# *Dietary Fiber*

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# Objectives

- Define dietary fiber
- List factors that affect fiber properties and health
- Recognize health benefits of consumption of isolated and synthetic dietary fibers

# Dietary Fiber

*Non-digestible soluble and insoluble carbohydrates ( ≥ 3 monomeric units), and lignin that are intrinsic and intact in plants; isolated or synthetic non-digestible carbohydrates (≥ 3 monomeric units) determined by FDA to have physiological effects that are beneficial to human health.*[1]

| | % Daily Value* |
|---|---|
| **Total Fat** 4g | **6%** |
| Saturated Fat 2g | **10%** |
| *Trans* Fat 0g | |
| **Cholesterol** 0mg | **0%** |
| **Sodium** 120mg | **5%** |
| **Total Carbohydrate** 44g | **15%** |
| Dietary Fiber 8g | **33%** |
| Total Sugars 12g | |
| Includes 10g Added Sugars | 20% |
| **Protein** 4g | |
| **Vitamin D** 2mcg | 10% |
| **Calcium** 260mg | 20% |
| **Iron** 8mg | 45% |
| **Potassium** 235mg | 6% |

1. U.S. Food & Drug Administration, 26 May 2016. Final ruling on dietary fiber definition.

# Dietary Fiber Intake

- Dietary Reference Adequate Intake Recommendation: ***14 g/1000 kcal or 25 g/d and 38 g/d***[1]

- Dietary patterns do ***not*** meet recommended intakes of fruits, vegetables, and whole grains

- ***Significant fiber gap***
  - Intake is ~15 – 18 g/d
  - 90% of women fail to meet recommendation
  - 97% of men fail to meet recommended intakes

1. Dietary Guidelines for Americans, 2020-2025

# Fibers: Foods & Functions

## *Foods*

- Bars
- Cereals
- Ice cream
- Juices
- Yogurt

## *Functions*

- Increase fiber content
- Sugar replacer
- Fat replacer
- Thickening agent
- Bulk

- ***Health benefits of the specific fiber***

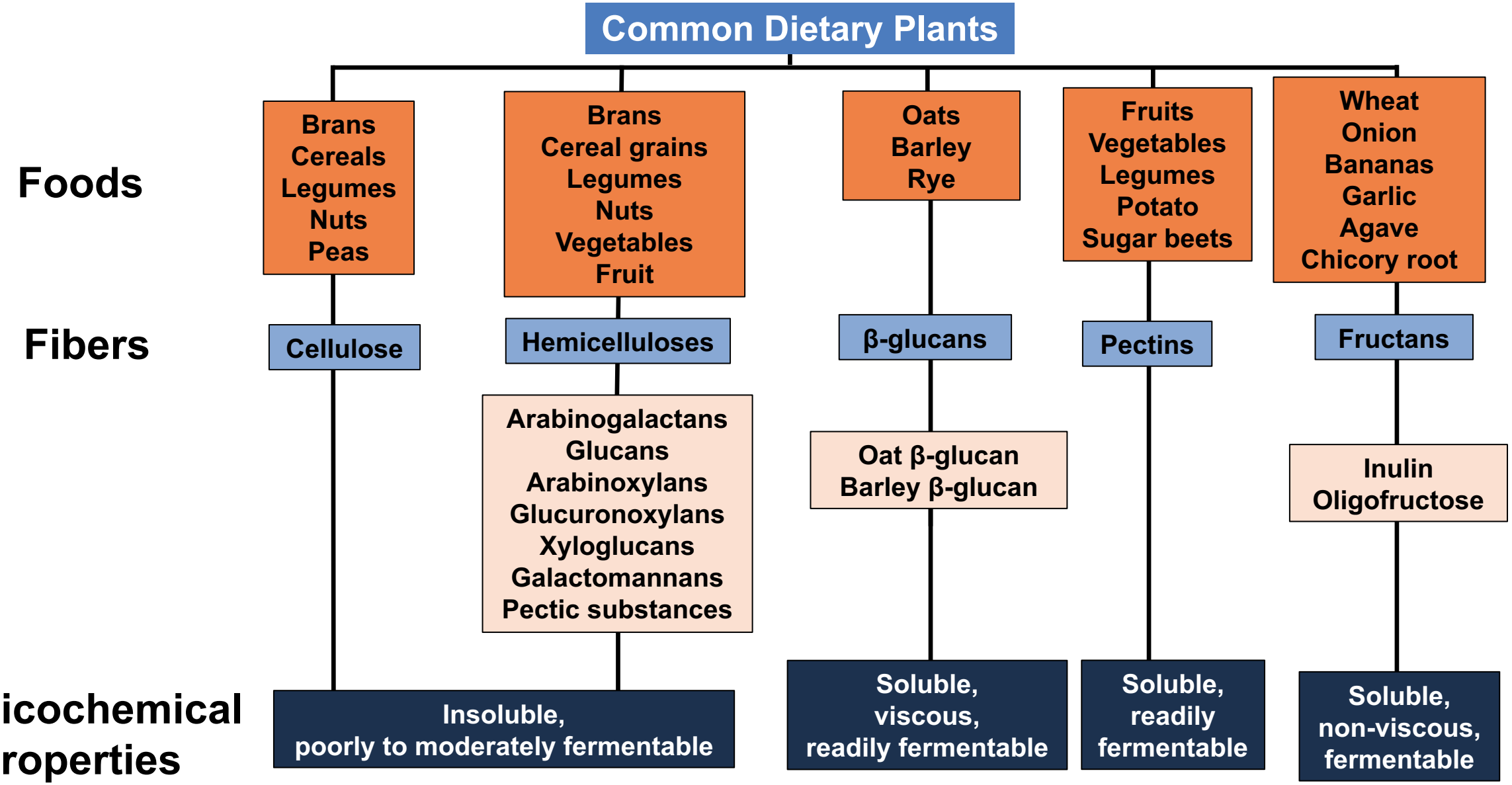
# Fiber Properties & Health Benefits

# Dietary Fibers are Heterogenous

- ***Dietary fiber*** intake differentially impacts health.
  - Botanical origin
  - Chemical composition
  - Physicochemical properties
  - Degree of polymerization
  - Dose

Holscher HD. (2017) Dietary fiber and prebiotics and the gastrointestinal microbiota. *Gut Microbes*, 8(2), 172-184.

# Dietary Fibers in Foods






Livingston KA, et al. (2016). Development of a Publicly Available, Comprehensive Database of Fiber and Health Outcomes: Rationale and Methods. PLoS ONE. 11(6)e0156961

# Dietary Fiber Health Benefits

**Solubility**: dissolve in water (soluble) or remain as discrete particles (insoluble).

**Viscosity:** thicken when hydrated (gel-forming).

**Fermentability:** degree to which fiber, after resisting digestion, can be metabolized by microbes.

- ***Insoluble (cellulose)***
  - laxative effect
- ***Soluble, viscous, non-fermented (psyllium)***
  - cholesterol-lowering, improve glycemia, weight loss, stool normalization
- ***Soluble, viscous, fermentable (β-glucan)***
  - cholesterol lowering, improve glycemia
- ***Soluble, non-viscous, fermentable* (inulin)**
  - Reduce inflammation, weight loss

# Dietary Fibers: Prebiotics

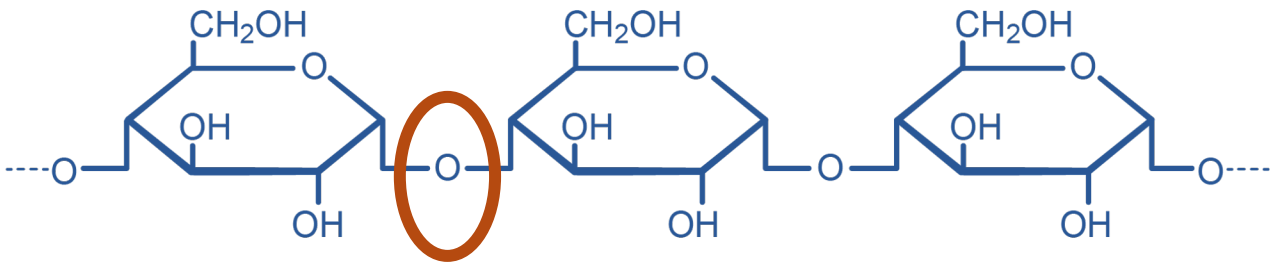
**Prebiotic** – *a substrate that is selectively utilized by host microorganisms* ***conferring a health benefit****.*

- ***Soluble, non-viscous, fermentable***:
  - Galactooligosaccharides (GOS)
  - Fructooligosaccharides (FOS)
  - Inulin

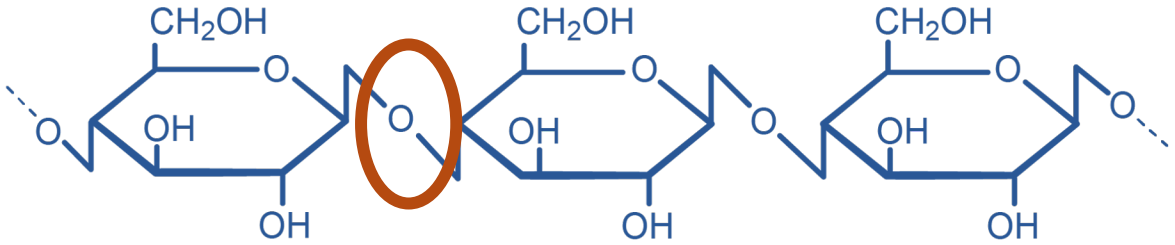
- Doses generally need to be 3.0 g/d or higher

Gibson, G. et al. Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. Nat Rev Gastroenterol Hepatol 14, 491–502 (2017).

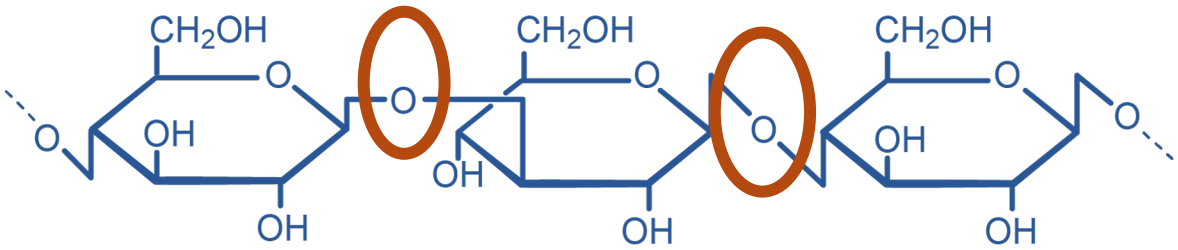
# Microbes Ferment Dietary Fiber




***Amylose***: α-1,4 glucosidic bonds




***Cellulose***: β-1,4 glucosidic bonds




***β-Glucan:*** *mixed β-1,3 and β-1,4 glucosidic bonds*

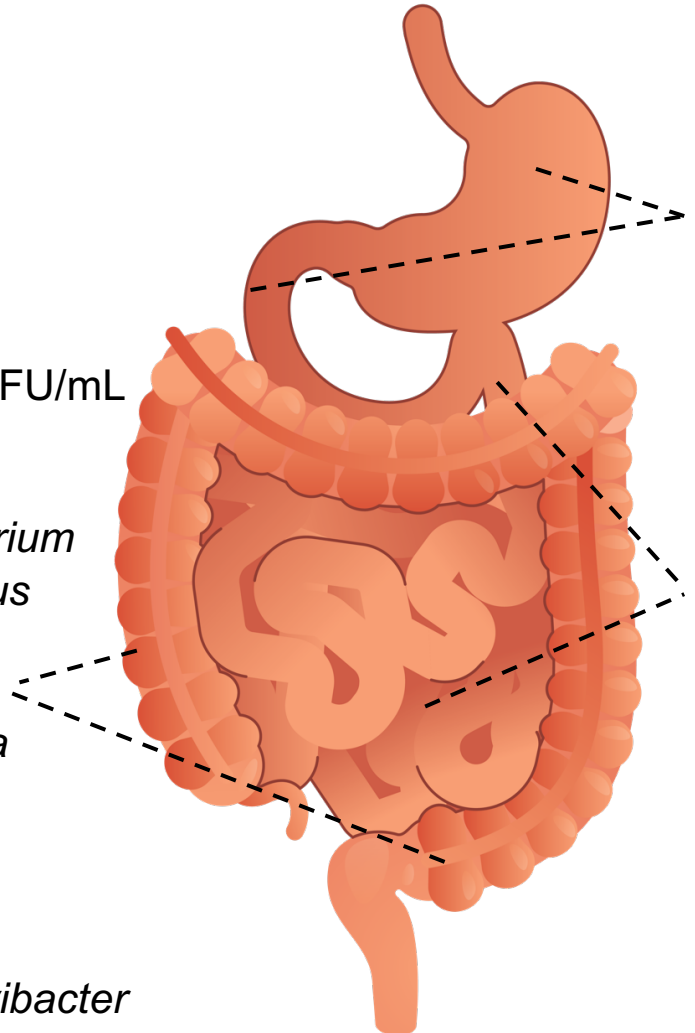
Image adapted from Linus Pauling Institute, OSU

# Definitions and Overview

***Microbiota*** *– a collection of microbes*

***Microbiome*** *- a collection of microbial genomes*

- **As many bacteria** as host cells in human body[1]
- **> 100x more bacterial genes** than our human genome[2]



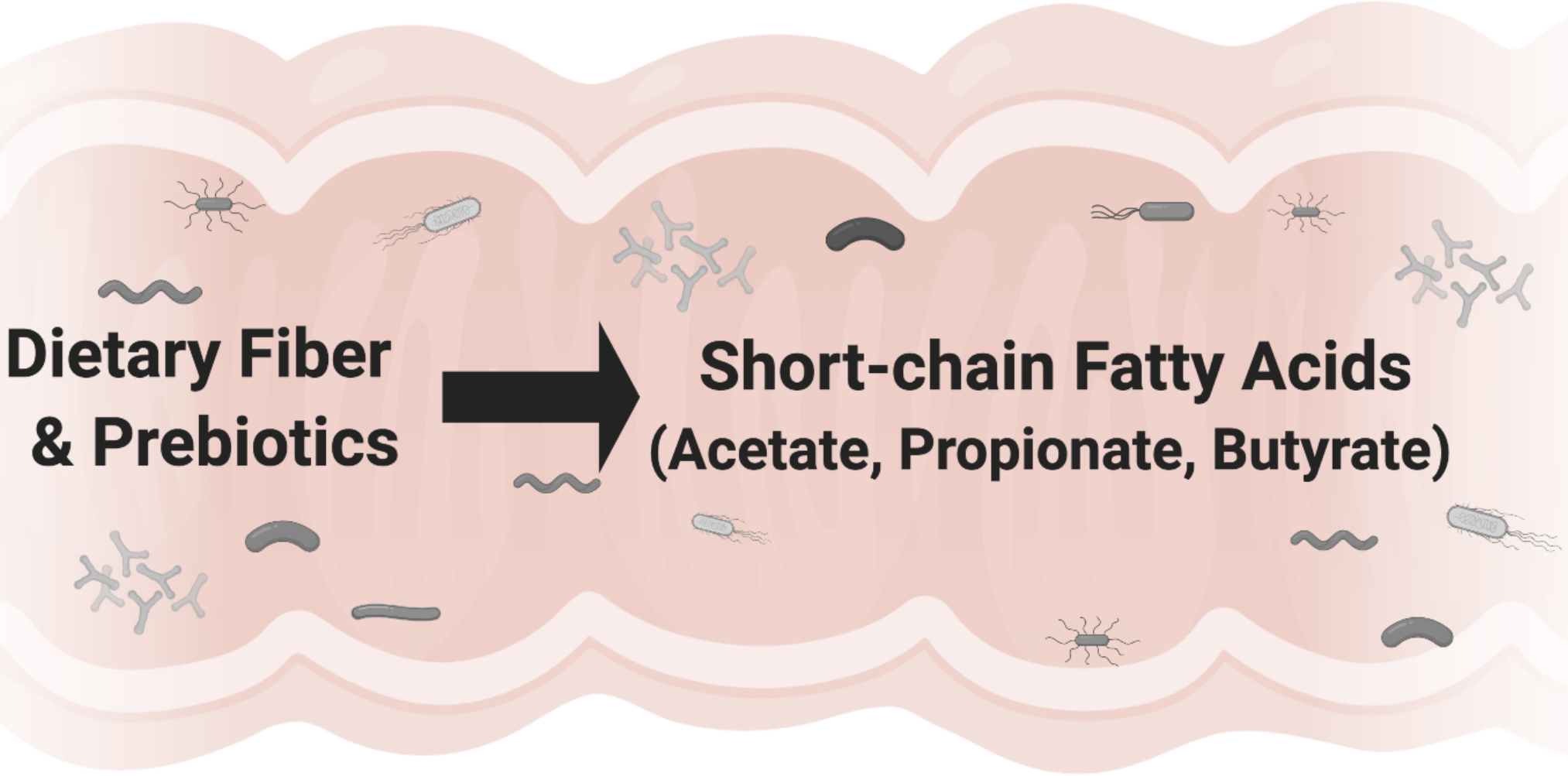
**Stomach & Duodenum**
$10^1$– $10^2$ CFU/mL
*Helicobacter*
*Streptococcus*

**Jejunum & Ileum**
$10^4$ – $10^8$ CFU/mL
*Bacteroides*
*Streptococcus*
*Lactobacillius*
*Bifidobacteria*
*Fusobacteria*

**Colon**
$10^{10}$ – $10^{12}$ CFU/mL
*Bacteroides*
*Prevotella*
*Facaelibacterium*
*Ruminococcus*
*Roseburia*
*Clostridium*
*Bifidobacteria*
*Collinsella*
*Desulfovibrio*
*Bilophila*
*Akkermansia*
*Methanobrevibacter*

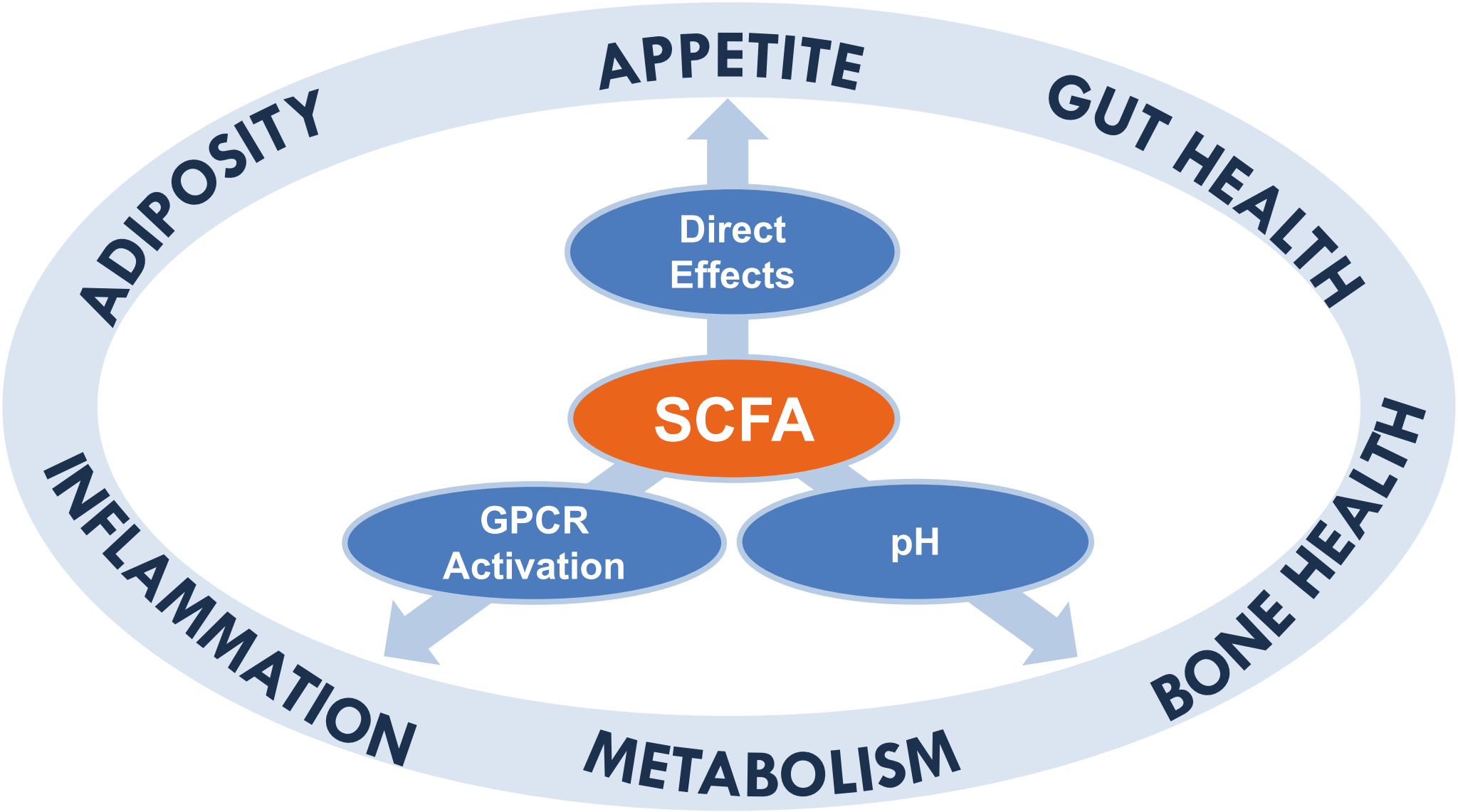
1. Sender R, et al. (2016) *Cell;* 2. Qin J, et al. (2010) *Nature*

# Microbes Ferment Fiber & Prebiotics




Holscher, H. D. (2017). Dietary fiber and prebiotics and the gastrointestinal microbiota. *Gut Microbes*, 8(2), 172-184.

# Microbiota-Derived Signaling




Alexander C et al., *Adv Nutr*, Perspective: physiological importance of short-chain fatty acids from nondigestible carbohydrate fermentation. 2019, 10(4); 576-589

# Diet & Gut Microbiota

***Gut microbes metabolize nondigested dietary substrates.***

| | % Daily Value* |
|---|---|
| **Total Fat** 4g | **6%** |
| Saturated Fat 2g | **10%** |
| *Trans* Fat 0g | |
| Polyunsaturated Fat 0g | |
| Monounsaturated Fat 0g | |
| **Cholesterol** 0mg | **0%** |
| **Sodium** 120mg | **5%** |
| **Total Carbohydrate** 44g | **15%** |
| Dietary Fiber 8g | **33%** |
| Soluble Fiber 5g | |
| Insoluble Fiber 3g | |
| Total Sugars 12g | |
| Includes 10g Added Sugars | 20% |
| **Protein** 4g | |

# Fiber Health Effects: Intrinsic & Intact

- Dietary fiber is protective against overweight and obesity, type 2 diabetes, cardiovascular disease, and cancer
- Observational studies:  decrease in all-cause and cardiovascular related mortality, and incidence of coronary heart disease, stroke incidence and mortality, type 2 diabetes, and colorectal cancer when comparing highest with lowest fiber consumers.
- Clinical trials:  lower body weight, systolic blood pressure, and total cholesterol when comparing higher with lower intakes of fiber.
  - Risk reduction was greatest with 25-29 g daily intake

1. Dahl et al., *J Acad Nutr Diet* 2015; 2. Reynolds et al., *Lancet* 2019

# Health Effects: Meta-analyses

- Soluble fiber treatments ***decreased energy intake*** and ***appetite***.[1]
- Insoluble and soluble fiber interventions resulted in ***weight loss*** with 14 g/d of additional dietary fiber.[2]
- Soluble fiber supplementation **reduced *BMI, body weight, % body fat, and fasting glucose and insulin***.[3]
- Soluble, fermentable, and non-viscous fiber treatments ***reduced postprandial glucose and insulin***.[4]
- Prebiotics **reduced c-reactive protein (CRP).**[5]
- Prebiotics ***reduced total and LDL cholesterol.*** [6]

1. Wanders AJ, et al. *Obes Rev*. 2011; *2.* Howarth NC, et al. *Nutr Rev*. 2001; 3. *Thompson SV, et al. Am J Clin Nutr. 2017;*
4. Kellow NJ, et al. *Br J Nutr*. 2014;. 5. RF McLoughlin, *et al. Am J Clin Nutr. 2017; 6*. Beserra BT, et al. (2015). *Clinical Nutrition*.

# Isolated & Synthesized Fibers

FDA, Science review of isolated and synthetic non-digestible carbohydrates, November 2016
FDA, Review of the scientific evidence on the physiological effects of certain non-digestible carbohydrates, June 2018

# Inulin Type Fibers

*Inulin, oligofructose, short chain fructooligosaccharides*

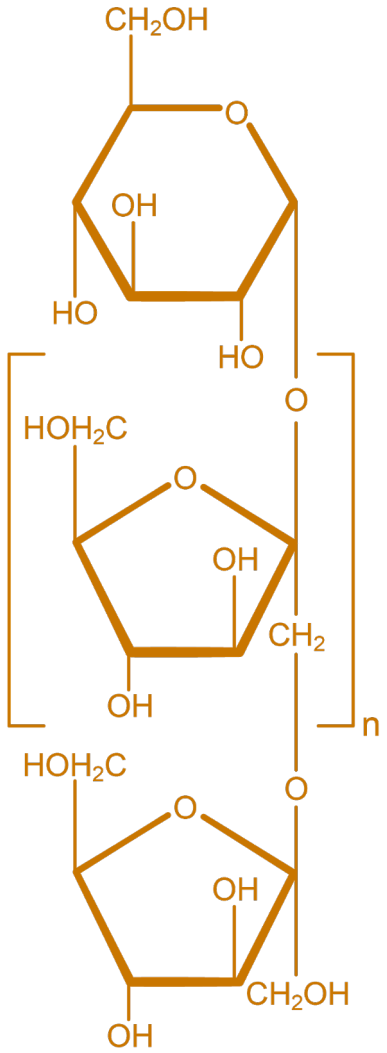
## *Plant Sources (g/100g)*

- Wheat (2.5 g)
- Onion (4.3 g)
- Garlic (12.5 g)
- Leeks (6.5 g)
- Asparagus (2.5 g)
- Bananas (0.5 g)

- Chicory root
- Agave
- Jerusalem artichoke

## *Food Sources*

- Bars
- Cereals
- Yogurt
- Ice cream




Moshfegh AJ (1999). Presence of Inulin and Oligofructose in the Diets of Americans. J Nutr. 129, 1407S-1411S.
Meyer TSM (2015). Biotechnological Production of Oligosaccharides — Applications in the Food Industry, Food Production and Industry.

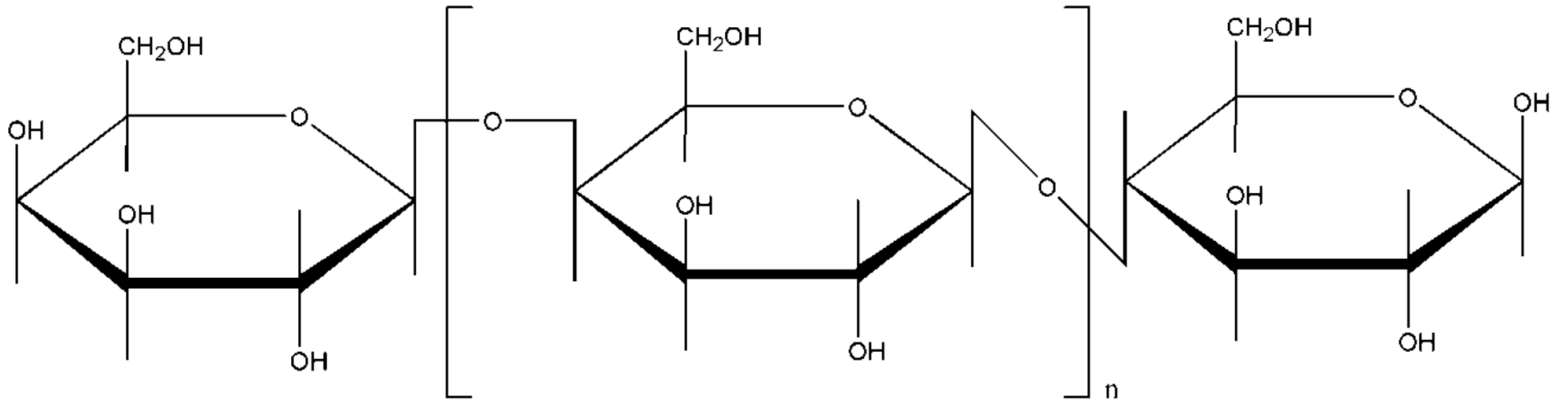
# Inulin Type Fibers & Health

- ***Microbial***
  - 5-16 g/d increase *Bifidobacterium and Faecalibacterium prausnitzii*
- ***Metabolic Health***
  - 12.5 - 21 g/d reduced body weight, fat mass, BMI, waist circumference
  - 10 - 16 g/d improved glycemic control
  - 10 g/d reduced inflammation
- ***Appetite, food intake, and satiety***
  - 8- 21 g/d reduced food intake
  - 8 - 12.5 g/d improved satiety
- ***Calcium Absorption***
  - FDA determined that evidence supports beneficial physiological effects on bone mineral density and calcium absorption
  - 5-8 g/d increased the percentage rate of calcium absorption in adolescents
  - 10 g/d increased calcium absorption in post-menopausal women

# Galactooligosaccharides (GOS)

*GOS is produced by enzymatic treatment of lactose*

- ***Functions***
  - Improve food texture
  - Bulking agent
- ***Structures***
  - β-(1,4) linked galactose oligomer, attached to glucose by β-(1,4) bond
  - Typically between 2 and 8 units long




Meyer TSM (2015). Biotechnological Production of Oligosaccharides — Applications in the Food Industry, Food Production and Industry.

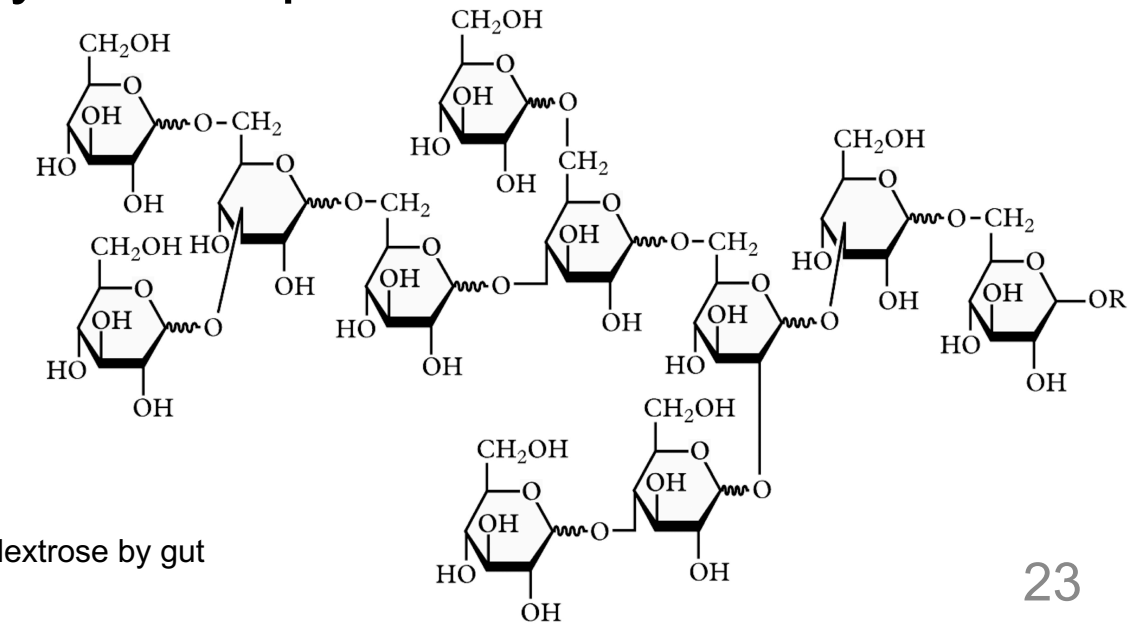
# GOS & Health

- ***Microbial***
  - Increases in *Bifidobacteria* and fecal lactate
- ***Immunomodulation***
  - 5.5 g/d for 10 wk increased anti-inflammatory and reduced pro-inflammatory cytokines
  - 5.5 g/d for 12 wk increased fecal secretory IgA and decreased systemic inflammation
- ***Psychological***
  - 5.5 g/day for 3 wk reduced waking salivary cortisol and increased attentional vigilance in the processing of positive versus negative stimuli
- ***Metabolic***
  - 5.5 g/day for 12 wk reduced total cholesterol concentrations
- ***Calcium Absorption***
  - FDA determined that evidence supports beneficial physiological effects on bone mineral density and calcium absorption
  - 20 g/day for 9 days increased calcium absorption

# Polydextrose

- ***Food Sources***
  - Synthesized fiber that is a multi-purpose food ingredient found in baked goods, dairy products, and beverages

- ***Structures***
  - Highly branched, randomly bonded glucose polysaccharide units with DP of 2-120 (average 12). Glucose linked by α- and β-linked 1,2, 1,3, 1,4, and 1,6 glycosidic linkages.



Lahtinen SJ,et al. Effect of molecule branching and glycosidic linkage on the degradation of polydextrose by gut microbiota. *Biosci Biotechnol Biochem* 2010;74:2016–21.

# Polydextrose & Health

- ***Microbial***
  - 8 g/d reduced snack consumption and increased butyrate producing bacteria
  - 21 g/d increased Bacteroidetes and reduced Firmicutes, reduced proteolytic fermentation
- ***Laxation***
  - 3.6 – 8 g/d reduced transit time and abdominal discomfort
- ***Metabolic***
  - 12.5 or 15 g/d decreased postprandial triglyceride response to high fat meal
- ***Appetite, satiety, and energy intake***
  - FDA determined that evidence supports beneficial physiological effects of reduced ***energy intake***.
  - 6.25 - 15 g decreased hunger and increased satiety
  - 12 - 25 g decreased energy intake

# Resistant Maltodextrin

*Oligosaccharide of glucose molecules joined by digestible and non-digestible α-1,2 and α-1,3 linkages. Produced from corn starch hydrolysis.*

- ***Common names***
  - Soluble corn fiber
  - Resistant dextrin
  - Resistant wheat dextrin
  - Soluble wheat fiber
  - Wheat dextrin

# Resistant Maltodextrin & Health

- ***Microbial***
  - 25 g/d increased Bifidobacterium
- ***Laxation***
  - Increased stool volume and stool frequency
- ***Glycemic control***
  - 25 g reduced postprandial blood glucose and insulin
- ***Calcium Absorption***
  - FDA determined that evidence supports beneficial physiological effects on bone mineral density and calcium absorption
  - 12 g/d and 20 g/d increased calcium absorption in adolescents and postmenopausal women

# High Amylose Starch (RS2)

*Cooked native starch comprised of α-1,4 glycosidic links*

- ***Sources***
  - Raw green bananas
  - Raw potatoes
  - Uncooked high amylose maize/corn, potato starch, wheat

# High Amylose Starch (RS2) & Health

- ***Microbial***
  - 14-19 g/d increased *Ruminococcus*
- ***Laxation/Bowel Function***
  - 17-39 g/d increased bowel movement or ease of defecation
- ***Energy intake***
  - 48 g/d reduced energy intake
  - 22.2 g/d reduced appetite but did not affect energy intake
- ***Glycemic control***
  - FDA determined that evidence supports beneficial physiological effect on ***post-prandial insulin levels***
  - 25 – 60 g reduced post-prandial insulin response and AUC after a second meal
  - 40 g reduced fasting blood glucose and insulin
  - 14-19 g reduced postprandial glucose and insulin

# Dietary Fiber: Physiological Benefits

**Demonstrated physiological benefits:**

- Lowering blood glucose, insulin
  - *Arabinoxylan, Alginate, High Amylose Starch (RS2)*
- Lowering cholesterol levels
  - *Guar gum, Glucomannon, Locust bean gum, Pectin, Hydroxypropyl-methylcellulose*
- Increasing mineral absorption in the intestinal tract
  - *Inulin and inulin-type fructans, Galactooligosaccharide, Resistant maltodextrin*
- Reducing energy intake (e.g., feelings of fullness)
  - *Polydextrose*
- Increasing frequency of bowel movements (improved laxation)
  - *Cellulose*

# Dietary Fiber: Physiological Benefits

**Isolated or synthetic fibers included in FDA fiber definition:**

- Beta-glucan soluble fiber
- Psyllium husk
- Cellulose
- Guar gum
- Pectin
- Locus bean gum
- Hydroxypropylmethylcellulose
- Mixed plant cell wall fibers
- Arabinoxylan
- Alginate
- Inulin and inulin-type fructans
- High amylose starch (RS2)
- Galactooligosaccharide
- Polydextrose
- Resistant maltodextrin/dextrin
- Cross linked phosphorylated RS4
- Glucomannan

# Dietary Fiber

*Non-digestible soluble and insoluble carbohydrates ( ≥ 3 monomeric units), and lignin that are intrinsic and intact in plants; isolated or synthetic non-digestible carbohydrates (≥ 3 monomeric units) determined by FDA to have* ***physiological effects that are beneficial to human health****.*[1]

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| **Calcium** 260mg | 20% |
| **Iron** 8mg | 45% |
| **Potassium** 235mg | 6% |

1. U.S. Food & Drug Administration, 26 May 2016. Final ruling on dietary fiber definition.

# Key Takeaways

1

FDA definition of dietary fiber.

2

Fibers are heterogeneous.

3

***Health benefits of isolated and synthetic fibers.***

# References


- ***Isolated & Synthetic Fiber***
  - FDA, Science review of isolated and synthetic non-digestible carbohydrates, November 2016
  - FDA, Review of the scientific evidence on the physiological effects of certain non-digestible carbohydrates, June 2018
- ***Inulin Type Fructans***
  - Parnell JA (2009) Weight loss during oligofructose supplementation is associated with decreased ghrelin and increased peptide YY in overweight and obese adults. AJCN; 89:1751–59.
  - Cani PD (2009). Gut microbiota fermentation of prebiotics increases satietogenic and incretin gut peptide production with consequences for appetite sensation & glucose response after a meal. AJCN;90(5),1236-43
  - Dewulf EM (2013). Insight into the prebiotic concept: lessons from an exploratory, double-blind intervention study with inulin-type fructans in obese women. Gut; 62: 1112-21.
  - Dehghan P (2013). Oligofructose-enriched inulin improves some inflammatory markers and metabolic endotoxemia in women with type 2 diabetes mellitus: A randomized controlled clinical trial. Nutrition; 30:418-23.
  - Genta (2009). Yacon syrup: beneficial effects on obesity and insulin resistance in humans. Clin Nutr 28, 182–187.
- ***Galactooligosaccharides (GOS)***
  - Davis LMG (2011). Barcoded Pyrosequencing Reveals That Consumption of Galactooligosaccharides Results in a Highly Specific Bifidogenic Response in Humans. PLoS
  - Vulevic J (2015). Influence of galacto-oligosaccharide mixture (B-GOS) on gut microbiota, immune parameters and metabonomics in elderly persons. BJN.
  - Vulevic J (2013) A Mixture of trans-Galactooligosaccharides Reduces Markers of Metabolic Syndrome and Modulates the Fecal Microbiota and Immune Function of Overweight Adults
  - Schmidt, K (2015) Prebiotic intake reduces the waking cortisol response and alters emotional bias in healthy volunteers. Psychopharmacology 232:1793–1801
  - Vulevic J (2013). A mixture of trans-galactooligosaccharides reduced markers of metabolic syndrome and modulates the fecal microbiota and immune function of overweight adults. Journal of Nutrition 2013;143:324-331.
  - van den Heuvel EGHM (2000). Trans galacto-oligosaccharides stimulate calcium absorption in postmenopausal women. Journal of Nutrition 2000; 130:2938-2942.
- ***Polydextrose***
  - Holscher HD et al. (2015) Fiber supplementation influences phylogenetic structure and functional capacity of the human intestinal microbiome: follow-up of a randomized controlled trial. AJCN 101: 55-64
  - Ramiro do Carmo MM et al. (2016). Polydextrose: Physiological Function, and Effects on Health. Nutrients 8:553.
  - Canfora EE and Blaak EE. The role of polydextrose in body weight control and glucose regulation. Curr Opin Clin Nutr Metab Care 2015, 18:395-400
- ***Resistant Maltodextrin***
  - Burns AM, et al. In healthy adults, resistant maltodextrin produces a greather change in fecal bifidobacterial counts and increases stool wet weight: a double blind, randomized controlled crossover study. Nutrition Research. 2018. 60: 33-42
  - Watanabe, Norikazu, et al. "Effects of resistant maltodextrin on bowel movements: a systematic review and meta-analysis." Clinical and experimental gastroenterology 11 (2018): 85.
- ***High Amylose Starch (RS2)***
  - Hughes RL, et al. Resistant starch type 2 from wheat reduces postprandial glycemic response with concurrent alterations in gut microbiota composition. Nutrients. 2021.