Incorporating meat quality in sheep breeding programmes: potential of non-invasive technologies

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Leading the way in Agriculture and Rural Research, Education and Consulting
Introduction

• Genetic selection for lamb meat quality rare
• Difficult / expensive/ time consuming to measure
  – Direct tests:
    • post-mortem - on relatives, difficult to standardise
    • destructive - expensive, not possible on-line
  – Predictive tests:
    • mainly post-mortem; often destructive / invasive / slow

• Other potential hindrances:
  – Data feedback from abattoir; reliable traceability
  – On-line implementation
### Genetic control of meat quality

<table>
<thead>
<tr>
<th>Species</th>
<th>Type</th>
<th>Country</th>
<th>Trait</th>
<th>Heritability</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td><em>Bos taurus</em></td>
<td>Taurine</td>
<td>USA</td>
<td>Marbling</td>
<td>0.57 ± 0.13</td>
<td>(Wheeler et al., 2001a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LT SF</td>
<td>0.22 ± 0.12</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Juiciness</td>
<td>0.09 ± 0.11</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Flavour</td>
<td>0.07 ± 0.11</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IMF</td>
<td>0.55 ± 0.14</td>
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</tr>
<tr>
<td>Taurine</td>
<td></td>
<td>Australia</td>
<td>LT SF</td>
<td>0.11 ± 0.06²</td>
<td>(Johnston et al., 2003)</td>
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<tr>
<td></td>
<td></td>
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<td>Juiciness</td>
<td>0.15 ± 0.06</td>
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<td></td>
<td></td>
<td></td>
<td>Flavour</td>
<td>0.05 ± 0.06</td>
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<td></td>
<td></td>
<td></td>
<td>MQ4</td>
<td>0.13 ± 0.06</td>
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<tr>
<td>Zebu³</td>
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<td>Australia</td>
<td>LT SF</td>
<td>0.31 ± 0.09</td>
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<td></td>
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<td>Juiciness</td>
<td>0.20 ± 0.08⁴</td>
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<td></td>
<td></td>
<td></td>
<td>Flavour</td>
<td>0.23 ± 0.08</td>
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<td></td>
<td></td>
<td></td>
<td>MQ4</td>
<td>0.32 ± 0.09</td>
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<tr>
<td>Taurine</td>
<td></td>
<td>Australia</td>
<td>IMF</td>
<td>0.38 ± 0.04⁴</td>
<td>(Reverter et al., 2003)</td>
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<tr>
<td>Zebu³</td>
<td></td>
<td>Australia</td>
<td>IMF</td>
<td>0.39 ± 0.03³</td>
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<tr>
<td><em>Gallus gallus</em></td>
<td>Broiler</td>
<td>France</td>
<td>Ultimate pH</td>
<td>0.49 ± 0.11</td>
<td>(Le Bihan-Duval et al., 1999)</td>
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<td>Lightness</td>
<td>0.75 ± 0.08</td>
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<td>Redness</td>
<td>0.81 ± 0.04</td>
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<td></td>
<td>Yellowness</td>
<td>0.64 ± 0.06</td>
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<td></td>
<td>IMF</td>
<td>0.08 ± 0.04</td>
<td>(Zerehdaran et al., 2004)</td>
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<tr>
<td><em>Ovis aries</em></td>
<td>Merino</td>
<td>Australia</td>
<td>Meat pH</td>
<td>0.27 ± 0.09</td>
<td>(Fogarty et al., 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lightness</td>
<td>0.14 ± 0.07</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Redness</td>
<td>0.02 ± 0.06</td>
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<td></td>
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<td>Yellowness</td>
<td>0.04 ± 0.06</td>
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<tr>
<td>Composite</td>
<td></td>
<td>France</td>
<td>IMF</td>
<td>0.22</td>
<td>(Moreno et al., 2001)</td>
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<tr>
<td><em>Sus scrofa</em></td>
<td>Large</td>
<td>Australia</td>
<td>Meat pH</td>
<td>0.14 ± 0.04</td>
<td>(Hermesch et al., 2000)</td>
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<tr>
<td>White/</td>
<td>Landrace</td>
<td>USA</td>
<td>Lightness</td>
<td>0.29 ± 0.06</td>
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<tr>
<td>Duroc/</td>
<td>Landrace</td>
<td>USA</td>
<td>Drip Loss</td>
<td>0.23 ± 0.05</td>
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<td></td>
<td>IMF</td>
<td>0.35 ± 0.06</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Meat pH</td>
<td>0.14 ± 0.08</td>
<td>(Lo et al., 1991)</td>
</tr>
<tr>
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<td>IMF</td>
<td>0.52 ± 0.13</td>
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<td></td>
<td></td>
<td>Cooking loss</td>
<td>0.06 ± 0.06</td>
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<td></td>
<td></td>
<td>Tenderness</td>
<td>0.17 ± 0.08</td>
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<td></td>
<td></td>
<td></td>
<td>Off flavour</td>
<td>0.03 ± 0.06</td>
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<td></td>
<td></td>
<td></td>
<td>Consumer acceptance</td>
<td>0.34 ± 0.11</td>
<td></td>
</tr>
</tbody>
</table>

¹ *Longissimus thoracis* shear force; ² SE of heritability given as a range of 0.04–0.08 for the table see original reference; ³ Mixture of purebred zebu (e.g. Brahman) and breeds with some zebu ancestry; ⁴ SE of heritability given as a range of 0.07–0.09 for the table see original reference; ⁵ SE personal communication A. Reverter; ⁶ this is the objective measure of tenderness, for taste panel tenderness, $h^2 = 0.45 ± 0.12$.  

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From: J.P. Kerry and David Ledward: 
*Improving the Sensory and Nutritional Quality of Fresh Meat* 
Elsevier, 2009
Introduction

- Few examples of commercial implementation
  - large scale progeny tests (NZ, Australia)
  - genomics
  - (SRUC “More taste, less waste” industry-led project)

- Accurate phenotypes are key
  - rapid, routine, non-destructive, non-invasive, cost-effective
  - Imaging technologies?
Non-invasive post-mortem predictors

Visible and Near Infra-red spectroscopy (VIS-NIR)

Predicts:
- Colour
- Cooking loss
- Composition
- IMF; fatty acids
- Mechanical tenderness
- Sensory traits

Pros:
- Fast, non-invasive, cost-effective, on-line
- High $R^2$ for colour & composition

Cons:
- $R^2 << 1$ for technological/sensory traits (Prieto et al., '09)
- Predictions complex
Non-invasive post-mortem predictors

- Hyperspectral imaging
  Predict:
  - Colour
  - Cooking loss
  - Mechanical tenderness
  - Composition; IMF
  - Fatty acid composition
  - Sensory traits

- Raman spectroscopy
  Pros:
  - non-invasive, cost-effective
  - wealth of information
  - $R^2 > 0.8$ for several traits\textsuperscript{1}

Cons:
  - practicality in plant
  - predictions complex
  - price?

\textsuperscript{1}review by Xiong et al., 2014
Non-invasive post-mortem predictors

- X-ray computed tomography (CT)

Predicts:
- IMF
  - beef ($R^2 = 0.71-0.76$)\(^1\)
  - pork ($R^2 = 0.63-0.83$)\(^2\)
  - lamb ($R^2 = 0.36$)\(^3\)
- fatty acid profile ($R^2 = 0.61-0.75$)\(^1\)
- low accuracy for tenderness and sensory traits

Pros:
- fast; non-invasive; packaged meat
- simultaneously predicts composition

Cons:
- $R^2 << 1$
- portability
- price

\(^1\) Prieto et al., 2010
\(^2\) Font-i-Furnols et al., 2013
\(^3\) Lambe et al., 2009
Non-invasive in-vivo predictors

- **Ultrasound**
  - predicts IMF in pigs and beef cattle with mod-high accuracy (Newcom et al. ‘02; Aass et al., ‘06,’09)

- not successful in sheep

http://bovineengineering.com/intra_mus_fat Ultra.html
Non-invasive in-vivo predictors

- X-ray computed tomography (CT)

- CT tissue density distributions reflect IMF levels in live lambs ($R^2 > 0.6$)
- Does not accurately predict mechanical tenderness or taste panel traits

Clelland, 2015; Lambe et al., 2008, 2009
Previous research: lamb IMF vs MQ

- Acceptable levels for IMF (loin)
  - > 2-3% grilled red meat / lamb\(^1\)
  - > 5% for “better than every day” eating quality\(^2\)
  - SRUC slaughter lamb mean IMF:
    - Texel 1.4-1.6%
    - Texel X Mule 2.2%
    - Scottish Blackface 2.3%

- Concerns about fat reduction for eating quality

\(^1\) Savell and Cross, 1988; Heylen et al., 1998; \(^2\) Hopkins et al., 2006
Genetic control of CT-IMF

- Data set from UK terminal sire breeding programme
  - ~2000 Texel ram lambs over 12 years
  - CT and performance records:
    2-stage selection for carcass composition
- Genetic analysis of CT-predicted IMF (ASReml):
  - heritability = 0.31 (s.e. 0.07)
  - genetic correlation with total carcass fat = 0.68 (s.e. 0.08)

Clelland et al., 2015
More taste, less waste

Industry led research project with SRUC as lead research partner
More taste, less waste project

Terminal sire rams
CT scanned

Mated to Mule ewes

EBVs based on
meat and carcass quality
of crossbred lambs

N= 5000
-crossbred
lambs

Nasal sampling

Tissue bank for
5000 DNA

CT scanned

NIR

CTT

VISNIR

eAbattoir

SRUC/EGENES

Loin info

Carcass info
More taste, less waste project – WP1

N = 300 across all specs

Prediction equations & correlations; windows of acceptability
### CT-predicted IMF converted to % band

<table>
<thead>
<tr>
<th>IMF % band</th>
<th>1-2%</th>
<th>2-3%</th>
<th>3-4%</th>
<th>4-5%</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2%</td>
<td>5</td>
<td>17</td>
<td></td>
<td></td>
<td>22</td>
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<tr>
<td>2-3%</td>
<td>3</td>
<td>70</td>
<td>55</td>
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<td>128</td>
</tr>
<tr>
<td>3-4%</td>
<td>34</td>
<td></td>
<td>83</td>
<td>1</td>
<td>118</td>
</tr>
<tr>
<td>4-5%</td>
<td>2</td>
<td>23</td>
<td></td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>&gt;5%</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>124</td>
<td>163</td>
<td>2</td>
<td>297</td>
</tr>
</tbody>
</table>

Prediction equations combining CT traits and weights of loin & carcass

**Best single CT predictor of all traits**

- % fat in sample (estimated by CT)

- 54% samples - band correct
- 63% samples with IMF <3% = < CT band 3-4%
- 25% samples with IMF >3% = < CT 3-4%
IMF influences sensory traits

Sensory traits significantly affected by IMF level:
- Assessed by chemical IMF extraction

![Graph showing the influence of IMF on sensory traits]
IMF influences sensory traits

Sensory traits significantly affected by IMF level:
- Assessed by chemical IMF extraction OR predicted by CT

<table>
<thead>
<tr>
<th>Texture</th>
<th>Flavour</th>
<th>Juiciness</th>
<th>Liking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adj-R²</td>
<td>&lt;3%</td>
<td>&gt;3%</td>
<td>P value</td>
</tr>
<tr>
<td>N</td>
<td>132</td>
<td>165</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Texture</td>
<td>7.0</td>
<td>5.55</td>
<td>5.85</td>
</tr>
<tr>
<td>Flavour</td>
<td>3.8</td>
<td>5.29</td>
<td>5.45</td>
</tr>
<tr>
<td>Juiciness</td>
<td>4.4</td>
<td>4.98</td>
<td>5.15</td>
</tr>
<tr>
<td>Liking</td>
<td>5.7</td>
<td>5.08</td>
<td>5.28</td>
</tr>
</tbody>
</table>
VISNIR to predict MQ in lamb meat cuts

• Spectra from 500-2400 nm used in analysis
• Median spectra of 10 replicates used
• Unscrambler (v10.3) multivariate analysis software
# VISNIR to predict MQ in lamb meat cuts

<table>
<thead>
<tr>
<th></th>
<th>Unpackaged</th>
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<th>Vacuum-packed</th>
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<tbody>
<tr>
<td></td>
<td>$R^2_{\text{Cal}}$</td>
<td>$R^2_{\text{Val}}$</td>
<td>$R^2_{\text{Cal}}$</td>
<td>$R^2_{\text{Val}}$</td>
</tr>
<tr>
<td>IMF</td>
<td>0.35</td>
<td>0.23</td>
<td>0.23</td>
<td>0.18</td>
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<tr>
<td>ShF</td>
<td>0.03</td>
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<tr>
<td>Texture</td>
<td>0.03</td>
<td>0.01</td>
<td>0.07</td>
<td>0.06</td>
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<tr>
<td>Flavour</td>
<td>0.02</td>
<td>0.01</td>
<td>0.05</td>
<td>0.02</td>
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<tr>
<td>Juiciness</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.003</td>
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<tr>
<td>Overall liking</td>
<td>0.008</td>
<td>NA</td>
<td>0.001</td>
<td>NA</td>
</tr>
</tbody>
</table>

$R^2_{\text{Cal}}$ = Coefficient of determination of calibration.
$R^2_{\text{Val}}$ = Coefficient of determination of validation.
Discussion - More taste, less waste

• Can we increase accuracies to predict IMF post-mortem?
  – VISNIR on fresh cut meat; analysis method
  – CT on whole carcasses

• Project has produced:
  – high accuracy in-vivo phenotypes for IMF
  – moderate accuracy post-mortem phenotypes for IMF
  – data set to develop SNP-keys for genomic selection

• A combination of in-vivo, post-mortem and genomic predictors could be used to develop a sustainable breeding programme including lamb meat quality traits
General discussion

• Clear breeding goals required
  – MQ and other traits - multi-trait selection index
  – genomic selection + phenotyping

• Need to overcome the barriers to practical implementation and routine phenotyping

• Move from R&D to commercial implementation
Supportive funding of the “More taste, less waste” project came from Innovate UK

SRUC receive financial support from the Scottish Government’s Strategic Research Programme

Thanks go to:
• SRUC CT unit
• Wm Morrison’s Woodhead Brothers abattoir in Turriff
• Ian Richardson and team, University of Bristol
Leading the way in Agriculture and Rural Research, Education and Consulting