Effect of fibre on piglet gut health

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Fiber and Starch

Plant Carbohydrates

Cell Content
Non-Structural Carbohydrates
- Organic Acids
- Sugars
- Starches
- Fructans

Cell Wall
Structural Carbohydrates
- Pectin
- β-Glucans
- Hemicellulose
- Cellulose
- Lignin

Not correct functionally, because resistant starch (RS) may act like fiber
Sugar, disaccharide (DP2), oligosaccharide (DP3-9), polysaccharide (DP≥10)
Problem and Partial Solution in Pigs

• Post-weaning diarrhea [short-term gut health]
  – Reduced feed intake & growth  – Unstable microflora
  – Reduced gut wall integrity   – Inflammation
  – Reduced digestibility  – Protein fermentation

• Solution: Dietary antibiotics – but, pressure to remove

• Prebiotic (revisited)
  – Selectively fermented ingredient that allows specific changes, both in composition and/or activity in the gastrointestinal microflora that confers benefits upon host well-being and health (Roberfroid, 2007)
  – Mostly fermentable carbohydrates
    • Oligosaccharides, inulin, resistant starch, pectin, β-glucan
    • Feedstuffs vs. Feed additives
CHO Fermentation & Energetic Efficiency

Low RS/fermentable fiber

Small Intestine → SCFA → Glucose

Cecum → Large Intestine → SCFA → Energy Lost → Energy ↑

High RS/fermentable fiber

Small Intestine → SCFA → Glucose

Cecum → Large Intestine → SCFA → Energy Lost → Energy ↓

Energy Lost ~60-80%
1. **Focus: Resistant Starch**

- Starch not digested into glucose but fermented into short-chain fatty acids (SCFA):

  [This is NOT the glycemic effect of starch]

Impact on:

- Microbial profiles & mediators
- Gut hormones
- Whole body energy metabolism
- Feed intake and growth

2. **Fermentable Fiber** (Similar to resistant starch)

3. **Gut health and growth performance**
Use Starch Chemistry to Study Starch vs. Fiber

<table>
<thead>
<tr>
<th>Source</th>
<th>Rice</th>
<th>Rice</th>
<th>Field pea</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amylose</td>
<td>0 %</td>
<td>18%</td>
<td>29%</td>
<td>63%</td>
</tr>
<tr>
<td>Resistant starch</td>
<td>3%</td>
<td>34%</td>
<td>61%</td>
<td>85%</td>
</tr>
</tbody>
</table>

Starch digestibility: amylose < amylopectin

(Van Kempen et al., 2010; Regmi et al., 2011ab; Fouhse et al., 2015; J. Nutr.)
## Four Diets

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>%, as fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>70</td>
</tr>
<tr>
<td>Casein</td>
<td>14</td>
</tr>
<tr>
<td>Fish meal</td>
<td>7.4</td>
</tr>
<tr>
<td>Cellulose</td>
<td>4</td>
</tr>
<tr>
<td>Canola oil</td>
<td>1</td>
</tr>
<tr>
<td>Minerals &amp; Vitamins</td>
<td>3.2</td>
</tr>
<tr>
<td>Marker (Titanium oxide)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

(Van Kempen et al., 2010; Regmi et al., 2011ab; ~Fouhse et al., 2015; J. Nutr.)
Ileal-cannulated pig

Total extent of digestion
• Can separate between small and large intestine
Starch Flow in Intestine; grower pig

Major advantage of most RS: complete fermentation in hindgut
Changes in gene expression in the gut

(Regmi et al., 2011a; J. Nutr.)
Net nutrient absorption or
Net insulin and incretin secretion =
(Portal – Carotid conc.) x blood flow
Glucose Absorption & Insulin Secretion

- Rapid > Slow
- Rapid > M-Rapid
- M-Rapid = M-slow
- Slow

* Reduced peak by ~50%

(Regmi et al., 2011a; J. Nutr.)
Incretins

- **Incretin**: gastrointestinal hormones in response to nutrients in gut
- Released from enteroendocrine
  - K cells, duodenum, jejunum; GIP
  - L cells, ileum; GLP-1
- Stimulate glucose dependent insulin secretion from pancreas

Glucose-dependent insulinotropic peptide (GIP)

Glucagon-like peptide (GLP)-1
AUC of GIP and GLP-1 Secretion; grower pig

Area under curve (AUC) = \[ \frac{1}{2} \sum_{i=0}^{n-1} (t_{i+1} - t_i)(y_i + y_{i+1}) \]

Where, \( t = \) time; 
\( y_i = \) value at time \( i \)

(Matthews et al., 1990)

\( P < 0.05 \)
Short-Chain Fatty Acids; grower pig

Ileal digesta and fecal conc., μmol/g DM Fed

**Butyrate**

**Total SCFA**

Extra butyrate flows into body

(Regmi et al., 2011a)
Bacterial Populations; grower pig

PCR-DGGE: No effect of starch source on bacterial diversity

(Regmi et al., 2011b; J. Nutr.)
Fermented Starch is a Prebiotic

- Bifidogenic effect of resistant starch (matches Topping et al.)
- Overall, relatively minor changes in microbiome numbers/g, but total increases (more g), and measured changes are unique
Evidence of fermentation; weaned pig

Bifidobacteria

- Cecal Bifidobacteria
  - $L, P < 0.003$
  - $Q, P = 0.012$
- Colon Bifidobacteria
  - $L, P < 0.001$
  - $Q, P < 0.001$

Short chain fatty acids

- Cecal total SCFA
  - $L, P < 0.001$
  - $Q, P < 0.001$

Do these changes in microbiota in digesta and feces really matter?

(Fouhse et al., 2015)
Meaning for Gut Health; Weaned pig

Fecal score: 0-3

Impact of RS requires further clarification

(Bhandari et al., 2009); mechanism not clear

(Krause et al., 2010); mechanism not clear
Energetic Efficiency; grower pig

SEM = 0.14
P < 0.001

SEM = 0.25
P < 0.001

(lower ATTD of CP; microbial protein) (indirect calorimetry)

(Yanez et al., 2012 DPP; meal-fed pigs)
Growth performance; weaned pig

- Avg Daily Gain
- Avg Daily Intake
- Efficiency (gain/feed)

**P < 0.05**

- *L, P < 0.05*

**RS, ↓ growth; ↓ glycemic response, may ↑ efficiency**

- 0% Amylose
- 20% Amylose
- 28% Amylose
- 63% Amylose

(Fouhse et al., 2015)
Functional properties, **viscosity & fermentability**, important for physiological effects of NSP in the gut (Dikeman and Fahey, 2007)

Microbial fermentation, SCFA production & absorption, gut health  
Positive  
(Metzler-Zebeli et al. 2011)
• β-glucan increased Propionate and Butyrate absorption rate
  • Increased fibre: increased thickness of gut wall & gut fill
  • Important role of butyrate

Fermentable Fiber and Gut Health; grower pig

Fermentable protein (FP) and fermentable carbohydrate (FC)

Control

Fermentable CHO

(nmol/g DM)

FC; $P < 0.05$

Tyramine

Spermidine

Undigested proteins may become fermentable substrate
Protein fermentation: Amine production

(Jeaurond et al. 2008)
## Cereal Grains

<table>
<thead>
<tr>
<th>Content, % DM</th>
<th>Hull-less barley</th>
<th>Hulled barley</th>
<th>Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highly fermentable, high β-glucan (HFB)</td>
<td>Highly fermentable, high amylose (HFA)</td>
<td>Low fermentable hulled barley (LFB)</td>
</tr>
<tr>
<td></td>
<td>(MFB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude protein</td>
<td>20</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Amylose</td>
<td>0</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>Total β-glucan</td>
<td>10</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Total dietary fiber</td>
<td>22</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>ADF</td>
<td>5.5</td>
<td>6.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Viscosity, mPa × s</td>
<td>342</td>
<td>316</td>
<td>303</td>
</tr>
</tbody>
</table>

Cereal grains were characterized in detail in ileal-cannulated grower pigs

(Fouhse et al., 2017a,b; J. Nutr.)
DE & ME are poor indicators of energy and carbohydrate flow within the gut

(Fouhse et al., 2017a; J. Nutr.)
Not just nutrient flow, also physical structure

Diets

Digesta

HFB: High-fermentable, high β-glucan

HFA: High-fermentable, high amylose

MFB: Moderate-fermentable

LFB: Low-fermentable

The role of undigested residue is poorly defined

(Fouhse et al., 2017a; J. Nutr.)
Crude protein digestibility lower ($P < 0.05$) for barley than wheat.

High but not medium fermentable carbohydrates reduced ($P < 0.05$) energy digestibility.
Fermentable carbohydrates reduced \((P < 0.05)\) ADFI at the end but not start of the trial
Starch and fiber fermentation did not affect ADG ($P > 0.05$)

Final BW tended to be lower ($P < 0.10$) for HFB and HFB than LFB

Increased gut fill may mask effects of reduced empty body weight/lean gain
In pigs

- Resistant starch or β-glucan

Ileum

- Low starch digestion

> starch into the large intestine

- Reduced energetic efficiency

Bacteria population

- Increased Bifidobacteria

Bacterial activity

- Increased production of SCFA, butyrate

Balance between Growth and Health
Conclusions

- Dietary carbohydrates have strong prebiotic activity
  - Change composition and activity of microbiota
  - Strongly associated with indicators of gut health
- Benefit during intestinal disease challenge unclear
  - Research priority
- Balance prebiotic activity with whole body energy metabolism
  - Too much activity will reduce growth
- Implications
  - Diet ingredient carbohydrate composition changes diet prebiotic activity and may affect prebiotic activity of food additives
- Diet formulation for low–diarrhea weaning pig diets
  1. Stimulate feed intake directly after weaning; no feed: gut damage;
  2. Include reasonable amount of fermentable carbohydrates;
  3. Prebiotic activity can come from feedstuffs or feed additives.
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