I. POST-HARVEST FACTORS

1. CARCASS PROCESSING: PH/TEMPERATURE

SHORTENING (ACTOMYOSIN CROSS-BRIDGE) IS AN INEVITABLE POSTMORTEM PROCESS, BUT

Heat toughening

Cold shortening

One of ways to prevent shortening - Electrical stimulation

POSTMORTEM TEMPERATURE AND pH DECLINE & AGING POTENTIAL

Pre rigor carcass processing (pH/ temperature) has a substantial impact on proteolytic enzyme activity (μ-calpain).


Heat toughening

Cold shortening

How do different pre rigor conditions in different plants influence aging potential (μ-calpain)?

Plant A: Mid-voltage ES & auto chiller carcass capacity
Plant B: High-voltage ES & conventional carcass chilling
TEMPERATURE DECLINE DURING THE FIRST 24 H POST MORTEM

Carcasses from Plant B had a slower cooling rate than carcasses from Plant A

PH DECLINE DURING THE FIRST 24 H POST MORTEM

Lamb carcasses from Plant B had more rapid decline in pH than the ones from Plant A

IMPACTS OF DIFFERENT PROCESSING CONDITIONS ON PROTEOLYTIC ACTIVITY OF LAMB LOINS AT 1 DAY POST MORTEM

Plant B had faster \( \mu \)-calpain autolysis (indicating more \( \mu \)-calpain activity) of loins at 1 day PM.

Resulted in greater extent of protein degradation of loins from Plant B at 1 day PM.

BUT!!

INFLUENCE OF CARCASS CHILLING TEMPERATURE ON MEAT COLOR

High pre-rigor temperature (42°C) significantly reduced the retail color display life of chilled lamb loins.

AN ANALOGY BETWEEN ‘AGING POTENTIAL’ AND ‘MARATHON’?

Early excitement – Early exhaustion

Slowly, but Surely!
Influence of Storage Temperature Abuse on Meat Color Stability

Increase in the storage temperature from the ideal storage temperature of -1.5°C to 2°C significantly decreased the color stability of lamb loins.

Long term T abuse: 2°C for 7wks
Short term T abuse: -1.5°C for 6 wks + 1 wk at 2°C.

(Mønsted & Wiklund, 2011)

I. Post-Harvest Factors

1. Carcass Processing: PH/Temperature

2. Aging & Freezing

NZ Sheepmeat Export

-NZ is the largest sheepmeat exporter accounting for 6.4% global production (92%).
- EU remains as for high-value chilled lamb, taking 71% of chilled lamb exports (worth $584 million) for the year (MIA, 2012).

(MIA Annual Report 2012)

Meat Quality Change During Chilled Storage

Substantial meat quality improvement (tenderness, juiciness and/or flavour) through endogenous enzymatic protein degradation.

Effect of Chilling Storage Periods on Color Stability of Lamb Loins

Meat color stability decreases with increasing chilling storage periods.

Significant economical issue! $$$

(Kim et al. Unpublished data)

Conventional Ideas on Fresh vs. Frozen Meat

Consumer perception

Meat quality:
Fresh (chilled never frozen) > Frozen

1. When?
(e.g. 1 day or 2 weeks p.m)

Very important Questions that We Often Overlook

[Images and diagrams related to the content are shown.]
**EFFECT OF AGEING/FREEZING ON SHEAR FORCE VALUES OF LAMB LOINS**

Ageing-then-freezing significantly improved tenderness of loins.

![Graph showing shear force values for different storage treatments.]

*Different letters indicate significant difference (P < 0.05).*

**EFFECT OF AGEING/FREEZING ON WATER-HOLDING CAPACITY (WHC) OF LAMB LOINS**

Ageing/freezing significantly improved WHC of loins.

![Graph showing WHC for different storage treatments.]

*Different letters indicate significant difference (P < 0.05).*

**EFFECT OF AGEING/FREEZING ON COLOUR STABILITY OF LAMB LOINS**

Ageing/freezing improved color stability of loins during retail display.

![Graph showing color stability for different display days.]

**EFFECT OF AGEING/FREEZING ON LIPID OXIDATION STABILITY OF LAMB LOINS**

Aged/frozen improved lipid oxidation stability of loins.

![Graph showing lipid oxidation for different storage treatments.]

**IMPROVING MEAT QUALITY OF FROZEN/THAWED MEAT**

Overall acceptability: Fresh (chilled never frozen) > Frozen

1. **When?**
   - (e.g. 1 day or 2 weeks p.m)

2. **How?**
   - (freezing rate: Fast vs. Slow)

Freezing rate substantially influences the size, shape and location (intra- or extracellular) of ice crystal formation within meat.

*Ice crystal formation by Greg Rob*
SNOW CRYSTAL FORMATION AT DIFFERENT TEMPERATURE AND HUMIDITY

FREEZING RATE & ICE CRYSTALLISATION

Slow freezing – mostly extracellular crystals (bigger size), which damage muscle proteins and cell membranes.

Fast freezing – mainly intracellular crystals (smaller size and uniformly distributed), so less damages to muscle.

IMPACT OF FREEZING RATE ON WATER-HOLDING CAPACITY OF BEEF LOINS

Fast freezing significantly decreased the amount of total water loss of frozen/thawed beef loins.

IMPACT OF FREEZING/THAWING RATE ON WATER-HOLDING CAPACITY OF LAMB LOINS

- Significant interaction between Freezing methods & Thawing methods in cook loss of the aged/frozen/thawed lamb loins
- Fast freezing x Fast thawing is okay, but Slow freezing x Fast thawing is NO!
**NEW PARADIGM FOR MEAT AGEING:**

**FREEZING FIRST THEN THAW-AGEING**

Since we know that:
1. Fast freezing substantially minimises muscle structural damage during freezing
2. Endogenous proteolytic enzymes are still functional after being frozen/thawed,

*Then what if we fast freeze the meat first and then thaw-age it later?*

- **Aging**
  - Fast @ -18°C
  - 4°C
  - -1.5°C

- **Freezing**
  - Fast F & No Age
  - Slow F & No Age

- **Thawing**
  - A 2 wks
  - Fast F & A 2 wk
  - Slow F & A 2 wk

**COLOR TRIANGLE**

- **DMb** (Decorative M, stable): Vacuum pack, very stable (weeks)
- **OMb** (Oxidative M, short): Oxidation
- **MMb** (Muscular M): Overwrap-PVC, short colour life (2-3 days)

**HIGH-OXYGEN MODIFIED ATMOSPHERE PACKAGING (HiOx-MAP) SYSTEM**

HiOx-MAP (80% O₂ + 20% CO₂) allows:
1) longer color shelf-life
2) CO₂ in the package preventing microbial growth
   - High solubility in both muscle and fat tissue
   - At higher temp, solubility of CO₂ hence is more effective in retarding microbial growth (10 to 14 days).
HIOX-MAP SYSTEM CREATES “OXIDATIVE CONDITIONS”

HiOx-MAP (80% O₂ + 20% CO₂) are likely to increase the incidence of oxidative changes in the meat, and thus it may negatively affect meat quality characteristics.

(Kim et al. 2010. Meat Sci.)

HIOX-MAP RESULTED IN PROTEIN POLYMERIZATION

Lamb loins vacuum-stored for 8 weeks @ -1.5°C. Then, either HiOx-MAP or PVC displayed for 8 days at 3°C.

• X-linking products in HiOx-MAP decreased meat tenderness

• More cross-linking observed in loins from older animals

(Kim et al. 2012. Food Chem.)

II. PRE-HARVEST FACTORS

1. FEEDING EFFECT

14 week old lambs (n =124) were randomly allocated to 7 different forage treatments for 12 weeks until slaughter:
(Clover 12wk, Clover 11wk, Clover 9wk, Lucerne, Chicory, Plantain and Ryegrass)

Paired loins from each carcass stored for 9 weeks @ -1.5°C

Packaged in either HiOx-MAP (80% O₂/20% CO₂) or LowOx-MAP (20% CO₂/80% N₂)/displayed for 7 days

To test, 1) Forage effect 2) Packaging effect

- Color stability: Minolta/Sensory color panel

(Kim et al. 2013. JAS)
EFFECTS OF FORAGE TYPES ON A* VALUES OF LONG-TERM CHILLED LOINS DURING DISPLAY UNDER HI0X-MAP

EFFECTS OF FORAGE TYPES ON DISCOLORATION OF LONG-TERM CHILLED LOINS DURING DISPLAY UNDER HI0X-MAP

EFFECTS OF FORAGE TYPES ON LIPID OXIDATION (TBARS) OF LONG-TERM CHILLED LOINS DURING DISPLAY UNDER HI0X-MAP

EFFECTS OF FORAGE TYPES ON SENSORY ATTRIBUTES OF LONG-TERM CHILLED LOINS AFTER 4 D DISPLAY UNDER HI0X-MAP

ULTRA LOOX-MAP

Acceptable color was maintained after 7d display under LoOx-MAP

Ultra LoOx-MAP substantially minimized oxidation during retail display time thus improved color/Flavour/Aroma of long-term stored meat.

(Kim et al. 2013. JAS)
GRAIN VS. GRASS-FED LAMB

<table>
<thead>
<tr>
<th></th>
<th>Grain-fed lamb</th>
<th>Grass-fed lamb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass weight (kg)</td>
<td>15.8*</td>
<td>14.7 (Less CW)</td>
</tr>
<tr>
<td>Fat color</td>
<td>14.8*</td>
<td>17.0 (more yellow fat)</td>
</tr>
<tr>
<td>Lean color – L*</td>
<td>49.2*</td>
<td>46.1 (darker in color)</td>
</tr>
<tr>
<td>Lean color – a*</td>
<td>7.4</td>
<td>7.6 (no difference)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensory attributes</th>
<th>Tenderness – 5.1*</th>
<th>Juiciness – 4.4*</th>
<th>Flavor – 4.6*</th>
<th>Livery flavor – 0.7*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.5</td>
<td>3.8</td>
<td>4.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

*P < 0.05

ANECDOOTAL CONCERN

Different gender/castration status influences meat quality attributes?

Ewe
Ram
Wether
Cryptorchid

- Meat from entire (ram) lambs is unsatisfactory?

OBJECTIVES

1) To determine effects of different gender or castration status on color and lipid oxidation stability of long-term chilled lamb meat

2) To evaluate the influence of different muscle types on color stability of lamb meat during retail display.

EXPERIMENT SCHEME

Total n= 76
(11 to 12 months)
Loin & leg

8 weeks chilled storage @ -1.5°C

-Colour stability: Minolta/Sensory colour panel
-pH
TBARS
MRA/myoglobin contents

EWE VS. WETHER VS. RAM VS. CRYPTORCHID

PRE- HARBVEST FACTORS

1. FEEDING EFFECT

2. GENDER/CASTRATION

EFFECTS OF GENDER/CASTRATION STATUS ON CARCASS WEIGHT AND pH OF LONG-TERM CHILLED MEAT

<table>
<thead>
<tr>
<th></th>
<th>Ewe (loin &amp; leg)</th>
<th>Wether (loin &amp; leg)</th>
<th>Ram</th>
<th>Cryptorchid</th>
<th>SEDP</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass weight (kg)</td>
<td>19.7*</td>
<td>19.6*</td>
<td>22.1*</td>
<td>22.9*</td>
<td>0.63</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>pH&lt;sub&gt;meat&lt;/sub&gt;</td>
<td>5.73*</td>
<td>5.79*</td>
<td>5.89*</td>
<td>5.88*</td>
<td>0.015</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>LD</th>
<th>SM</th>
<th>BF</th>
<th>ST</th>
<th>SED</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH&lt;sub&gt;meat&lt;/sub&gt;</td>
<td>5.81*</td>
<td>5.7*</td>
<td>5.86*</td>
<td>5.92*</td>
<td>0.016</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*Means with different superscripts in a row differ (P < 0.05)
* Standard errors of differences
* LD was only determined for the 8 weeks of storage.

(Purdue University)
EFFECTS OF GENDER/CASTRATION STATUS ON LIGHTNESS (L* VALUES) OF LONG-TERM CHILLED MEAT UNDER HIOX-MAP

No gender effects on lightness of the lamb cuts (P > 0.05)

EFFECTS OF MUSCLE TYPES ON LIGHTNESS (L* VALUES) OF LONG-TERM CHILLED MEAT UNDER HIOX-MAP

Lightness: ST > LD = BF > SM (P < 0.05)

EFFECTS OF GENDER/CASTRATION/MUSCLE TYPE ON COLOR STABILITY OF LAMB MUSCLES

Color stability: Ram > Cryptorchid > Wether > Ewe

EFFECTS OF GENDER/CASTRATION/MUSCLE TYPE ON MYOGLOBIN CONTENTS OF LAMB MEAT

Myoglobin contents

- Dark/red
- Susceptible to oxidation

Effects of gender/castration status on lipid oxidation stability of long-term chilled loin during display under HIOx-MAP

Lipid oxidation & Discoloration (Myoglobin oxidation)
**EFFECTS OF GENDER/CASTRATION/MUSCLE TYPE ON SENSORY ATTRIBUTES OF LAMB MEAT**

- In general, no gender/castration status effects on eating quality attributes of lamb meat (< 12 months).

- However, small differences in eating quality attributes were reported in older animals:
  
  Shear force values: Ram > Ewe  
  Wether > Ewe  

(Cloete et al., 2012; Hopkins et al. 2007)

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**EFFECTS OF BREED/GENOTYPE ON QUALITY ATTRIBUTES OF LAMB MEAT**

- In general, no large breed/genotype effects on eating quality attributes of lamb meat.  
(Hopkins, 2015)

- Merino lambs showed slightly lower eating quality attributes (juiciness, flavor liking, tenderness, and overall liking scores) and color stability.

Possibly due to high ultimate pH of meat from Merino lambs (pHu > 6.0)

---

**CALLIPYGE LAMB (BEAUTIFUL BUTTOKS)**

Callipyge lambs are well known for their muscular hypertrophy of the loin and rump. Their meat is leaner, but noticeably tougher and less palatable than meat from normal counterparts.

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**SUMMARY: FACTORS AFFECTING LAMB MEAT QUALITY & FUTURE IMPLICATIONS**

**POST - HARVEST FACTORS**

1. Carcass processing  
   - Optimizing aging potential: pH/temperature modifications
2. Aging & Freezing  
   - Fast Freeze/Thaw: Aging
3. Packaging  
   - Developing novel packaging systems

**PRE - HARVEST FACTORS**

1. Feeding effect  
   - Antioxidant property through feeding strategy (e.g., Ryegrass/Plantain + Se/Vit-E supplementation)
2. Gender/Castration  
   - Display color stability?
3. Breed/Genotype  
   - Revisiting potential values of Callipyge lambs?
STRATEGY TO IMPROVE LAMB MEAT QUALITY
- WHOLE VALUE-CHAIN MANAGEMENT

**Producer**
- Animal productivity
- Genetic influence on meat-quality attributes
- Feeding & growth rate effects on muscle fiber type and meat quality
- Animal handling/stress

**Meat Processor**
- Optimized carcass chilling technology
- Pre-rigor hot-boned meat processing
- Innovative chilling/processing/shaping methods

**Retailer**
- Novel packaging system
- Novel aging method
- Display/storage condition

ACKNOWLEDGEMENTS
- Meat Industry Association, NZ
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- Alliance Group Ltd. NZ
- Silver Fern Farms Ltd. NZ
- AgResearch Meat Sci. Team
- Purdue Univ. Meat Sci. Lab

KIA ORA!!
(THANK YOU!!)

Any questions for me???

EFFECTS OF STRESS ON QUALITY ATTRIBUTES OF LAMB MEAT

**Ultimate pH & aging potential**

Meat having Intermediate pH has the least aging potential.

**Table 1** Effect of pre-slaughter transport on ultimate pH of different lamb muscles

<table>
<thead>
<tr>
<th>Cut (Lamb muscle name)</th>
<th>Transportation</th>
<th>Untransported</th>
<th>Stressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>But (Lamb muscle name)</td>
<td>Stress Transport</td>
<td>Stress</td>
<td>Not Stress</td>
</tr>
<tr>
<td>Eye of round (Semimembranosus)</td>
<td>6.12</td>
<td>5.94</td>
<td>5.86</td>
</tr>
<tr>
<td>Breast (Vicentia, Puberulent)</td>
<td>6.00</td>
<td>5.90</td>
<td>5.80</td>
</tr>
<tr>
<td>X-cut blade (Triceps)</td>
<td>6.25</td>
<td>5.95</td>
<td>5.85</td>
</tr>
<tr>
<td>Eye meat (Vicentia, Puberulent)</td>
<td>6.10</td>
<td>6.00</td>
<td>5.90</td>
</tr>
<tr>
<td>Outside round (Semimembranosus)</td>
<td>5.95</td>
<td>5.95</td>
<td>5.85</td>
</tr>
<tr>
<td>Eye meat (Vicentia, Posterior)</td>
<td>5.70</td>
<td>5.70</td>
<td>5.60</td>
</tr>
<tr>
<td>Brisket strip (capitare)</td>
<td>5.70</td>
<td>5.70</td>
<td>5.60</td>
</tr>
</tbody>
</table>

**µ-calpain autolysis**

- Optimizing aging potential: pH/temperature modifications

**Not all meats are same!**

(Loor, 2011)
The effects of pH decline rate on the meat and eating quality of beef carcasses

**EFFECTS OF FORAGE TYPES ON pH OF LONG TERM CHILLED LOINS**

Rye Grass, Clover 3 and Clover 1 resulted in higher pH after 9 weeks of chilled-storage.