Modelling beef meat quality traits during ageing by early post-mortem pH decay descriptors

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1 Introduction
   - Meat quality
   - Meat tenderness is a complex trait

2 Material and Methods
   - Data collection
   - Data analysis

3 Results
   - pH/temperature decay descriptors
   - Effect of animal/carcass descriptors
   - Modelling meat tenderness

4 Conclusions

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Modelling beef meat quality traits
Meat tenderness

- **Inconsistency** in the eating-quality characteristics of meat
  - Is one problem faced by the meat industry worldwide
- **Meat tenderness** - Most important sensory quality attribute
- If the beef is tender - We are able to evaluate the Juiciness and Flavour
- Consumers are even **willing to pay more** for beef of higher or guaranteed tenderness
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Meat tenderness

Depends on various physiological factors

- Proteolytic degradation
- Muscle contraction
- Intra-muscular connective tissue
- Marbling
- etc
Meat quality

Meat tenderness is a complex trait

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Meat tenderness

Critical periods for meat tenderness

- Immediately pre-slaughter
- During slaughter
- Immediately post-slaughter
  - Interaction between the pH and temperature decline
  - Ideal window
Critical periods for meat tenderness

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Meat quality

Meat tenderness is a complex trait

Ideal window

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Modelling beef meat quality traits
Objectives

1. to model the decrease in temperature and pH during chilling of beef carcasses early post-mortem
2. to evaluate the extent of influence of live-animal/carcass characteristics (i.e., sex, weight, age, breed, class, fat cover, conformation, and transport and lairage time) on the pH and temperature decline rates
3. Classification of beef carcasses into optimal quality (OQ) and cold-shortened (CS) taking into account the ideal window rule
4. Assess the combined effects of early post-mortem pH/temperature decline and animal/carcass characteristics on meat tenderness
5. The ultimate aim is to build practical models that can be used to predict the minimum ageing period of a beef carcass
Study 1: Modelling pH/temperature decline
- 126 beef animals (74 cross-breed and 52 Mirandesa breed)
  - 85 males and 41 females
  - Average age of 10.1 ± 2.32 months

Study 2: Modelling meat quality
- 51 Mirandesa breed animals
  - 34 males and 17 females
  - Hot carcass weight: 209.7 ± 65.60 kg
Study 1 and 2

- pH and temperature were recorded
  - Intervals of 10 min during 24 h of carcass chilling
  - *longissimus thoracis* muscle at 4\textsuperscript{th} rib level
  - OMEGA wireless receiver/host (UWTC-REC1)
Meat tenderness

**Study 2: Meat samples**

- *longissimus thoracis et lumborum* muscle from the 12th thoracic vertebrae to the 3rd lumbar vertebrae
- Meat blocks were vacuum packed (1, 2 or 3) and randomly assigned to one of three ageing periods (3, 8 and 13 days)
- Tenderness
  - Cooked at 70°C until the sample reached an internal temperature of 70°C
  - 1-cm cork-borer to give the maximum number of sub-samples
  - Ten to fifteen replicates of 1 cm² cross-sectional area
  - TA.XTPlus texture analyser - Warner-Bratzler
Modelling of pH/temperature decline

- **Exponential Decay** function proposed by Hwang and Thompson (2001)

\[ Y(t) = A(u) + (A(i) - A(u)) \times e^{-k \times t} \]

- where:
  - \( Y(t) \) is the \( pH \) or \( temperature \) at time \( t \)
  - \( A(u) \) is the final \( pH \) or \( temperature \)
  - \( A(i) \) is the initial \( pH \) or \( temperature \)
  - \( k \) is the exponential constant of decay
  - \( t \) is the time in hours after slaughtering
pH/temperature descriptors

- **pH**: 1.5, 3.0, 4.5, 6.0 and 24 hours
- **Temperature**: 1.5, 3.0, 4.5 and 6.0 hours
- **time\(pH6.0\)**: time at \(pH = 6.0\)
- **Temppp\(H6.0\)**: Temperature at \(pH6.0\)
- **\(k_{pH}\)**: exponential decay parameter for pH decline
- **\(k_{Temp}\)**: exponential decay parameter for temperature decline
Animal/carcass characteristics considered as regressors

- sex, age, breed
- hot carcass weight (HCW)
- transport time (tTransport), lairage time (tLairage)
- animal class: Calf, Vealer or Yearling
Modelling shear force during ageing

Linear mixed-effects model

\[ SF_{ij} = \beta_{0j} + \beta_{1j} \times \text{Ageing}_{ij} + \beta_{2} \times \text{Ageing}_{i}^2 + \beta_{3} \times pH_{ep} + \beta_{4} \times k_{pH} \times \text{Ageing}_{i} + \beta_{5} \times \text{Sex} + \varepsilon_{ij} \]

\[ \beta_{0j} = \beta_0' + u_j \]
\[ \beta_{1j} = \beta_1' + v_j \]

Random-effects terms \( u_j \) and \( v_j \) were added to the mean of the intercept \( \beta_0 \) and time slope \( \beta_1 \) to account for random shifts due to carcass \( j \).
pH/temperature decay modelling
Mean, median and range of pH/temperature decline descriptors

<table>
<thead>
<tr>
<th>Estimated values and model parameters</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH₁₅</td>
<td>6.52</td>
<td>6.53</td>
<td>6.01</td>
<td>6.93</td>
</tr>
<tr>
<td>pH₃₀</td>
<td>6.24</td>
<td>6.25</td>
<td>5.62</td>
<td>6.87</td>
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<tr>
<td>pH₄₅</td>
<td>6.08</td>
<td>6.07</td>
<td>5.45</td>
<td>6.81</td>
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<td>pH₆₀</td>
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<td>5.95</td>
<td>5.38</td>
<td>6.76</td>
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<tr>
<td>pH₂₄</td>
<td>5.78</td>
<td>5.74</td>
<td>5.30</td>
<td>6.51</td>
</tr>
<tr>
<td>Temp₁₅ (°C)</td>
<td>32.9</td>
<td>33.1</td>
<td>27.2</td>
<td>36.4</td>
</tr>
<tr>
<td>Temp₃₀ (°C)</td>
<td>27.8</td>
<td>28.0</td>
<td>19.2</td>
<td>33.9</td>
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<tr>
<td>Temp₄₅ (°C)</td>
<td>23.7</td>
<td>23.7</td>
<td>13.8</td>
<td>31.5</td>
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<tr>
<td>Temp₆₀ (°C)</td>
<td>20.1</td>
<td>20.1</td>
<td>10.1</td>
<td>29.3</td>
</tr>
<tr>
<td>kₚH (h⁻¹)</td>
<td>0.335</td>
<td>0.344</td>
<td>0.079</td>
<td>0.697</td>
</tr>
<tr>
<td>kₚTemp (°C/h)</td>
<td>0.113</td>
<td>0.101</td>
<td>0.022</td>
<td>0.256</td>
</tr>
<tr>
<td>TimeₚH₆₀ (h)</td>
<td>4.92</td>
<td>3.85</td>
<td>1.52</td>
<td>20.2</td>
</tr>
<tr>
<td>TempₚH₆₀ (°C)</td>
<td>24.4</td>
<td>25.7</td>
<td>1.96</td>
<td>35.0</td>
</tr>
</tbody>
</table>
### pH at 3 hours

<table>
<thead>
<tr>
<th>pH at 3.0 h (pH$_{3.0}$)</th>
<th>HCW</th>
<th>Class – Vealer</th>
<th>Class – Yearling</th>
<th>SEUROP – O R</th>
<th>SEUROP – O U</th>
<th>Class – Calf</th>
<th>Vealer</th>
<th>Yearling</th>
<th>SEUROP – P O</th>
<th>SEUROP – P R</th>
<th>SEUROP – P U</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.001</td>
<td>0.206</td>
<td>0.149</td>
<td>-0.035</td>
<td>-0.072</td>
<td>6.110$^a$</td>
<td>6.317$^b$</td>
<td>6.259$^{ab}$</td>
<td>6.343$^a$</td>
<td>6.308$^a$</td>
<td>6.047$^b$</td>
</tr>
<tr>
<td></td>
<td>0.0005</td>
<td>0.0690</td>
<td>0.1137</td>
<td>0.0904</td>
<td>0.0916</td>
<td>0.0548</td>
<td>0.0385</td>
<td>0.0916</td>
<td>0.0694</td>
<td>0.0579</td>
<td>0.1180</td>
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<tr>
<td></td>
<td>0.036</td>
<td>0.004</td>
<td>0.193</td>
<td>0.696</td>
<td>0.436</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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Modelling beef meat quality traits
## pH decay rate - $k_{pH}$

<table>
<thead>
<tr>
<th>pH decay rate ($k_{pH}$)</th>
<th>Class – Vealer</th>
<th>Class – Yearling</th>
<th>SEUROP – O</th>
<th>R</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.058</td>
<td>0.004</td>
<td>0.018</td>
<td>0.008</td>
<td>0.155</td>
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<tr>
<td></td>
<td>0.0266</td>
<td>0.0421</td>
<td>0.0378</td>
<td>0.0383</td>
<td>0.0571</td>
</tr>
<tr>
<td></td>
<td>0.025</td>
<td>0.297</td>
<td>0.624</td>
<td>0.832</td>
<td>0.008</td>
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<tr>
<td>Temperature decay rate</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class – Calf</th>
<th>Vealer</th>
<th>Yearling</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.367&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.309&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.371&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.0212</td>
<td>0.0161</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SEUROP – P</th>
<th>O</th>
<th>R</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.298&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.316&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.306&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.453&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.0290</td>
<td>0.0242</td>
<td>0.0250</td>
<td>0.0492</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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Modelling beef meat quality traits
### Time to $pH_{6.0}$ and Temperature at $pH_{6.0}$

<table>
<thead>
<tr>
<th>Time to pH 6.0 (h) (Time$<em>{pH</em>{6.0}}$)</th>
<th>Fat – 3</th>
<th>Fat – 2</th>
<th>Fat – 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.379</td>
<td>0.8060</td>
<td>0.200</td>
</tr>
<tr>
<td></td>
<td>4.518$^a$</td>
<td>5.896$^b$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature at pH 6.0 (°C) (Temp$<em>{pH</em>{6.0}}$)</th>
<th>HCW</th>
<th>Class – Vealer</th>
<th>Class – Yearling</th>
<th>SEUROP – O</th>
<th>SEUROP – U</th>
<th>Class – Calf</th>
<th>Vealer</th>
<th>Yearling</th>
<th>SEUROP – P</th>
<th>SEUROP – O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.620</td>
<td>7.200</td>
<td>23.54$^a$</td>
<td>24.02$^a$</td>
<td>29.05$^b$</td>
<td>20.73$^a$</td>
<td>24.36$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.370</td>
<td>3.5000</td>
<td>1.2800</td>
<td>1.0560</td>
<td>2.2900</td>
<td>1.975</td>
<td>1.755</td>
</tr>
</tbody>
</table>
## Temperature decay date - $k_{Temp}$

| Temperature decay rate ($k_{Temp}$) | HCW | Breed – Mirandesa | Gender – Male | Class – Vealer | Class – Yearling | Fat – 3 | SEUROP – O | R | U | Breed – Cross | Mirandesa | Gender – Female | Male | Class – Calf | Vealer | Yearling | Fat – 2 | 3 | SEUROP – P | O | R | U |
|-------------------------------------|-----|------------------|---------------|---------------|-----------------|--------|------------|---|---|--------------|-----------|----------------|------|--------------|--------|------------|--------|---------|--------|---|--------|---|---|---|
|                                    |     |                  |               |               |                 |        |            |   |   |              | 0.102<sup>a</sup> | 0.122<sup>b</sup> | 0.105<sup>a</sup> | 0.119<sup>b</sup> | **0.134**<sup>a</sup> | 0.118<sup>b</sup> | 0.095<sup>c</sup> |     |     | 0.109<sup>a</sup> | 0.080<sup>b</sup> | 0.143<sup>a</sup> | 0.105<sup>b</sup> | 0.076<sup>cd</sup> | 0.055<sup>d</sup> | 0.0001 | 0.0070 | <.0001 | 0.0094 | <.0001 | 0.0095 | <.0001 | 0.0141 | <.0001 |

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Modelling beef meat quality traits
## Compliance discrimination

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Prediction</th>
<th>Reference</th>
<th>Accuracy (95% CI)</th>
<th>Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>RLDA</td>
<td>CS</td>
<td>13</td>
<td>0.946</td>
<td>0.885</td>
</tr>
<tr>
<td></td>
<td>OQ</td>
<td>1</td>
<td>(0.818 – 0.993)</td>
<td></td>
</tr>
<tr>
<td>LDA</td>
<td>CS</td>
<td>13</td>
<td>0.919</td>
<td>0.830</td>
</tr>
<tr>
<td></td>
<td>OQ</td>
<td>1</td>
<td>(0.781 – 0.983)</td>
<td></td>
</tr>
<tr>
<td>kNN</td>
<td>CS</td>
<td>12</td>
<td>0.892</td>
<td>0.770</td>
</tr>
<tr>
<td></td>
<td>OQ</td>
<td>2</td>
<td>(0.746 – 0.970)</td>
<td></td>
</tr>
<tr>
<td>SVM</td>
<td>CS</td>
<td>12</td>
<td>0.892</td>
<td>0.770</td>
</tr>
<tr>
<td></td>
<td>OQ</td>
<td>2</td>
<td>(0.746 – 0.970)</td>
<td></td>
</tr>
<tr>
<td>NSC</td>
<td>CS</td>
<td>10</td>
<td>0.864</td>
<td>0.700</td>
</tr>
<tr>
<td></td>
<td>OQ</td>
<td>4</td>
<td>(0.712 – 0.955)</td>
<td></td>
</tr>
</tbody>
</table>
 Compliance discrimination

Individuals factor map - PCA

Dim1 (48.6%)

Dim2 (39.1%)

Groups
- CS
- OQ

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Modelling beef meat quality traits
Sex effect on meat tenderness

Sex
- Female
- Male

Shear force (Kgf)
- 5.0
- 4.5
- 4.0
- 3.5

Ageing (Day)
- 3
- 8
- 13
Class effect on meat tenderness

Shear force (Kgf)

Ageing (Day)

- Calf
- Vealer

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Modelling beef meat quality traits
Compliance

Shear force (Kgf)

Ageing (Day)

- Cold shortened
- Optimum quality
Considerable variation in:

1. Rigor time: 1.5 – 20.2 hours
2. Rigor temperature: 2.0 – 35.0°C

Quality of meat tenderness could be either optimal (~61%) or cold-shortened (~39%)

A two-dimensional principal component analysis showed that five variables – HCW, $k_{pH}$, $k_T$, $pH_{3.0}$ and $T_{3.0}$ hours post-slaughter - can be used to distinguish the beef meat quality into cold-shortened and optimal quality

The rate of tenderisation is higher in the early post-mortem carcasses and slows down as ageing time elapses for the carcasses
Carcasses of low final pH produced the least tender meat throughout the ageing period but with a sharp decline in shear force attained tenderness levels at 13 days post-mortem comparable to those of high pH meat.

This study clearly shows that a quality control system can be implemented based on the pH/temperature descriptors.
Thank You for Your Attention

Obrigado pela Atenção

Hvala na Pozornosti