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The positive and negative effects of fibre in swine diets

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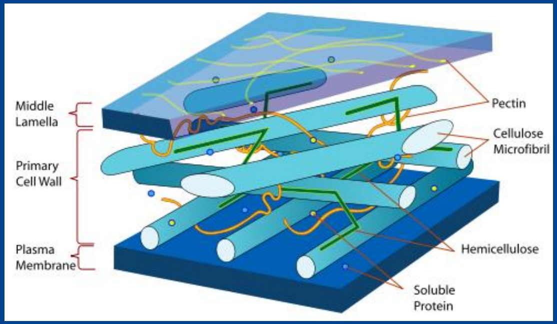
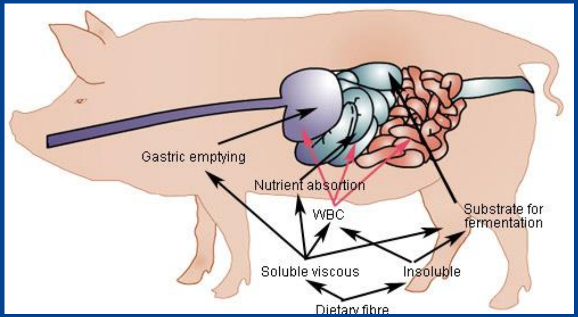








Points to be addressed

- Introduction
  - Who I am?
  - General remarks
- Dietary fibre/fibre definition, terminology, chemistry and physicochemical properties
- Dietary fibre in feedstuffs
- Direct effects of fibre in the gastrointestinal tract
- Indirect effects of fibre in the gastrointestinal tract
- Can dietary fibre proactively be used to influence gut health?
- Fibre and short-chain fatty acids
- Take-home message

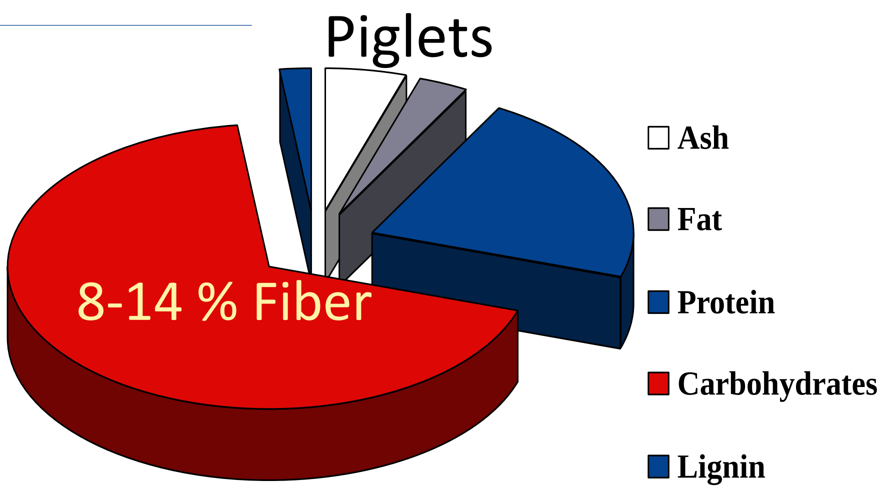
Introduction: Who I am?

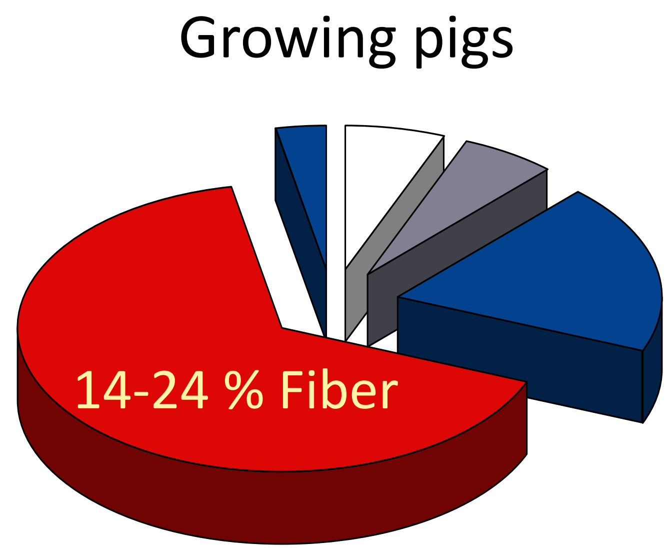
- Worked 30+ y with carbohydrates and cell wall associated phytochemicals:
  - analytically
  - nutritional context primarily with monogastric species

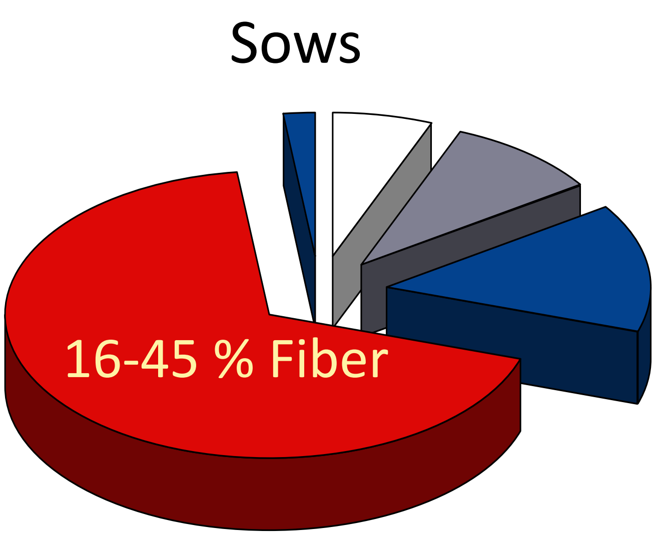
Introduction – general remarks

- Dietary fibres are present in almost all plant materials
- Dietary fibres represent the part of the diet that cannot be digested by endogenous enzymes but potentially can be fermented by the microflora
- Dietary fibre influences digestion and absorption at all sites of the gastrointestinal tract – influence on digestibility and energy utilisation
- There are age differences in how well pigs can ferment dietary fibre
- Some dietary fibres may influence gut health
- Dietary fibre influences amount and types of short-chain fatty acids produced

Introduction – carbohydrates in diets for pigs







Carbohydrates represents 60-70 % of the dry matter in diets for pigs

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Dietary fibre definition, terminology, chemistry and physicochemical properties

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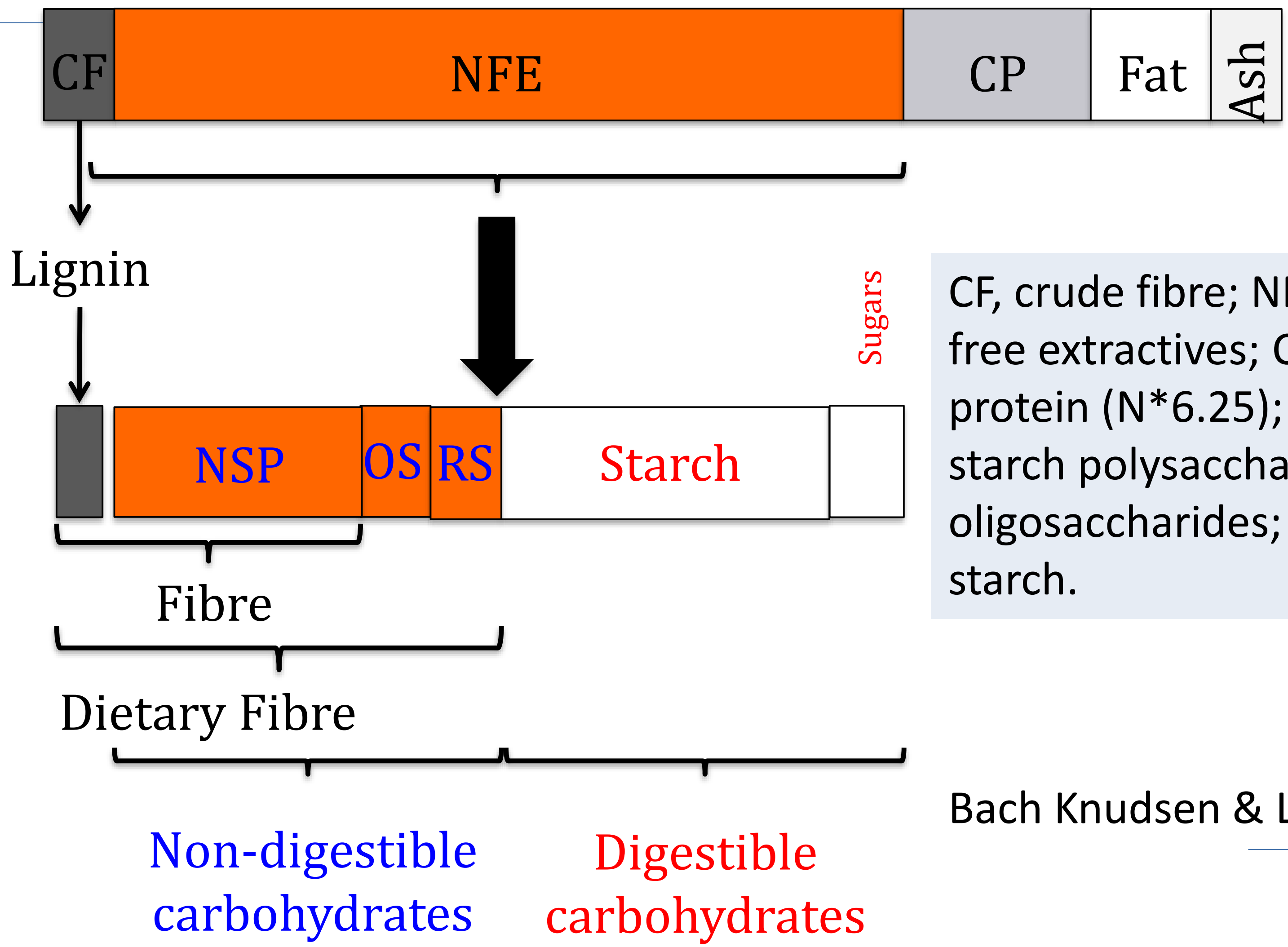
Classification of feed carbohydrates

Category	Type of component	Example
Sugars (DP 1-2)	Monosaccharides	Glucose, fructose
	Disaccharides	Sucrose, lactose
	Sugar alcohols	Sorbitol
Oligosaccharides (DP 3-9)	Maltodextrins	Enzyme treated materials
	Resistant* oligosaccharides	Raffinose-oligosaccharides, Fructo-oligosaccharides
Polysaccharides (DP ≥10)		
A. Starch	Rapidly digestible	Cereals
	Slowly digestible	Peas
	Resistant*	Beans, potato
B. Non-starch (NSP)		
Cell-wall NSP	Soluble	Oats, soyabean meal
	Insoluble	Cereal by-products
Non-cell-wall NSP	Storage polysaccharides	Jerusalem artichoke
	Feed additives	Pectins, gums

DP, degree of polymerisation.

Resistant* means resistant to endogenous enzymes in the small intestine of pigs.

The classical way of characterizing feed vs. chemical/nutritional classification of carbohydrates



CF, crude fibre; NFE, nitrogen free extractives; CP, crude protein (N*6.25); NSP, non-starch polysaccharides; OS, oligosaccharides; RS, resistant starch.

Bach Knudsen & Lærke (2018).

Definition of dietary fibre/fibre

Dietary Fibre

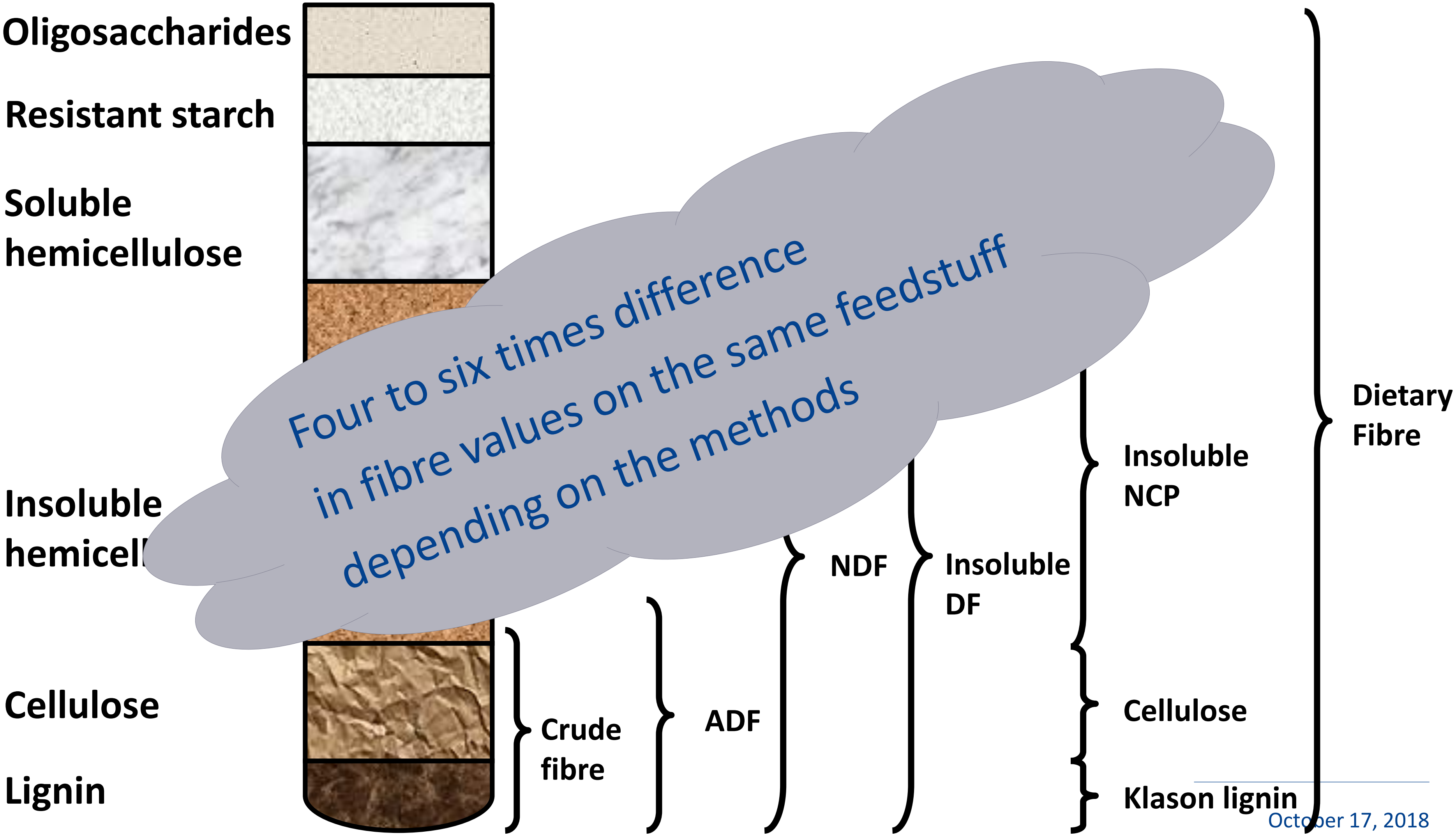
- Carbohydrate polymers with three and more monomeric units (and lignin) which are neither digested nor absorbed in the human small intestine

Codex Alimentarius and the European Commission (2009)

Fibre

- Total fibre = non-starch polysaccharides and lignin
- Neutral detergent fibre (NDF)
- Acid detergent fibre (ADF)
- Crude fibre (CF)

Relation between different procedures



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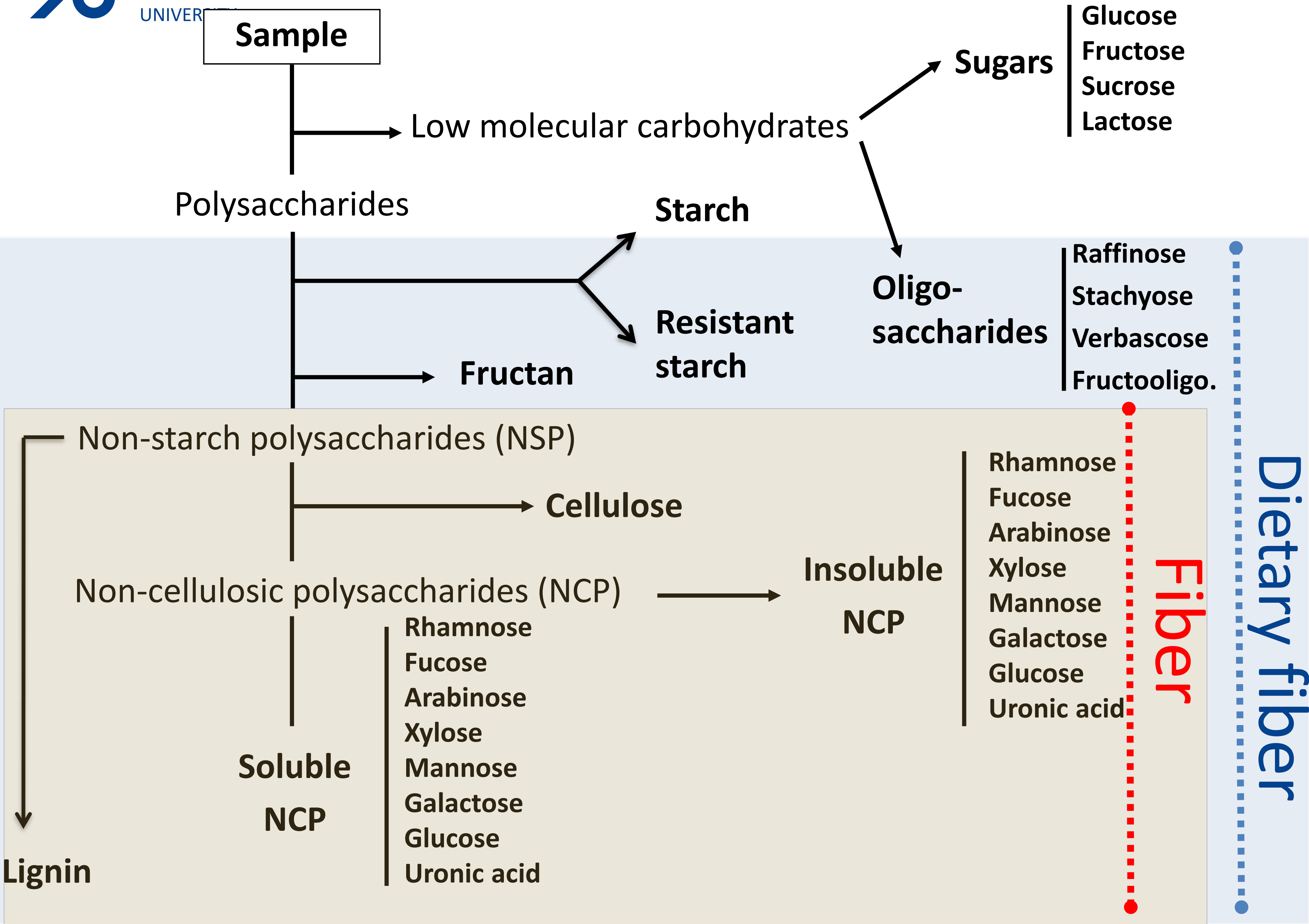
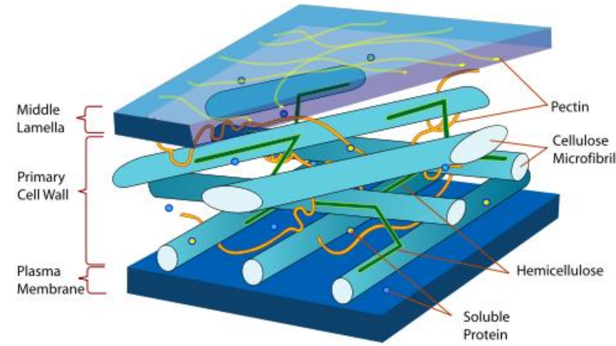
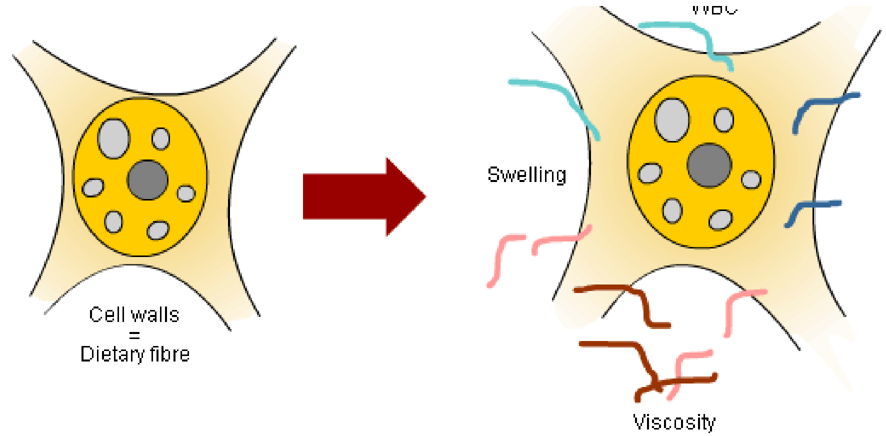


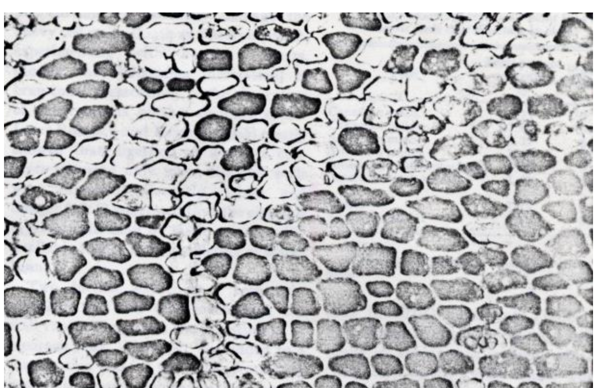
Features of the cell walls – fibre



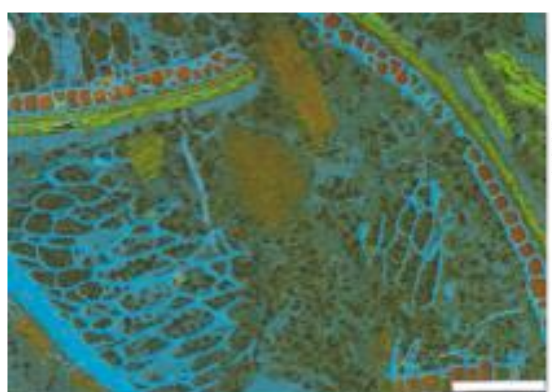
- Protect the cell content against digestion by endogenous enzymes
- Hydrate, i.e. hold water in the cell wall matrix
- Cause viscosity of the liquid phase

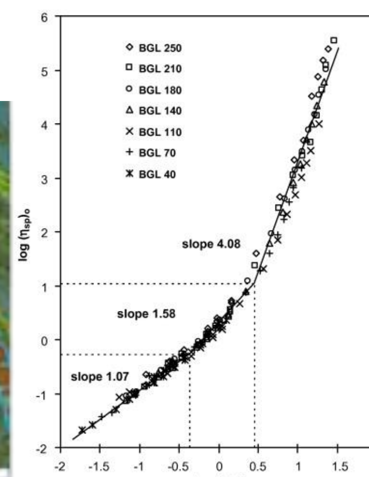


Saunders et al. (1969).



Tervilä-Wilo et al. (1996).





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Dietary fibre/fibre in feedstuffs

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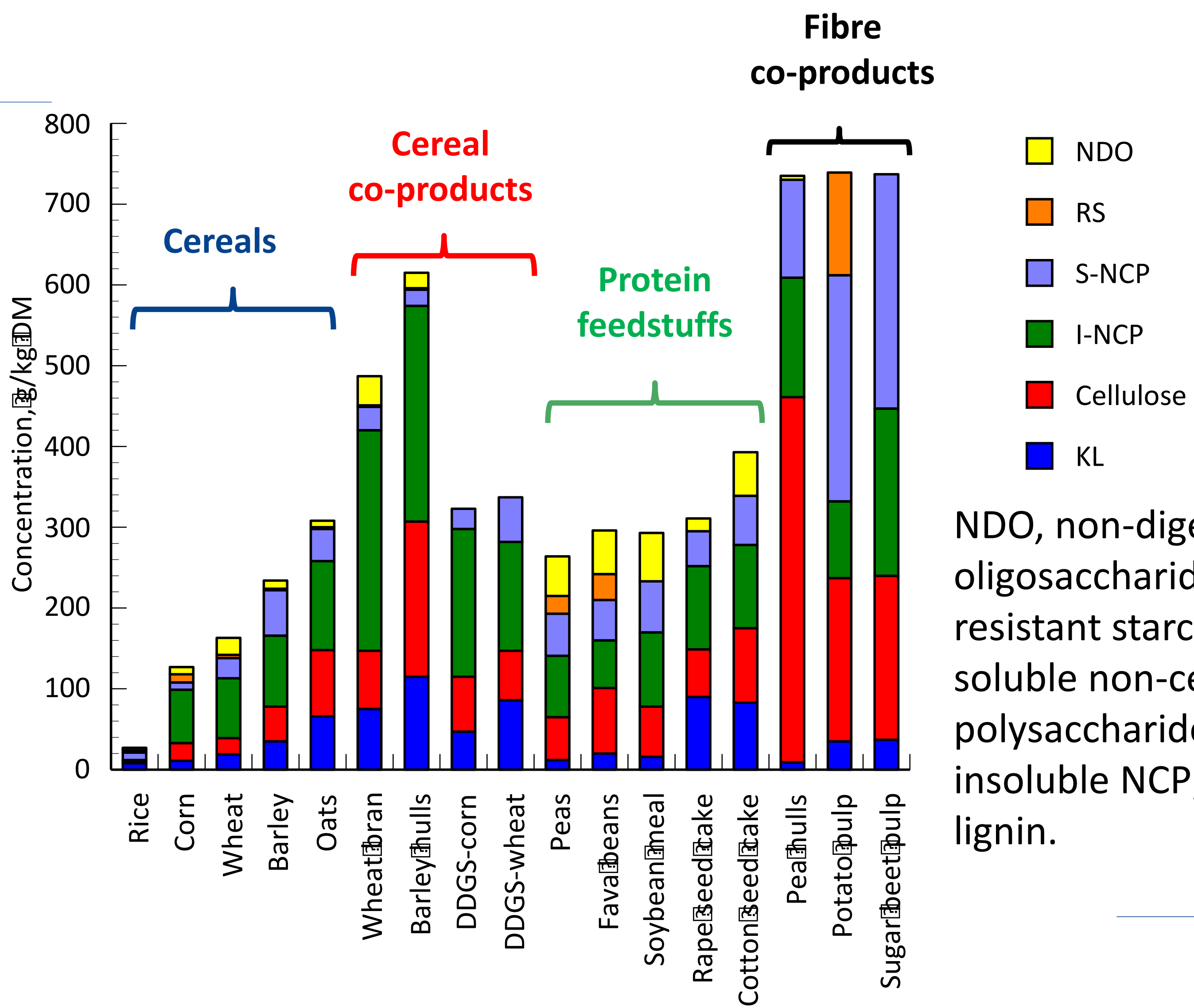
Dietary fibre in feedstuffs



NDO, non-digestible oligosaccharides; RS, resistant starch; S-NCP, soluble non-cellulosic polysaccharides; I-NCP, insoluble NCP; KL, Klason lignin.

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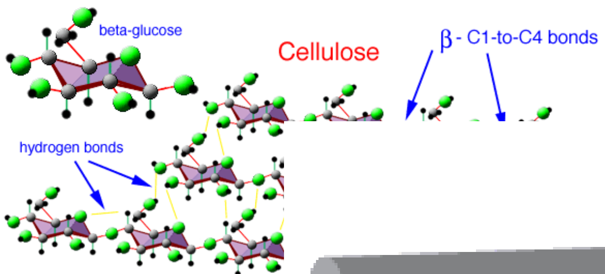
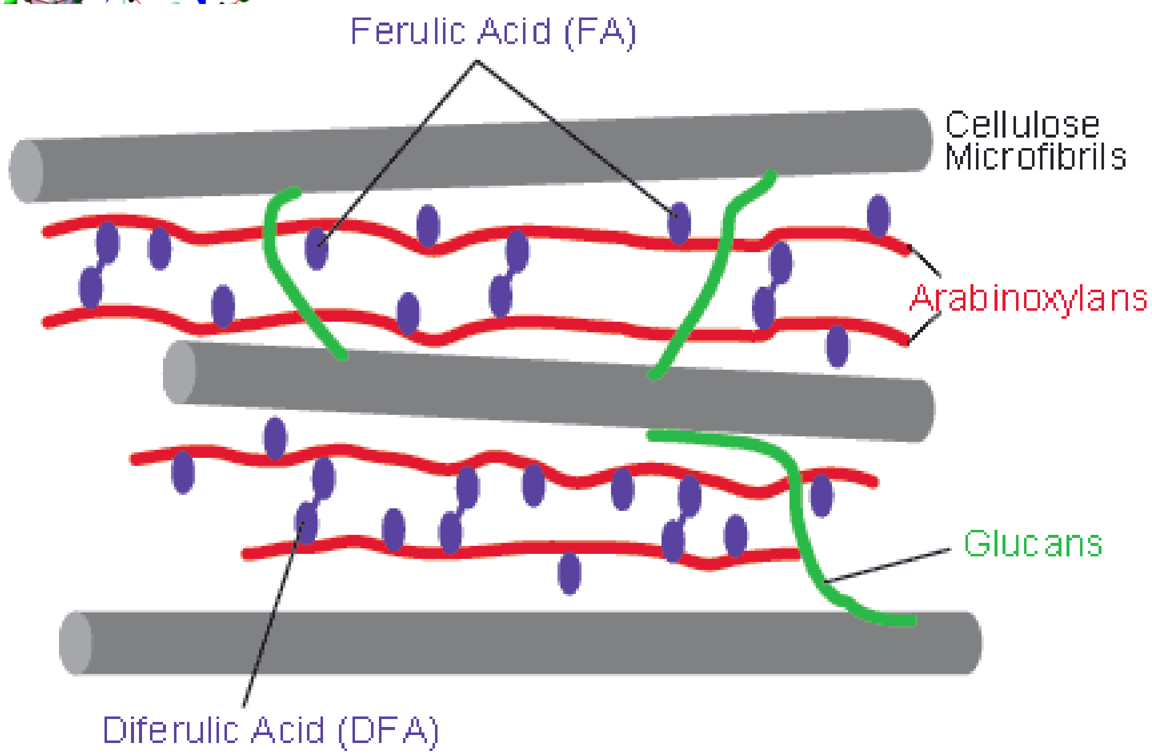
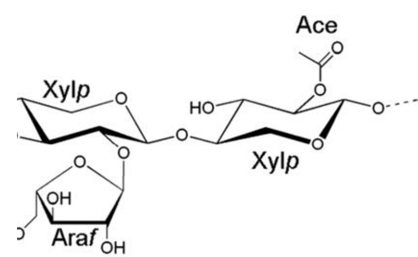
The main NSPs of cereals





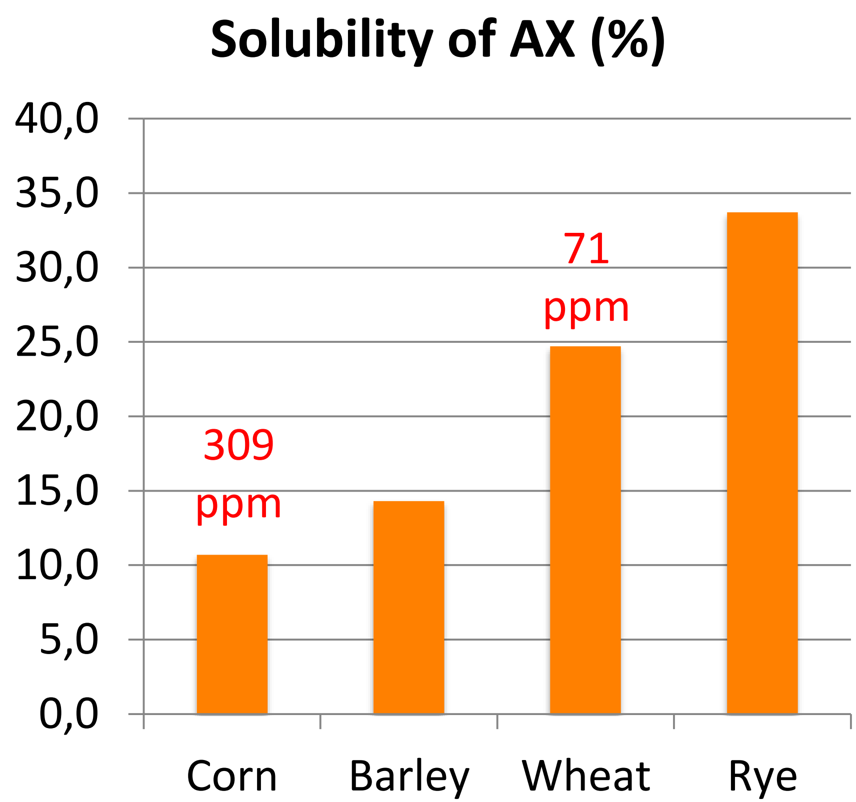
β-glucan

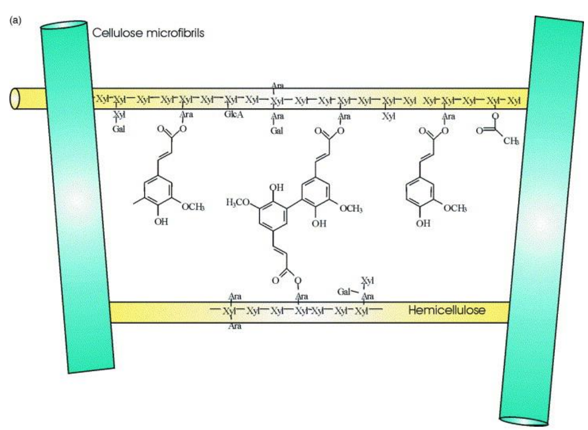


Araf = α-L-arabinofuranose
Xylp = β-D-xylopyranosse
Fae = ferulate
4-O-MeGlcA = 4-O-α-D-methyl glucuronic acid

The AX structure and solubility

- Low solubility for corn AX because of high degree of cross-linkage with phenolic acids (ferulic acids)
- Low solubility for barley AX because of AX structure





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Non-starch polysaccharides and lignin (% of DM) in cereals, legumes and protein rich feedstuffs

	Corn	Wheat	Barley	Soybean meal	Peas	Rape seed cake	Sun flower
NSP							
Cellulose	2.0	1.8	4.0	5.9	5.3	5.9	12.4
NCP	7.0	9.5	14.6	15.1	12.1	14.6	18.9
Rhamnose	0.0	0.0	0.0	0.2	0.1	0.2	0.4
Arabinose	2.0	2.8	2.7	2.6	3.6	4.4	3.0
Xylose	2.7	4.5	5.6	1.7	1.3	1.7	6.1
Mannose	0.2	0.2	0.4	1.3	0.2	0.5	1.3
Galactose	0.5	0.4	0.3	4.2	0.6	2.0	1.3
Glucose	0.8	1.2	5.0	0.6	3.1	0.8	0.7
Uronic acids	0.7	0.4	0.5	4.5	3.0	5.0	6.0
Total NSP	9.0	11.3	18.6	21.0	17.4	20.5	31.2
Klason lignin	1.1	1.8	3.2	1.8	1.0	9.0	13.0
Fibre	10.1	13.1	21.8	22.8	18.4	29.5	44.2

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Direct effects of fibre in the gastrointestinal tract

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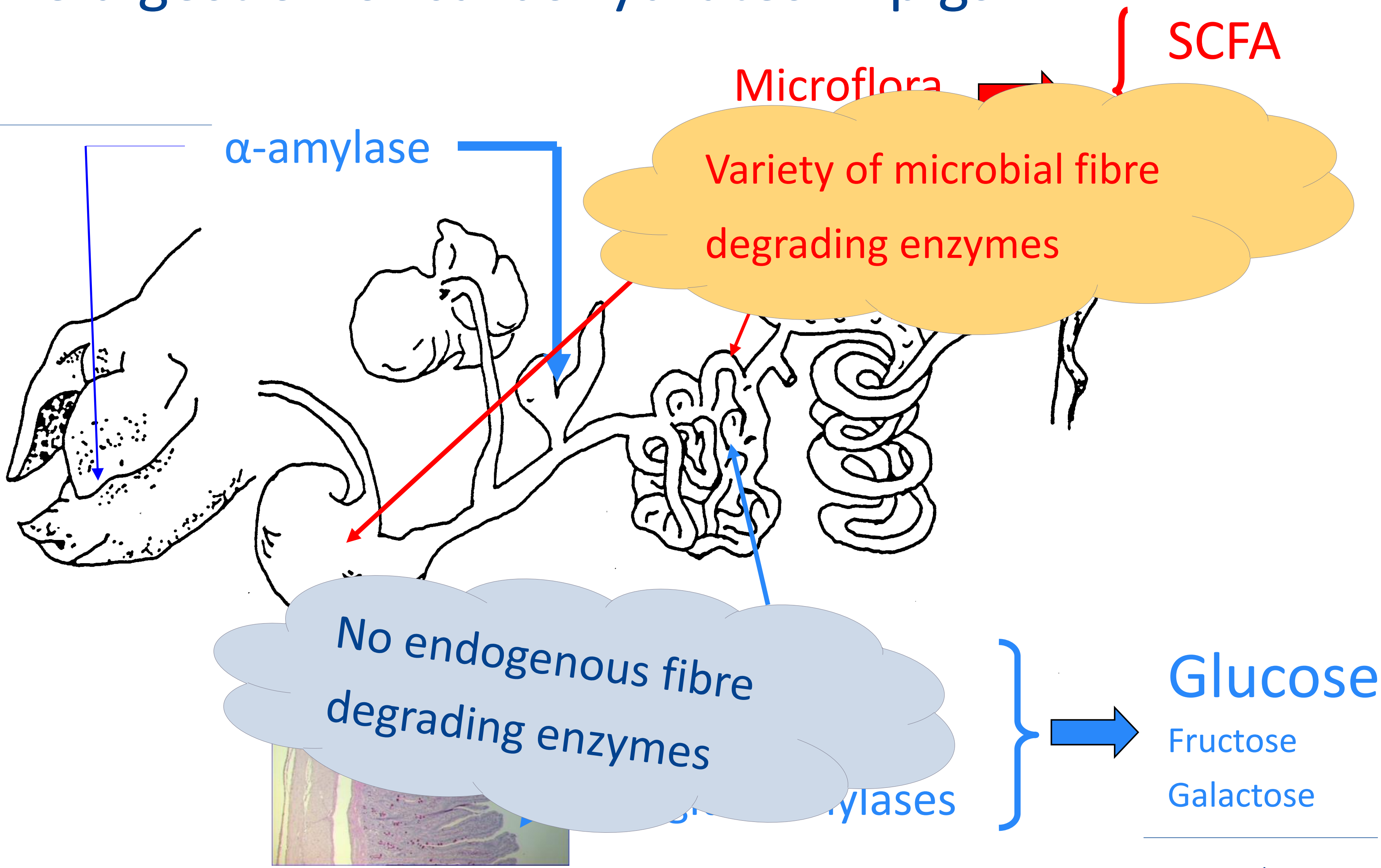
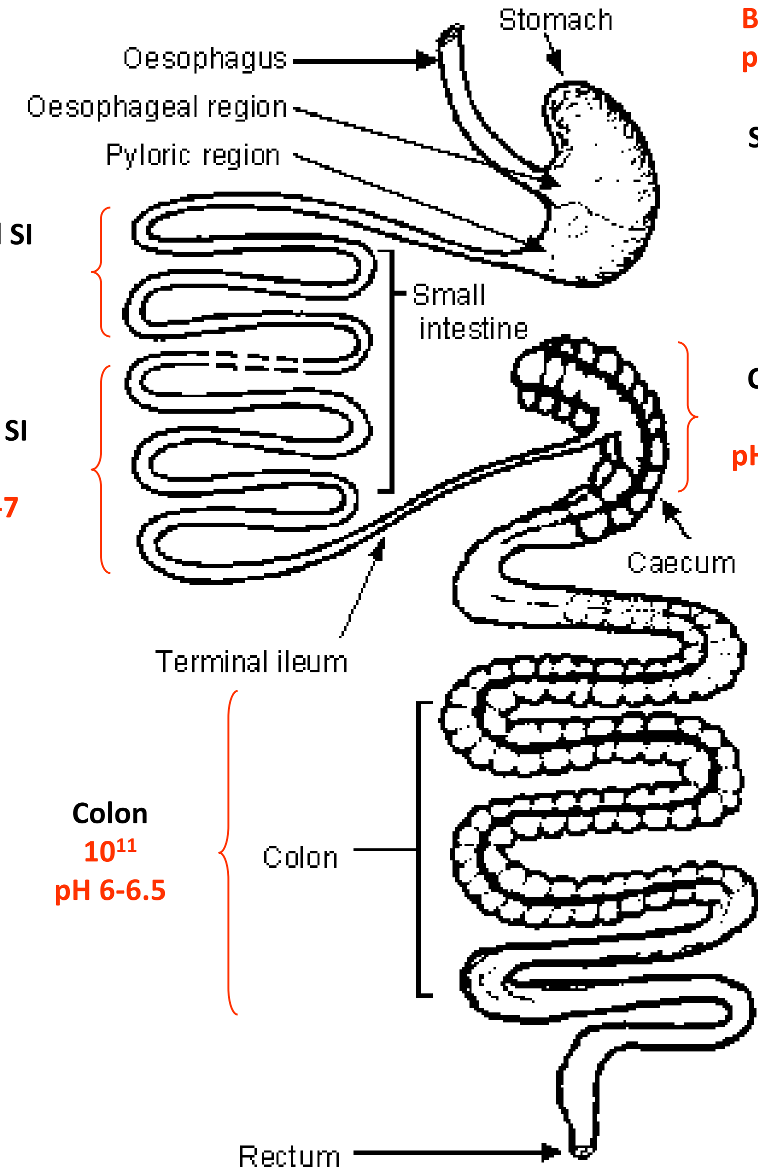
The digestion of carbohydrates in pigs



Bacteria in the gastrointestinal tract of the pig

Low diversity (dominated by G+, Firmicutes)

Bacteria (cells per g digesta)
pH



Stomach
10^{8-9}
pH 2-5

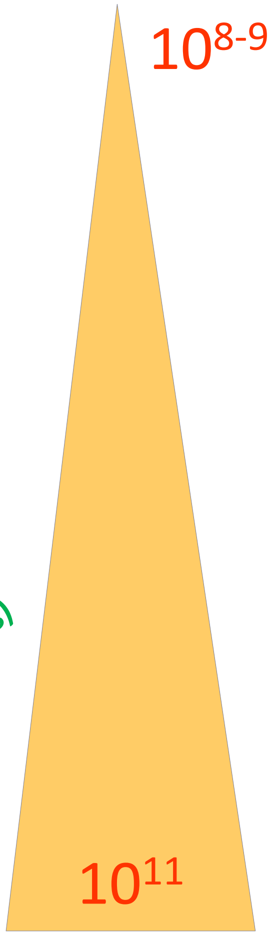
Proximal SI
10^{8}
pH ~6

Distal SI
10^{9}
pH 6-7

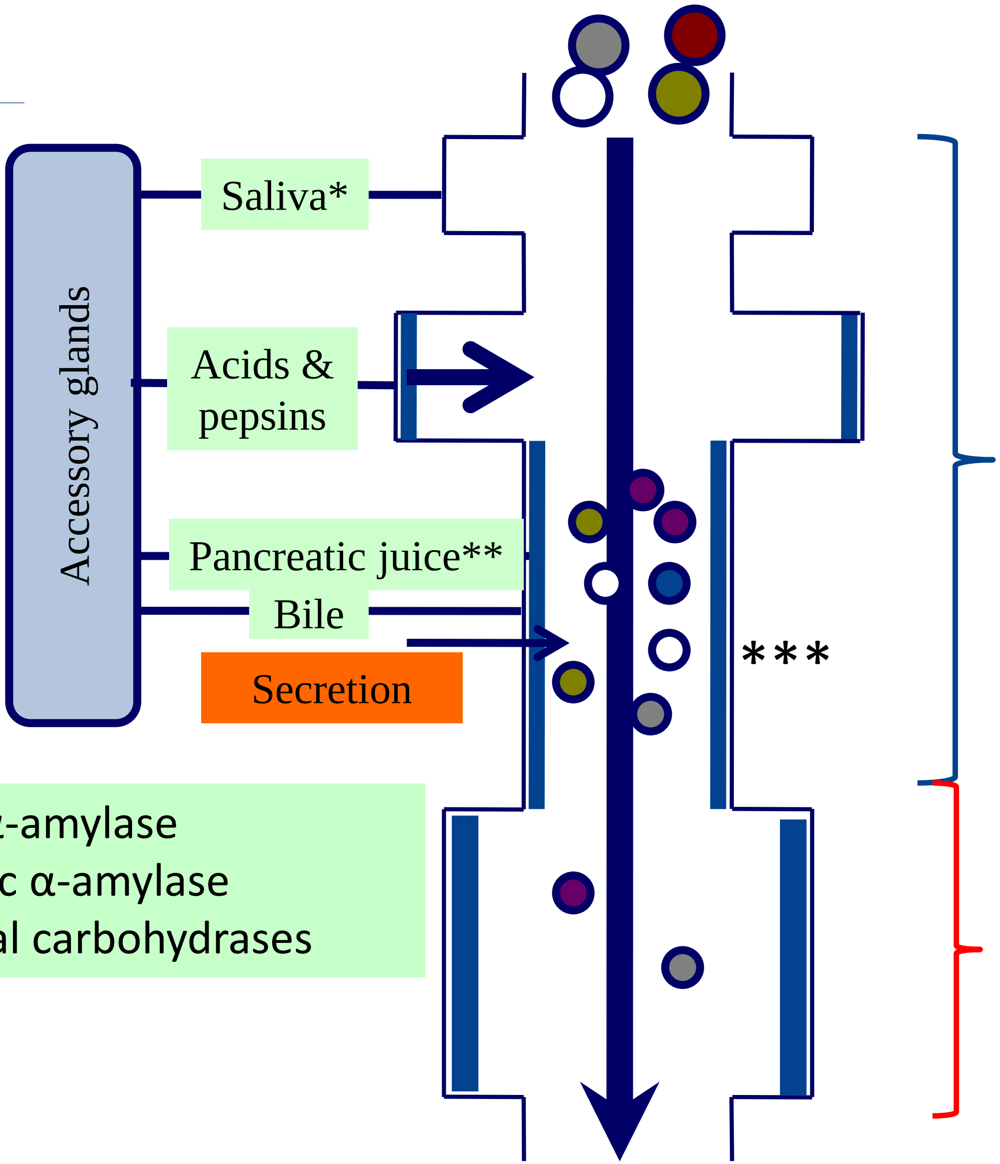
Caecum
10^{10}
pH 5.5-6.5

Colon
10^{11}
pH 6-6.5

High diversity (more G-; Firmicutes and Bacteroidetes)



The gastrointestinal tract of pigs



Carbohydrases activities: mostly endogenous but also microbial

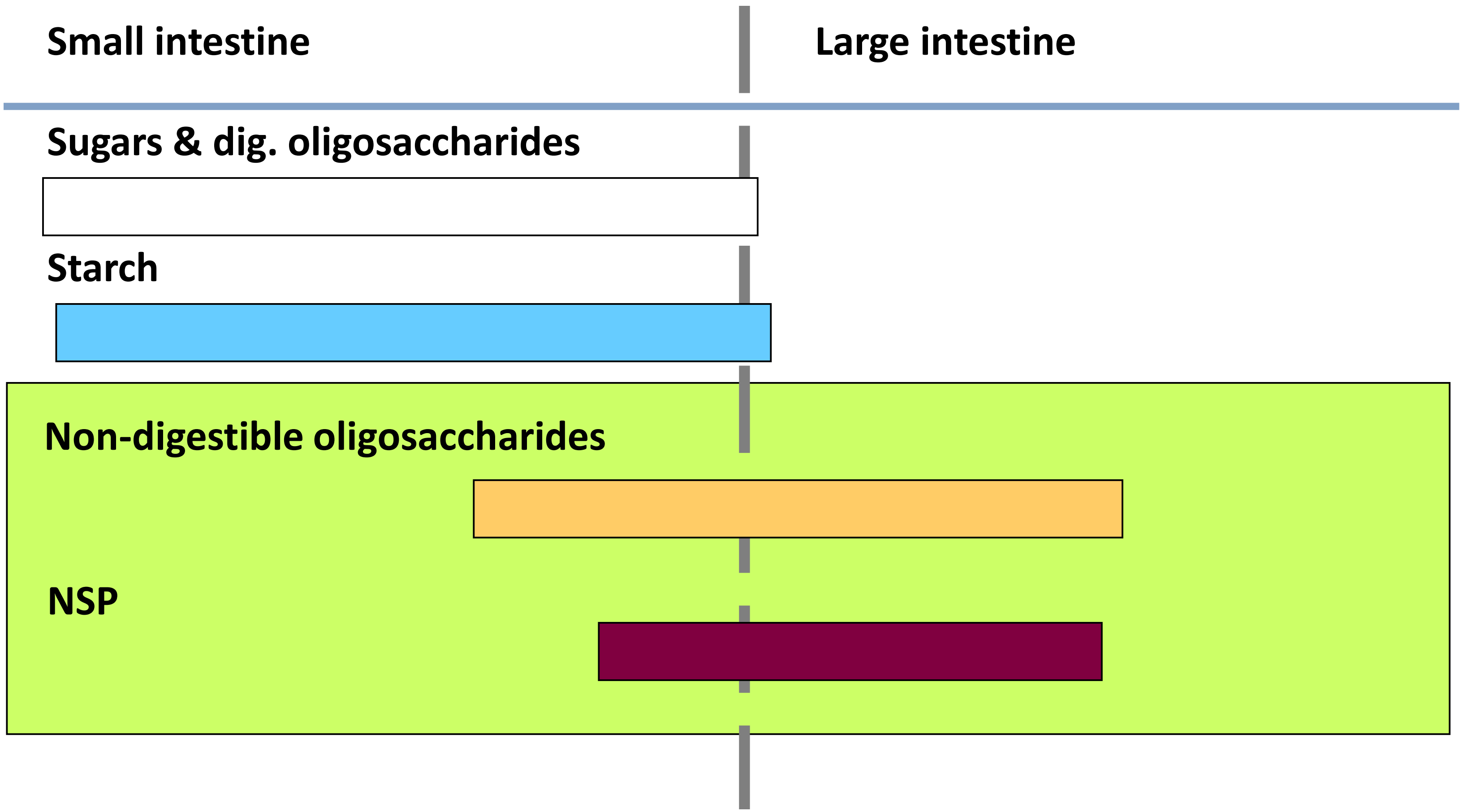
Carbohydrases activities: predominantly microbial

- Salivary α-amylase

** Pancreatic α-amylase

*** Intestinal carbohydrases

Digestion and fermentation of carbohydrates in the gastrointestinal tract



Bach Knudsen et al. (2013).

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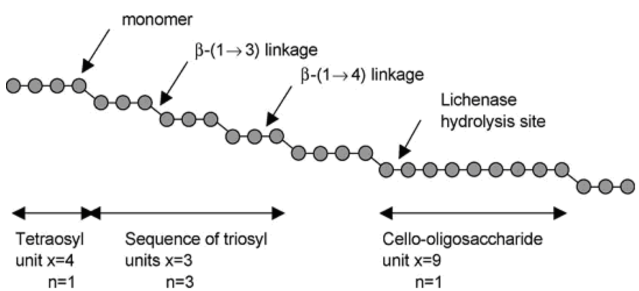
Ileal degradation (% of intake) of cereal NSPs

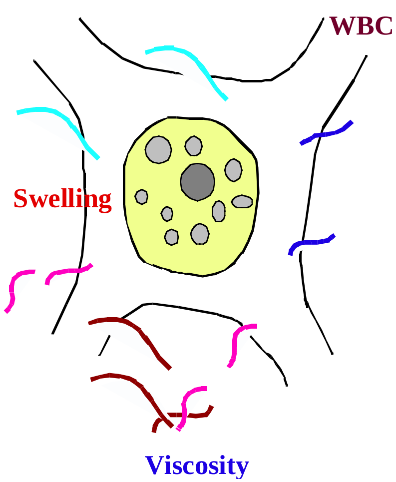
	N	Average	Range
Total NSP	78	21	-10 to 62
Cellulose	46	16	-47 to 56
β-glucan		65	
Barley	8	79	40 to 97
Oats	10	43	17 to 73
Rye	1	48	-
Arabinoxylan		13	
Barley	6	40	17 to 51
Oats	10	2	-8 to 11
Wheat	9	2	-10 to 12
Rye	4	8	-7 to 16

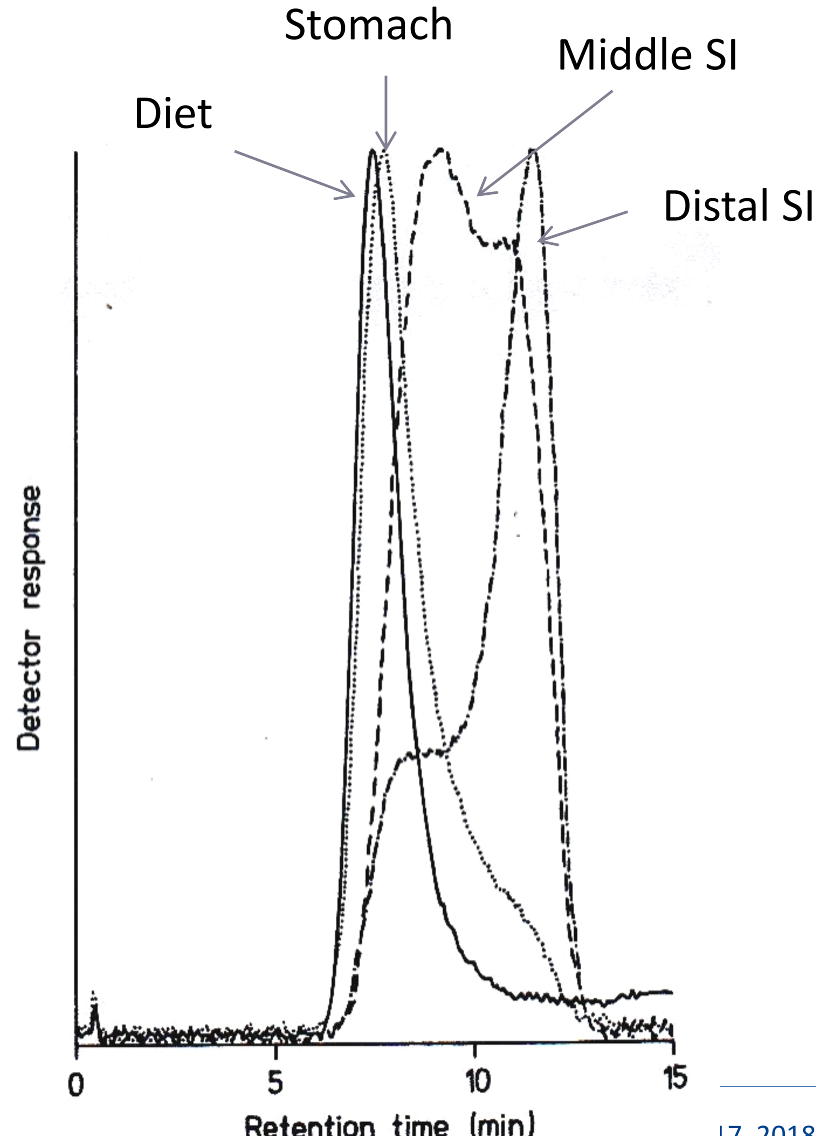
NSP, non-starch polysaccharides.

β-glucan is heavily depolymerise as it passes along the length of the small intestine

› The molecular weight of ®–glucan is reduced up to 20-fold – relatively smaller effect of ®–glucan on luminal viscosity than its molecular weight in the feed would indicate







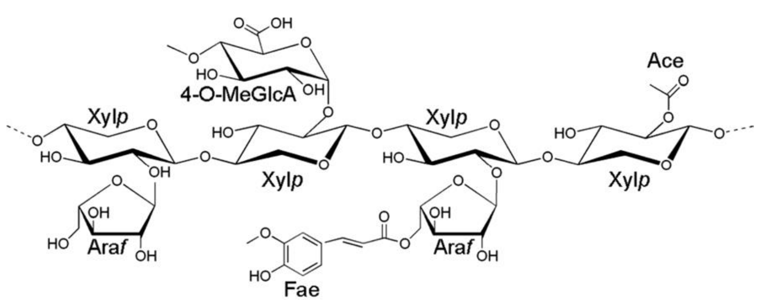
Johansen et al.(1997)

Arabinoxylan is depolymerised to a lower extent than is the case with β-glucan when passing the small intestine

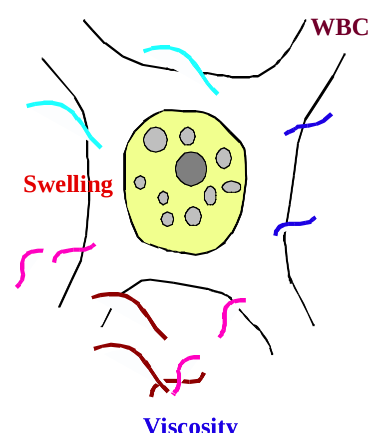
	$MW_w \times 10^5$			
	WFL	WWG	WAF	RAF
Water extract from diet	2.2	1.8[b]	2.6	3.8[a]
Ileal soluble extract from digesta	2.2	2.2[a]	2.6	2.8[b]
T-test	>0.05	0.02	>0.05	0.001

MW_w,weight average molecular weight; WFL, wheat flour and cellulose; WWG, whole wheat grain; WAF, wheat aleurone flour; RAF, rye aleurone flour.

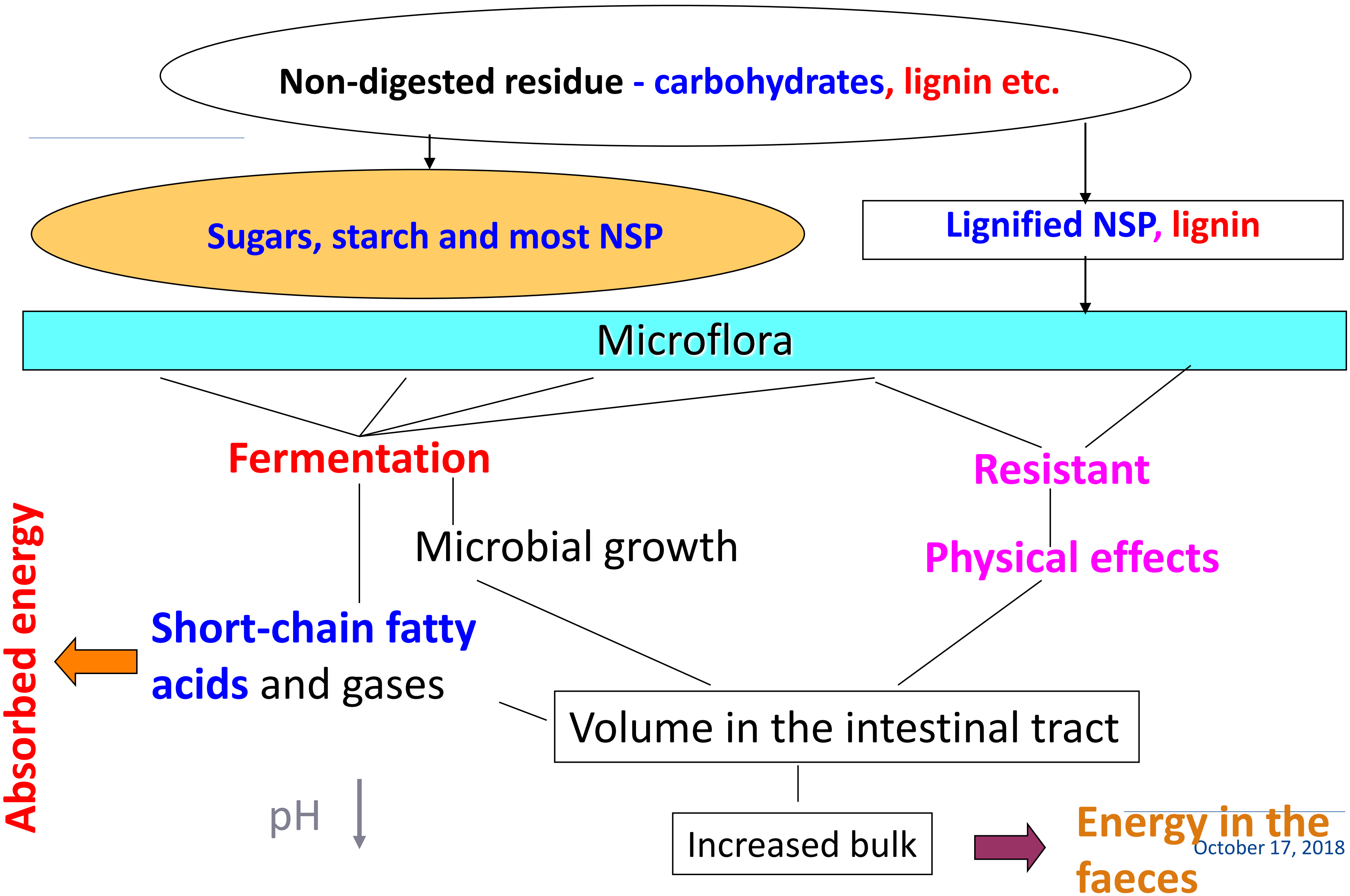
Le Gall et al. (2010).



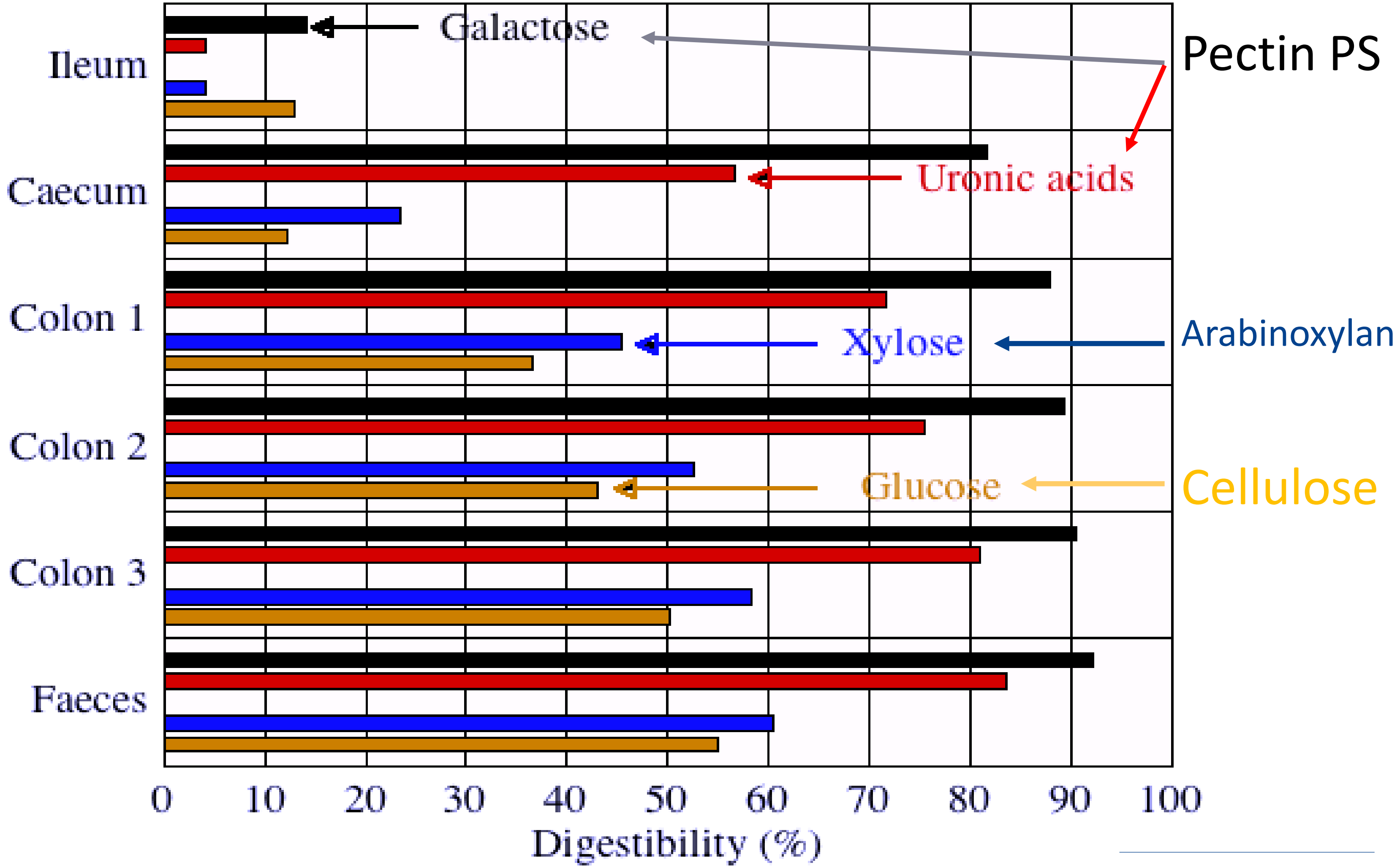
Ace = acetate
Araf = α-L-arabinofuranose
Xylp = β-D-xylopyranosse
Fae = ferulate
4-O-MeGlcA = 4-O-α-D-methyl glucuronic acid



Not all fibres can be handled by the microflora

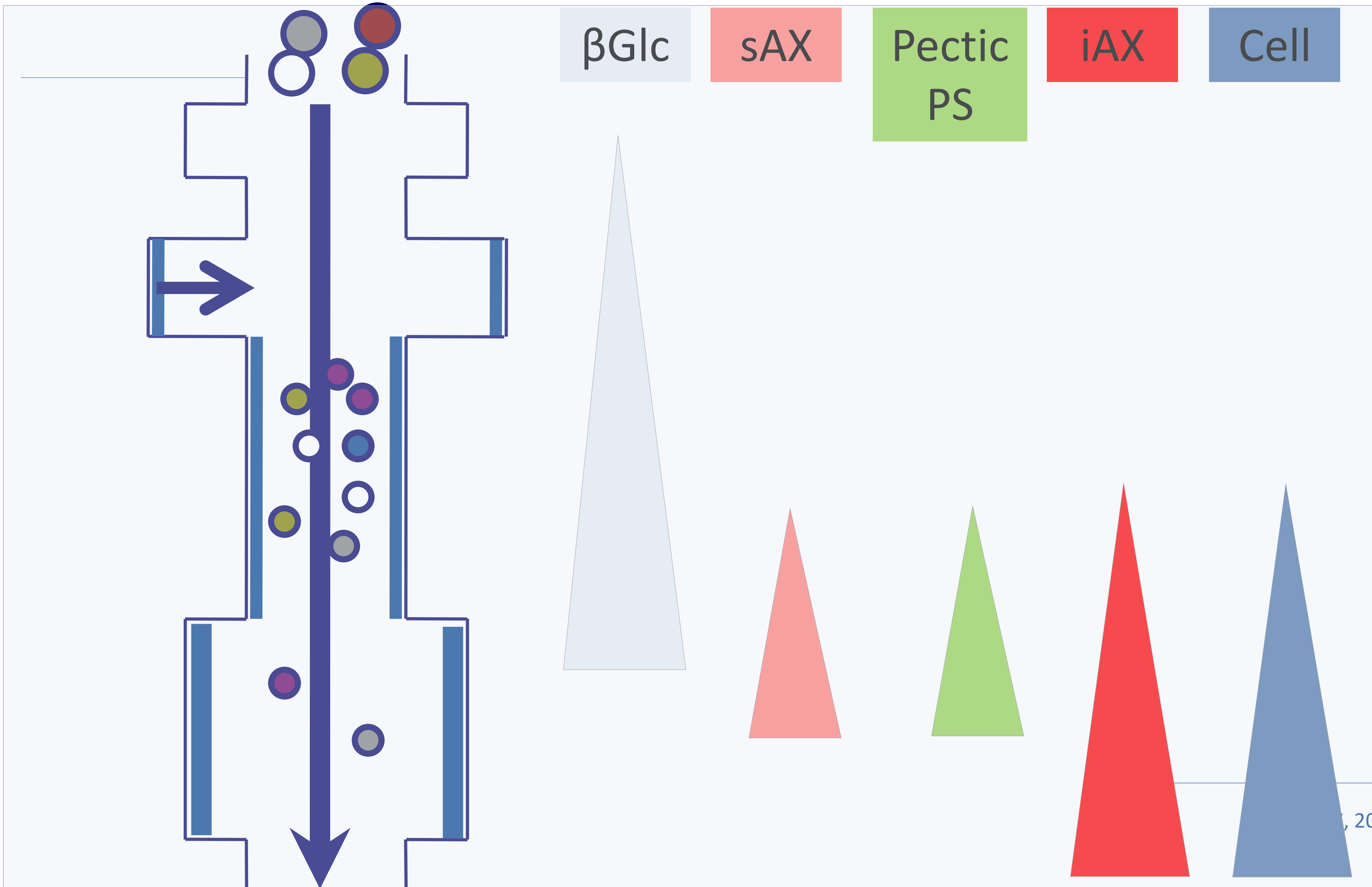


Fermentation of NSP residues



Gdala et al. (1997).

Digestion and fermentation of fibre components in the gastrointestinal tract



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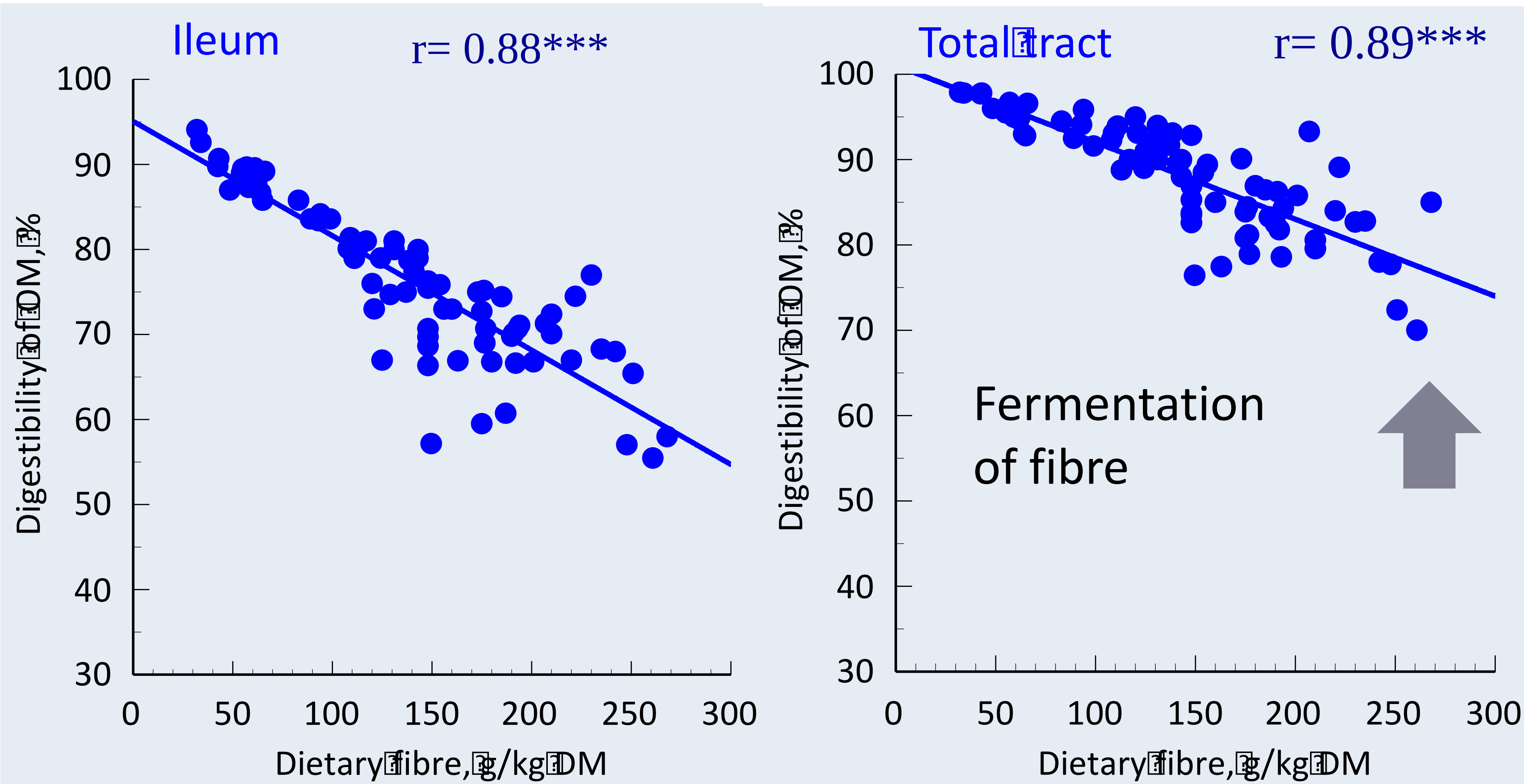
Fibre and ileal and total tract digestibility of organic matter (energy)



Comparative digestibility and metabolic energy content in growing pigs and sows

	Mean of 72 diets[1]		**Mean of 14 diets[2]**	
	Growing pigs	Sows	Growing pigs	Sows
Nitrogen, %	50	60	75	85
Fat, %	38	42	55	69
Fibre, %	49	55	38	64
Metabolisable energy, MJ/kg DM	12.23			

[1]Data from Fernandez et al. (1986

[2]Data from Noblet and Shi (1993).

The higher digestibility of energy in heavier pigs is caused by a longer retention time in the large intestine and a modified microflora

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Indirect effects of fibre in the gastrointestinal tract

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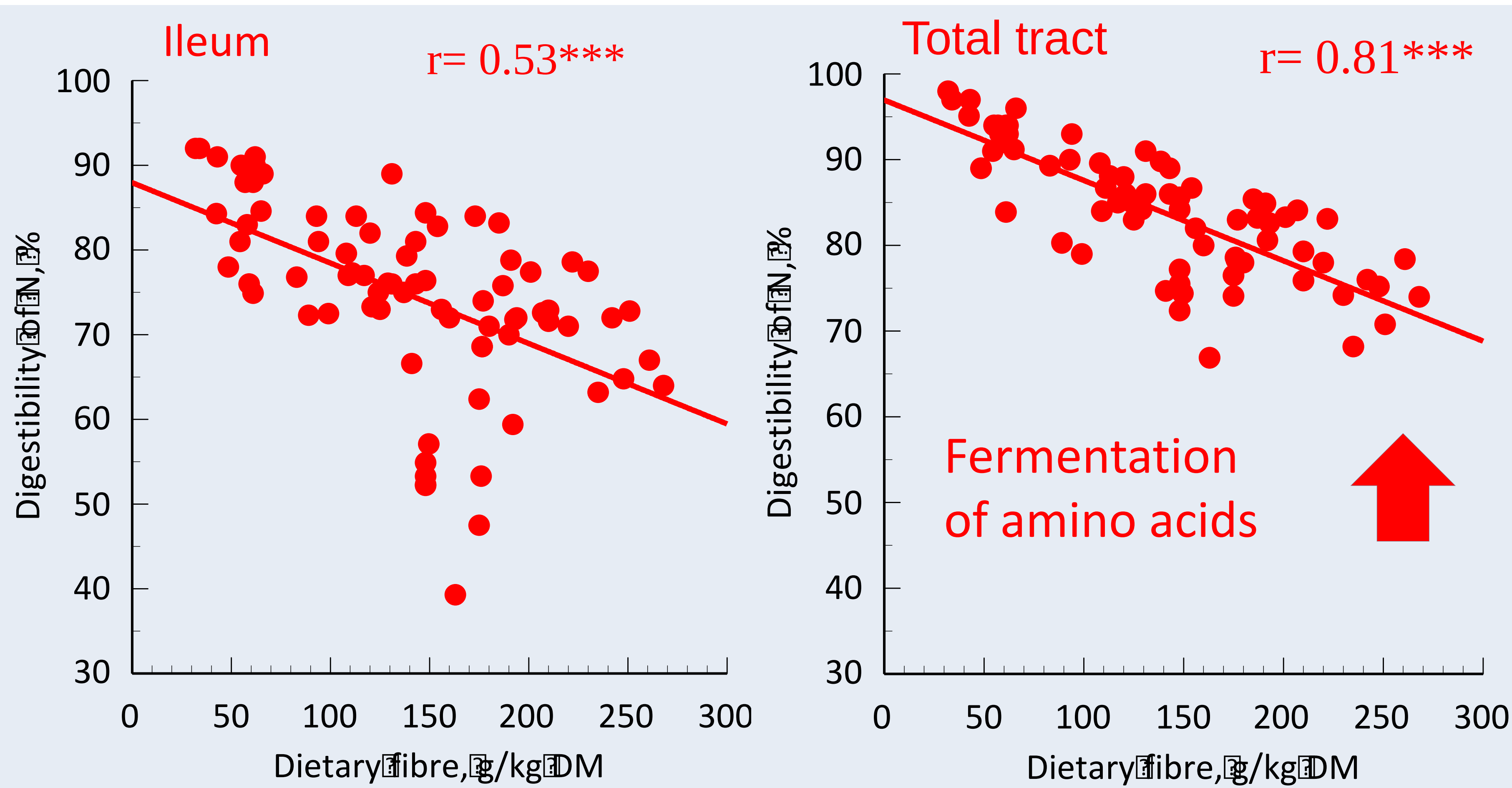
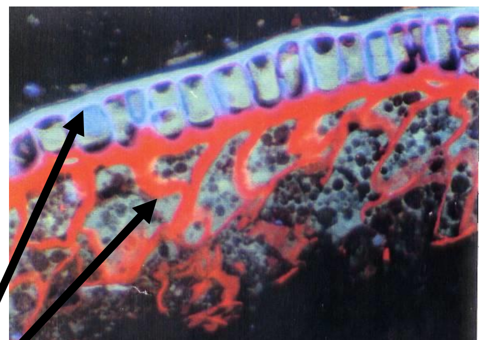
Fibre and ileal and total tract digestibility of nitrogen



Why fibre influences the ileal digestibility of nitrogen?

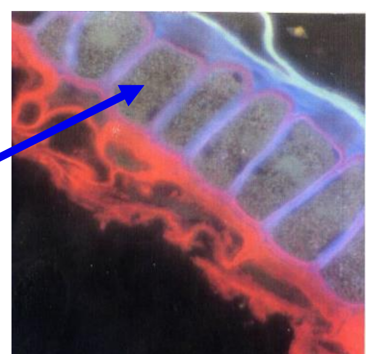
Encapsulation of nutrients

Feed



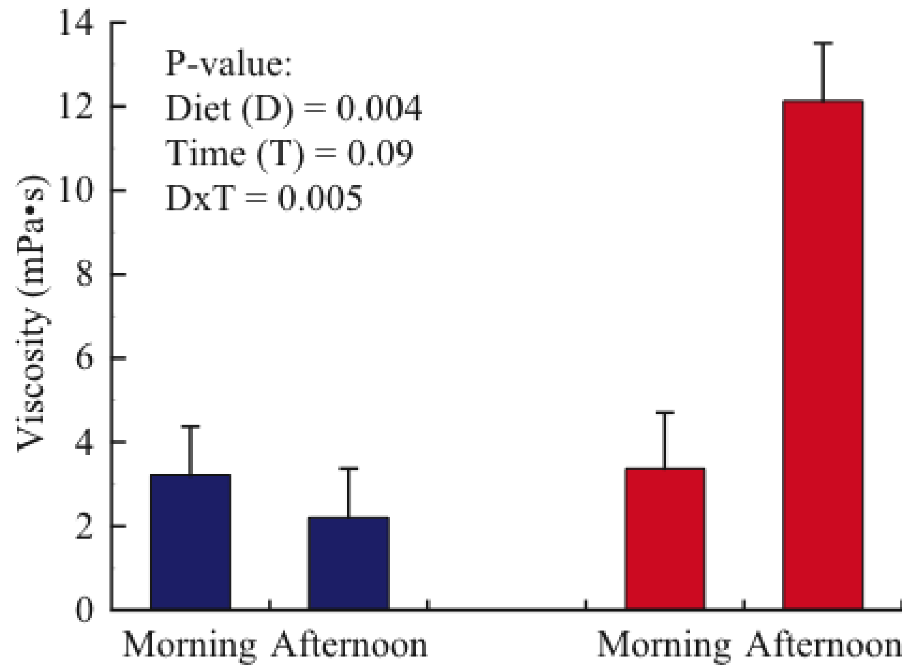
Protein, fat and starch

Ileum digesta



Protein and fat

Viscosity



Wheat

Rye

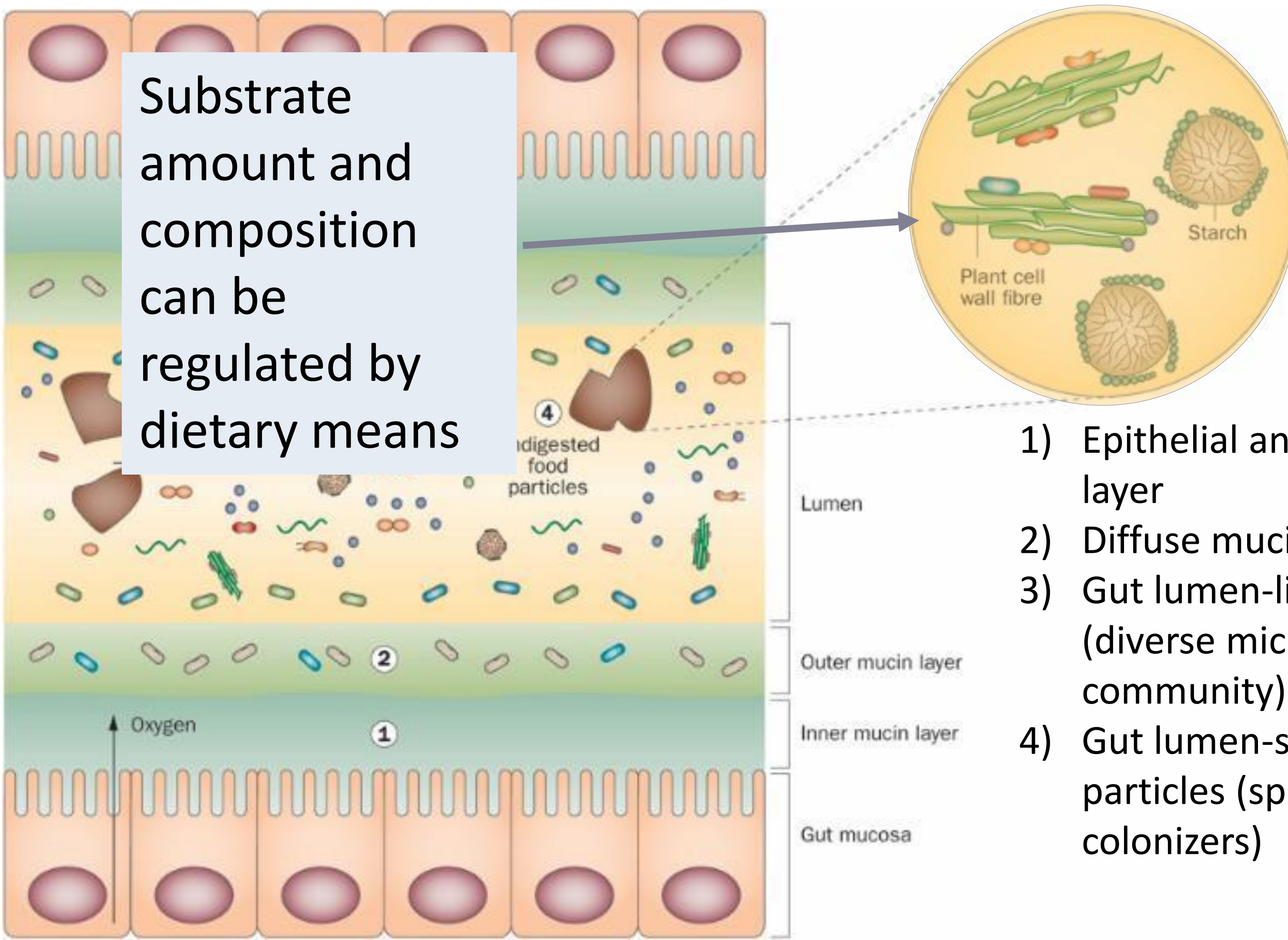
Can dietary fibre proactively be used to influence gut health?

… and the answer is:

definitively **yes** for some age groups

but more problematic for other age groups

Microbial microenvironments within the large intestine



Substrate amount and composition can be regulated by dietary means

1) Epithelial and inner mucin layer
2) Diffuse mucin layer
3) Gut lumen-liquid phase (diverse microbial community)
4) Gut lumen-substrate particles (specialist primary colonizers)

Flint, H. J. *et al.* (2012).

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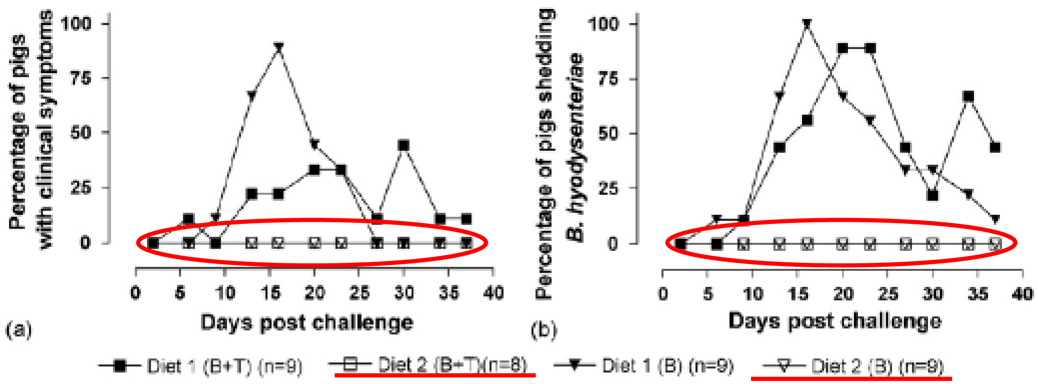
Fructans/inulin as prebiotics to protect against experimental infections with *Brachyospira hyodysenteriae*

	Diet 1	Diet 2
Fructans	10	78
Fibre	240	236



- DNA-fingerprint technique (T-RFLP)
- 16S rRNA

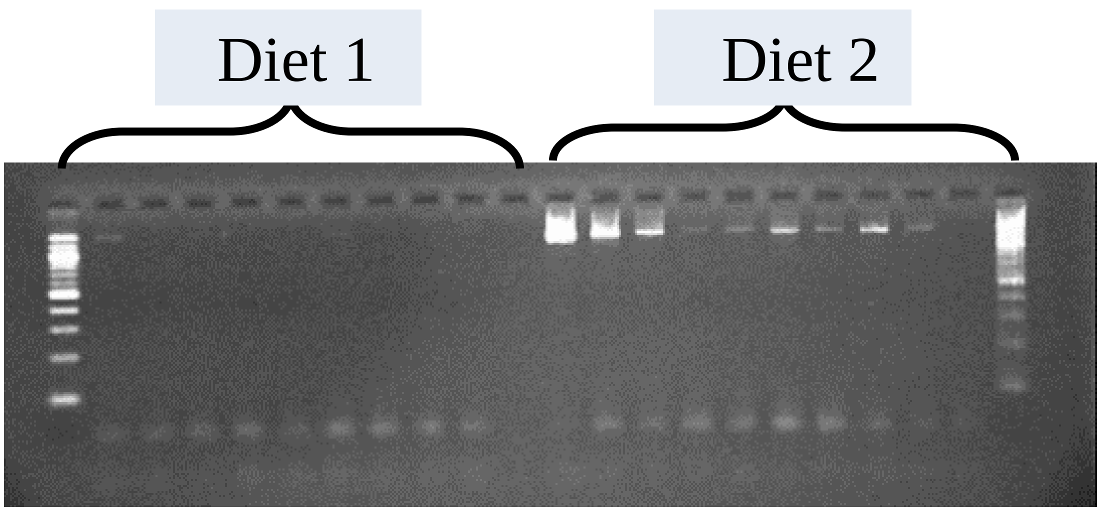
Diet 1 (control)

- Sporobacter

Diet 2 (fructan)

- *Bifidobacterium thermoacidophilum*
- *Megasphaera elsdenii*

Detection of *Bifidobacteria* by specific primers



Thomsen et al. (2007); Mølbak et al. (2007)

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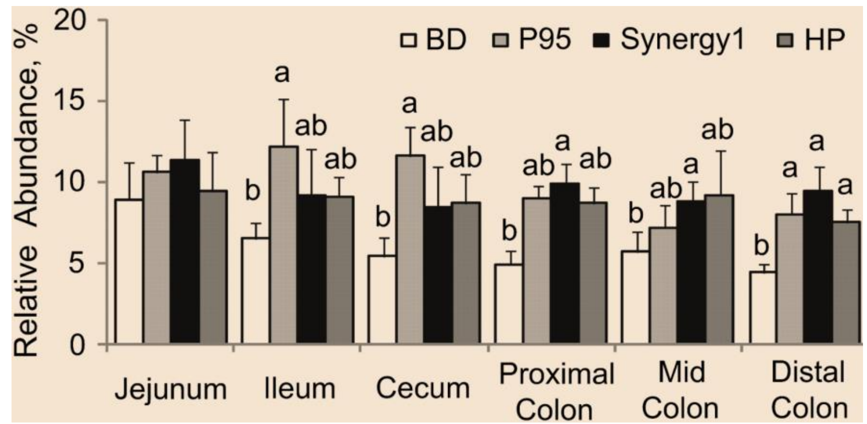
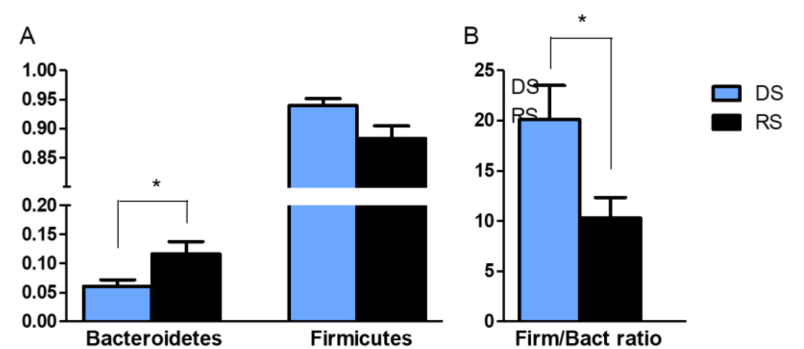
Influence of dietary carbohydrate on phyla composition

- Inulin with variable chain length influence the abundance of phytolytes belonging to *Lactobacillus* spp. and *Bifidobacterium* spp.
  - BD, background diet; HP, long chained inulin (DP 10-60); P95, short-chained (DP 2-7); Synergy = HP:P95 (1:1);

- Resistant starch type 3 influence the Firmicutes to Bacteroides ratio

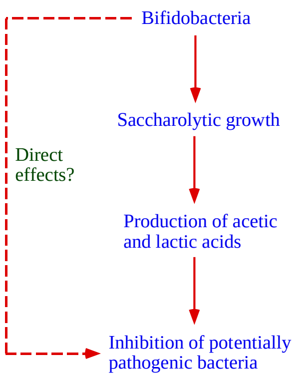


Patterson et al (2010).

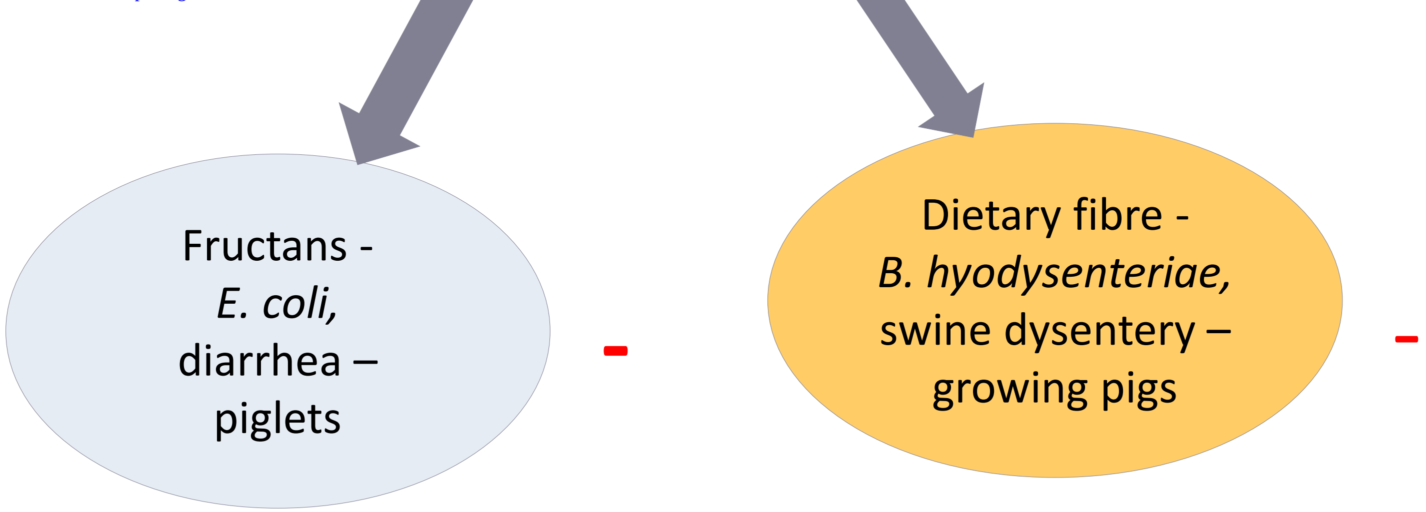


Haenen et al (2013).

Fructans/dietary fibre as prebiotics



Thomsen et al. (2007);
Mølbak et al. (2007)



Hedemann and Bach Knudsen (2010a,b)

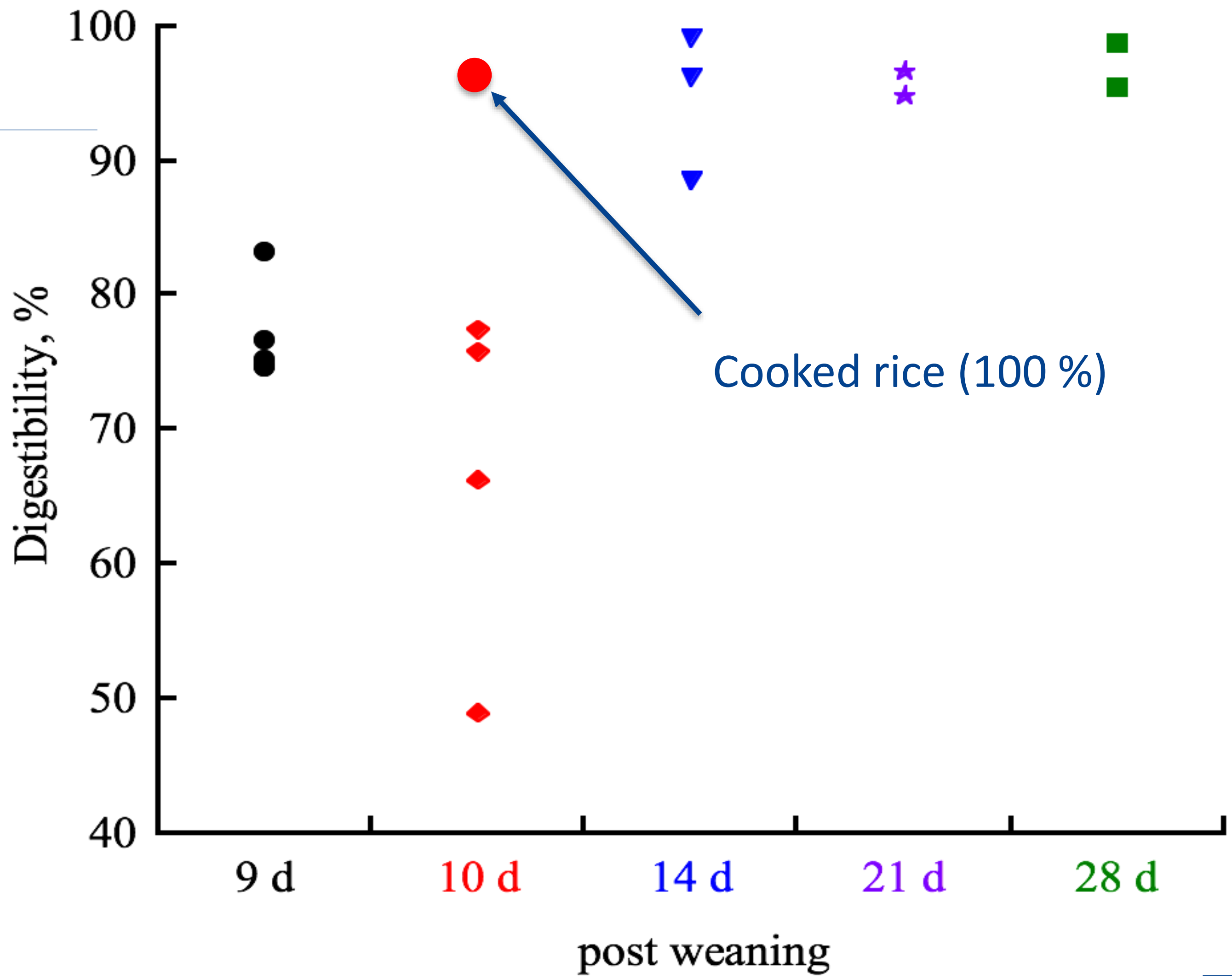
Digestion carbohydrates (% of intake) at the end of the small intestine as influenced by age

	N	Starch	NSP
Piglets, 0-10 days post-weaning	9	**73**	3
Piglets, 14-28 days post weaning	8	95	14
Growing pigs	78	96	21
Sows	3	93	30

NSP, non-starch polysaccharides.

Bach Knudsen et al. (2012).

Digestibility of starch in non-heated feeds 9-28 days post weaning



Lærke et al. (2003); Hopwood et al. (2004); Pluske et al. (2007); Jensen et al. (1998); Gdala et al. (1997).

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The capacity to digest in the small intestine influences amount and composition of substrate for the large intestine

	NSP, g/kg DM		
	7	80	120
Intake: 300 g/d			
Recovery (g), 0-14 d p.w.			
Starch	52	46	42
NSP	2	24	36
T-CHO	54	70	78

Bach Knudsen (2018).

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Fibre and short-chain fatty acids

October 17, 2018

Experimental design

WSD **7 % fiber** | **RSD** **19 % fiber** | **AXD** **19 % fiber**

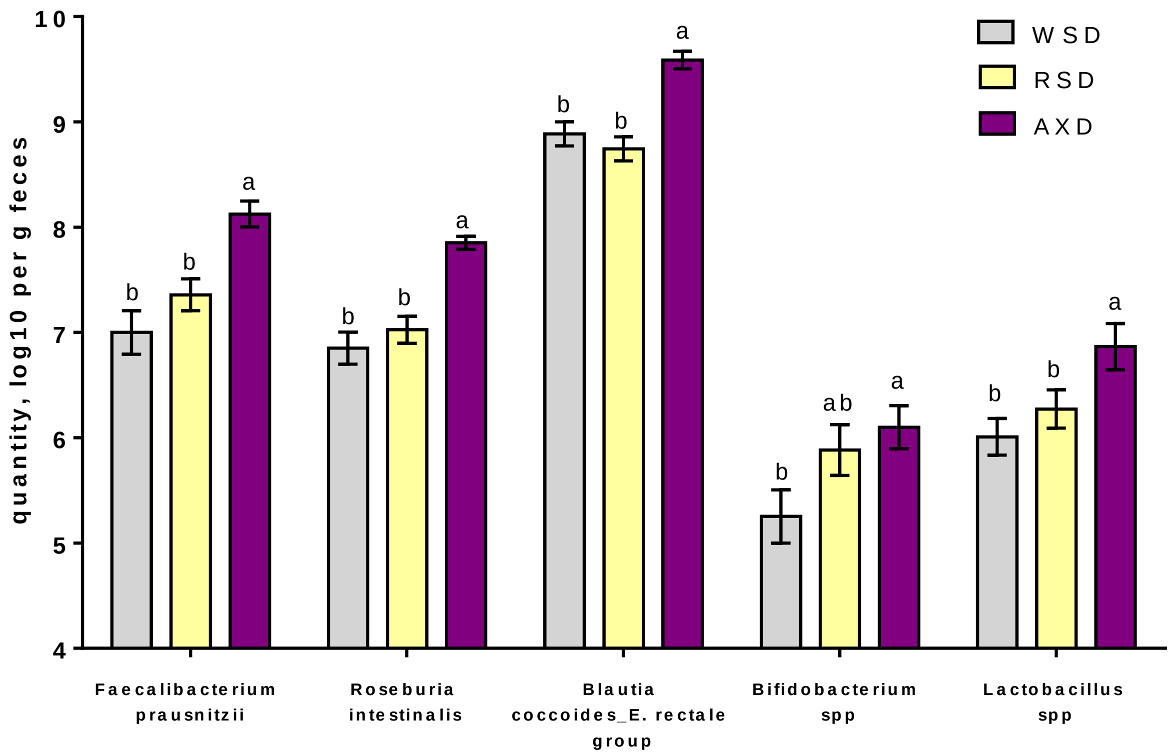
15% fat, 20% protein, equal available CHO

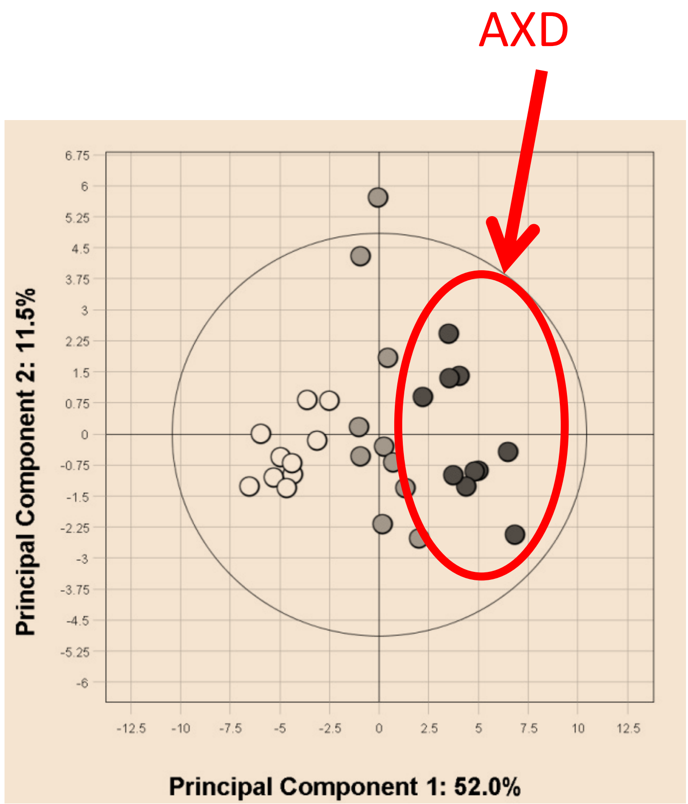
% of DM	WSD	RSD	AXD
Total NSP	5.8	5.5	14.4
AX	1.8	1.5	7.2
RS	0.6	11.3	0.8
Fructan	0	0.3	2.2
AXOS	0.2	0.2	0.7
Lignin	0.6	1.3	1.5
Total DF	7.2	18.6	19.6

10 intact pigs. Weekly blood and faecal sampling. At slaughter sampling of gut content and tissues

6 pigs with catheters placed in the mesenteric artery, portal vein and hepatic vein

Influence of resistant starch and arabinoxylan on microbial composition





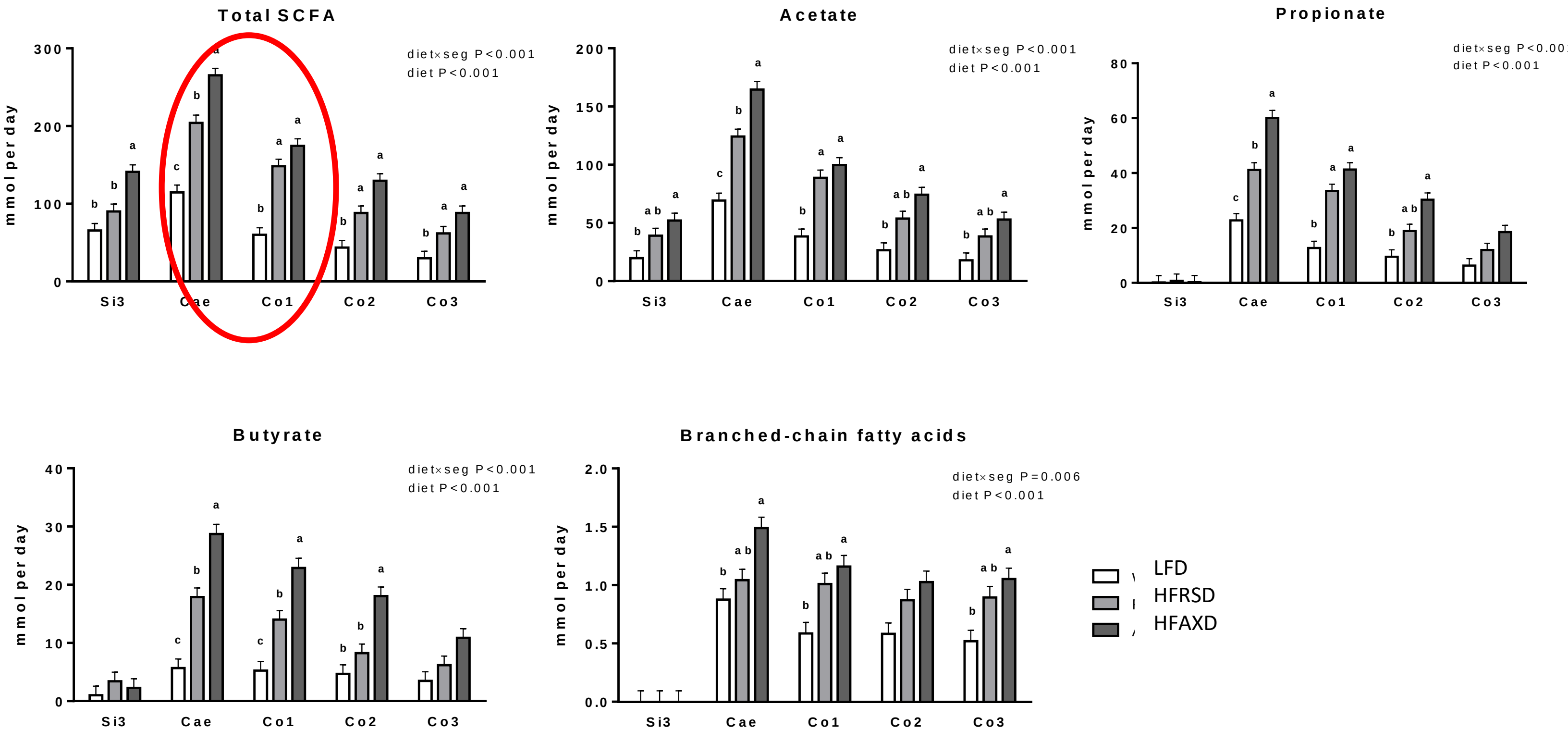
WSD: Low fibre control: 70 g/kg DM

RSD: High fibre with added RS: 190 g/kg DM

AXD: High fibre with added AX: 190 g/kg DM

Nielsen et al (2014).

SCFA production at different sites



LFD: Low fibre control: 70 g/kg DM

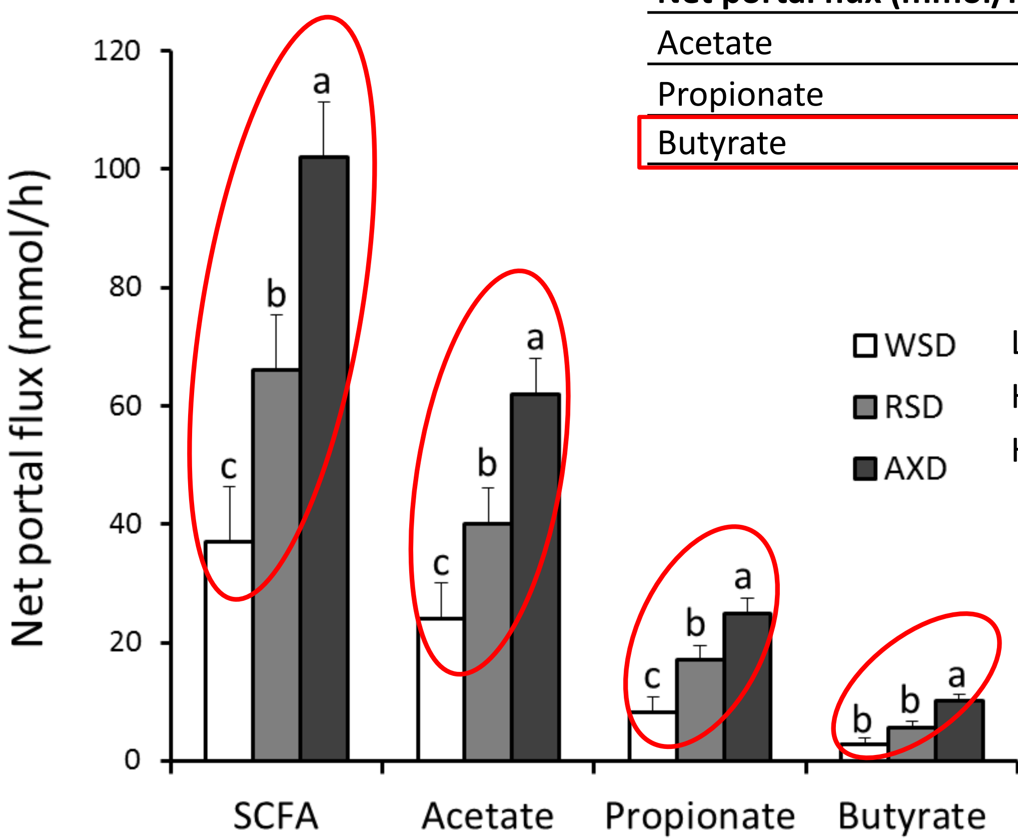
RSD: High fibre with added RS: 190 g/kg DM

AXD: High fibre with added AX: 190 g/kg DM

Nielsen et al (2014).

SCFA absorption

Net portal flux (mmol/h)	WSD	AXD	Fold change
Acetate	24	62	2.5
Propionate	8.2	25	3.0
Butyrate	2.8	10.2	3.6



Low fibre control: 70 g/kg DM

High fibre with added RS: 190 g/kg DM

High fibre with added AX: 190 g/kg DM

(Ingerslev et al 2014)

Take-home messages

- The dietary fibre fraction represent the most complex composed part of the feed
  - The different fibre methods give rise to different results!
- Dietary fibre are, depending of the type, modified as they pass along the small intestine; the main site for the fermentation dietary fibre is the large intestine
- Overall, dietary fibre reduces the digestibility of organic matter (energy) and nitrogen at ileum and over the entire gastrointestinal tract
- Dietary fibre can proactively be used to influence gut health in some situation
- Dietary fibre influences amount and composition of short-chain fatty acids produced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Thank you very much for your attention!

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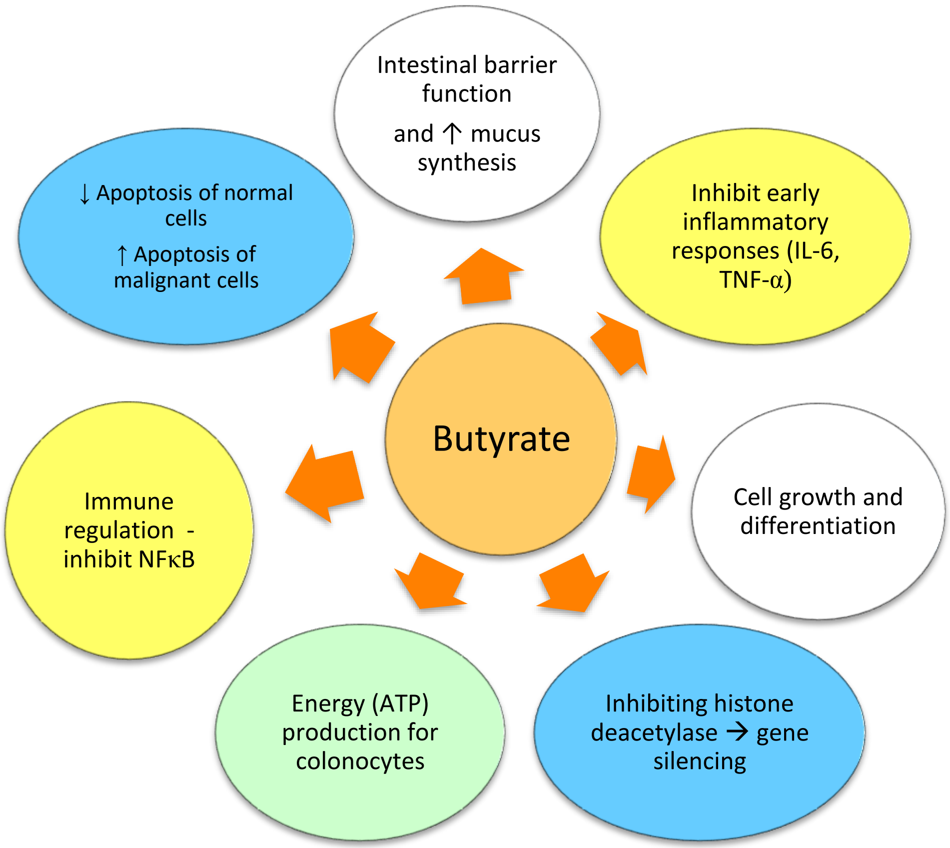
Effects of butyrate – *in vitro* and *in vivo*

Intestinal level



R. C. Canani et al., World J Gastroenterol (2011), 17(12): 1519-28.

Systemic level

- ↑ satiety hormone PYY
- ↑ Glucagon-like peptide-1 (GLP-1) secretion

→ Reduce food intake

- Improving insulin sensitivity

- Butyrate protects against diet induced obesity and insulin resistance in mice

→ Mechanism of action related to promotion of **energy expenditure** and **induction of mitochondria function**

(Z. Gao et al. (2009), Diabetes 58; 1509-17)

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Influence of butyrate in vitro and in vivo on parameters related to gut health

Journal of Functional Foods 40 (2018) 9–17

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Effects of Resistant Starch and Arabinoxylan on Parameters Related to Large Intestinal and Metabolic Health in Pigs Fed Fat-Rich Diets

Tina Skau Nielsen,* Peter Kappel Theil, Stig Purup, Natalia P. Nørskov, and Knud Erik Bach Knudsen

Department of Animal Science, Aa

ABSTRACT: This study compa
control diet (all high-fat) on larg
slaughtered after 3 weeks of trea
glucose, insulin, and insulin resis
genes involved in nutrient transp
mid or distal colon) and some g

nutrients

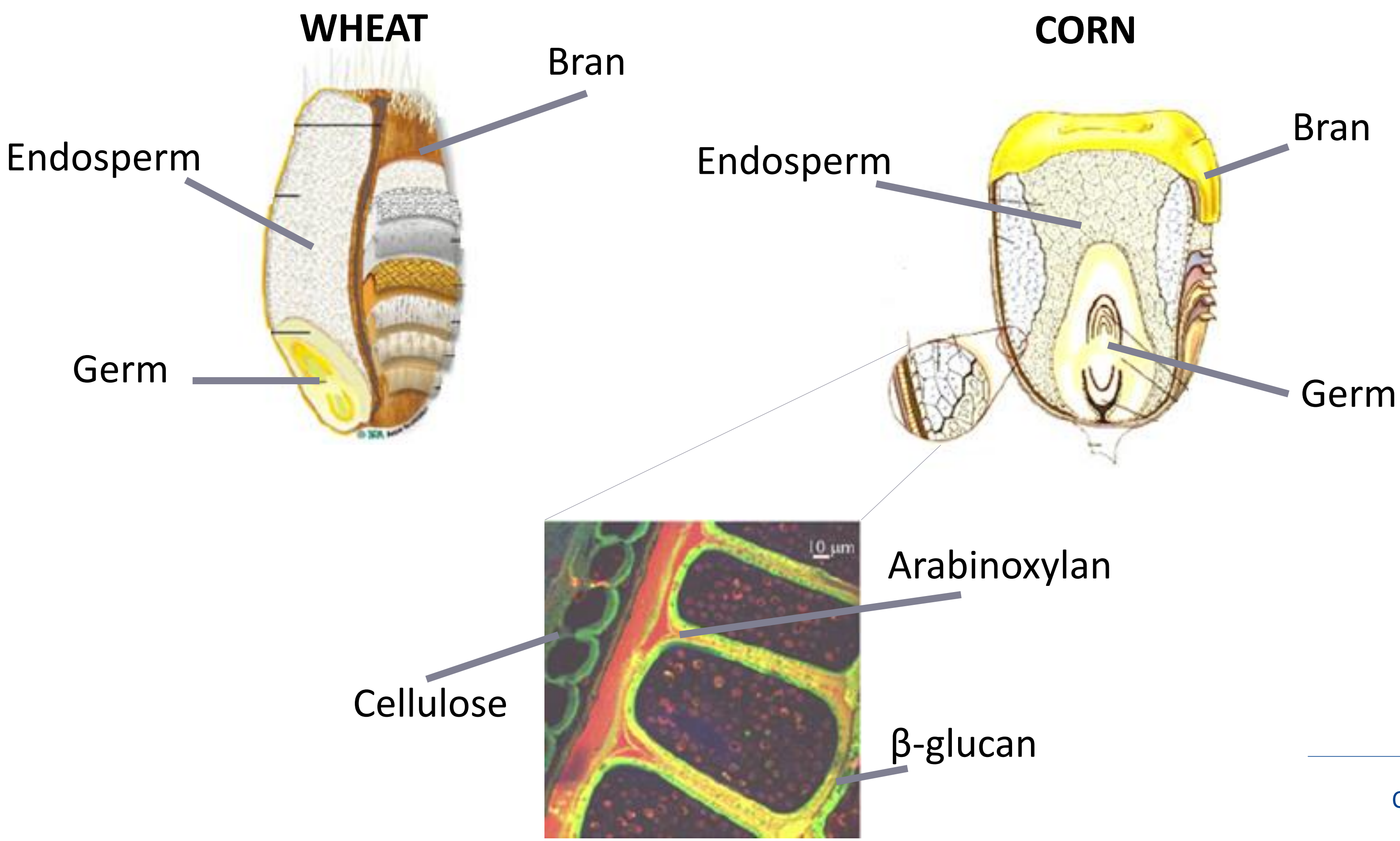
MDPI

Review

Impact of Diet-Modulated Butyrate Production on Intestinal Barrier Function and Inflammation

Knud Erik Bach Knudsen [1,*], Helle Nygaard Lærke [1], Mette Skou Hedemann [1], Tina Skau Nielsen [1], Anne Krog Ingerslev [1], Ditte Søvsø Gundelund Nielsen [1], Peter Kappel Theil [1], Stig Purup [1], Stine Hald [2], Anne Grethe Schioldan [3], Maria L. Marco [4], Søren Gregersen [3] and Kjeld Hermansen [3]

Location of fibre in wheat and corn



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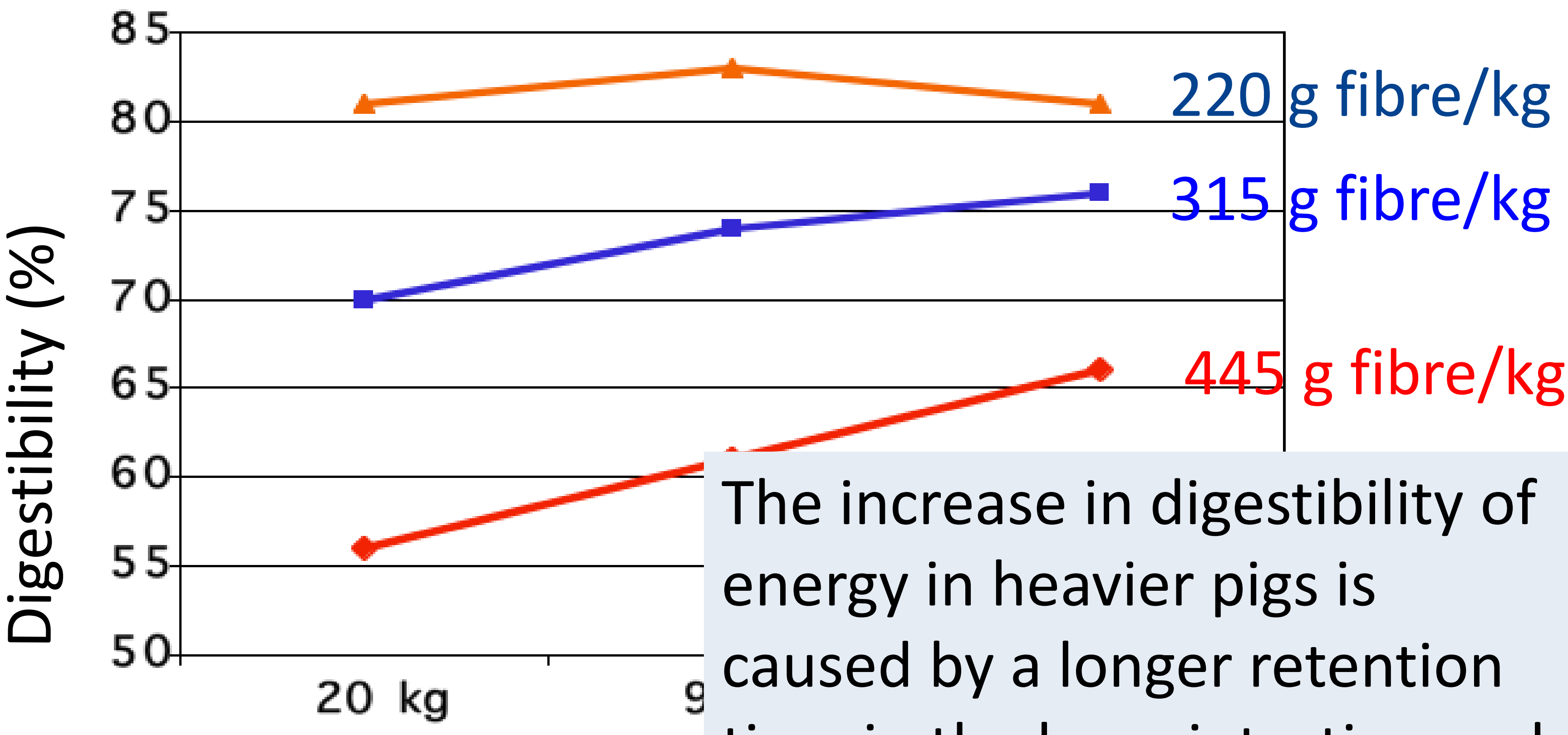
Digestibility of energy as influenced by weight and fibre level



The increase in digestibility of energy in heavier pigs is caused by a longer retention time in the large intestine and a modified microflora

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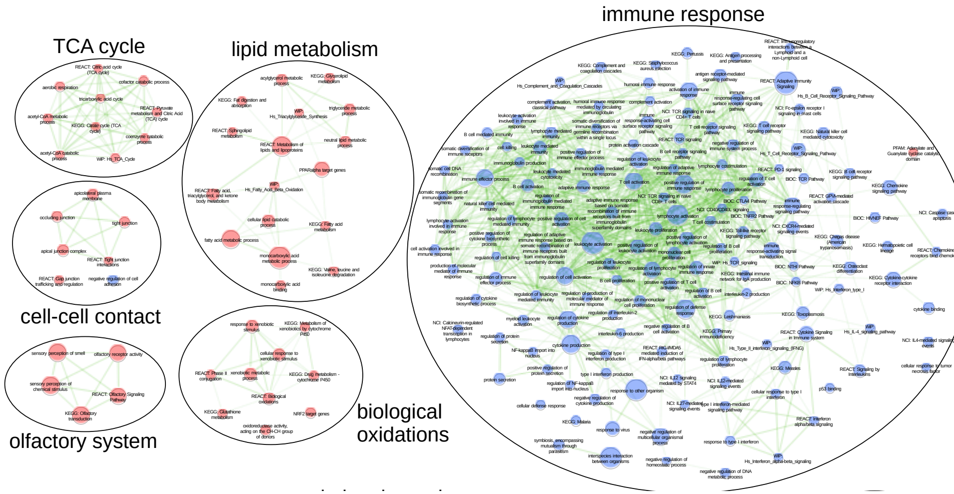
Resistant starch (RS) as a prebiotic - influence on gut epithelium

- Genome-wide transcriptional profiling have shown increased expression of the genes involved in fatty acids β-oxidation and the TCA cycle and suppression of genes involved in both innate and adaptive immune response
- The colon **less immunoactive** due to **RS induced SCFA and butyrate production** and **lower exposure of potential pathogenic microorganisms**
- Shift in the balance of **energy expenditure for maintenance and growth?**



(Haenen et al. 2013)