Fats and fatty acids in dairy nutrition

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Types of fats in feedstuffs

• Free fatty acid: Nutritional “currency” unit of fat; form for absorption into body

• Triglyceride: energy storage in plants and animals; found in grains, oilseeds

• Galactolipid: structural fat of forages

• Phospholipid: structure of cell membranes in animals and plants; secreted into intestine in bile and pancreatic juice and aids digestion

Courtesy: Dr. J. Drackley
Where dietary fat comes from

- Basal feeds (forages, cereals, protein meals) – total fat content 3 – 6 %
- Whole oilseeds (cottonseed, soybeans -- ~20 % fat)
- Byproducts (distillers) ~ 10% fat
- Animal fats (tallow) ~ 100% fat
- Commercial fat sources ~ 80 to 100% fat

Why feed added fats?
Many Different Fat Supplements

"Rumen-Active"
- Animal Fat - rendered fats from beef or pork
- Blended Animal Fats - blends of tallow, grease, poultry fat, restaurant grease
- Vegetable Fat - corn, soybean, canola, etc
- Oilseeds - cottonseed, soybeans, sunflower
- High fat byproducts from food processing

"Rumen-Inert"
- Calcium salts of fatty acids
- Saturated fats and fatty acids
- Fatty amides
- Formaldehyde
- Oilseeds?

Courtesy Dr. Adam Lock

"Rumen Inert" Fat Supplements

- Designed to avoid digestibility problems
- Dry fats for easy transport and mixing

Calcium Salts of FFA (e.g. Megalac, EnerG-II, etc)
- BH may occur of UFA present in Ca-salts
- Calcium is removed from the FA before digestion

Saturated FFA (e.g. Energy Booster 100)
- Requires no modification before digestion
- 99% FFA; FA profile similar to duodenal contents

High Palmitic Acid Fats (e.g., Bergafat, Palmit 80)
- Also highly saturated
- > 80% palmitic acid content

Other Dry Fats
- PHF’s - Partially hydrogenated fats (triglycerides)
- Hydrolysis (lipolysis) must occur prior to digestion
- High melting point may limit hydrolysis

Adapted from Dr. Adam Lock
Dietary fat and fatty acids, it’s not just about crude fat (ether extract) anymore!!

Triglycerides

- Glycerol backbone, and 3 fatty acids
- Major lipid class in concentrates
- Main lipid store in animal tissues
- Diverse range of fatty acids, rich in linoleic acid (18:2)

Courtesy: Dr. A. Lock
Galactolipids

- Glycerol backbone, 2 fatty acids, and one or two galactose
- Major lipid class in forages
- Rich in linolenic acid (18:3)

Fatty Acids

- Long carbon chains that contain a methyl group (CH3) at one end and a carboxyl group (COOH) at the other
- Fatty acids are what make lipids energy-rich
- Characterized by:
  - Number of carbons (chain length)
  - Number of double bonds (degree of unsaturation)
  - Location and orientation of these bonds (non-conjugated, conjugated; cis, trans)
Nomenclature and Structure

**Saturated – single bonds**

\[ R_1 - C - C - C - C - C - R_2 \]

**Unsaturated – double bonds**

\[ R_1 - C \equiv C - C - C \equiv C - R_2 \]

*Courtesy: Dr. A. Lock*

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**Saturated vs. Unsaturated**

- Myristic  C14:0
- Palmitic  C16:0
- Stearic   C18:0
- Palmitoleic  C16:1
- Oleic     C18:1
- Linoleic  C18:2 (omega 6)
- Linolenic C18:3 (omega 3)
- Eicosapentaenoic acid (EPA) C20:5 (omega 3)
- Docosahexanoic acid (DHA) C22:3 (omega 3)
### Fatty Acid Composition of Typical Feedstuffs

<table>
<thead>
<tr>
<th>Feed Name</th>
<th>C14:0</th>
<th>C16:0</th>
<th>C16:1</th>
<th>C18:0</th>
<th>C18:1C</th>
<th>C18:2</th>
<th>C18:3</th>
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<tbody>
<tr>
<td>CrnSil6Cp60Ndf11LNdf</td>
<td>0.46</td>
<td>17.83</td>
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<td>19.24</td>
<td>47.74</td>
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<td>AlShl7Cp43Ndf20LNdf</td>
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<td>15.91</td>
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<td>AlHy17Cp46Ndf20LNdf</td>
<td>0.85</td>
<td>25.01</td>
<td>2.23</td>
<td>4.01</td>
<td>2.43</td>
<td>18.49</td>
<td>36.79</td>
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<tr>
<td>BakeryByProd</td>
<td>3.16</td>
<td>15.82</td>
<td>0.18</td>
<td>9.29</td>
<td>26.41</td>
<td>33.51</td>
<td>0.85</td>
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<tr>
<td>CornGrainCrkd</td>
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<td>13.21</td>
<td>0.12</td>
<td>1.99</td>
<td>24.09</td>
<td>55.70</td>
<td>1.62</td>
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<td>CornGrainGrndFine</td>
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<td>13.21</td>
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<td>41.62</td>
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<td>0.53</td>
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<td>FatCornOil</td>
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<td>11.08</td>
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<td>58.95</td>
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<td>FatSoybeanOil</td>
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<td>SoybeanMealExtrd</td>
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<td>GrssSil7Cp72Ndf13Lndf</td>
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<td>16.76</td>
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<td>3.80</td>
<td>19.96</td>
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<td>16.44</td>
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<td>2.53</td>
<td>23.38</td>
<td>49.99</td>
</tr>
</tbody>
</table>

**Digestion in the Rumen**

**Hydrolysis**

Lipids → Bacterial lipases → Free fatty acids

Courtesy: Dr. A. Lock
Pathways for Rumen Biohydrogenation

- **Linolenic Acid (cis-9, cis-12, cis-15 C_{18:3})**
  - cis-9, trans-11, cis-15 C_{18:3}
  - trans-11, cis-15 C_{18:2}
  - trans-15 or cis-15 C_{18:1}

- **Linoleic Acid (cis-9, cis-12 C_{18:2})**
  - cis-9, trans-11 CLA
  - trans-11 C_{18:1}
  - Stearic Acid C_{18:0}

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- Process extensive, but not complete
- All intermediates formed potentially pass to the small intestine

Harfoot and Hazlewood, 1997
Relationship Between Linoleic Acid (18:2) Intake and Duodenal Flow

Lock et al., 2006

Relationship Between Stearic Acid (18:0) Intake and Duodenal Flow

Lock et al., 2006
• 15 studies containing 61 treatments
• Total and individual FA duodenal flows and calculations of apparent intestinal digestibility

Duodenal flow of total FA is linearly related to total FA intake

\[
\text{FA flow (g/d)} = 92.89 + 0.838 \times \text{total FA intake}
\]

Digestion of dietary lipids: small intestine

- Fatty acids (and triglycerides) emulsified by bile salts; micelles formed with lysolecithin.
- Fatty acids absorbed into intestinal cells; converted to triglycerides and packaged into very-low-density lipoproteins (VLDL).
- VLDL enter lymph; VLDL-TG (from dietary fatty acids) provide fatty acids to heart, muscle, adipose, and mammary.
- Dietary fats thus bypass liver (mostly).

Intestinal digestibilities of individual FA vary slightly

<table>
<thead>
<tr>
<th>FA</th>
<th>n</th>
<th>Estimate</th>
<th>SE</th>
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<th>Upper limit</th>
<th>P-value</th>
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<td>61</td>
<td>76.0</td>
<td>1.04</td>
<td>74.0</td>
<td>78.1</td>
<td>&lt;0.001</td>
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<td>18:0</td>
<td>61</td>
<td>73.3</td>
<td>1.04</td>
<td>74.0</td>
<td>78.1</td>
<td>&lt;0.001</td>
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<tr>
<td>18:1</td>
<td>56</td>
<td>81.6</td>
<td>1.04</td>
<td>80.5</td>
<td>82.7</td>
<td>0.002</td>
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<td>18:2</td>
<td>61</td>
<td>77.7</td>
<td>1.04</td>
<td>73.9</td>
<td>81.5</td>
<td>0.18</td>
</tr>
<tr>
<td>18:3</td>
<td>46</td>
<td>79.2</td>
<td>1.04</td>
<td>78.0</td>
<td>81.3</td>
<td>0.03</td>
</tr>
<tr>
<td>Total</td>
<td>61</td>
<td>74.7</td>
<td>1.04</td>
<td>71.5</td>
<td>78.0</td>
<td>0.64</td>
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</tbody>
</table>

1. Lower and upper limit represent a 95% confidence interval.
2. P-value associated with comparing individual FA digestibility against C18:0.

Courtesy: Dr. J. Drackley

Effects of specific fatty acids on metabolism, immune function and reproduction

- α-linolenic acid (omega-3)
- linoleic acid (omega-6)
- EPA and DHA (fish FA – omega 3)
- CLA isomers

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• 42 multiparous Holstein cows
• Four treatments (- 35 to 84 DIM)
  – Control
  – Whole flaxseed (omega-3)
    • 60 g/kg prepartum diet; 80 g/kg postpartum diet
  – Whole raw soybeans (omega-6)
    • 120 g/kg prepartum diet; 160 g/kg postpartum diet
  – Ca-salts unsaturated FA (omega-6)
    • 24 g/kg prepartum diet; 32 g/kg postpartum diet

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## EE and fatty acid profiles

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Prepartum</th>
<th>Postpartum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CON</td>
<td>WF</td>
</tr>
<tr>
<td>EE, %</td>
<td>2.88</td>
<td>4.83</td>
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<td>FA, g/100g FA</td>
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<td>C14:0</td>
<td>0.83</td>
<td>0.47</td>
</tr>
<tr>
<td>C18:0</td>
<td>5.81</td>
<td>2.97</td>
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<tr>
<td>C18:1 cis</td>
<td>22.72</td>
<td>17.57</td>
</tr>
<tr>
<td>C18:2 n-6</td>
<td>29.38</td>
<td>26.04</td>
</tr>
<tr>
<td>C18:3 n-3</td>
<td>2.52</td>
<td>37.91</td>
</tr>
<tr>
<td>Other</td>
<td>6.79</td>
<td>3.26</td>
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</tbody>
</table>

Gandra et al., 2016

## Phagocytosis capacity and intensity

<table>
<thead>
<tr>
<th>Item</th>
<th>Prepartum</th>
<th>Contrast, P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CON</td>
<td>WF</td>
</tr>
<tr>
<td>% positive for phagocytosis</td>
<td></td>
<td></td>
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<tr>
<td>Monocytes prepartum</td>
<td>32.7</td>
<td>41.2</td>
</tr>
<tr>
<td>postpartum</td>
<td>77.7</td>
<td>77.5</td>
</tr>
<tr>
<td>Neutrophils prepartum</td>
<td>73.1</td>
<td>77.7</td>
</tr>
<tr>
<td>postpartum</td>
<td>543</td>
<td>543</td>
</tr>
</tbody>
</table>

Phagocytosis of *S. aureus*

| Monocytes prepartum   | 528  | 665 | 573 | 487  | 0.05 | 0.004       | 0.01            | 0.52       |
| postpartum            | 432  | 432 | 432 | 432  | 0.08 | 0.98        | 0.15            | 0.04       |
| Neutrophils prepartum | 535  | 634 | 634 | 634  | 0.07 | 0.98        | 0.15            | 0.04       |
| postpartum            | 474  | 477 | 477 | 477  | 0.07 | 0.98        | 0.15            | 0.04       |

Note – also indications of effects of fat and FA on adaptive immunity

Gandra et al., 2016
Conclusions – Gandra et al., 2016

• Diets containing omega-3 and omega-6 FA can modulate innate immune activity
  – Phagocytosis capacity and activity of monocytes
  – Effects of omega-3 greater than omega-6 on monocytes and neutrophils
• Supplemental FA also affected adaptive immunity
  – T-helper cells, T-cytotoxic cells, adhesion molecules

Alpha-linolenic acid and reproductive performance

  – 121 Holstein cows
  – Diets (28 d before breeding to 32 d after timed AI)
    • Rolled flaxseed – 56.7% ALA; 16.5% C18:2
    • Rolled sunflower seed – 0.1% ALA; 74.1% C18:2
  – Targeted 750 g/d of oil – diets ~ 7.2% EE

  – Results:
    • Similar DMI, milk yield, milk composition
    • Mean diameter ovulatory follicles larger in cows fed FLAX
    • Follicle number, CL size, plasma progesterone similar
    • Conception rates greater (72.6 vs 47.5%) and pregnancy losses lower (9.8 vs. 27.3%) for cows fed FLAX
Alpha-linolenic acid and reproductive performance

  – Pen study on 3 commercial dairies (~ 1,500 cows)
  – Two diets starting ~ 10 DIM
  – Control (~ 4.0% fat)
  – Rolled flaxseed (~ 0.85 kg/d) -- ~ 4.5% fat
  – Achieved ~ 2X increase in C18:3

  – Results
    • Similar milk yield (~ 39 kg/d) and milk composition (3.4% fat; 2.8% protein)
    • Modest changes in milk FA composition consistent with treatments
    • No effect on conception rate at 1st (~ 34%) or 2nd (~28%) services or pregnancy loss (4.0%)

EPA and DHA and reproduction

• 46 Holstein cow replicates (2 consecutive lactation switchback)
• Treatments (calving to 2 months after calving)
  – Control (toasted soybeans at 1.8% of DM)
  – Protected fish oil (1% of DM)

• Results
  – Similar DMI, milk yield, milk composition
  – Trends for increased # large follicles, decreased early embryonic death, and increased conception rate for cows fed protected fish oil
DHA and reproduction

• 739 Holstein cows on commercial Ca dairy farm
• Treatments (27 to 147 d postpartum)
  – Control diet
  – Control diet plus 100 g/d of algae product containing 10% DHA

• Results
  – Algae increased resumption of estrous cyclicity at 58 d postpartum (77.6 vs. 65.9%) in primiparous cows and conception rate across all services (47.6 vs. 32.8%) in all cows (effects greater in primiparous)
  – Algae increased milk yield by 0.9 kg/d, decreased milk fat % by ~0.2% units and did not affect milk protein %

• 1,380 Holstein cows on commercial FL dairy
• Treatments (30 d prepartum to 30 d postpartum)
  – Ca salts PFAD (control); 1.5% of DM
  – Ca salts safflower oil; 1.5% of DM
• Further randomized at 30 DIM until 160 DIM
  – Ca salts PFAD (control); 1.5% of DM
  – Ca salts fish oil; 1.5% of DM
### EE and fatty acid profiles

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Prepartum</th>
<th>Postpartum</th>
<th>Breeding</th>
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<tr>
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<td>PFAD</td>
<td>SAFF</td>
<td>PFAD</td>
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<tr>
<td>EE, %</td>
<td>3.7</td>
<td>3.7</td>
<td>4.3</td>
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<tr>
<td>FA, g/100g FA</td>
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<td>C14:0</td>
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<td>C16:0</td>
<td>28.11</td>
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<td>C18:0</td>
<td>3.54</td>
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<td>C18:1 cis</td>
<td>23.59</td>
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<td>C22:6 n-3</td>
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### Pregnancies per AI and pregnancy loss

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<tr>
<td>d 32</td>
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<td>d 60 Loss</td>
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<td>d 32</td>
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<td>26.7</td>
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<td>d 60 Loss</td>
<td>21.0</td>
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<td>d 32</td>
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<td>0.10</td>
<td>0.07</td>
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Note – milk yield greater for cows fed SAFF during transition period (0.7 kg/d) but milk composition not reported

Cows fed SAFF had greater neutrophil function during postpartum period.

Neutrophils from cows fed SAFF had greater responses to LPS in vitro.

Neutrophils from cows fed FISH had attenuated responses to LPS in vitro.
• 48 Holstein cows fed same basal TMR
• Treatments (beginning at 38 DIM and continuing for 70 d)
  – Control (500 g/d high-palmitic fat source)
  – FLAX (200 g/d pressed flaxseed containing 72 g/d of alpha-linolenic acid)
  – CLA (100 g/d supplement containing 10 g/d each of trans-10, cis-12 CLA and cis-9, trans-11 CLA)
  – 300 g/d partially rumen-protected fish oil containing 30 g/d each of EPA and DHA

Results – Hutchinson et al., 2012. Theriogenology. 78:12-27.

• Fat supplementation had little effect on follicle development
• Cows receiving FLAX or FISH had lower progesterone concentrations and smaller CL
All of these are C18:2 but have dramatically different metabolic effects!!

| trans-10, cis-12 CLA | cis-9, trans-11 CLA | linoleic acid |

Summary and conclusions

- Dramatic refocusing on fat as fatty acids and not simply energy
- Extensive (but not complete) biohydrogenation of unsaturated FA from feeds and plant-based sources
- Overall high intestinal digestibility of total FA, but some differences among certain FA
- Increasing attention and potential for effects of specific FA on metabolism, immune function and reproduction