Stress and Handling
Factors that Impact
Pork Quality
AMI
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Dan Hale dhale@tamu.edu
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http://www.grandin.com/
www.animalhandling.org/
Jason Apple
Don Down
Temple Grandin
David “Andy” King
Elisabeth Huff-Lonergan
Steven Lonergan
Floyd McKeith
Claudia Terlouw
Melvin Hunt
Ellen Hambrecht

“The Connection” Between Pig Responses to Stress and Pork Quality

Glucose Metabolism

Principles of Meat Science
Aberle et al. Textbook
Glucose Metabolism Postmortem

Principles of Meat Science Aberle et al. Textbook
Pituitary Gland
ACTH - Stimulation of corticoid release
Adrenocorticotropic hormone

Adrenal Gland
Corticoid - synthesis of carbohydrates, maintenance of cell response

Epinephrine and Norepinephrine - Influence blood flow and heart rate, breakdown glycogen and lipid

Thyroid Gland
Thyroid Gland - stimulation of oxidative metabolism, Increases metabolic rate

Adapted from Principles of Meat Science Aberle et al. Textbook
What is Quality?

- Color
- Marbling
- Fatness/Muscling
- Tenderness
- Flavor
- Processing characteristics
- Nutrition
- Food Safety
Meat (Instrumental) Quality

- pH45-min post-mortem
- pHu – 24 hours post-mortem
- Color
- Drip Loss
- Purge Loss
- Water-holding Capacity
- Water-binding Capacity
- Firmness of Lean
- Texture/Tenderness/Juiciness
- Shear Force
- Firmness/Color of Fat

Eating (Sensory) Quality

- Tenderness
- Juiciness
- Flavor/Aroma
- Off-flavor
- Fat content/FA composition

Taken from - http://www.meatami.com/ht/a/GetDocumentAction/1/48273
Chemistry Of Meat Protein

Myofibrillar (contractile)
~ 55% of total muscle protein but 70-80%+ of WHC and binding properties

Stromal proteins (connective tissue)
10 - 15% of total muscle protein primarily collagen

Sarcoplasmic proteins (water soluble, intracellular fluid)
30% of total muscle protein (~ 20% of binding ability)
isoelectric points generally between pH 6 - pH 7
hundreds of enzymes in cells for energy, growth, etc.
most are relatively low molecular weight (small) proteins
Chemistry Of Meat Protein

- Myosin is generally considered the singly most important because:
  - Long filamentous molecule (similar to a 1 inch garden hose that is 8 feet long)
  - amino acid composition gives highly-charged, polar molecule
  - present in large quantity in lean muscle

Water

present in greatest quantity in most products
important to eating quality and economics
remember: water is both a meat component and a non-meat
(added) ingredient
Bound by proteins
In order to understand water in meat systems it is necessary to understand
  water : protein interactions
water : water interactions

Water is a unique compound with a unique structure

Water attracts Water
“Free” water is loosely held and very dependent upon capillary space between and within proteins.

• pH at which charge on protein = 0
• minimum water binding
• dependent on amino acid composition
  i.e. will be different for different proteins

Isoelectric Point

protein

\[\text{pH 6.0} \quad \text{net charge} = -3\]
protein $\quad - \quad H^+ \quad - \quad - \quad + \quad - \quad +H$

$pH\ 5.1 \quad \text{net charge} = 0$

*Isoelectric Point*
Ultimate pH has been shown to be genetically and phenotypically correlated with many economically important criteria such as meat color, meat tenderness, water-holding capacity (WHC), and sensory qualities; i.e. achieving pork pHu > 5.70 effectively eliminates PSE pork (Bidner et al., 2004; Cameron, 1990;
Relationship between Muscle Ultimate pH and Water-holding Capacity

Post-Mortem Conversion of Muscle to Meat:

M. Longissimus (Loin) pH Decline Curves

GLYCOGEN=MUSCLE Fuel

ATP

LAC

pH

Time Postmortem, hrs.

A; drip = 1.85%
B; drip = 3.43%
C; drip = 2.54%
D; drip = 1.56%

Taken from - http://www.meatami.com/ht/a/GetDocumentAction/i/48273
Hunter has been largely adopted for meat color measurement because

\[ L = \text{lightness} \]
\[ a = \text{redness} \ (+) \rightarrow \text{green} \ (-) \]
\[ b = \text{yellow} \ (+) \rightarrow \text{blue} \ (-) \]
L measures
Lightness
100 - perfect
whiteness
0 - Black

a Redness +
Gray 0
Greenness -

b Yellowness +
Gray 0
Blueness -
Meat Color

PSE meat less red and more yellow. The low pH in PSE also promotes the oxidation of heme pigments from purple or red myoglobin (Mb) and oxymyoglobin (MbO2) to brown metmyoglobin (met Mb).

Adzitey, F. and *Nurul, H. Review Article: Pale soft exudative (PSE) and dark firm dry (DFD) meats: causes and measures to reduce these incidences - a mini reviewInternational Food Research Journal 18: 11-20 (2011)
# PSE DFD Characteristics

Table 3. Color and drip loss values in meat of different quality

<table>
<thead>
<tr>
<th>No.</th>
<th>Meat type</th>
<th>DFD</th>
<th>Normal</th>
<th>PSE</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Lightness (L*)</td>
<td>Pork</td>
<td>42-48</td>
<td>54</td>
<td>60-66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beef</td>
<td>37-40.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turkey</td>
<td>47.31-48.99</td>
<td>54.72-56.85</td>
<td>Muchenje et al. (2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pork</td>
<td>45.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2.</td>
<td>Hue (°)</td>
<td>Pork</td>
<td>1-22</td>
<td>38</td>
<td>48-53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pork</td>
<td>7.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>Saturation (chroma)</td>
<td>Pork</td>
<td>3-5</td>
<td>7</td>
<td>9-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pork</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4.</td>
<td>Reflectance (EEL)</td>
<td>Pork</td>
<td>20-32</td>
<td>44</td>
<td>56-67</td>
</tr>
<tr>
<td>5.</td>
<td>Drip loss (%)</td>
<td>Pork</td>
<td>0-5</td>
<td>10</td>
<td>13-15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turkey</td>
<td>-</td>
<td>0.72</td>
<td>2.52</td>
</tr>
<tr>
<td>6.</td>
<td>Colour</td>
<td>Beef</td>
<td>4.8±1.6</td>
<td>6.1±1.9</td>
<td>-</td>
</tr>
</tbody>
</table>

Adzitey, F. and *Nurul, H. Review Article: Pale soft exudative (PSE) and dark firm dry (DFD) meats: causes and measures to reduce these incidences - a mini review International Food Research Journal 18: 11-20 (2011)
Much of the variation in protein functionality and fresh pork quality can still be linked to variation in early postmortem metabolism. The contributions of pH and temperature to protein denaturation and PSE development are well documented.

Handling and Stressors and Meat Quality

The Stressors of Marketing

- From farm to slaughter animals are subjected to:
  - Removal from their home environment
  - Loading and unloading from vehicles
  - Transport and holding in unfamiliar surroundings
- In addition to:
  - Noise
  - Strange odors
  - Deprivation of food and water
  - Vibration and changes in velocity
  - Temperature Extremes
  - Confinement

Genetics
Environment
Nutrition
Climatic
Handling
Transport
Genetic X Environment
How to measure stress?
*Physiological indices*

**Blood hormone concentrations:**
- Adrenaline
- Noradrenaline
- Corticotropin-releasing factor
- Adrenocorticotrophic hormone
- Glucocorticoids (e.g. cortisol)
- Prolactin

**Blood metabolite concentrations:**
- Glucose
- Lactic acid
- Free fatty acids
- $\beta$-hydroxybutyrate
- Creatine kinase (CPK)

**Other variables:**
- Heart rate
- Breathing (rate and depth)
- Packed cell volume
- Sweat production
- Muscle tremor
- Body temperature
- Plasma $\alpha$-acid glycoprotein levels
- Blood leukocyte levels
- Cellular immune responses
- Humoral immune response

*Matteri et al., 2000*
Stress reactions to the slaughter procedure influence ante- and post-mortem muscle metabolism and, consequently, the rate and extent of glycogen breakdown and pH decline, color and drip loss.

Effects are principally due to variations in ATPase activity and muscle glycogen reserves.

Behavioral, physiological and metabolic responses to aversive situations depend on genetic background and prior experience of the animals.

Claudia Terlouw
Meat Research Station; INRA de Theix-France Livestock Production Science 94 (2005) 125–135
1. **Evaluation of situation** (pig stress/welfare)
   - Action
2. **Behavioral and physiological response**
   - **Muscle metabolism**
   - **Pork Quality**

Rearing conditions → Actual stress situation → Genetics

Taken from - http://www.meatami.com/ht/a/GetDocumentAction/i/48273
Stress and Pork Quality

Pre-harvest Stress and Pork Quality

- Long term stress $\rightarrow$ DFD pork
  - Low muscle glycogen
  - Normal rate of pH decline
  - Meat has high ultimate pH

- Short term stress $\rightarrow$ PSE pork
  - Elevated body temperature
  - Metabolic acidosis
  - Increased rate of muscle pH decline

An important observation is that quality features like water-holding capacity can vary so much at intermediate and low pH. This observation suggests that additional factors contribute to variation in pork quality.

A newer hypothesis suggesting that variation in protein oxidation, in response to antemortem stress and early postmortem tissue environment, can contribute to development of PSE pork is also discussed.

Oxidation can inhibit postmortem proteolysis of meat proteins. It is also clear that proteins are susceptible to oxidation in postmortem muscle. Conditions that stimulate oxidation in meat early postmortem can effectively arrest activation of \(u\)-calpain (determined by measuring extent of autolysis) and degradation of muscle proteins during postmortem storage (Rowe, Maddock, Lonergan, & Huff-Lonergan, 2004b). The lack of degradation manifests itself in a less tender product, even after aging 14 days (Rowe et al., 2004b). Stress can elevated oxidation of mitochondrial proteins in response to acute stress immediately prior to slaughter decreased sarcoplasmic reticulum Ca\(^{2+}\) transport. It is known that oxidation of the sarcoplasmic reticulum stimulates Ca\(^{2+}\) release.

u-Calpain Activity and pH decline


a  μ-calpain activity on casein zymogram 45 min post-exsanguination.

<table>
<thead>
<tr>
<th>Time</th>
<th>pH</th>
<th>μ-calpain Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 min</td>
<td>6.63</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>45 min</td>
<td>5.76</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

b  μ-calpain activity on casein zymogram 6 hr post-exsanguination.

<table>
<thead>
<tr>
<th>Time</th>
<th>pH</th>
<th>μ-calpain Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 hr</td>
<td>6.03</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>6 hr</td>
<td>5.37</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>

48 hr shear force (kg) 2.9 4.3

Drip loss 1.1% 6.8%

c  45 min 120 hr

<table>
<thead>
<tr>
<th>Time</th>
<th>pH</th>
<th><img src="image5.png" alt="Image" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>45 min</td>
<td>normal</td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>45 min</td>
<td>rapid</td>
<td><img src="image7.png" alt="Image" /></td>
</tr>
<tr>
<td>120 hr</td>
<td>normal</td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>120 hr</td>
<td>rapid</td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Titin (T₁) T₂
Oxidation

It is becoming evident that free radical accumulation does occur in muscle following acute exercise (Bailey et al., 2007) and that this change in redox potential can result in a change in control of intracellular Ca2+ levels (Hool & Corry, 2007). Clearly loss of Ca2+ regulation is a common theme in development of PSE meat.

Acute stress prior to exsanguination may result in production of reactive oxygen species in muscle and oxidation of calcium channels and premature loss of calcium regulation in early postmortem muscle. This arguably could initiate the cascade events that lead to rapid pH decline and protein denaturation.
FATIGUED PIG

“Multi-factorial”

Gut Fill  Trucking  Ambient Temperature
Muscling
Stress gene
Genetics
Soundness
Nutrition
Health
Live weight
Grouping
Handling
Facilities
Density
Human Exposure


SBU 2044
Fatigue pig

NORMAL PIG

Open-mouthed breathing
Blotchy skin
Refusal to move

Muscle tremors
Abnormal vocalization
Collapse (fatigue)

Death

Ritter et al. 2005; Ritter 2006
# Packing Plant Assessments: Comparison of Fatigued vs. Non-Fatigued

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fatigued</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress hormones</td>
<td>Higher</td>
</tr>
<tr>
<td>(Cortisol, Catecholamines)</td>
<td></td>
</tr>
<tr>
<td>Insulin</td>
<td>Lower</td>
</tr>
<tr>
<td>Blood lactate</td>
<td>Higher (11 vs 32mM)</td>
</tr>
<tr>
<td>Blood pH</td>
<td>Lower (7.35 vs 7.11)</td>
</tr>
<tr>
<td>Base excess</td>
<td>Lower</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Higher</td>
</tr>
<tr>
<td>Lipid mobilization</td>
<td>Higher</td>
</tr>
<tr>
<td>(Re-esterified)</td>
<td></td>
</tr>
<tr>
<td>Glycolytic potential</td>
<td>Lower</td>
</tr>
<tr>
<td>(LD, ST\text{red}, Liver)</td>
<td></td>
</tr>
<tr>
<td>Liver glycogen</td>
<td>Lower</td>
</tr>
</tbody>
</table>

Livers, et al., 2002a
Perez et al. (2002) found that either no lairage time or an excessively long lairage time compromised both welfare and pork quality.

For both meat quality and welfare reasons, pigs should be rested for 2 hours before slaughter (Milligan et al., 1998).


1900 pigs. Transport times were 50 min and 2 h, and resting periods at the abattoir were < 30 min, 3 h and 6 h.

The shorter (50 min) transport time was associated with the highest (P ≤ 0.05) incidence of pale and soft/exudative loins.

A longer transport time reduced the incidence of pale and soft/exudative loins; it also increased (P ≤ 0.05) the incidence of dark and firm/dry loins; particularly during winter.
1900 pigs. Transport times were 50 min and 2 h, and resting periods at the abattoir were < 30 min, 3 h and 6 h.

A resting period of < 30 min resulted in the highest ($P \leq 0.01$) incidence of pale and soft/exudative loins.

A 3 h resting period significantly improved ($P \leq 0.01$) quality by reducing the incidence of pale loins and soft/exudative loins.

Extending the resting period from 3 h to 6 h provided inconsistent improvements in quality due to interactions with season ($P \leq 0.05$) and producer/management ($P \leq 0.05$).
Crossbred, halothane-free pigs (n = 192) were processed in eight groups (24 pigs per group) on various days at one of two commercial processing plants operating different stunning systems (electrical and CO2 stunning in Plants A and B, respectively). In each group, half the pigs were exposed to either minimal or high preslaughter stress.

Pigs in the minimal stress group were guided to the stunning area without the use of electric goads and were handled as calmly as possible, whereas pigs in the high-stress group were forced, by yells and electric goads, to move four times back and forth in the corridor leading to the stunning area.

At both plants, high stress increased (P < 0.05) 30-min muscle temperature and decreased (P < 0.05) 30-min muscle pH.

Ultimate pH was increased (P < 0.05) and muscle glycolytic potential was decreased (P < 0.05) by high preslaughter stress.

High stress resulted in inferior pork quality attributes (P < 0.05), including reflectance, electrical conductivity, filter paper moisture, drip loss, and L* value. The effect of stress was greater on water-holding capacity than on pork color, with drip losses increased by 56%.

Of all stress indicators measured at exsanguination, only blood lactate was strongly correlated with pork quality attributes.

Reducing PSE and Maximizing WHC

Multiple regression analysis

Drip vs Lactate \[ R^2 = 0.32 \]

Drip vs Lactate + GP \[ R^2 = 0.52 \]

Hambrecht, et al., 2004
Dietary Interventions

Magnesium
Several studies have shown that dietary magnesium supplementation in pigs resulted in improved pork quality such as improved meat colour and reduced drip loss (e.g. Apple, Maxwell, deRodas, Watson, & Johnson, 2000; D’Souza, Warner, Dunshea, & Leury, 1999; Otten, Berrer, Hartmann, Bergerhoff, & Eichinger, 1992). Moreover, dietary organic magnesium supplementation has been validated under commercial conditions as a viable method to improve meat quality in pigs (Hofmeyr, Dunshea, Walker, & D’Souza, 1999).

Dietary Interventions

Tryptophan – Inconclusive
Electrolytes – Sodium is the major determinant of extracellular and total body water, whereas potassium is the primary determinant of intracellular fluid volume (Tasker, 1980). Both these cations are lost during antemortem stress.


Pork quality and Lactate

Known*:
Increased exsanguination LAC
• increased drip loss
• lighter muscle color

No work reported on relationship of LAC to meat quality at other portions of marketing process.

* Hambrechrt et al., 2004, 2005; Warriss et al., 1994, 1998
Minimize Stress

- Aggressive handling, restricted transport floor space, and long distance moved treatments had additive effects on rectal temperature, blood acid-base balance, and loin muscle lactate values (Ritter et al., 2007)

\[ Y = 1.40 + 3.25X \ (R^2 = 0.35) \]
Blood Lactate:
- Is **high** in fatigued pigs
- Increases with aggressive handling
- Increases in high stress commercial systems
- Is a **quick** and **sensitive** responder to stress
- Related to meat **quality**
<table>
<thead>
<tr>
<th>Lactate Level</th>
<th>Benjamin et al., 2001</th>
<th>Hambrecht et al., 2004</th>
<th>Hambrecht et al., 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Gentle”</td>
<td>4.0</td>
<td>15.6</td>
<td>17.7</td>
</tr>
<tr>
<td>Aggressive</td>
<td>25.2</td>
<td>27.7</td>
<td>30.9</td>
</tr>
</tbody>
</table>
Lactate High Stress and Low Stress Pigs

(Warris et al., 1994)
Blood Lactate:

- Is **high** in fatigued pigs
- Increases with aggressive handling
- Increases in high stress commercial systems
- Is a **quick** and **sensitive** responder to stress
- Related to meat **quality**
(Benjamin et al., 2001)
Blood Lactate:
- Is **high** in fatigued pigs
- **Increases** with aggressive handling
- ** Increases** in high stress commercial systems
- Is a **quick** and **sensitive** responder to stress
- Related to meat **quality**
Pre-stun handling and Lactate

- Electric prod use
- Vocalization with prod
- Jamming
- Rearing
- Turning back
- Backing up
- Falling
- Rooting behavior
- Vocalization score (Exp 2 only)
- Time in handling area
## Pre-stun handling and Lactate

<table>
<thead>
<tr>
<th>Handling Parameter</th>
<th>Presence of parameter (# of animals)</th>
<th>Absence of parameter (# of animals)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXPERIMENT 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jamming</td>
<td>22</td>
<td>54</td>
<td>0.05</td>
</tr>
<tr>
<td>Backing up</td>
<td>17</td>
<td>59</td>
<td>0.01</td>
</tr>
<tr>
<td>Rear and/or Jam</td>
<td>30</td>
<td>46</td>
<td>0.06</td>
</tr>
<tr>
<td>Rear, Jam and/or Back up</td>
<td>41</td>
<td>35</td>
<td>0.005</td>
</tr>
<tr>
<td>EXPERIMENT 2 – SINGLE-FILE CHUTE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jamming</td>
<td>42</td>
<td>98</td>
<td>0.005</td>
</tr>
<tr>
<td>Backing up</td>
<td>36</td>
<td>104</td>
<td>0.06</td>
</tr>
<tr>
<td>Rear and/or Jam</td>
<td>46</td>
<td>94</td>
<td>0.003</td>
</tr>
<tr>
<td>Rear, Jam and/or Back up</td>
<td>69</td>
<td>71</td>
<td>0.03</td>
</tr>
<tr>
<td>Vocalization</td>
<td>61</td>
<td>79</td>
<td>0.05</td>
</tr>
</tbody>
</table>
# Pre-Stunning Lactate

<table>
<thead>
<tr>
<th>Handling Parameter</th>
<th>Presence of parameter (# of animals)</th>
<th>Absence of parameter (# of animals)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EXPERIMENT 2 – CIRCLE CORRAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Prod Use</td>
<td>11</td>
<td>129</td>
<td>0.03</td>
</tr>
<tr>
<td>Vocalization w/ Prod Use</td>
<td>7</td>
<td>133</td>
<td>0.07</td>
</tr>
</tbody>
</table>

## Pre-stun handling and Lactate

- Electric prod use
- Vocalization with prod
- Jamming
- Rearing
- Turning back
- Backing up
- Falling
- Rooting behavior
- Vocalization score (Exp 2 only)
- Time in handling area

![Diagram](image.png)
Lactate at Different Management Points

Blood sampling points - Study 1

1. baseline at the farm
2. following loading
3. following transport
4. following unloading
5. following lairage
6. following movement to stun
7. at exsanguination.
Reducing PSE and Maximizing WHC

Study 2: (Quebec; n=128). Low-stress loading - flat ramp, hydraulic deck. Each test animal was sampled at exsanguination only.
Lactate changes during marketing

Study 1 - Hormel
Study 2 - F. Menard

Blood Lactate Concentration (mM)

Baseline, Post Load, Pre Unload, Post Unload, Post Laiage, Post Movement, Exsanguination

FARM → PLANT
Reducing PSE and Maximizing WHC

Pork quality and Lactate

Increased [LAC] associated with REDUCED pork quality

Study 2; Wariss et al., 1994; Hambrecht et al., 2004v

Blood Lactate Concentration (mM)

Baseline | Post Load | PreUnload | PostUnload | Post Laiage | Post Movement | Exsanguination

FARM | PLANT
Reducing PSE and Maximizing WHC

Temple Grandin

Pork quality and Lactate

Increased [LAC] associated with IMPROVED pork quality
Study 1

Increased [LAC] associated with REDUCED pork quality
Study 2; Wariss et al., 1994; Hambrecht et al., 2004v

No relationship to pork quality
Study 1

Blood Lactate Concentration

Baseline, Post Load, PreUnload, Post Unload, Post Laiage, Post Movement, Exsanguination

FARM → PLANT
Increased [LAC] associated with IMPROVED pork quality

Study 1

Blood Lactate Concentration

Baseline, Post Load, Pre Unload, Post Unload, Post LAirage, Post Movement, Exsanguination

FARM → PLANT
### Blood lactate after loading at the farm

<table>
<thead>
<tr>
<th></th>
<th>Study 1, Exp1</th>
<th>Study 1, Exp2</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="mM">LAC</a> Range</td>
<td>4.7 + 0.4</td>
<td>7.1 = 0.4</td>
</tr>
<tr>
<td></td>
<td>1.2 - 16.9</td>
<td>1.5 - 24.3</td>
</tr>
<tr>
<td>24 hr pH</td>
<td>0.36</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td><strong>0.002</strong></td>
<td><strong>0.0001</strong></td>
</tr>
<tr>
<td>L*</td>
<td>-0.25</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td><strong>0.03</strong></td>
<td><strong>0.001</strong></td>
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<tr>
<td>Drip Loss</td>
<td>-0.28</td>
<td>-0.28</td>
</tr>
<tr>
<td></td>
<td><strong>0.02</strong></td>
<td><strong>0.002</strong></td>
</tr>
<tr>
<td>Glycolytic Potential</td>
<td>-0.18</td>
<td>-0.16</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Increased [LAC] associated with IMPROVED pork quality

Study 1

Blood Lactate Concentration

FARM → PLANT
### Exsanguination blood lactate

<table>
<thead>
<tr>
<th>Study 2</th>
<th>N = 118-119</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="mM">LAC</a></td>
<td>8.9 + 0.2</td>
</tr>
<tr>
<td>Range</td>
<td>4.0 - 19.7</td>
</tr>
<tr>
<td>60 min pH</td>
<td>-0.36 0.002</td>
</tr>
<tr>
<td>Drip Loss</td>
<td>0.22 0.02</td>
</tr>
</tbody>
</table>

Increased [LAC] associated with REDUCED pork quality
Study 2; Wariss et al., 1994; Hambrecht et al., 2004v
Reducing PSE and Maximizing WHC

Preventing PSE (Pale Soft Exudative Pork) in Pigs
1. Provide adequate pen space in holding pens at the plant. 6 sq feet (.55sq meters) per 250lb (113kg) pig. All pigs must have room to lie down.
2. During hot weather wet animals down with sprinklers.
3. Allow 2 to 4 hours of rest prior to stunning.
4. Handle and drive animals quietly and reduce or eliminate electric prod usage. Excited pigs are more likely to have poorer quality pork. Pork quality can be ruined during the last five minutes prior to stunning. This is why it is so important to handle pigs quietly.
5. NEVER fill the forcing pen more than one half to three quarters full. Animals need room to turn so they can enter the race more easily.
6. Pigs must always have access to water.
7. Measuring the levels of lactate in the blood at bleeding can be used as a test to monitor handling in the stunning area. High lactate at bleeding is associated with higher drip loss and poorer pork quality.