assignments for the spectra indicate that increasing fatty acid concentrations may contribute to the prediction of juiciness, as evident at approximately 1020-1130 cm^{-1} where increasing intensity has been associated with increasing C-C stretch vibrations from increasing concentrations of saturated fatty acids (Fowler et al. 2015a). This is reinforced by the vibration at approximately 1300 cm^{-1} that has been associated with increasing saturated fatty acids as it represents the spectral contributions from CH_2 twists (Fowler et al. 2015a). It is hypothesised that the increases in saturated fatty acid signals are a reflection of increasing intramuscular fat (IMF) with increasing juiciness, given that the level of saturated fat increases with increasing levels of IMF (Smith, Tatum & Belk 2008).

Further spectral assignments completed by Beattie et al. (2004) identify several changes which are evident in spectra between 1400-1500 cm^{-1} and which may be associated with increasing hydrophobicity of proteins. This indicates loins with increasing juiciness scores have a greater ability to lose water contained within the myofibril during processing procedures including packaging, cooking (Pearce, Rosenvold, Andersen & Hopkins 2011) and consumption (Perry et al. 2001).

This study demonstrates that Raman spectroscopy may be a better predictor of the biochemical and biophysical changes associated with eating quality traits determined by untrained consumer panels compared to shear force values. Given the small number of samples in the current study, further research is warranted to determine whether the accuracy and error of the predictions is repeatable on an independent data set. Furthermore, it is unclear whether heat shortening has affected the predictions of eating quality traits. Consequently, further research needs to be conducted to determine whether the predictions can be improved by including data from other beef carcases including normal carcases and dark cutting carcases, which would also be measured in commercial situations.

Acknowledgements

The authors would like to thank the Australian Meat Processors Corporation for funding this research, Jordan Hoban (NSW DPI), Gerlane DeBrito (São Paulo State University Brazil) and Matt Kerr (NSW DPI) for their assistance with collecting and analysing data.

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