Impact of Food Structure on Fermentation by Gut Microbiota

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Impact of Food Structure on Fermentation by Gut Microbiota

• What gets to the large intestine?

• What happens in the large intestine?

• Effects of food structure

• Nutrition and health implications
What gets to the large intestine?

The sum of all diet components and secreta that have not been absorbed in the stomach or small intestine
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- All non-starch polysaccharides and oligosaccharides
- Some protein (dietary and secreted)
- Some starch (= resistant starch)
- Lipid?
- Water / minerals
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- Digesta contents can be studied in model animals e.g. pigs, but how predictive of human response?
Arabinoxylan added to pig diets reduces protein digestibility throughout tract

Zhang et al, submitted for publication
Arabinoxylan added to pig diets reduces protein digestibility throughout tract.

More protein enters large intestine in presence of soluble fibre.

(Diets 1 & 2 lower protein content than diets 3 & 4)
SI digestion and passage rates both important

Very limited current knowledge of digesta structure / properties

Gidley, Current Opinion in Colloid and Interface Science, 2013, 18, 371-378
Resistant starch entering the large intestine depends on:

- extent of salivary/pancreatic $\alpha$-amylase hydrolysis
Complexities of *in vivo* starch digestion

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- extent of salivary/pancreatic α-amylase hydrolysis
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- levels of enzyme secreted
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- small intestinal residence time
- extent of mixing in small intestine
- other food / meal components
- etc
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- analogous factors likely to be important for protein
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- a combination of intrinsic (starch) and extrinsic (animal) factors i.e. RS contents can depend on both the food and the eater
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- with enough enzyme and time, all starch and dietary protein can be digested – it’s all about kinetics
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- Amount of starch / protein / lipid that reaches large intestine depends not only on food structure but also individual passage rate, digestive enzyme levels etc
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- Food structure (and chewing) has major role – digesta composition at end of SI cannot be predicted accurately from food compositional analysis
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- ‘Co-passengers’
  1. micro- and macro-nutrients trapped in e.g. plant cells
  2. micronutrients bound to food components e.g. plant cell walls
Co-passengers – type 1

- Encapsulation delivers micro/macronutrients to the colon
  - plant tissue foods - vegetables, fruits, cereals, nuts
  - food gels / capsules / structured emulsions
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Cooked carrot puree

Co-pассengers – type 1

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Cooked carrot puree before and after gastric and small intestinal digestion

Co-passengers – type 1

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  - food gels / capsules / structured emulsions

Almond nut tissue fragments recovered from faeces of human volunteers showing oil bodies trapped inside cellular structure

Ellis et al Am J Clin Nutr, 2004; 80, 604-613
Co-passengers – type 2

Anthocyanins in purple carrot puree

1. <5% of bound anthocyanins are released during digestion
2. ~65% of purple carrot puree anthocyanins predicted to be delivered to the colon

Padayachee et al, Food and Function, 4, 906-916 (2013)
Phenolic acids in purple carrot puree (mostly chlorogenic)

Co-passengers – type 2

1. <5% of bound phenolic acids are released during digestion
2. ~ 65% of purple carrot puree phenolic acids are predicted to be delivered to the colon

Padayachee et al, Food and Function, 4, 906-916 (2013)
What happens in the colon?

Residual digesta and secreta available for fermentation by microbiota. Factors important for nutrition and health:

- Rate (related to site) of fermentation
- End-products
- Microbiota amounts and population shifts
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Factors important for nutrition and health:

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Some key questions:

- Who does what with whom and where?
- Effects of single polysaccharides vs cell wall composites
- Particle size effects for grains and vegetables
- [Consequences of bound micronutrients]
Cellulosic material from the caecal digesta of a pig, stained with Pontamine Red, is colonised by large amounts of bacteria (labelled green with a broad spectrum 16S rRNA probe), with Eubacterium rectale species (labelled yellow) particularly prevalent at the surface of cellulosic particles. (courtesy of Mr John Gorham)

Gidley, Current Opinion in Colloid and Interface Science, 2013, 18, 371-378

Very limited current information on which bacterial species / classes do what with whom and where in the large intestine
Fermentation and microstructure

Rate of fermentation influences site of fermentation
- particularly important to ensure fermentation persists to the distal colon as this is the site of many cancers
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Fibre polysaccharides associated with cellulose in plant cell walls. How does this affect the rate and end-products of fermentation?
Fermentation and microstructure

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Fibre polysaccharides associated with cellulose in plant cell walls. How does this affect the rate and end-products of fermentation?
- Compare fermentation of dissolved polysaccharides with bacterial cellulose composites
  - defined chemistry and microstructure

- Use *in vitro* fermentation with faecal inocula from pigs adapted to a low fibre diet
  - defined inocula leading to reproducible fermentations

Micro-architecture of model composites

- BC
- BC-AX (no cross-linking)
- BC-XG (cross-linking)
- BC-MLG (no cross-linking)

- Bacterial cell
- Cellulose fibrils
- AX
- MLG
- XG
Fermentation of bacterial cellulose vs cotton & wheat bran substrates
Comparison of gas profiles from dissolved polysaccharides and model composites

Composites with cellulose have reduced lag compared to pure cellulose but extended fermentation compared to soluble polymers - composite profiles similar to wheat bran.
### Fermentation end-products

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Acetic</th>
<th>Propionic</th>
<th>Butyric</th>
<th>Total SCFA</th>
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<tbody>
<tr>
<td></td>
<td>mmoles/g DM</td>
<td>mmoles/g DM</td>
<td>mmoles/g DM</td>
<td>mmoles/g DM</td>
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<tr>
<td>AX</td>
<td>8.55&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.24&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.33&lt;sup&gt;b,c&lt;/sup&gt;</td>
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<tr>
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<td>4.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.11&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>1.56&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.30&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td>AX Composite</td>
<td>9.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.11&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.82&lt;sup&gt;c,d&lt;/sup&gt;</td>
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<tr>
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</tr>
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</table>

**Probability:**
- <0.0001
- <0.0001
- <0.0001
- <0.0001

**MSD***
- 0.58
- 0.30
- 0.04
- 0.68

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*a,b,c... Different superscripts in the same column indicated significant differences*

**NSPs in model composites produce significantly increased butyric acid. Therefore, both fermentation rates and end products are altered by local microstructure effects**

Effects of food structure

- Rate (= site) of fermentation depends on physical form and chemistry

- Smaller particle size of wheat bran or wheat aleurone resulted in faster fermentation (Stewart and Slavin, Br J Nutr 2009; 102, 1404-1407)

- Smaller particle size of carrots resulted in slower fermentation (Day et al, J Ag Food Chem 2012; 60, 3282-3290)

![Graph showing fermentation time vs. dry matter cumulative volume for different samples:](A)
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- Rate (= site) of fermentation depends on physical form and chemistry
  - low molecular weight carbohydrates can be fermented rapidly (cf. lactose intolerance)
  - dense and/or lignified structures may hardly be fermented at all (e.g. wheat bran)
  - larger particle size can lead to faster (e.g. carrots) or slower (e.g. cereal grain fractions) fermentation
  - some soluble polymers fermented slower than some insoluble polymers (e.g. psyllium vs cereal endosperm)

- No necessary correlation between solubility and fermentation rate / extent of dietary fibres
1. Residual digesta entering large intestine difficult to predict and likely to show large inter- and intra-individual variation, particularly protein/starch levels and micronutrient load
Nutrition and health implications

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4. How quantitatively predictive can *in vitro* techniques be for whole foods/meals/diets, given intra- and inter-subject variation?
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5. Faecal and other biomarkers (self-measured in the future?) will become important in assessing impacts of dietary choices/changes.
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Acknowledgements

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