Packaging & Processing
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Masforskgk-Norwegian Food Research Institute
51st International Congress of Meat Science and Technology

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Current Research in Meat Color: A Review

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Scope of the Review:

1. Suggestions from other scientists

2. Principally 4 journals, 1999 - 2004:
   - Meat Science
   - Journal of Animal Science
   - Journal of Food Science
   - Journal of Muscle Foods
Scope of the Review:

3. Over 250 papers considered

4. Papers had to be:
   • Principally “Fresh Meat”
   • “Meat Color” objectives
Scope of the Review:

% of surveyed articles

Packaging
Antimicrobials
Beef pre-harvest
Mb chemistry
Cooked color
Measurement
Pork pre-harvest
Meat Color is:

1. A critically important attribute
2. One of the most frequent quality issues
3. Complex
4. Sometimes confusing
5. Often studied as “just another variable”
Myoglobin Chemistry
Visible Myoglobin Chemistry

DIOXYMYOGLOBIN
DMb- Fe ++

OXYMYOGLOBIN
OMb- Fe ++

CARBOXYMYOGLOBIN
COMb- Fe ++

METMYOGLOBIN
MMb- Fe +++

Mancini and Hunt, 2005
Pigment Chemistry

Postmortem Dynamics of NADH

MB Redox Form

Pigment Reduction Systems

Oxygen Utilization
Reducing Systems vs. NADH

- Not straightforward

- NADH more important than MRA in beef
  *Bekhit et al, 2003*

- MRA less important in lamb color stability
  *Bekhit et al, 2000*

- Location of the MRA in muscle is critical
  *Bekhit et al, 2004*
Chilling and MRA

- Slow chilling damages MRA
- Muscle location effects:
  - Superficial SM
  - Deep SM

Sammel et al, 2002a,b
OMb Stability

• Aldehydes decrease Mb redox stability
  – 4-hydroxy-2-nonenal
    Alderton et al, 2003; Faustman et al, 1999;
    Lynch & Faustman, 2000; and Lee et al, 2003

• Peroxynitrite induced OMb instability
  – Due to direct iron oxidation

• Glutathione improved OMb stability
  Connolly et al, 2002
  Tang et al, 2003
Proposed Mechanism: Fresh Meat Color Stabilization via Added Lactate

\[
\text{Lactate} \rightarrow \text{Pyruvate} \quad \text{LDH} \quad \text{NAD}^{+} \quad \text{MRA} \quad \text{MMb} \rightarrow \text{DMb}
\]

Mancini et al, 2004
Kim et al, 2005
New Approaches for Color Measurement

Visual: The Gold Standard?

Researchers tend to Misuse Color Methodology
Computer Vision / Image Analysis

- Digital image analysis
- Combined with:
  - Neural network or
  - Statistical modeling
- Predicted pork loin visual color

Lu et al, 2000
Ringkob 2002

Prediction errors using partial least squares
Measurement of Surface OMB

Historically have used:
- Isobestic wavelengths for DMB and MMB
- OMB determined by *difference* from 100%

OMB can be quantified **directly** using:
- Ratio of 610nm / 525nm

*Mancini et al, 2003*
Updated Krzywicki Equations

New wavelengths suggested:

Tang et al, 2004

<table>
<thead>
<tr>
<th>Mb Form</th>
<th>Old nm</th>
<th>New nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMBb</td>
<td>545</td>
<td>503</td>
</tr>
<tr>
<td>DMBb</td>
<td>565</td>
<td>557</td>
</tr>
<tr>
<td>OMBb</td>
<td>572</td>
<td>582</td>
</tr>
</tbody>
</table>
Pre-harvest: Beef
Pre-harvest Beef Color

Forage vs. grain based diets
- Promote oxidative metabolism
- Limit glycogen storage
- Increase muscle pH and darkness
  \[\text{Vestergaard et al, 2000}\]
- Decrease \(a^*\) and color stability
- More 18:3 FA and less \(\alpha\)-tocopherol
  \[\text{Lynch et al, 2002}\]
Pre-harvest Beef Color

Forage vs. grain based diets

- Decreases subcutaneous fat
- Increases postmortem chilling
- Slows pH decline
- Subcutaneous fat & inst color correlations

L* (0.63), a* (0.60), b* (0.67) pH (-0.82)

Bruce et al, 2004
Pre-harvest Beef Color

Environment – Loose housing vs. Tie stall

- Increased:
  - Pigmentation
  - Slow-contracting fibers
  - Vascularization
  - Pyruvate oxidation

  Vestergaard et al, 2000

- $\alpha$- and $\beta$-red fiber diameter correlate with $a^*$
  (0.32, 0.30)

  Ozawa et al, 2000
Pre-harvest: Pork
Quantitative Trait Loci

Genomic regions accounting for phenotypic variation in pork color were:

– Detected for:
  • \(L^*, a^*,\) and pigment

– Not detected for:
  • \(b^*,\) hue angle, or chroma

\textit{de Koning et al, 2001}
\textit{Ovilo et al, 2002}
Alleles for the Napole (RN) Gene

- Breed affects Mb content & color
- Previous alleles: RN⁻ and rn⁺
- New mutant allele: V199I at PRKAG3 = rn*  

**Genotype** | **pH** | **FO Probe**
---|---|---
RN⁻ / RN⁻ | Lowest | Greatest
rn⁺ / rn⁺ | Intermediate | Intermediate
rn⁺ / rn*  
| Highest | Least
rn* / rn* |
**Alleles for the Napole (RN) Gene**

<table>
<thead>
<tr>
<th>RN⁻</th>
<th>rn⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redder, greater a*</td>
<td>Less red</td>
</tr>
<tr>
<td>More yellow</td>
<td>Less yellow</td>
</tr>
<tr>
<td>Faster pH decline</td>
<td>Slower pH decline</td>
</tr>
<tr>
<td>Greater bloom</td>
<td>Less bloom</td>
</tr>
</tbody>
</table>

Color differences attributed to Mb redox state and pH effects on OCR and MRA

*Lindahl et al, 2004a,b*
Vitamin D Supplementation

- Decreased loin chop L* and increased a*
  \[ \text{Wiegand et al. 2002} \]
- May benefit pork for export markets

- Possible mechanisms:
  - via slowing postmortem pH decline
  - \( \uparrow \) oxidative metabolism by \( \uparrow \) intracellular \( \text{Ca}^{++} \)
  \[ \text{Wilborn et al. 2004} \]
Magnesium influences muscle via altered energy metabolism

- ↑ Ca\(^{2+}\) uptake
- ↑ Ca\(^{2+}\) ATPase activity in normal pigs
- Competition between Mg and Ca

Lahucky et al. 2004
Magnesium Supplementation

- Inconsistent results
- Benefits depended on stress susceptibility
- Little quality improvements when pigs are not stressed beyond routine slaughter

Apple et al. 2000, 2001
Geesink et al. 2004
Glycolytic Potential

- Positively correlated to $L^*$ values
  - $r = 0.23$ *Hamilton et al, 2003*
  - $r = 0.33$ *Moeller et al, 2003*
  - $\uparrow$Glycolytic potential = $\uparrow$Paleness
    *Meadus & MacInnis, 2000*
  - $L^*$ increases 0.99 units for every standard deviation in antemortem glycolytic potential
    *Hamilton et al, 2003b*
Glycolytic Potential

- Diets low in digestible carbohydrates
  - Reduce muscle glycogen
  - Improve pork color

Rosenvold et al, 2001b

Reducing glycolytic potential and free glucose may improve pork muscle color
Antimicrobials
Antimicrobials

• Researchers often:
  – Evaluate only microbial growth
  – Fail to consider affects on color

• Antimicrobial technologies are ideal if:
  – They minimize microbial growth
  – They have no affect or improve color
Antimicrobials and Ground Beef

- Organic acids (lactic or acetic)
- 0.5% cetylpyridinium chloride and/or
- 10% trisodium polyphosphate

- Promise as antimicrobial, but
- $\downarrow$ pH and $\uparrow$ lightness
- Decreases redness and OMb stability

*Pohlman et al, 2002 a,b,c, Jiminez-Villarreal et al, 2002, and Stivarius et al, 2002a,b*
Modified Atmosphere Packaging
Modified Atmosphere Packaging

- Most Common Systems
  - High oxygen (70 to 80% O₂)
  - “No” or “ultra-low” oxygen
  - 0.4% CO in “low” oxygen

- Topic of the following speaker
Carbon Monoxide in MAP

- Used in Norway for years, phasing out
- 2002 - US approved as GRAS for fresh meat
  - CO limited to 0.4%
  - Two current systems
    - CO in Master Bag, but removed at retail
    - CO in MAP at retail
- “Cold Smoke” system in fish
Current Issues involving CO:
- Basic COMb chemistry not well defined
- Quantitation of COMb vs. OMb
- Muscle differences
- CO penetration into the meat
- Meat / gas ratio
- COMb heat denaturation – Persistent pink
Bone Marrow Discoloration
Bone Marrow Discoloration

- Change in color on the surface of cut bones from bright-red to gray, tan, or black

- A major obstacle facing high-oxygen MAP case-ready packaging

- Decreases product shelf life
Marrow Types

Two types of marrow:

1. Red or erythropoietic (vertebrae and ribs)
   – Discolors

2. Yellow or fatty (long bones)
   – Little or no discoloration

Grobbel et al, 2004
Bone Marrow Discoloration

Marrow color: likely due to hemoglobin redox

Key was maintaining ferrous hemoglobin
  - Ascorbic acid
  - Ultra-low oxygen
  - 0.4% CO MAP

Mancini et al, 2004
Factors Involved in Marrow Color

Hemoglobin redox

Reducing agents

Packaging atmosphere

Greater Importance
Lesser Importance

Lipid antioxidants

Metal content

Lipid oxidation

Marrow color
Cooked Color
Cooked Color

Issues:

- Normal cooked color development
  - Red to Pink to Tan/Brown Color

- Premature Browning
  - Brown at unsafe temperatures

- Persistent Pink Color
  - Pink at safe temperatures
Cooked Color

Interactive Factors:

- pH
- Redox pigment form
  - MMb and O Mb
  - DMb and COMb
  - MAP Influence
- Endpoint temperature
- Cooking time
- Cooking rate

[Diagram showing interactions between different factors and outcomes such as PMB, Normal or PPC, SAFETY ISSUES]
Premature Browning and Hi O₂ MAP

Seyfert et al, 2004

ICoMST 2005 USA Mancini and Hunt Kansas State University
Cooked Color - MAP

Erythorbate:
• Increases total reducing activity
• Usage will inhibit PMB

Suman et al, 2005

Muscle source:
• PMB: *Psoas > Longissimus*

Suman et al, 2004
Cooked Color - MAP

Carbon monoxide:
- May affect consumer acceptance
- Inhibits PMB (John et al, 2004)
- Great need for understanding
  - Thermal denaturation
  - Chemical binding and penetration
Summary
Summary

• Fundamental concepts still unanswered
• Need more myoglobin chemistry research
• Future areas of **MEAT COLOR RESEARCH:**
  – Need a “practical” method for OCR
  – Relationship between MRA and OCR
  – Genetics / Quantitative trait loci
  – Proteomics
  – Color vision analyses
  – Nanotechnology