Controlling cheese acidity by adjustment of lactose to protein content of cheese milk

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Introduction

Acidity is a common defect in Cheddar cheese

Retail Cheddar Cheese Survey

Smukowski et al. 2003, CDR Dairy Pipeline 15:1-7
Introduction

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Acidity is a common defect in Cheddar cheese

Excessive acidity was the major flavor defect identified

Smukowski et al. 2003, CDR Dairy Pipeline 15:1-7
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Retail Cheddar Cheese Survey

Formation of Calcium Lactate Crystals

Smukowski et al. 2003, CDR Dairy Pipeline 15:1-7
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Current methods to control acidity in cheese

Whey Dilution  
Curd Rinse  
Curd Soaking
Use of whey dilution, curd rinse or curd soak

Lactose \rightarrow \text{Acidity} \rightarrow \text{pH}

Diluted Whey or Water
Introduction

Current methods to control acidity in cheese

Whey Dilution  Curd Rinse  Curd Soaking
Introduction

Current methods to control acidity in cheese

Whey Dilution

Curd Rinse

Curd Soaking

Size of Curd cubes
Current methods to control acidity in cheese

- Whey Dilution
- Curd Rinse
- Curd Soaking

- Size of Curd cubes
- Amount of water used
Introduction

Current methods to control acidity in cheese

- Whey Dilution
- Curd Rinse
- Curd Soaking

Size of Curd cubes

Temperature

Amount of water used
Introduction

Current methods to control acidity in cheese

- Whey Dilution
- Curd Rinse
- Curd Soaking

Factors:

- Temperature
- Size of Curd cubes
- Amount of water used
- Time

Images of cheese production processes.
Introduction

Current methods to control acidity in cheese

- Whey Dilution
- Curd Rinse
- Curd Soaking

Time

Size of Curd cubes

Cheesemaker

Temperature

Amount of water used

Wesley Dilution

Soaking

In cheese
Introduction

Current methods to control acidity in cheese

Whey Dilution
Curd Rinse
Curd Soaking

Acidification rate

Temperature
Cheesemaker

Size of Curd cubes

Amount of water used

Time

Acidification rate
Introduction

Can we adjust the lactose content of milk prior cheese manufacture?

- Standardization of cheese milk based on fat and casein content.

- Can we also standardized the lactose content?
Introduction

What controls final cheese pH?

[Lactose] >>> [Casein]

[Lactose] >>>> [Casein]
Introduction

What controls final cheese pH?

[Lactose] <<< [Casein]

High pH

[Lactose] <<< [Casein]
What controls final cheese pH?

Balance between Lactose to Casein ratio (L:CN)
Introduction

Use of low-concentration-factor ultrafiltration (LCF-UF) to standardize milk prior cheesemaking
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Increasing of CN content
Lactose remains constant
Introduction

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Leads to changes in the Lactose to Casein ratio (L:CN)
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Increasing of CN content
Lactose remains constant

Leads to changes in the Lactose to Casein ratio (L:CN)

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<thead>
<tr>
<th>Concentration</th>
<th>CN (%)</th>
<th>Lactose (%)</th>
<th>L:CN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Milk</td>
<td>2.54</td>
<td>4.35</td>
<td>1.71</td>
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<tr>
<td>UF Retentate (3x)</td>
<td>7.73</td>
<td>4.35</td>
<td>0.56</td>
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Govindasamy-Lucey et al. (2004)
Balance between Lactose to Casein ratio (L:CN)
Introduction

UF Retentate → UF Permeate → Water

Blending → Standardized L:CN Milk
Introduction

Recent work from our group using LCF-UF to standardize L:CN ratio of cheesemilk in:

Mozzarella cheese

Low-fat and reduced-fat Gouda cheese.
Controlling acidity in Cheddar cheese

Investigating the impact of lactose standardization of milk on the properties of Cheddar cheese

Impact of increasing levels of solids in milk at constant L:CN ratio on the properties of Cheddar cheese
Controlling acidity in Cheddar cheese

Investigating the impact of lactose standardization of milk on the properties of Cheddar cheese

Impact of increasing levels of solids in milk at constant L:CN ratio on the properties of Cheddar cheese
Adjustment of lactose content in cheese milk

Cheese milk standardization

Milk → Low concentration UF

UF Concentrated milk → ~18% TS

UF Permeate → Standardization

Water → 4.2% Lactose 2.3% CN

Cream → 2.1% Lactose 2.3% CN

3.2% Lactose 2.3% CN → 2.6% Lactose 2.3% CN
Adjustment of lactose content in cheese milk

Cheese milk standardization

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UF Concentrated milk
~18% TS

UF Permeate

Water

Standardization

Cream

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Adjustment of lactose content in cheese milk

Cheese milk standardization

- Lactose content in cheese milks (%)
  - 4.2
  - 3.2
  - 2.6
  - 2.1

Kg/1000 kg cheese milk:

- Water
- UF Permeate
- UF Retentate
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Values represent means of four replicate trials.
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<th>Mean 2</th>
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Cheese manufacture

- Cheese milks standardized to different levels of lactose, maintaining levels of casein (CN) constant:

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<th>Lactose Level</th>
<th>Description</th>
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<tbody>
<tr>
<td>4.2% Lactose</td>
<td>Control</td>
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<tr>
<td>3.2% Lactose</td>
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<tr>
<td>2.6% Lactose</td>
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<tr>
<td>2.1% Lactose</td>
<td></td>
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- Fat content were kept constant for all treatments.

- Standard milled curd direct-salted Cheddar cheese manufacture

- Ripening period of 270 d.

- Four independent replicate trials
Cheese composition at 14 d of ripening

<table>
<thead>
<tr>
<th>Item</th>
<th>4.2</th>
<th>3.2</th>
<th>2.6</th>
<th>2.1</th>
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<tbody>
<tr>
<td>Lactose content in cheesemilk (%)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Moisture (%)</td>
<td>36.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.59&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>MNFS (%)</td>
<td>55.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>54.77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55.63&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>FDM (%)</td>
<td>53.65&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>53.58&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>53.35&lt;sup&gt;b&lt;/sup&gt;</td>
<td>53.85&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>S/M (%)</td>
<td>4.59&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.92&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.95&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Ca (mg/100g)</td>
<td>736&lt;sup&gt;a&lt;/sup&gt;</td>
<td>701&lt;sup&gt;a&lt;/sup&gt;</td>
<td>727&lt;sup&gt;a&lt;/sup&gt;</td>
<td>748&lt;sup&gt;a&lt;/sup&gt;</td>
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<sup>a,b,c</sup> Means within the same row not sharing a common lowercase superscript differ (<i>P</i>&lt;0.05)

Values represent means of four replicate trials.
Cheese composition at 14 d of ripening

<table>
<thead>
<tr>
<th>Item</th>
<th>Lactose content in cheemilk (%)</th>
<th></th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>4.2</td>
<td>3.2</td>
<td>2.6</td>
<td></td>
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<tr>
<td>Moisture (%)</td>
<td>36.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.59&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Fat (%)</td>
<td>33.88&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Protein (%)</td>
<td>24.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24.45&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>24.76&lt;sup&gt;ab&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Salt (%)</td>
<td>1.69&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.81&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>MNFS (%)</td>
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<td>54.77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55.63&lt;sup&gt;a&lt;/sup&gt;</td>
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Values represent means of four replicate trials.
Residual lactose at 1 d of ripening

Residual Lactose (%)

Lactose content in cheesemilk treatments (%)

ND: Not Detected
Residual lactose at 1 d of ripening

<table>
<thead>
<tr>
<th>Lactose content in cheesemilk treatments (%)</th>
<th>Residual Lactose (%)</th>
</tr>
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<tbody>
<tr>
<td>4.2</td>
<td>a</td>
</tr>
<tr>
<td>3.2</td>
<td>ab</td>
</tr>
<tr>
<td>2.6</td>
<td>b</td>
</tr>
<tr>
<td>2.1</td>
<td>ND: Not Detected</td>
</tr>
</tbody>
</table>

ND: Not Detected
Concentration of lactic acid during ripening

Concentration of lactose in cheesemilk:
- 4.2%
- 3.2%
- 2.6%
- 2.1%
Concentration of lactic acid during ripening

Concentration of lactose in cheesemilk:

- ● 4.2%
- ○ 3.2%
- ▼ 2.6%
- △ 2.1%

Cheeses made from milk with lower lactose had lower amount of lactic acid
Changes of pH during ripening

Concentration of lactose in cheesemilk:
- 4.2%
- 3.2%
- 2.6%
- 2.1%
Changes of pH during ripening

Concentration of lactose in cheesemilk:

- 4.2%
- 3.2%
- 2.6%
- 2.1%

Cheeses made from milk with lower lactose had higher pH
Sensory analysis – Acid flavor

Analysis performed by trained panelists (12).
Sensory analysis – Acid flavor

- 4.2%
- 3.2%
- 2.6%
- 2.1%

Analysis performed by trained panelists (12).

Cheeses made from milk with lower lactose were less acidic.
Proportion of insoluble Ca (INSOL Ca)

Concentration of lactose in cheesemilk:

- 4.2%
- 3.2%
- 2.6%
- 2.1%
Proportion of insoluble Ca (INSOL Ca)

Concentration of lactose in cheesemilk:
- 4.2%
- 3.2%
- 2.6%
- △ 2.1%

Highest pH
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca

Highest pH
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca

More water added

Highest pH
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca

More water added

Higher pH

• 4.2%
• 3.2%
▼ 2.6%
△ 2.1%

Lower lactic acid
TPA hardness during ripening

- Texture Profile Analysis (TPA)
- Two-bite compression on cheese cylinders performed at 30% strain.
TPA hardness during ripening

- Texture Profile Analysis (TPA)
- Two-bite compression on cheese cylinders performed at 30% strain.
TPA hardness during ripening

Concentration of lactose in cheesemilk:
- 4.2%
- 3.2%
- 2.6%
- 2.1%

Cheeses made from milk with lower lactose had no differences in TPA hardness.
### Sensory analysis – Hand firmness

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<tr>
<th>Ripening (d)</th>
<th>Lactose content in cheesemilk (%)</th>
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<tbody>
<tr>
<td></td>
<td>4.2</td>
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<tr>
<td>45</td>
<td>12.4\textsuperscript{a,A}</td>
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<td>120</td>
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<td>180</td>
<td>11.9\textsuperscript{a,A}</td>
</tr>
<tr>
<td>270</td>
<td>12.8\textsuperscript{a,A}</td>
</tr>
</tbody>
</table>

\textsuperscript{a,b,c} Means within the same row not sharing a common superscript differ \((P<0.05)\).

\textsuperscript{A,B,C} Means within the same column not sharing a common superscript differ \((P<0.05)\).

Values represent means of four replicate trials.

Analysis performed by trained panelists \((12)\).

Cheeses made from milk with lower lactose had no differences in TPA firmness.
Cheese rheology ($LT_{\text{max}}$) during heating

- **Rheological Analysis:**
  - Cheese heated from 5 to 85°C at 1°C/min
  - 0.5% strain
  - 0.08 Hz frequency

- **Parameters measured:**
  - Loss tangent (LT)

  \[
  LT = \frac{\text{Viscous Modulus (G'')}}{\text{Elastic Modulus (G')}}
  \]
Cheese rheology ($LT_{\text{max}}$) during heating

$LT_{\text{max}}$ (melting indicator)

- Rheological Analysis:
  - Cheese heated from 5 to 85°C at 1°C/min
  - 0.5% strain
  - 0.08 Hz frequency

- Parameters measured:
  - Loss tangent (LT)

$LT = \frac{\text{Viscous Modulus (G'')}}{\text{Elastic Modulus (G')}}$
Cheese rheology (LT$_{\text{max}}$) during heating

- 4.2%
- 3.2%
- ▼ 2.6%
- Δ 2.1%
Cheeses made from milk with lower lactose were more meltable.
• Decreasing lactose content of milk reduced cheese acidity.

• The addition of water during cheesemilk standardization led to a reduction of the proportion of insoluble Ca, which increased cheese meltability.
Controlling acidity in Cheddar cheese

Investigating the impact of lactose standardization of milk on the properties of Cheddar cheese

Impact of increasing levels of solids in milk at constant L:CN ratio on the properties of Cheddar cheese
Controlling acidity in Cheddar cheese

*Investigating the impact of lactose standardization of milk on the properties of Cheddar cheese*

*Impact of increasing levels of solids in milk at constant L:CN ratio on the properties of Cheddar cheese*
Cheesemilk standardization

- Milk
- LCF-UF
  - UF Retentate (~18% TS)
  - UF Permeate
- Standardization
  - Water
  - Cream
- 2.3% CN
- 2.6% CN
- 2.9% CN
- 3.2% CN
- L:CN 1.2
Adjustment of casein and lactose content in cheese milk

Cheesemilk standardization

- Milk
- LCF-UF
- ~18% TS
  - UF Retentate
  - UF Permeate
- Standardization
  - Water
  - Cream
  - 2.3% CN
  - 2.6% CN
  - 2.9% CN
  - 3.2% CN

L:CN
- 1.2
- 1.2
- 1.2
- 1.2
## Cheesemilk composition

<table>
<thead>
<tr>
<th></th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
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</thead>
<tbody>
<tr>
<td>Casein (%)</td>
<td>2.32&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.61&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.15&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>Lactose (%)</td>
<td>2.76&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>Casein to fat</td>
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<td>Total Ca (mg/100 g)</td>
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<td>Insoluble Ca (mg/100 g)</td>
<td>63.6&lt;sup&gt;d&lt;/sup&gt;</td>
<td>71.0&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>Total Solids (%)</td>
<td>9.94&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>12.33&lt;sup&gt;b&lt;/sup&gt;</td>
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Values represent means of four replicate trials.
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<td><strong>Cheesemilk composition</strong></td>
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<td>63.6&lt;sup&gt;d&lt;/sup&gt;</td>
<td>71.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>80.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>86.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Ca (mg/g CN)</td>
<td>38.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>37.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Insoluble Ca (mg/g CN)</td>
<td>27.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Solids (%)</td>
<td>9.94&lt;sup&gt;d&lt;/sup&gt;</td>
<td>11.17&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.33&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.57&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b,c</sup> Means within the same row not sharing a common superscript differ ($P<0.05$)

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<table>
<thead>
<tr>
<th>Cheesemilk composition</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Casein (%)</td>
<td>2.32&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.61&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.15&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Lactose (%)</td>
<td>2.76&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.12&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.48&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.86&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lactose to casein (L:CN)</td>
<td>1.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.18&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Casein to fat</td>
<td>0.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Ca (mg/100 g)</td>
<td>88.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>96.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>108.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>116.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
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Values represent means of four replicate trials.
Cheese manufacture

- Cheesemilks standardized to different levels of casein, maintaining a constant lactose to casein ratio:
  - 2.3% CN (Control)
  - 2.6% CN
  - 2.9% CN
  - 3.2% CN

- Casein (CN) and fat content were kept constant for all treatments.

- Standard milled curd direct-salted Cheddar cheese manufacture

- Ripening period of 270 d.

- Four independent replicate trials
Cheese composition from preliminary trials

<table>
<thead>
<tr>
<th>Item</th>
<th>Casein content in cheesemilk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.3</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>37.53&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>33.13&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>24.50&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Salt (%)</td>
<td>1.84&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>MNFS (%)</td>
<td>56.12&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>FDM (%)</td>
<td>53.04&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>S/M (%)</td>
<td>4.90&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Ca (mg/100g)</td>
<td>690&lt;sup&gt;a&lt;/sup&gt;</td>
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</table>

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Values represent means of four replicate trials.
## Cheese composition from preliminary trials

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<tr>
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</tr>
<tr>
<td>Fat (%)</td>
<td>33.13&lt;sup&gt;c&lt;/sup&gt;</td>
<td>33.81&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>34.41&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>34.55&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>24.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.78&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Salt (%)</td>
<td>1.84&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>1.82&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>S/M (%)</td>
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<td>5.09&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.03&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Ca (mg/100g)</td>
<td>690&lt;sup&gt;a&lt;/sup&gt;</td>
<td>681&lt;sup&gt;a&lt;/sup&gt;</td>
<td>733&lt;sup&gt;a&lt;/sup&gt;</td>
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</table>

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Values represent means of four replicate trials.

Modification of cheesemaking protocols to obtain similar moisture content.
Cheese composition with moisture adjustments

<table>
<thead>
<tr>
<th>Item</th>
<th>2.3</th>
<th>2.6</th>
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<th>3.2</th>
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<tbody>
<tr>
<td>Moisture (%)</td>
<td>37.89\textsuperscript{a}</td>
<td>36.41\textsuperscript{b}</td>
<td>37.44\textsuperscript{ab}</td>
<td>37.45\textsuperscript{ab}</td>
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<tr>
<td>Fat (%)</td>
<td>32.69\textsuperscript{b}</td>
<td>34.17\textsuperscript{a}</td>
<td>33.65\textsuperscript{a}</td>
<td>33.64\textsuperscript{a}</td>
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<tr>
<td>Protein (%)</td>
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<td>24.62\textsuperscript{a}</td>
<td>24.00\textsuperscript{c}</td>
<td>24.06\textsuperscript{bc}</td>
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<tr>
<td>Salt (%)</td>
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<td>1.90\textsuperscript{a}</td>
<td>1.78\textsuperscript{a}</td>
<td>1.73\textsuperscript{a}</td>
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<tr>
<td>MNFS (%)</td>
<td>56.29\textsuperscript{a}</td>
<td>55.31\textsuperscript{a}</td>
<td>56.42\textsuperscript{a}</td>
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<td>FDM (%)</td>
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<td>4.61\textsuperscript{a}</td>
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<tr>
<td>Total Ca (mg/100g)</td>
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<td>691\textsuperscript{a}</td>
<td>726\textsuperscript{a}</td>
<td>718\textsuperscript{a}</td>
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Values represent means of four replicate trials.
## Cheese composition with moisture adjustments

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Values represent means of four replicate trials.
Residual Lactose, Lactic Acid and pH during ripening

Concentration of CN in cheesemilk:
- 2.3%
- ▼ 2.9%
- ▼ 3.2%
Residual Lactose, Lactic Acid and pH during ripening

High CN and Lactose

Low CN and Lactose

Concentration of CN in cheese milk:
- 2.3%
- 2.9%
- 3.2%
Residual Lactose, Lactic Acid and pH during ripening

Concentration of CN in cheesemilk:
- ● 2.3%
- ▼ 2.9%
- ▼ 3.2%
Residual Lactose, Lactic Acid and pH during ripening

Concentration of CN in cheesemilk:
- ● 2.3%
- ▼ 2.9%
- ▼ 3.2%

High Residual Lactose
Low Residual Lactose
Residual Lactose, Lactic Acid and pH during ripening

<table>
<thead>
<tr>
<th>Ripening time (d)</th>
<th>Lactic Acid (%)</th>
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<tr>
<td>0</td>
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<tr>
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<td>1.0</td>
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<tr>
<td>180</td>
<td>1.1</td>
</tr>
<tr>
<td>225</td>
<td>1.2</td>
</tr>
<tr>
<td>270</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Concentration of CN in cheesemilk:
- ● 2.3%
- ▼ 2.9%
- ▼ 3.2%
Residual Lactose, Lactic Acid and pH during ripening

Concentration of CN in cheesemilk:
- ● 2.3%
- ▼ 2.9%
- ▼ 3.2%

Low Lactic Acid
High Lactic Acid
Sensory analysis – Acid flavor

Analysis performed by trained panelists (12).
Cheeses made from milk with higher lactose and casein were more acidic.
Proportion of insoluble Ca (INSOL Ca)

Concentration of CN in cheesemilk:

- 2.3%
- 2.9%
- 3.2%
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca

- 2.3% CN
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca

- 2.3% CN

Highest amount of water added

Casein content in cheesemilks

- Water
- UF Permeate
- UF Retentate

kg/1000 kg cheesemilk
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca

- 2.3% CN

Highest amount of water added

Lowest content of Lactic Acid

Casein content in cheesemilks

- Water
- UF Permeate
- UF Retentate

kg/1000 kg cheesemilk:

2.3 CN

Water: 800 kg
UF Permeate: 100 kg
UF Retentate: 100 kg

2.6 CN

Water: 750 kg
UF Permeate: 150 kg
UF Retentate: 100 kg

2.9 CN

Water: 700 kg
UF Permeate: 200 kg
UF Retentate: 100 kg

3.2 CN

Water: 650 kg
UF Permeate: 250 kg
UF Retentate: 100 kg
Proportion of insoluble Ca (INSOL Ca)

Highest INSOL Ca at 1 d
Proportion of insoluble Ca (INSOL Ca)

Highest INSOL Ca at 1 d

Lowest amount of water added

Water

UF Permeate

UF Retentate

Casein content in cheesemilks

kg/1000 kg cheesemilk

Ripening time (d)

% INSOL Ca/Total Ca

Proportion of insoluble Ca (INSOL Ca)
Proportion of insoluble Ca (INSOL Ca)

Lowest INSOL Ca thereafter

Highest content of Lactic Acid

Ripening time (d)

% INSOL Ca/Total Ca

3.2% CN

Casein content in cheesemilks

kg/1000 kg cheesemilk

Water

UF Permeate

UF Retentate

2.3 CN

2.6 CN

2.9 CN

3.2 CN
TPA Hardness

- Texture Profile Analysis (TPA)
- Two-bite compression on cheese cylinders performed at 30% strain.
TPA Hardness

- Texture Profile Analysis (TPA)
- Two-bite compression on cheese cylinders performed at 30% strain.
TPA Hardness

Ripening time (d)

0 45 90 135 180 225 270

TPA Hardness (N)

0 20 25 30 35 40

Concentration of CN in cheesemilk:

● 2.3%
▼ 2.9%
▼ 3.2%
No differences were found in TPA Hardness.
Similar trend was also found by Trained Sensory Panelists.
Cheese rheology ($LT_{\text{max}}$) during heating

- Rheological Analysis:
  - Cheese heated from 5 to 85°C at 1°C/min
  - 0.5% strain
  - 0.08 Hz frequency

- Parameters measured:
  - Loss tangent ($LT$)

$LT = \frac{\text{Viscous Modulus (G’’)}}{\text{Elastic Modulus (G’)}}$
Cheese rheology ($LT_{\text{max}}$) during heating

$LT_{\text{max}}$ (melting indicator)

- Rheological Analysis:
  - Cheese heated from 5 to 85°C at 1°C/min
  - 0.5% strain
  - 0.08 Hz frequency

- Parameters measured:
  - Loss tangent (LT)

$$LT = \frac{\text{Viscous Modulus (G'')}}{\text{Elastic Modulus (G')}}$$
Cheese rheology ($LT_{\text{max}}$) during heating

- 2.3% 3% CN
- 2.6% 9% CN
- 2.9% 2% CN

Δ 3.2%
Cheese rheology ($LT_{max}$) during heating

- 2.3% 3% CN
- 2.6% 9% CN
- 2.9% 2% CN

Lower CN content
High water added
Higher final pH
Summary

• Increasing the casein content of cheesemilk at constant L:CN ratio led to cheeses with higher acidity.

• The addition of water reduced levels of insoluble Ca, which affected cheese functionality.
Conclusions

• Reducing lactose content of cheese milk successfully reduced acidity and increased pH of Cheddar cheese.

• Increasing the casein content of cheese milk has to consider adjustments in lactose content to maintain optimum cheese pH.

• Addition of water impacted lactose content, but also Ca.  
  – Use if NF permeate as an alternative?

• Controlling the L:CN ratio seems a promising technique to target optimum acidity and pH in cheese.
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Controlling cheese acidity by adjustment of lactose to protein content of cheese milk

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