**Review: Beef Eating Quality - A European Journey**

L. J. Farmer and D. T. Farrell

Journal: Animal

**Supplementary Tables S1 and S2**

**Table S1. A summary of instrumental research to predict eating quality or parameters which influence eating quality of beef (2000-2017)**

| **Technique** | **Parameters studieda** | **Reference** |
| --- | --- | --- |
| Robotic pH | pH45mins Root Mean Square Error | (Roehe *et al.*, 2014) |
| Computer Vision | Sensory (overall acceptability), WBSF | Jackman *et al.*, 2008) |
| WBSF day 21, Acceptability, Tender, Hard, Juice, Flavour, based on tenderness and acceptability scores | (Jackman *et al.*, 2009) |
| Ultrasound | IMF in lean meat | (Aass *et al.*, 2009) |
| IMF, Marbling | (Indurain *et al.*, 2009) |
| Carcass fat depth | (Roehe *et al.*, 2014) |
| Computerised Tomography (CT scan) | Fat, Muscle, Bone, *Total Carcass tissue* | (Navajas *et al.*, 2010) |
| Cut composition, sensory, IMF, and fatty acid composition | (Prieto *et al.*, 2010) |
| Magnetic Resonance Imaging | IMF | (Lee *et al.*, 2015) |
| Raman Spectroscopy | Acceptability of Aroma, Flavour, Texture, Overall Satisfaction; Intensity of Aroma, Flavour, Tenderness, Juiciness; WBSF | (Beattie *et al.*, 2004) |
| Near infra-red (NIR) Spectroscopy | WBSF, D14 | (Venel *et al.*, 2001) |
| Fatty acids | (Sierra *et al.*, 2008) |
| Individual fatty acids, SFA, MUFA, PUFA, n-6, n-3, IMF | (Prieto *et al.*, 2011) |
| Fat, protein, moisture | (Su *et al.*, 2014) |
| Visible (VIS) and NIR spectroscopy | WBSF, *Longissimus dorsi* | (Park *et al.*, 2001) |
| Colour L, a\*, b\*, E  Chewiness, Juiciness  WBSF, Tender/ tough classification (based on predicted/ measured WBSF) | (Liu *et al.*, 2003) |
| Tenderness (Slice Shear Force) | (Shackelford *et al.*, 2005) |
| pH24hrs,Sarcomere length, Cooking loss, WBSF; Colour L, a\*, b\* | (Andres *et al.*, 2008) |
| Colour L, a\*, b\*; Cooking loss %, Volodkevitch Shear Force, Slice Shear Force day 3, Slice Shear Force day 14, Sensory Tenderness, Juiciness, Flavour, Abnormal flavour, Overall Liking | (Prieto *et al.*, 2009) |
| n-3 fatty acids, Conjugated linolenic, Conjugated linoleic, Trans monounsaturated fatty acids | (Prieto *et al.*, 2012) |
| Tenderness (SSF) | (Shackelford *et al.*, 2012) |
| Dark Cutting Beef % correct classification | (Prieto *et al.*, 2014) |
| Beef eating quality (Tenderness-SSF#) | (Qiao *et al.*, 2015a) |
| Hyperspectral imaging | SSF | (Naganathan *et al.*, 2008) |
| Total fat, SFA, Unsaturated fatty acids, Individual fatty acids | (Kobayashi *et al.*, 2010) |
| WBSF; pH48hours; Colour L, a\*, b\* | (Wu *et al.*, 2010) |
| Drip loss (WHC) | (ElMasry *et al.*, 2011) |
| Colour L, Colour b\*; pH, Tenderness (SSF) | (ElMasry *et al.*, 2012 and 2013) |
| WBSF, Colour L, a\*, b\* | (Wu *et al.*, 2012) |
| Water, Fat, Protein | (ElMasry *et al.*, 2013) |
| Tenderness (SSF) | (Cluff *et al.*, 2013) |
| Tenderness (SSF) | (Naganathan *et al.*, 2015a) |
| Tenderness, pH | (Qiao *et al.*, 2015b) |
| Tenderness (SSF) | (Naganathan *et al.*, 2015b) |
| Tenderness (WBSF) | (Naganathan *et al.*, 2016) |
| IMF distribution | (Lohumi *et al.*, 2016) |

a pH45mins- pH 45 minutes post-mortem, pH24hours- pH 24hours post-mortem, pH48hours- pH 48 hours post-mortem, SSF = slice shear force, WBSF –Warner Bratzler Shear Force, IMF- Intramuscular fat; SFA- Saturated fatty acids, MUFA- Monounsaturated fatty acids, PUFA- Polyunsaturated fatty acids, n-6- Omega 6 fatty acids, n-3 Omega 3 fatty acids, WHC = water holding capacity,

**Yancey**

**Table S2. Summary of grading systems currently in use to predict beef quality / eating quality (Farmer *et al.*, 2010, Polkinghorne and Thompson, 2010, Bonny *et al.*, 2017)**

| **Grading scheme** | **Country** | **Grading unit** | **Number of grades\*** | **Basis of grading** |
| --- | --- | --- | --- | --- |
| USDA# | USA | Carcase | 8 Quality grades | Sex; carcase weight; marbling; ossification; meat colour, texture; eye muscle area, rib fat; kidney and perirenal fat. |
| Canada | Canada | Carcase | 5 Quality grades (+ subgrades) | Sex; conformation; carcase weight; marbling; meat colour, texture; fat colour, thickness |
| EUROP | Europe | Carcase | 5 Classification grades for conformation and fat (+ subgrades) | Sex; conformation; carcase weight; fat cover. |
| JMGA# | Japan | Carcase | 5 Quality grades | Sex; carcase weight; marbling; meat colour, brightness, texture; fat colour, lustre, texture, firmness, thickness; eye muscle area, rib thickness. |
| Korea | South Korea | Carcase | 5 Quality grades | Sex; carcase weight; marbling; meat colour; fat colour, firmness, texture, thickness; lean maturity; eye muscle area, rib thickness. |
| South Africa | South Africa | Carcase | 3 Classification grades (+ subgrades) | Sex; carcase weight; dentition; ribfat; damage. |
| Quality Mark | New Zealand | Carcase | Pass/fail Quality grades | Country of origin; age; handling; absence of growth promoters; licensed plant; ultimate pH |
| MLC# Blueprints (+ updates) | UK | Carcase | Pass/fail Quality grades | Age/sex; growth rate; diet; EUROP grade/fat class; transport and lairage handling; slaughter techniques, defects; hanging; electrical stimulation, chilling and pH/T decline; maturation. |
| Red Tractor and Quality Standard Marks | UK | Carcase | Pass/fail Quality grades | Age/sex;; EUROP grade/fat class; maturation; |
| AUS-MEAT | Australia | Carcase | Classification grades | Diet; carcase wt; dentition; p\* fat; sex; shape; marbling; meat colour; fat colour. |
| MSA# | Australia | Cut | 3 Quality grades | Bos indicus %; hormonal growth promoter implants; carcass wt; sex; hump height; electrical stimulation; hang; marbling; ossification; meat colour; pHu; ageing time; cooking method. |

\* Classification grades are descriptive terms for the carcase to aid trading while Quality grades aim to place a value on the carcase on the basis of its perceived quality. Grades may also indicate yield (Polkinghorne and Thompson, 2010) but this aspect is not discussed in this paper.

# USDA = United States Department of Agriculture; JMGA = Japanese Meat Grading Association; MLC = Meat and Livestock Commission (now Agriculture and Horticulture Development Board); MSA = Meat Standards Australia.

**References for Supplementary Tables S1 and S2**

Aass L, Fristedt CG and Gresham JD 2009. Ultrasound prediction of intramuscular fat content in lean cattle. Livestock Science 125, 177-186.

Andres S, Silva A, Soares-Pereira AL, Martins C, Bruno-Soares AM and Murray I 2008. The use of visible and near infrared reflectance spectroscopy to predict beef M-longissimus thoracic et lumborum quality attributes. Meat Science 78, 217-224.

Beattie RJ, Bell SJ, Farmer LJ, Moss BW and Desmond PD 2004. Preliminary investigation of the application of Raman spectroscopy to the prediction of the sensory quality of beef silverside. Meat Science 66, 903-913.

Bonny S, Polkinghorne R, Strydom P, Matthews K, Lopez-Fandino R, Nishimura T, Scollan N, Pethick D and Hocquette JF 2017. Quality assurance schemes in major beef-producing countries. In New Aspects of Meat Quality (ed. PP Purslow), pp. 223-255. Elsevier Ltd, Oxford, UK.

Cluff K, Naganathan GK, Subbiah J, Samal A and Calkins CR 2013. Optical scattering with hyperspectral imaging to classify longissimus dorsi muscle based on beef tenderness using multivariate modeling. Meat Science 95, 42-50.

ElMasry G, Sun DW and Allen P 2011. Non-destructive determination of water-holding capacity in fresh beef by using NIR hyperspectral imaging. Food Research International 44, 2624-2633.

ElMasry G, Sun DW and Allen P 2012. Near-infrared hyperspectral imaging for predicting colour, pH and tenderness of fresh beef. Journal of Food Engineering 110, 127-140.

ElMasry G, Sun DW and Allen P 2013. Chemical-free assessment and mapping of major constituents in beef using hyperspectral imaging. Journal of Food Engineering 117, 235-246.

Farmer LJ, Devlin DJ, Gault NFS, Gordon AW, Moss BW, Tolland ELC and Tollerton IJ 2010. Comparison of systems for assuring the eating quality of beef. Advances in Animal Biosciences 1, 231-231.

Indurain G, Carr TR, Goni MV, Insausti K and Beriain MJ 2009. The relationship of carcass measurements to carcass composition and intramuscular fat in Spanish beef. Meat Science 82, 155-161.

Jackman P, Sun DW, Du CJ and Allen P 2009. Prediction of beef eating qualities from colour, marbling and wavelet surface texture features using homogenous carcass treatment. Pattern Recognition 42, 751-763.

Jackman P, Sun DW, Du CJ, Allen P and Downey G 2008. Prediction of beef eating quality from colour, marbling and wavelet texture features. Meat Science 80, 1273-1281.

Kobayashi K, Matsui Y, Maebuchi Y, Toyota T and Nakauchi S 2010. Near infrared spectroscopy and hyperspectral imaging for prediction and visualisation of fat and fatty acid content in intact raw beef cuts. Journal of near Infrared Spectroscopy 18, 301-315.

Lee S, Lohumi S, Lim HS, Gotoh T, Cho BK and Jung S 2015. Determination of Intramuscular Fat Content in Beef using Magnetic Resonance Imaging. Journal of the Faculty of Agriculture Kyushu University 60, 157-162.

Liu YL, Lyon BG, Windham WR, Realini CE, Pringle TDD and Duckett S 2003. Prediction of color, texture, and sensory characteristics of beef steaks by visible and near infrared reflectance spectroscopy. A feasibility study. Meat Science 65, 1107-1115.

Lohumi S, Lee S, Lee H, Kim MS, Lee WH and Cho BK 2016. Application of hyperspectral imaging for characterization of intramuscular fat distribution in beef. Infrared Physics & Technology 74, 1-10.

Naganathan GK, Grimes LM, Subbiah J, Calkins CR, Samal A and Meyer GE 2008. Visible/near-infrared hyperspectral imaging for beef tenderness prediction. Computers and Electronics in Agriculture 64, 225-233.

Naganathan GK, Cluff K, Samal A, Calkins CR, Jones DD, Lorenzen CL and Subbiah J 2015a. A prototype on-line AOTF hyperspectral image acquisition system for tenderness assessment of beef carcasses. Journal of Food Engineering 154, 1-9.

Naganathan GK, Cluff K, Samal A, Calkins CR, Jones DD, Lorenzen CL and Subbiah J 2015b. Hyperspectral imaging of ribeye muscle on hanging beef carcasses for tenderness assessment. Computers and Electronics in Agriculture 116, 55-64.

Naganathan GK, Cluff K, Samal A, Calkins CR, Jones DD, Meyer GE and Subbiah J 2016. Three dimensional chemometric analyses of hyperspectral images for beef tenderness forecasting. Journal of Food Engineering 169, 309-320.

Navajas EA, Glasbey CA, Fisher AV, Ross DW, Hyslop JJ, Richardson RI, Simm G and Roehe R 2010. Assessing beef carcass tissue weights using computed tomography spirals of primal cuts. Meat Science 84, 30-38.

Park B, Chen YR, Hruschka WR, Shackelford SD and Koohmaraie M 2001. Principal component regression of near-infrared reflectance spectra for beef tenderness prediction. Transactions of the ASAE 44, 609-615.

Polkinghorne RJ and Thompson JM 2010. Meat standards and grading A world view. Meat Science 86, 227-235.

Prieto N, Lopez-Campos O, Zijlstra RT, Uttaro B and Aalhus JL 2014. Discrimination of beef dark cutters using visible and near infrared reflectance spectroscopy. Canadian Journal of Animal Science 94, 445-454.

Prieto N, Dugan MER, Lopez-Campos O, McAllister TA, Aalhus JL and Uttaro B 2012. Near infrared reflectance spectroscopy predicts the content of polyunsaturated fatty acids and biohydrogenation products in the subcutaneous fat of beef cows fed flaxseed. Meat Science 90, 43-51.

Prieto N, Navajas EA, Richardson RI, Ross DW, Hyslop JJ, Simm G and Roehe R 2010. Predicting beef cuts composition, fatty acids and meat quality characteristics by spiral computed tomography. Meat Science 86, 770-779.

Prieto N, Ross DW, Navajas EA, Richardson RI, Hyslop JJ, Simm G and Roehe R 2011. Online prediction of fatty acid profiles in crossbred Limousin and Aberdeen Angus beef cattle using near infrared reflectance spectroscopy. Animal 5, 155-165.

Prieto N, Ross DW, Navajas EA, Nute GR, Richardson RI, Hyslop JJ, Simm G and Roehe R 2009. On-line application of visible and near infrared reflectance spectroscopy to predict chemical-physical and sensory characteristics of beef quality. Meat Science 83, 96-103.

Qiao T, Ren J, Craigie C, Zabalza J, Maltin C and Marshall S 2015a. Quantitative Prediction of Beef Quality Using Visible and NIR Spectroscopy with Large Data Samples Under Industry Conditions. Journal of Applied Spectroscopy 82, 137-144.

Qiao T, Ren JC, Craigie C, Zabalza J, Maltin C and Marshall S 2015b. Singular spectrum analysis for improving hyperspectral imaging based beef eating quality evaluation. Computers and Electronics in Agriculture 115, 21-25.

Roehe R, Ross D, Duthie C-A, Lambe N, Anderson C, Broadbent C, Bunger L, England S, Picken A, Robertson R, Peacock A, Green A, Hinz A, Gilchrist J, Richardson RI, Nath M and Glasbey C 2014. Research Towards an Integrated Measurement of Meat Eating Quality (IMEQ). Final Report 2013. Retrieved on 24 April 2018 from https://www.sruc.ac.uk/download/downloads/id/1875/imeq\_report.pdf.

Shackelford SD, Wheeler TL and Koohmaraie M 2005. On-line classification of US Select beef carcasses for longissimus tenderness using visible and near-infrared reflectance spectroscopy. Meat Science 69, 409-415.

Shackelford SD, Wheeler TL, King DA and Koohmaraie M 2012. Field testing of a system for online classification of beef carcasses for longissimus tenderness using visible and near-infrared reflectance spectroscopy. Journal of Animal Science 90, 978-988.

Sierra V, Aldai N, Castro P, Osoro K, Coto-Montes A and Olivan M 2008. Prediction of the fatty acid composition of beef by near infrared transmittance spectroscopy. Meat Science 78, 248-255.

Su HW, Sha K, Zhang L, Zhang Q, Xu YL, Zhang R, Li HP and Sun BZ 2014. Development of near infrared reflectance spectroscopy to predict chemical composition with a wide range of variability in beef. Meat Science 98, 110-114.

Venel C, Mullen AM, Downey G and Troy DJ 2001. Prediction of tenderness and other quality attributes of beef by near infrared reflectance spectroscopy between 750 and 1100 nm; further studies. Journal of near Infrared Spectroscopy 9, 185-198.

Wu JH, Peng YK, Chen JJ, Wang W, Gao XD and Huang H 2010. Study of Spatially Resolved Hyperspectral Scattering Images for Assessing Beef Quality Characteristics. Spectroscopy and Spectral Analysis 30, 1815-1819.

Wu JH, Peng YK, Li YY, Wang W, Chen JJ and Dhakal S 2012. Prediction of beef quality attributes using VIS/NIR hyperspectral scattering imaging technique. Journal of Food Engineering 109, 267-273.