Muscle Energy Metabolism, Growth and Meat Quality

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15% of all retail beef does not meet consumer’s standard for color
(Smith et al., 2000; Kilinger et al., 2004)

$1 Billion economic loss to the US beef industry annually
(Smith et al., 2000)
1.3% Canada
(Beef Research Council, 2013)

3.2% USA
(Moore et al., 2012)
$172 million
(Underwood et al., 2007)

30% Brazil
(Silva, pcomm)

17-40% Chile
(Gallo, 2004)

9% Uruguay
(del Campo et al., 2016)

11.8% South Africa
(Viljoen et al., 2000)

1.5 - 12.4% Australia
(Mcilchrist, Perovic, Gardner, Pethick, & Jose, 2014)
$36 million
(MLA, 2014)
Hypothesis

Dark beef also results from different rearing paradigms, altering muscle characteristics, postmortem metabolism and ultimate color development.
Postweaning Exposure to High Concentrates versus Forages Alters Marbling Deposition and Lipid Metabolism in Steers

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<table>
<thead>
<tr>
<th>Item</th>
<th>CONC</th>
<th>FOR</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial body weight, kg</td>
<td>260</td>
<td>262</td>
<td>7.1</td>
<td>0.825</td>
</tr>
<tr>
<td>Shrunk final body weight, kg</td>
<td>422</td>
<td>338</td>
<td>10.4</td>
<td>&lt; 0.001</td>
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<tr>
<td>Average daily gain, kg/d</td>
<td>1.36</td>
<td>0.68</td>
<td>0.058</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Dry matter intake, kg/d</td>
<td>7.82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed efficiency, feed/gain</td>
<td>5.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot carcass weight, kg</td>
<td>248</td>
<td>179</td>
<td>6.0</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Dressing percentage, %</td>
<td>58.1</td>
<td>52.9</td>
<td>5.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Ribeye area, cm²</td>
<td>72.3</td>
<td>57.9</td>
<td>2.44</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Fat thickness, cm</td>
<td>0.45</td>
<td>0.14</td>
<td>0.052</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Kidney, pelvic, heart fat, %</td>
<td>1.77</td>
<td>0.75</td>
<td>0.209</td>
<td>0.0004</td>
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<tr>
<td>Yield grade</td>
<td>1.79</td>
<td>1.51</td>
<td>0.125</td>
<td>0.228</td>
</tr>
<tr>
<td>Skeletal maturity (100 = A)</td>
<td>152</td>
<td>149</td>
<td>2.17</td>
<td>0.342</td>
</tr>
<tr>
<td>Marbling score (500 = small)</td>
<td>548</td>
<td>340</td>
<td>14.4</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Percent Choice</td>
<td>80</td>
<td>0</td>
<td>9.4</td>
<td>&lt; 0.0001</td>
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</tbody>
</table>
Grain-Fed cattle possess a lighter lean.
Grain-Fed cattle have less red lean

![Graph showing redness comparison between Grain-Fed and Grass-Fed cattle. Grain-Fed cattle have a significantly higher redness value, indicated by an asterisk.]
pH of lean from Grass-Fed cattle is NOT ALWAYS high
The image contains a graph comparing the relative LDH abundance (AU) in grain-fed and grass-fed animals. The graph shows significantly higher LDH abundance in grain-fed animals compared to grass-fed animals. The chemical reaction involving LDH, NADH, and NAD+ is also depicted in the image, along with the conversion of pyruvate to lactate.
Grain-Fed cattle muscle is more glycolytic
Grass-Fed cattle have oxidative muscle
Grass-Fed cattle have increased abundance of myoglobin.
Mitochondrial abundance does not differ
Glycolysis may arrest sooner in muscle of Grass-Fed cattle

Phosphogen System

PCr + ADP ↔ ATP + Cr

ATP → ADP + PO₄⁻ + H⁺

Energy Charge

2 ADP ↔ ATP + AMP ↔ IMP + NH₄⁺
Glycolysis may arrest sooner in muscle of Grass-Fed cattle

Phosphogen System

$\text{PCr} + \text{ADP} \leftrightarrow \text{ATP} + \text{Cr}$

$\rightarrow \text{ATP} \rightarrow \text{ADP} + \text{PO}_4^- + \text{H}^+$

Energy Charge

$2 \text{ADP} \leftrightarrow \text{ATP} + \text{AMP} \leftrightarrow \text{IMP} + \text{NH}_4^+$

A: ATP (μmol/kg)

B: ADP (μmol/kg)

C: AMP (μmol/kg)

D: IMP (μmol/kg)
Excess glycogen does not resolve high ultimate pH of oxidative muscle

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The *in vitro* system

**Scopes buffer**
- 5 mM, MgCl$_2$
- 10 mM, Na$_2$HPO$_4$
- 60 mM KCl
- 40 mM, Glycogen
- 5 mM, ATP
- 0.5 mM, ADP
- 0.5 mM, NAD$^+$
- 25 mM, Carnosine
- 30 mM, Creatine
- 10 mM, Sodium acetate

**Muscle : Buffer**
1:10 W/V

**Treatment: Mitochondria**

Grinding

Grinding

Grinding
Muscle from grass and grain-fed differ in their ability to metabolize carbohydrate.
Presence of oxygen and mitochondria in skeletal muscle early postmortem

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Fig. 2. (A) Mean postmortem muscle oxygenation (%) of the beef longissimus dorsi et lumborum. (B) Mean postmortem pH decline of the beef longissimus dorsi et lumborum. Data are presented as mean ± SEM. Means without a common superscript are significantly different (P < 0.05).
Nutrient Signaling

Lipid Metabolism

Energy Charge

Acetyl-CoA

ATP

Nucleotide Metabolism

Hexosamine Biosynthetic Pathway (HBP)

Uridine

UDP-GlcNAc

Adapted from Hanover et al., (2012)
The color of normal (fresh or packaged) meat is bright cherry red and consumers tend to reject any deviation from this due to a perceived degradation in quality (Tarrant 1989; Sawyer and others 2009). (in Ponnampalam et al., 2017).
Conclusions

What we know:
- Feeding regime impacts beef color
- Muscle from ‘fed’ cattle have altered nutrient sensing
- High forage-fed beef has more myoglobin
- Lean from forage-fed beef is metabolically different
- Dark beef has more oxidative metabolism
- Forage and grain fed cattle modulate energy metabolism in vitro differently
- Mitochondria modulate PM energy metabolism in vitro

What we don’t know:
- How mitochondria fully participate in PM muscle
- What impact ‘moderate’ exercise has on beef color/quality
- Feeding
  - How much
  - How long
  - Reduced nutrient intake/weight loss
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• Saulo da Luz e Silva, USP
• Luzardo, Brito, del Campo, Montossi, INIA
• Aalhus, AAFC/AAC
• Ariel Apaoblaza