What's Exciting in the Way of Whey?

Don Otter
Center for Dairy Research
University of Wisconsin-Madison

A Dairy Australia/ National Centre for Dairy Education webinar

Center for Dairy Research *"Solution Based Research Backed by Experience, Passion and Tradition"*

New Zealand Dairy Inc.

Kiwi Entrepreneur (Donald Duck McOtter)

- Bought 10,000 hectares ($200m)
- Milking 20,000 cows
- 1,000,000 L/day milk
- Built cheese plant
- 100,000 kg/day cheese ($0.15m)
- 900,000 L/day whey (TS 6.5%)

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- 900,000 L/day whey (TS 6.5%)
- Plonked a bag of money down

- **Make me a billion dollars with the whey!**

How to Make a Billion!!!

- Nonfat Dry Whey $0.13/kg = $14,625 (187 yrs)

- Protein (0.8 %wt/wt) = 3273 kg

Protein (Sigma)	Percent (%)	Amount (kg)	Price ($/g)	Total ($)
β-Lactoglobulin	51	1669	100	$167,000,000
α-Lactalbumin	19	622	500	$311,000,000
Lactoferrin	1	32.7	4000	$131,000,000
Lactoperoxidase	0.25	8.2	12000	$98,000,000
Osteopontin	0.15	4.9	8,000,000	$39,300,000,000

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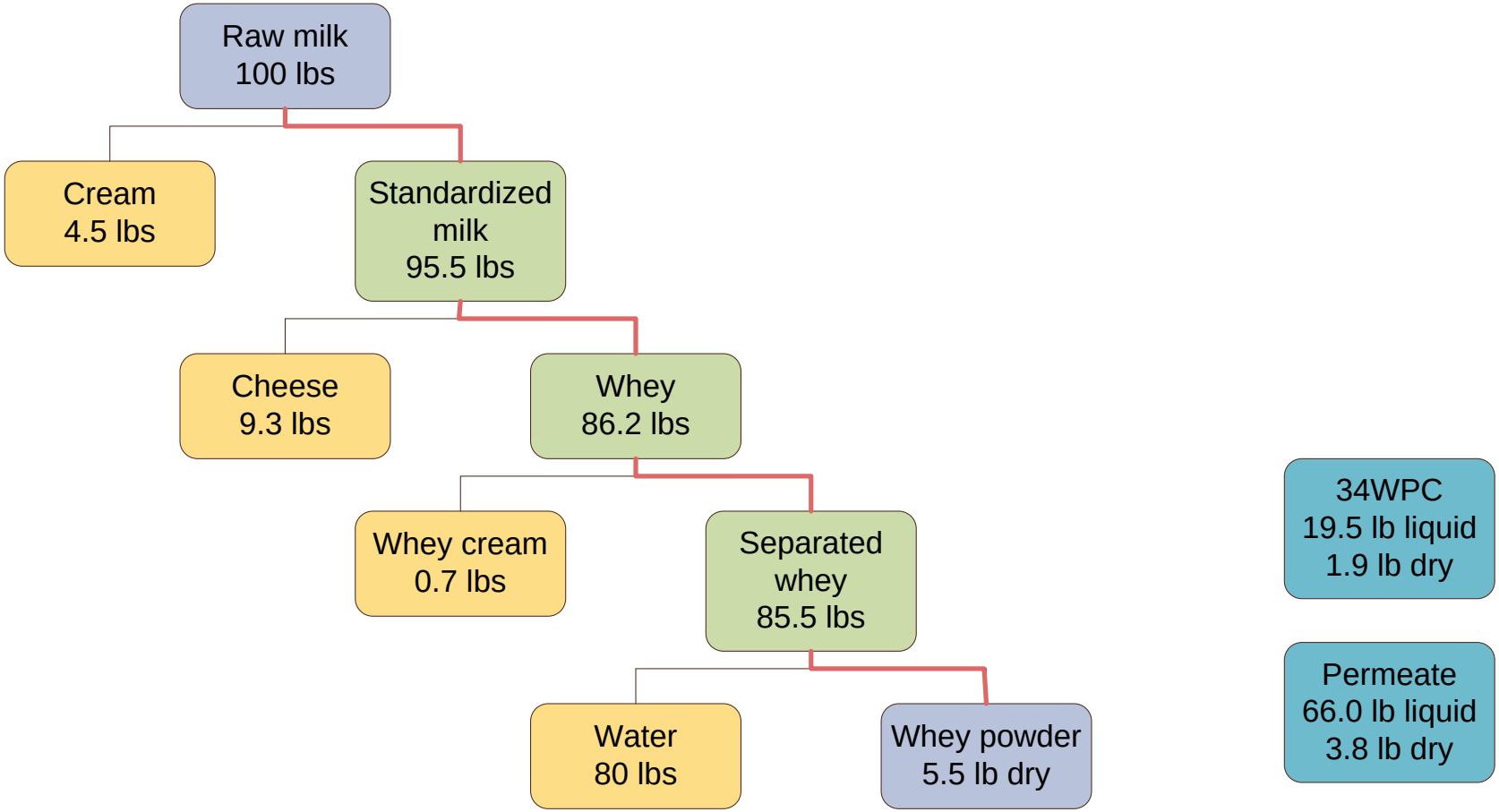
- BUT – you need a market/buyer

Product Mix

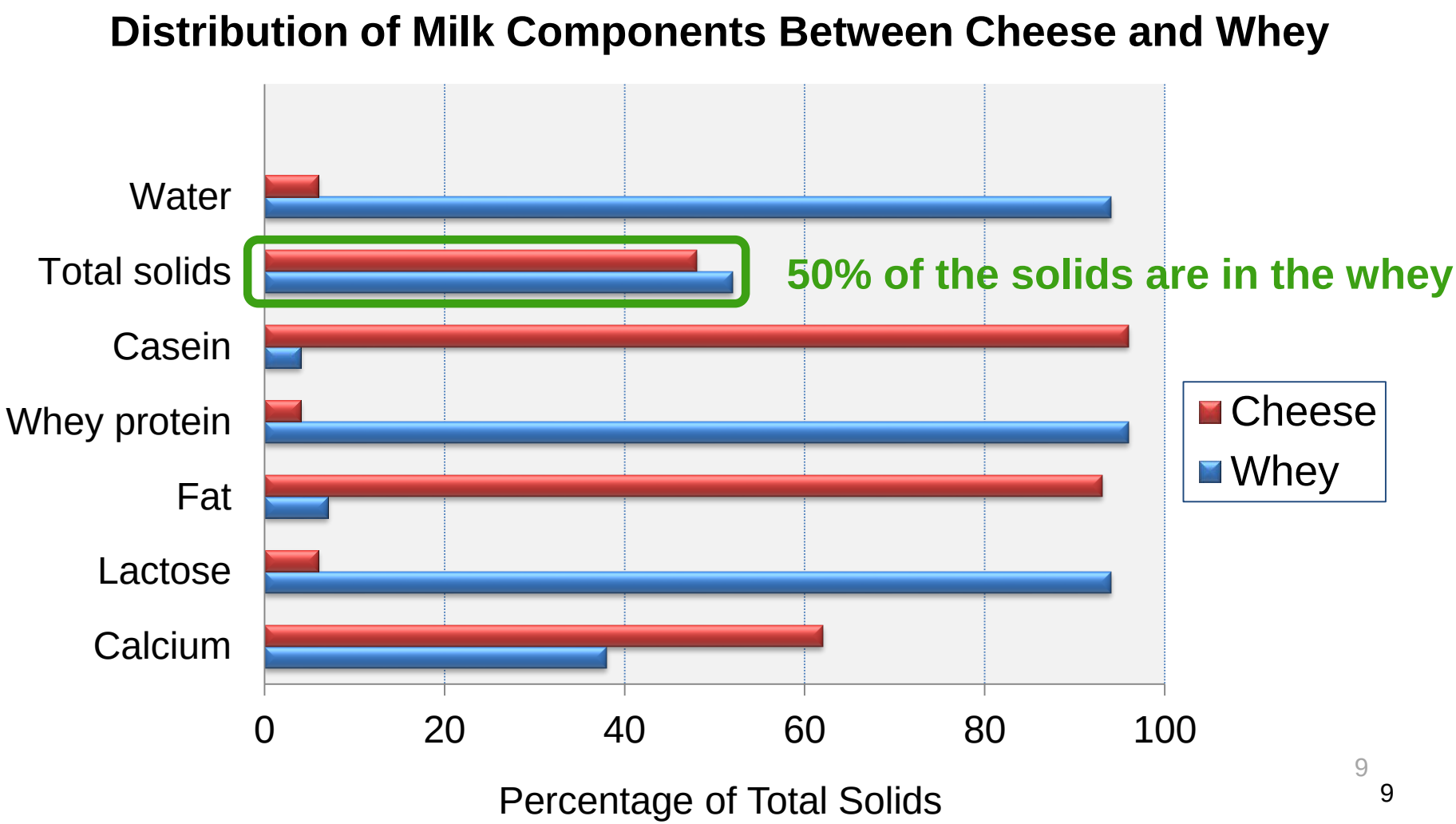
- Commodities
  - High volume
  - Low value
  - Low production costs
- Value-added
  - Low volume
  - High value
  - High production costs

- Fertilizer
- Fuel
- Feed
- Food

Mozzarella Cheese and Byproducts



Why Process the Whey?



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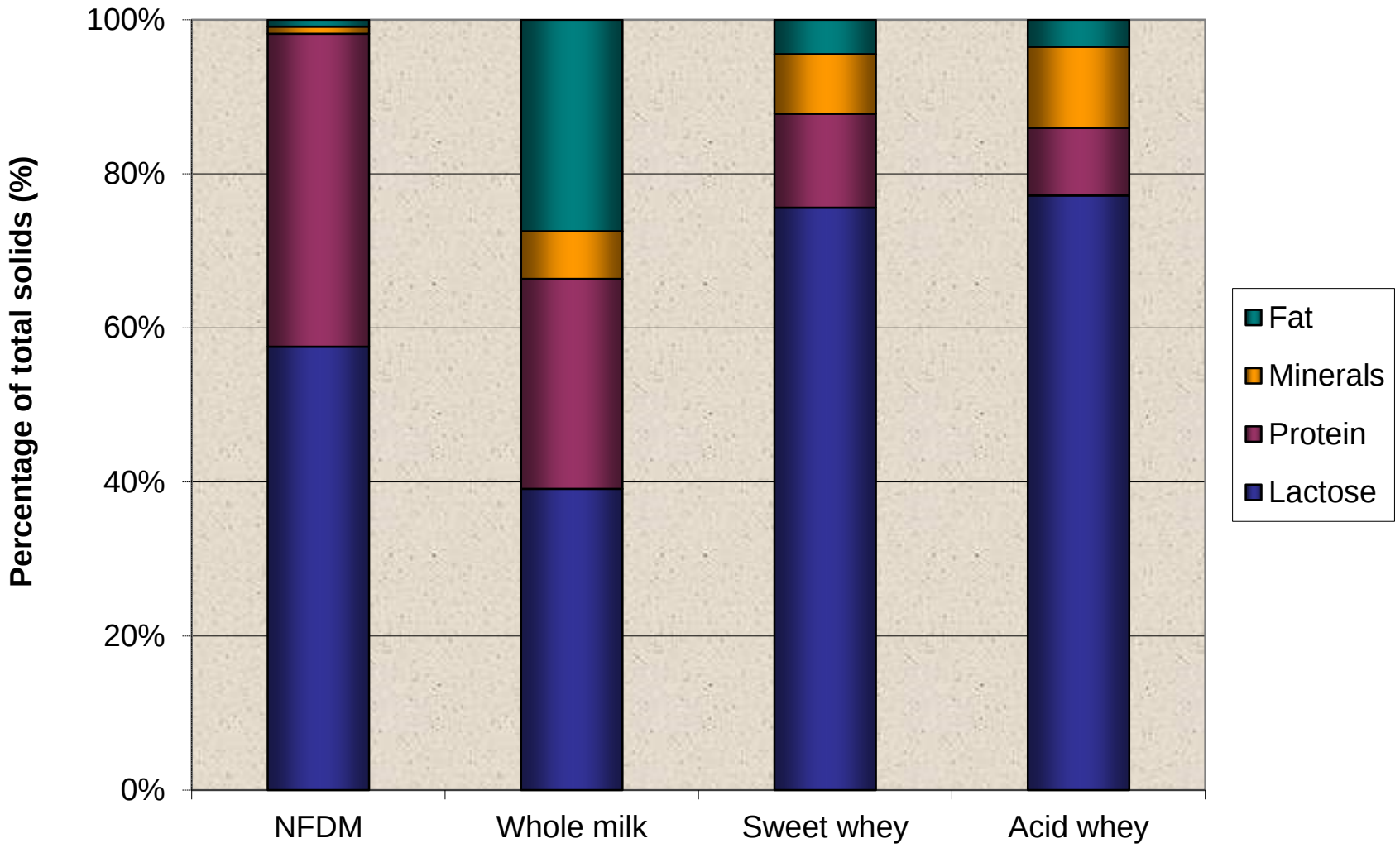
Types of Whey

- Sweet
  - Whey - insignificant conversion of lactose to lactic acid
  - < 0.16% titratable acidity,
  - Contains glycomacropeptide (GMP)
  - Examples: Cheddar, Mozzarella
- Acid
  - Whey - significant lactose converted to lactic acid, or from curd formation by direct milk acidification
  - > 0.35% titratable acidity
  - No GMP unless rennet is used
  - Examples: Cottage, ricotta, cream

Types of Whey (continued)

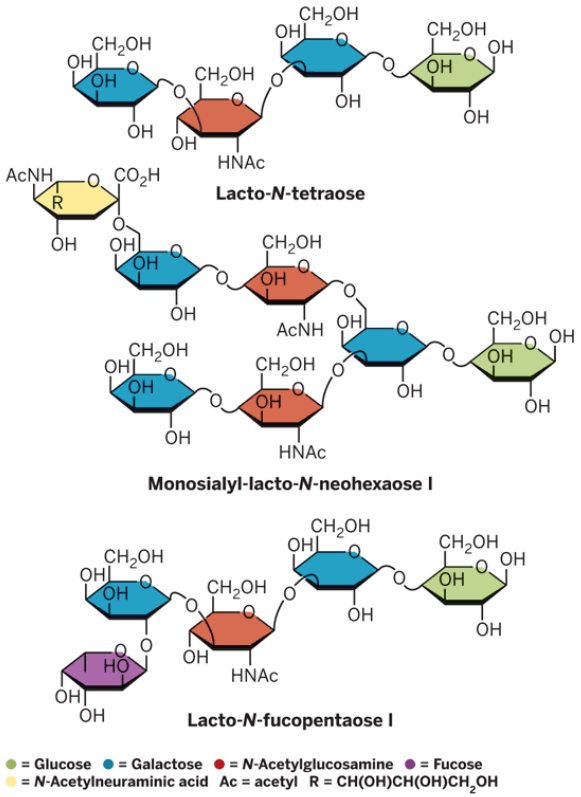
- Fermented
  - Sweet whey that has a lower pH due to action of cheese starter culture
  - Typically undesired
  - Calcium content of sweet whey
- Salty
  - Whey released from salted cheese during pressing
  - Contains high levels of salt
  - Use/disposal problem

Composition of Milk and Whey



What Else is in Whey?

- Oligosaccharides
- Enzymes (proteins)
  - Lactoperoxidase
  - Lysozyme
- Growth factors
  - IGF-1
  - TGF-β
- Vitamins (water soluble)
- Etc…



Options for the Use of Whey

Increasing Value and Complexity to Produce

- Individual proteins
  - Lactoferrin
  - GMP
- Oligosaccharides
- Whey protein isolates
- Lactose
- Whey protein concentrates
  - WPC 80
  - WPC 34
- Whole whey
- Feed
- Land application

Nutritional Aspects of Whey Proteins

- Contain all of the essential amino acids
- High PDCAAS (Protein Digestibility Corrected Amino Acid Score)
- High in branched chain amino acids (leucine, isoleucine and valine)
- Helps build and maintain muscle
- Infant formula (hydrolysates)
- Oligosaccharides
- GMP – no phenylalanine – phenylketonuria

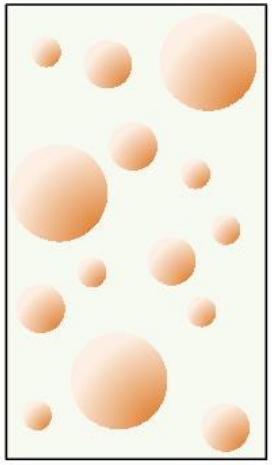
Functional Components

- Protein – most important component
  - Gelation, solubility, water binding, emulsification, nutrition
- Minerals
  - Calcium
- Lactose
  - Browning, slight sweetness

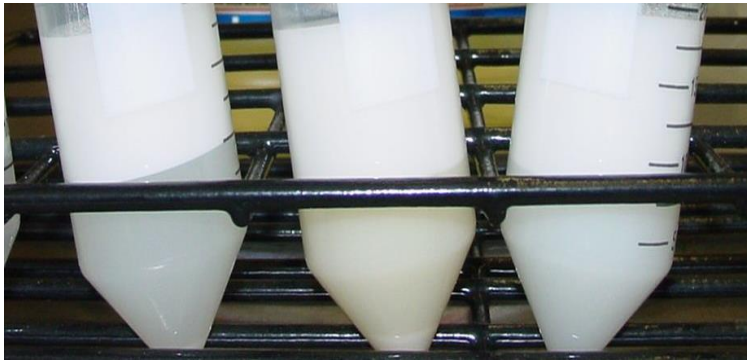
Processes used to produce the ingredient may alter functional properties

Functional Properties of Whey Proteins

- Solubility
  - Undenatured form soluble over wide pH range
  - Not heat stable
- Emulsification
  - Whey proteins have both hydrophilic and hydrophobic areas



stable emulsion



Functional Properties of Whey Proteins

- Whipping and foaming
  - Related to emulsification

Foaming ability

Foam stability: collapse over time

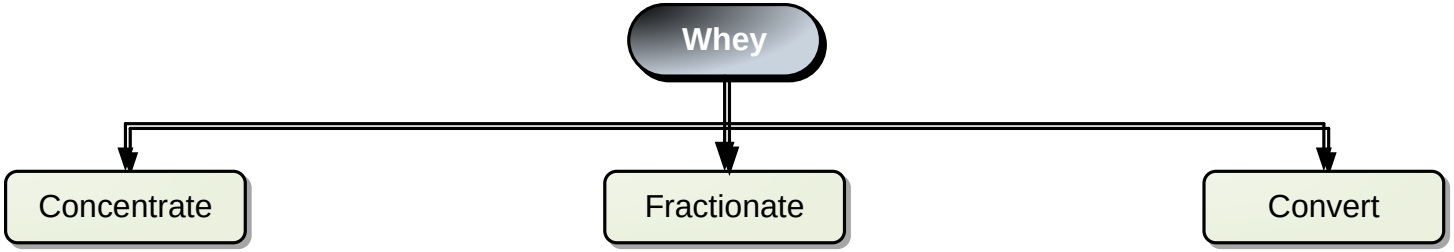
Water Binding/Gelling

- Whey proteins have low viscosity compared to other proteins
- Viscosity increases with heat treatment
- Can form gels at higher protein concentrations

Functional Properties of Lactose

- Absorbs and enhances flavors
- Absorbs pigments
- Browning - bakery and confections
- Tableting agent
- Fermentation substrate

Some Processing Options for Whey



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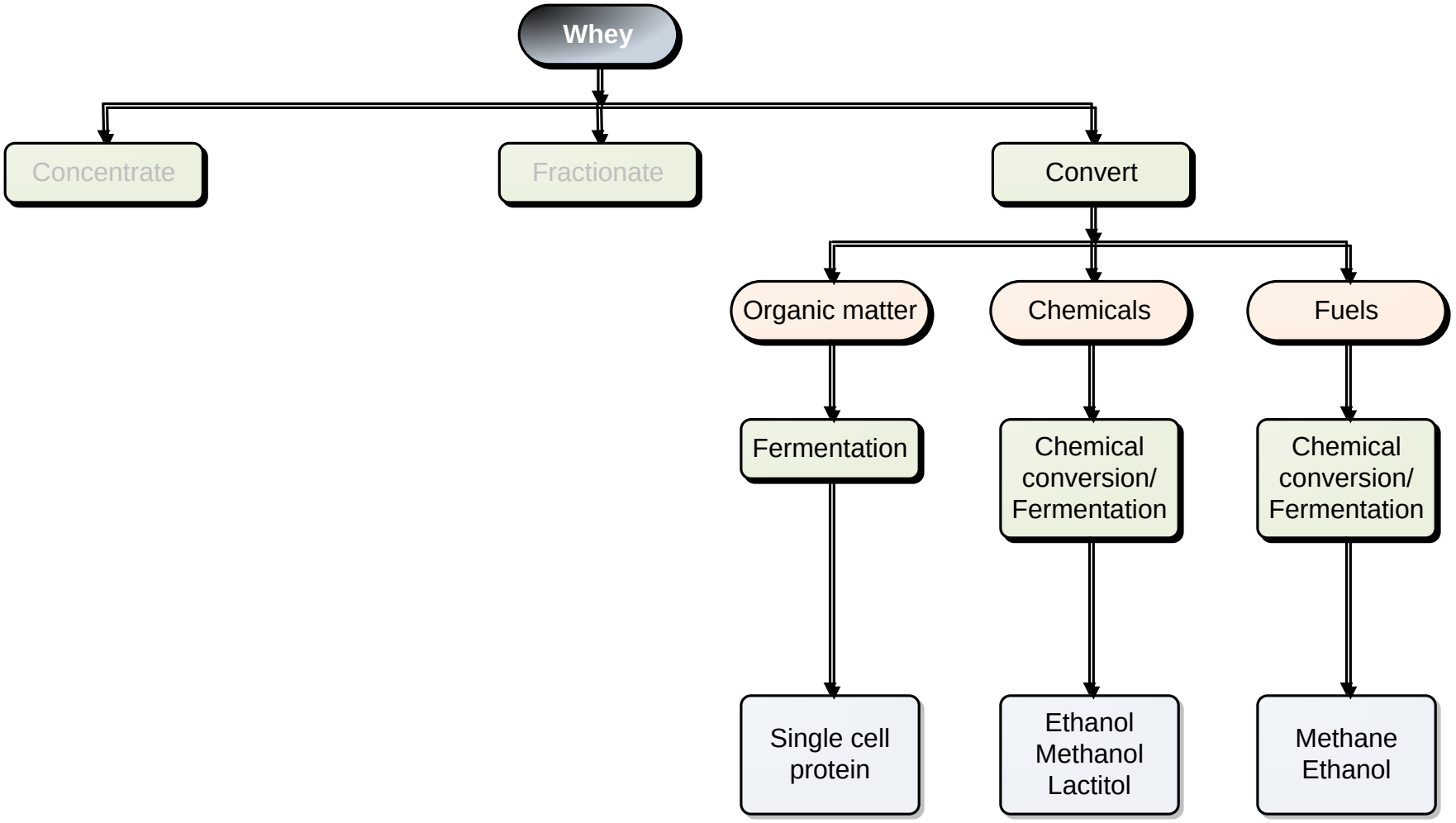

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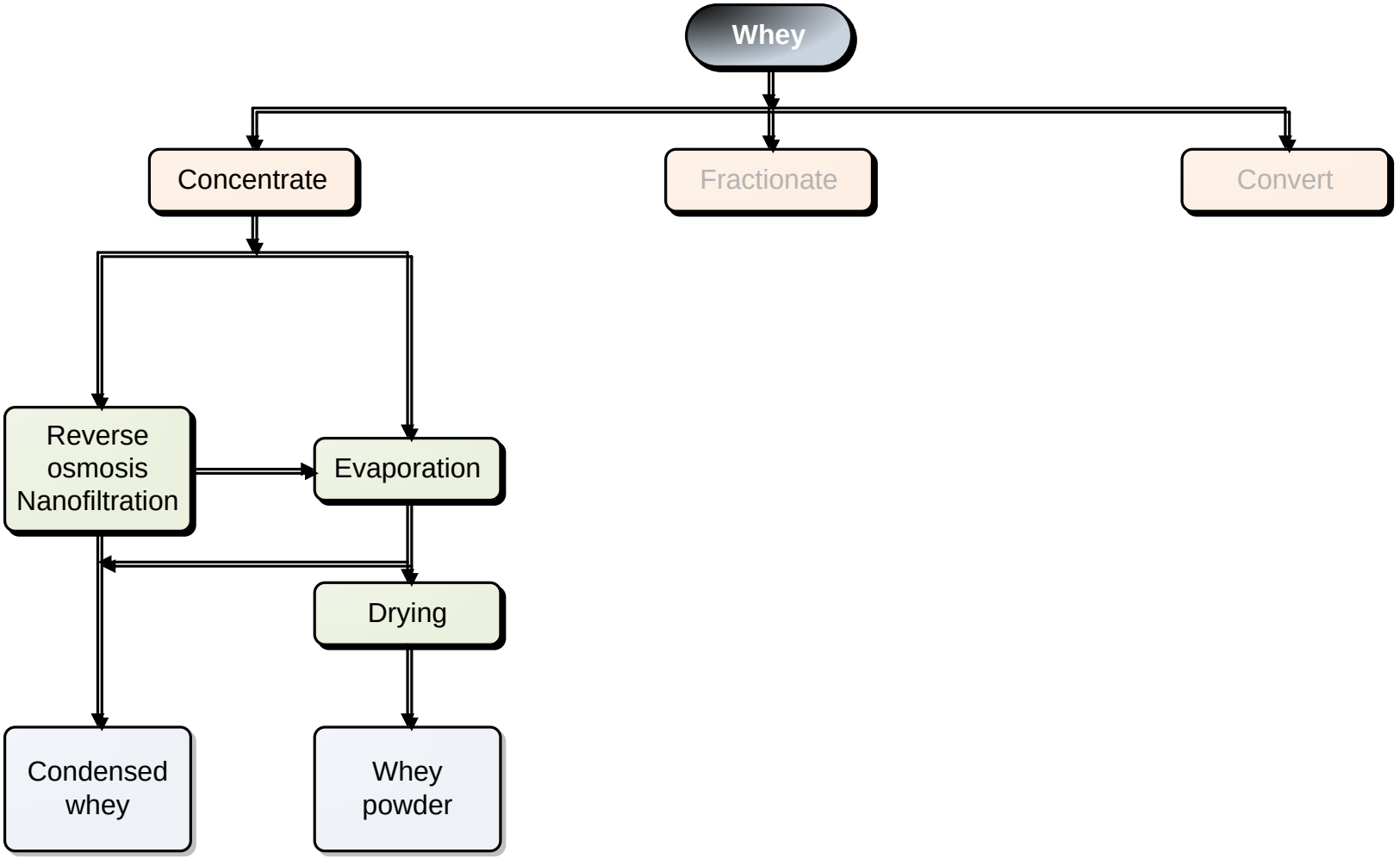

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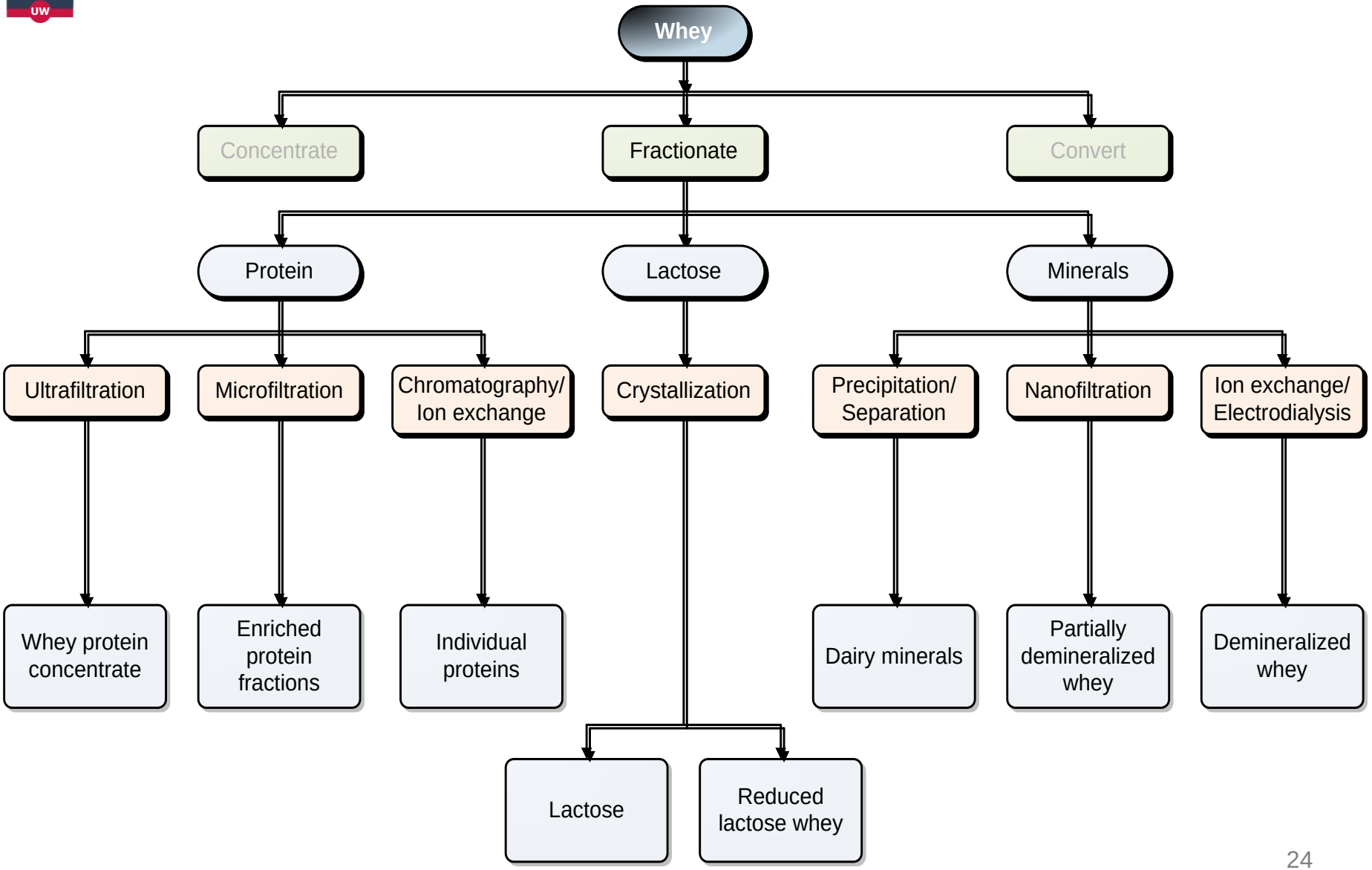
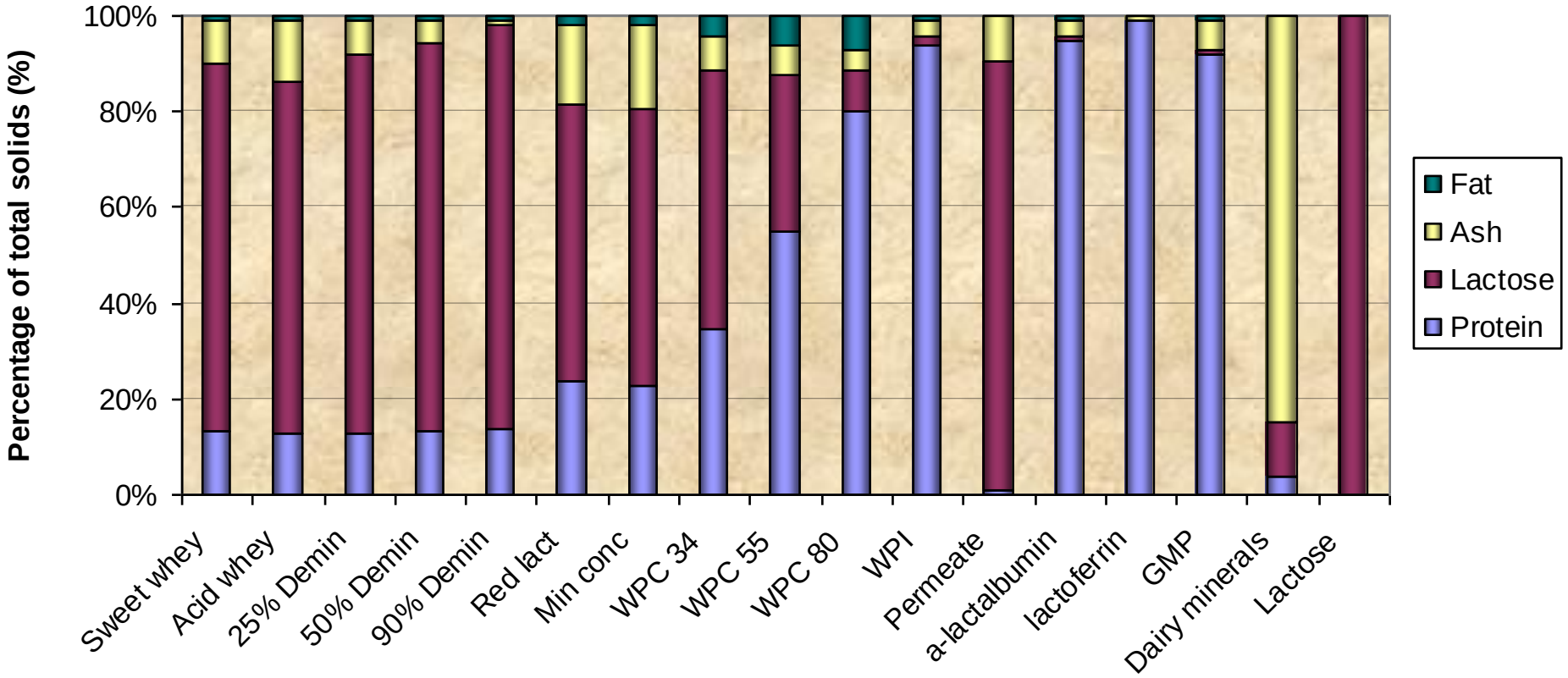


Whey Products

- Condensed/dried whey
  - sweet, acid
- Demineralized whey
  - 25, 50 and 90%
- Reduced lactose whey (mineral-concentrated)
- Whey protein concentrate
  - 34, 50, 60, 75 and 80%
- Whey protein isolate
- Lactose hydrolyze whey
- Protein hydrolyzed whey

- Lactose
  - industrial, food and pharmaceutical
- Lactose derivatives
  - lactitol, lactulose and galacto-oligosaccharides
- Individual proteins
  - lactoferrin, lactoperoxidase and glycomacropeptide
- Dairy minerals
- Permeate

Composition of dairy ingredients made from whey



What else can we do?

Composition of Milk

Robert Jenness

Milk is secreted by all species of mammals to supply nutrition and immunological protection to the young. It performs these functions with a large array of distinctive compounds. Interspecies differences in the quantitative composition of milk (Jenness and Sloan 1970) probably reflect differences in the metabolic processes of the lactating mother and in the nutritive requirements of the suckling young.

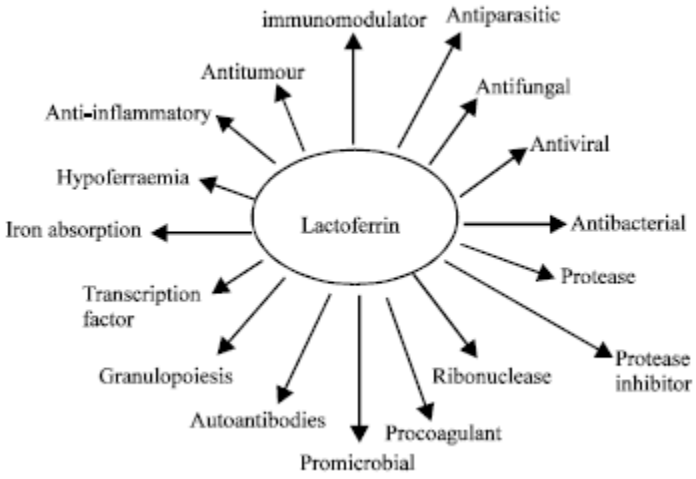
In the United States, milk is defined for commercial purposes as the lacteal secretion, practically free from colostrum, obtained by the complete milking of one or more healthy cows, which contains not less than 8.25% of milk-solids-not-fat and not less than 3.25% milk fat. Minimal standards in the various states may vary from 8.0 to 8.5% for milk-solids-not-fat and from 3.0 to 3.8% for milk fat (U.S. Dept. Agr. 1980).

CONSTITUENTS OF MILK

Milk consists of water, lipids, carbohydrates, proteins, salts, and a long list of miscellaneous constituents. It may contain as many as 10^5 different kinds of molecules. Refinement of qualitative and quantitative techniques continues to add new molecular species to the list. The constituents fall into four categories:

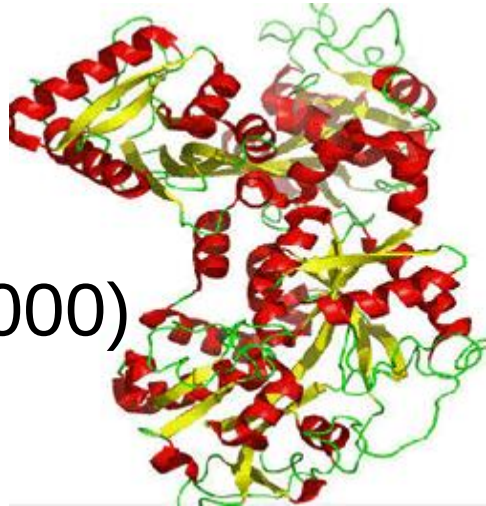
N. P. Wong et al. (eds.), *Fundamentals of Dairy Chemistry*

1 million ‘bits’ but what products…



Protein

- Over 100 proteins/enzymes
- Lactoferrin – IEX, whey stream
- MFGM
  - Anti-inflammatory properties
  - Membrane proteins and phospholipids
  - Multiple health benefits for infants
- Proteose peptones
- CMP (GMP) – phenylketonuria (1:10,000)
- Hydrolysates/Peptides - bioactivity



Sugars and NPN

Sugars

- Lactose
- GOS
  - IF
  - Prebiotic
- Oligosaccharides
  - IF
  - EFSA, safe, efficacy?
- Lactose laurel ester – antimicrobial

NPN

- Urea (~50%), ammonia
- α-Amino acid, peptides
- Creatine, creatinine
- Uric acid, orotic acid, hippuric acid

Growth factors

- IGF, TGF, PDGF, FGF

Minerals

- Calcium
  - Bioavailability
  - High adsorption rate
- Phosphate
- Alamin 995, 996, 997
- Capolac
- What's new?

- Salt replacer

Table 1 Components and mineral components of Alamin996.

Conponents of Alamin996 (%)	
Moisture	2.88
Ash	79.63
Protein	6.55
Fat	0.69
Lactose	2.92
Others	7.33
Mineral conponents of Alamin996 (mg%)	
Na	431.01
K	248.41
Ca	29.25
Mg	1127.99
P	15.79
Cl	151.46

Arla Foods Ingredients products

- α-Lactalbumin
- Casein glycomacropeptide
- Functional Milk Proteins
- Hydrolysates
- Lactose
- Milk minerals
- Osteopontin
- Phospholipids
- Phospholipids & MFGM
- Permeate
- Whey protein concentrate
- Whey protein isolate

High Protein Products

- High protein aseptic milk
- Smoothies (with fruit)
- Protein
  - Bars
  - Gels
  - Powder
  - Shakes
- Yogurt – drinkable,
- Kefir
- Whey cheese
- Ice cream – high protein without hardening
- Whey cheese, ricotta

Whey Bioactivity

- Muscle mass/ recovery
- Weight management/loss
- Enhance the immune system
- Food intake/satiety
- Lower blood pressure
- Anti-microbial, anti-viral
- Peptides/hydrolysates
- Sarcopenia

Red Whey is a recovery drink (tart cherry juice and whey protein beverage) that is made in Wisconsin, with Wisconsin products, for Wisconsinites, namely UW-Madison student-athletes and was developed by the Wisconsin Center for Dairy Research (CDR).

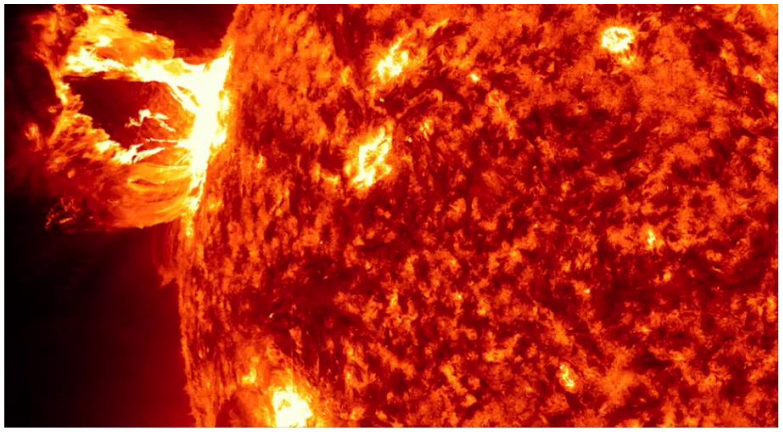
Clinical Studies – story to tell

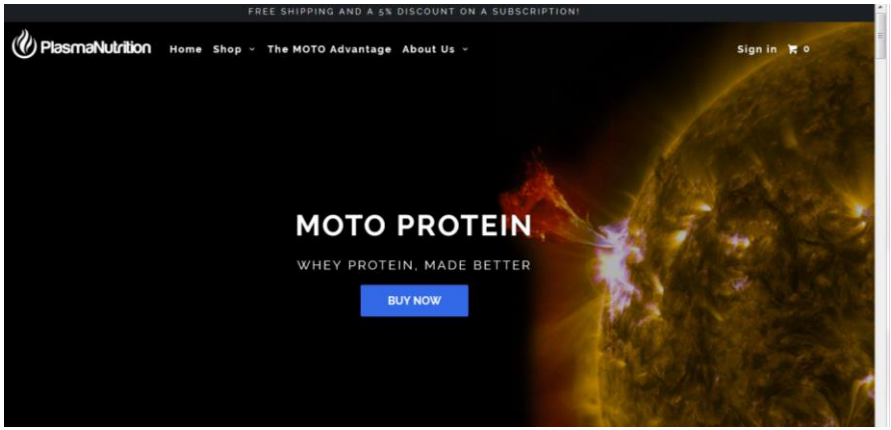
Functional Ingredients

- Functional
  - Foaming
  - Gelling
  - Emulsification
  - Water binding
  - Solubility
  - Microstructures
  - Texturizers
- Altered functionality
  - High intensity ultrasound
  - Pulsed electric field
  - HPP
  - Gas plasma processing
  - Conjugation/cross-linking
  - Individual whey proteins e.g. PP3

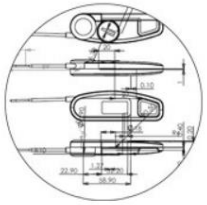
New Product Potential

Plasma Whey Powder





After over four years of development and with five patents pending, Plasma Nutrition has created a brand new state of protein powder. Unlike the three ordinary types of protein powders traditionally available (isolate, concentrate and hydrolyzed), Plasma Nutrition has created an unprecedented fourth state of protein powder through the application of gas plasma (similar to the surface of the sun): MOTO Protein Powder. Using the latest research and a patent pending processing application, we offer our customers unparalleled advancements through:



OVER 5 PATENTS PENDING

We have over 5 patents pending on our method of using plasma to make Whey Protein better. Only product In the world to increase Protein solubility by 71%, hydrophobicity by 27% and surface area by 26%.

180% GREATER MUSCLE GAIN AND 96% STRENGTH GAIN

A study conducted by Baylor University showed that a blend of whey isolate and casein allowed participants to gain nearly 4 more pounds of lean muscle mass compared to 100% whey alone.

71% INCREASE IN SOLUBILITY

We are the only protein powder that is able to increase solubility by 71%. This improves mixability and maximizes bioavailability.

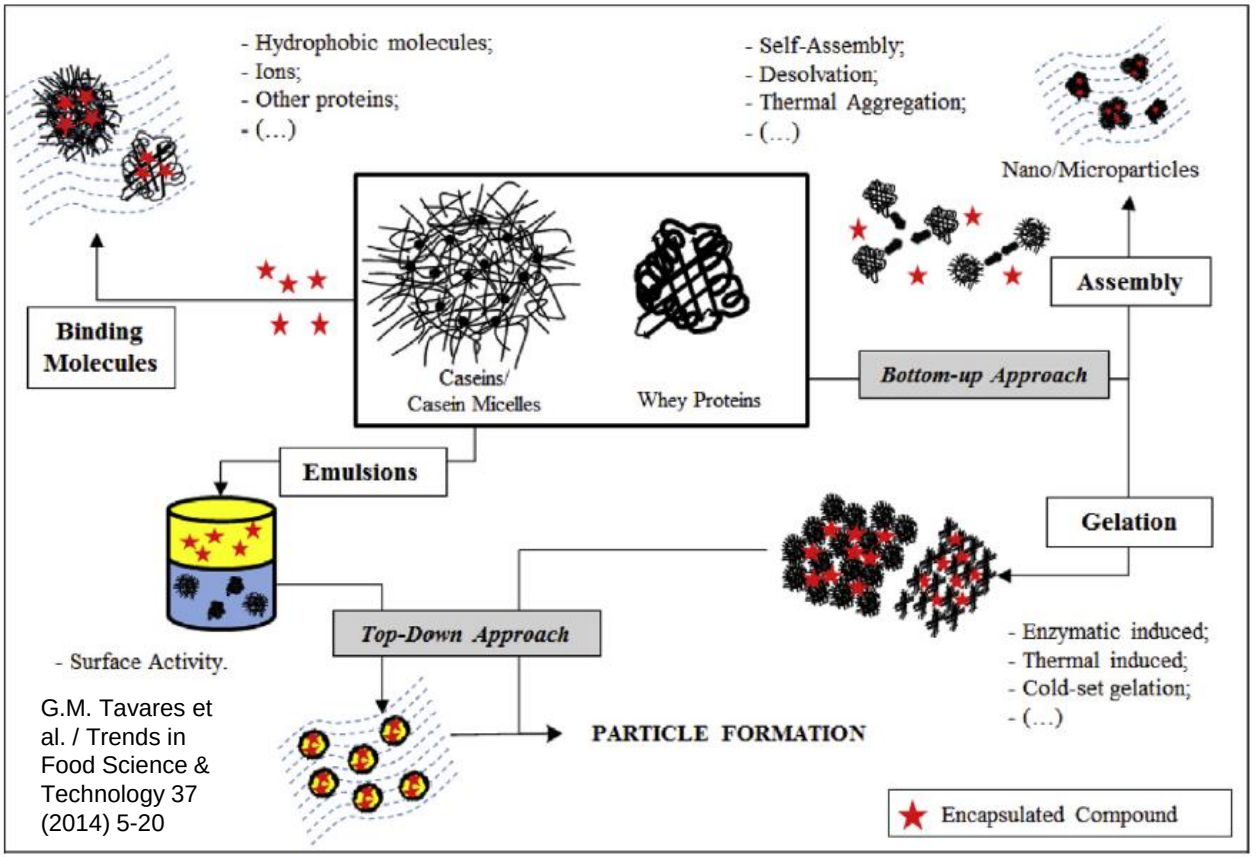
27% BETTER HYDROPHOBICITY AND SURFACE AREA

We use atmospheric plasma to increase absorption and improve digestibility by increasing exposure to digestive enzymes.

http://www.plasmanutrition.com/

Encapsulation by Whey Proteins

- Curcumin WPI microencapsulation J Food Eng 169 (2016) 189-195
- Polyphenol WPI meso-structures Food Funct., (2016), 7, 1306-1318
- Electrospinning WPC Innovative Food Science and Emerging Technologies 13 (2012) 200–206
- Vitamins
- Flavor compounds
- Minerals
- Drugs
- Oils



G.M. Tavares et al. / Trends in Food Science & Technology 37 (2014) 5-20

WPI Biofilms

- Edible antimicrobial films from WPI, hydrolysed WPI and glycerol

  J Food Sci., 2013, 78(4), M560-M566

- Activate-at-home WPI and lysozyme for smoked salmon

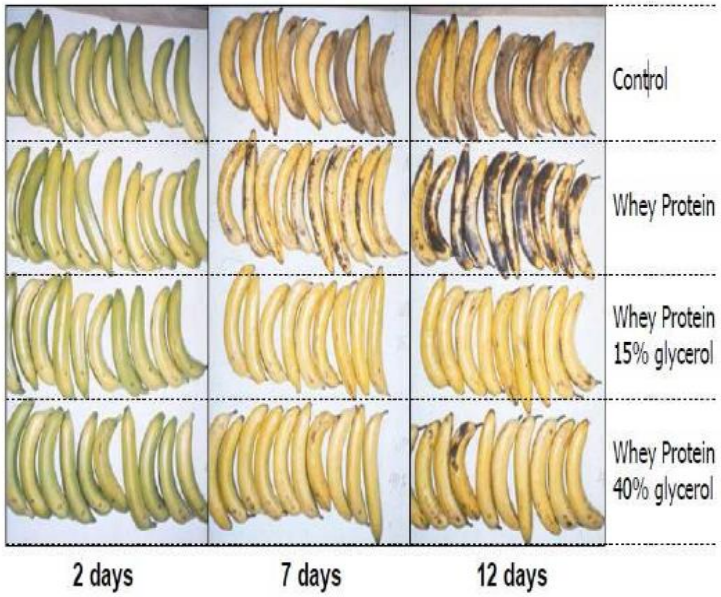
  Food Hydrocolloids 60 (2016) 170e178

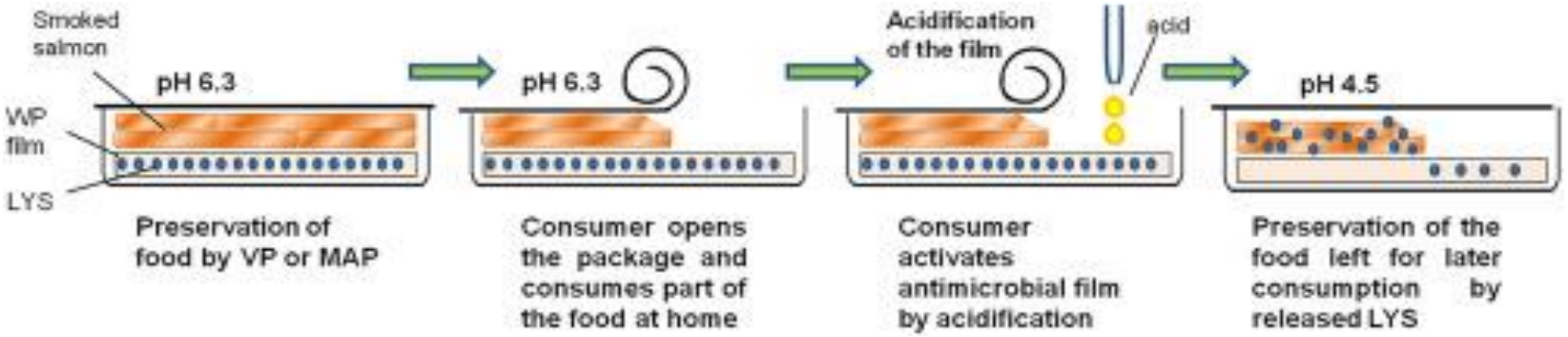
- Moisture-permeable cheese membranes to pack and preserve cheeses?

  J Sci Food Agric 2016; **96**: 2328–2336

Food Science and Quality Management
ISSN 2224-6088 (Paper) ISSN 2225-0557 (Online)
Vol 3, 2012

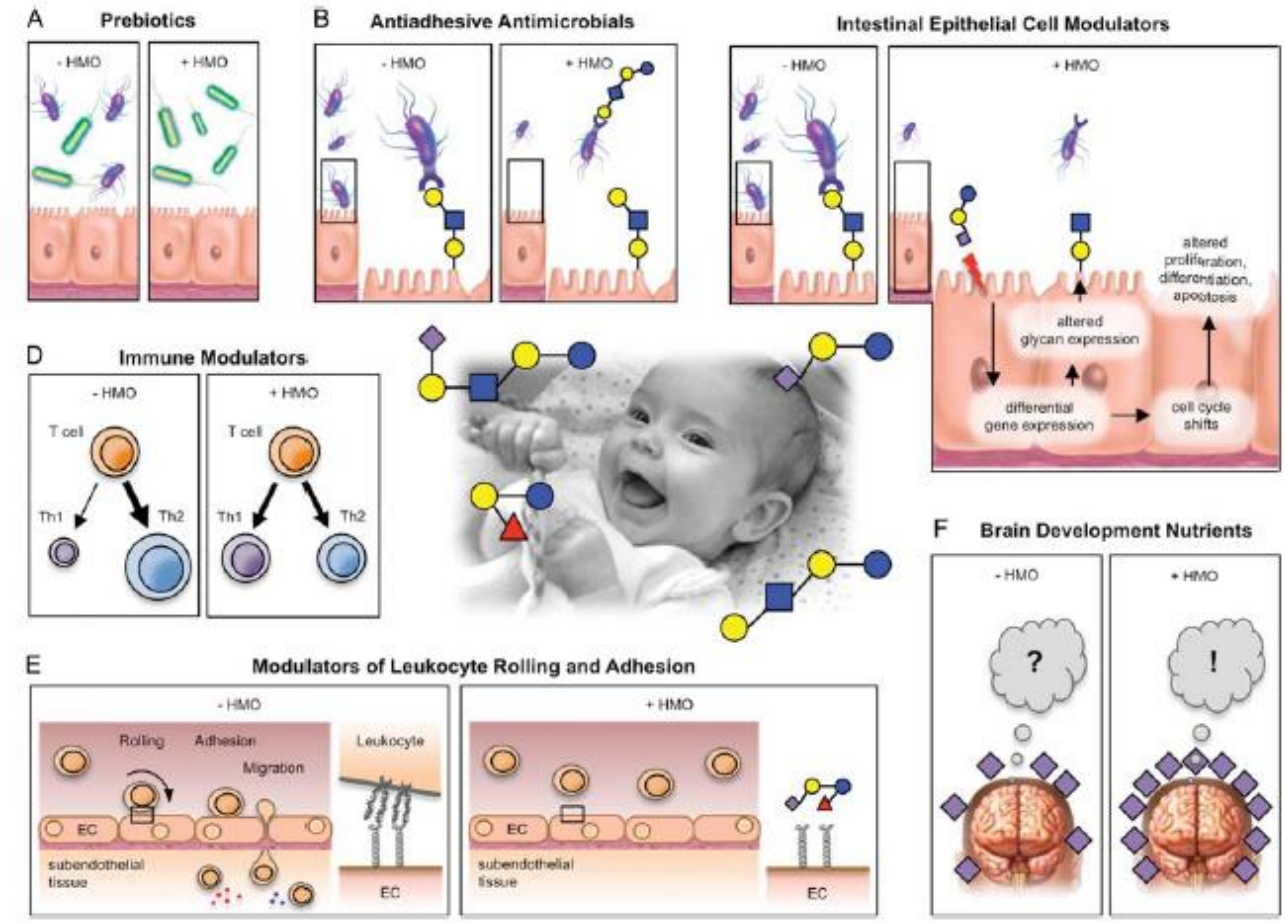
5:*Coatings can reduce physical changes in the fresh-cut product*





Oligosaccharides

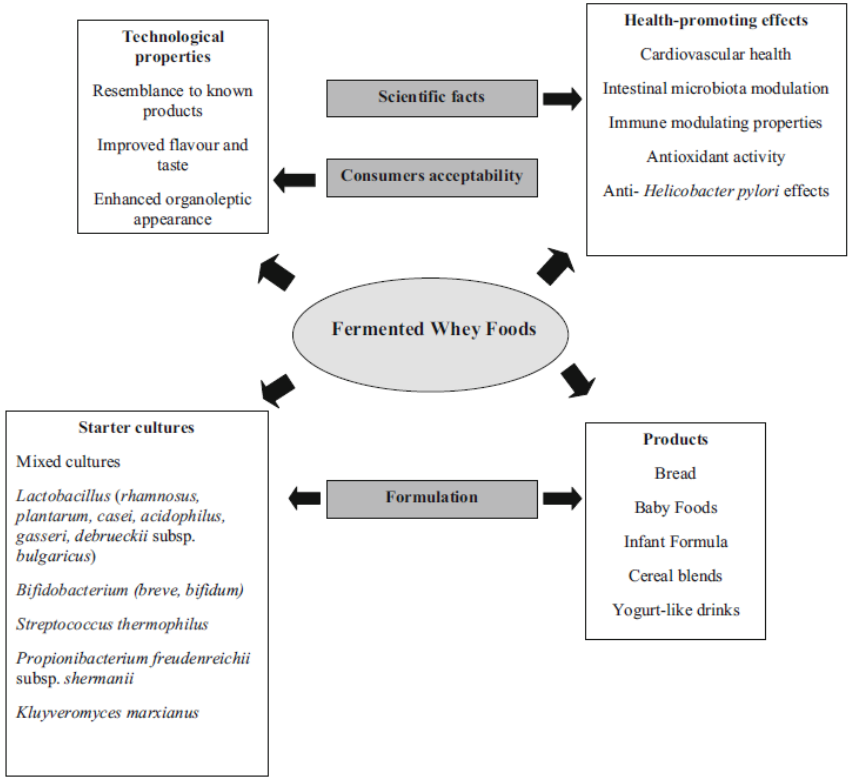
- Mimic human breast milk OS in infant formula
- Purification by filtration procedures
- Complexity
- Efficacy?
- Hilmar
- GOS



Glycobiology vol. 22 no. 9 pp. 1147–1162, 2012

Whey/Permeate Fermentation

- Bacterial and yeast
- Algae
- Biofuels
- Cost effective

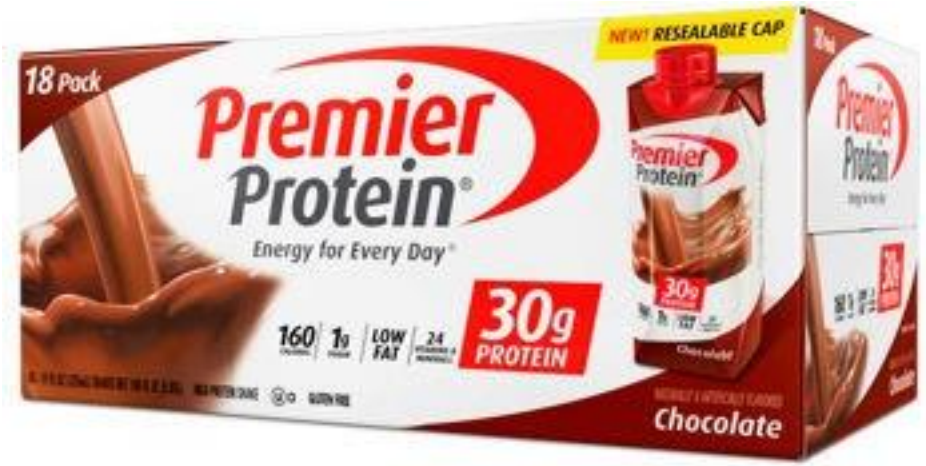


Appl Microbiol Biotechnol (2015) 99:6183–6196

- Bioactive compounds
- Exopolysaccharides
- Malleable protein matrix decreases TAG in metabolic syndrome patients British Journal of Nutrition (2012), 107, 1694–1706

Weight Management

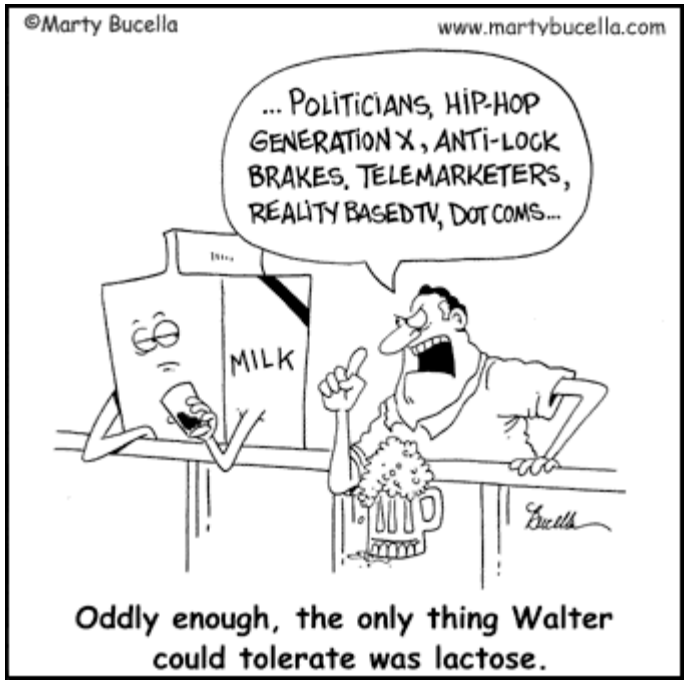
- Both putting weight on and reducing weight
- Higher protein diet promotes greater lean mass gain and fat mass loss Am J Clin Nutr 2016;103:738–46 & JAMDA 13 (2012) 713e719
- Age affects
- Satiety
- Palatability



Lactose products

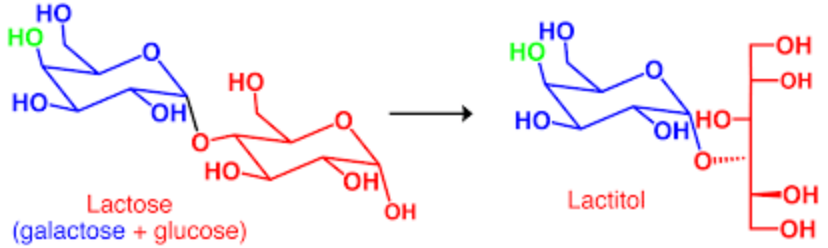
- Current products - Alcohol
- GOS
- Hetero-oligosaccharides
- Conversion products
- Green plastics
- Conjugates
- LP

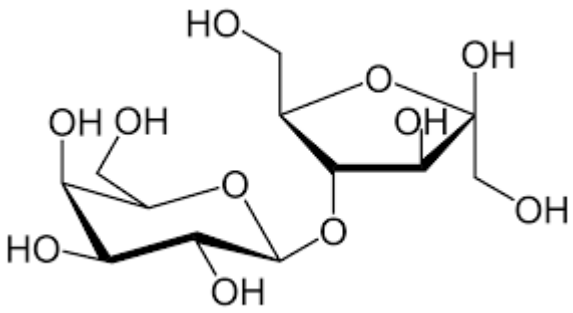
- Good
- Bad
- Nutrient value
- Functionality

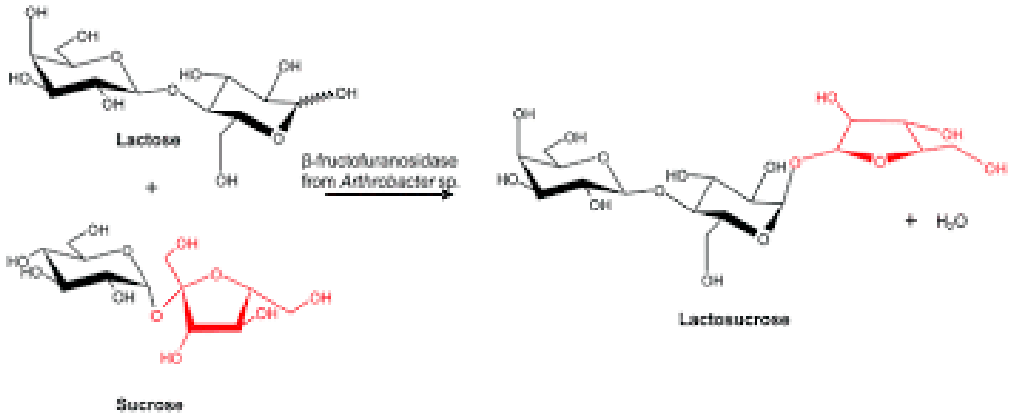


Commercial lactose derivatives

- Galactooligosaccharides (GOS)
- Lactitol – artificial sweetener – E966
- Lactulose - laxative
- Lactosucrose
- Lactobionic acid



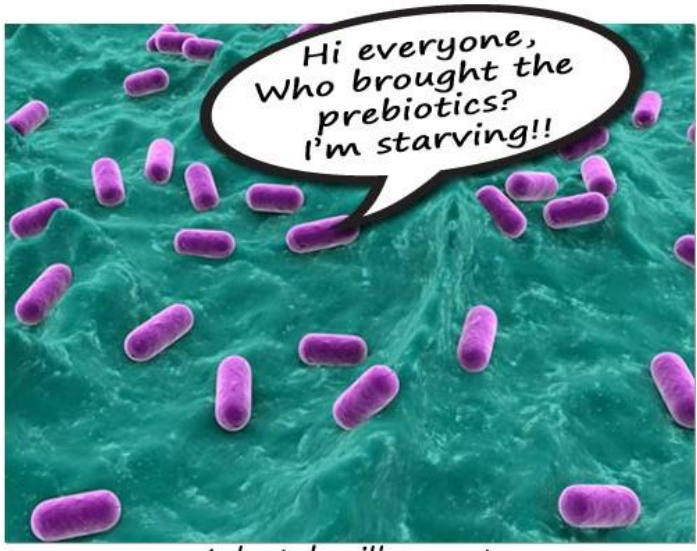




GOS

- β-Linked oligosaccharides with a degree of polymerization (DP) of 2 to 9
- Composed of galactose and may contain one glucose unit, typically at the reducing end
- Includes disaccharides though lactose is generally excluded because it is digestible in human infants
- Produced by β-galactosidase (β-Gal)-catalysed transgalactosylation with lactose as glycosyl-acceptor and -donor

GOS

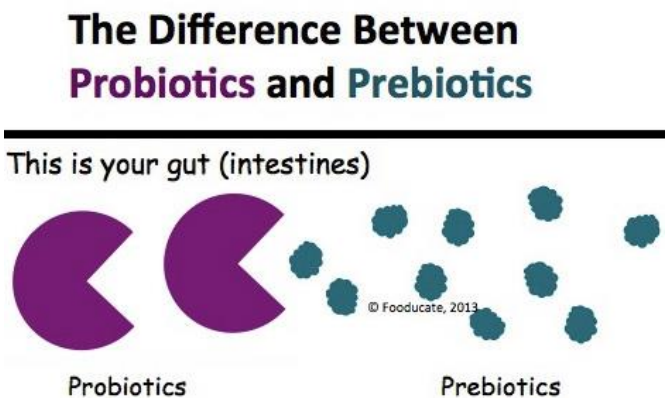


A lactobacillus party

- Low caloric and non-cariogenic
- Prebiotic properties
- Prevent attachment of some pathogens to intestinal cells
- Binding of toxins and/or pathogens
- Based on human milk oligosaccharides (HMO)
- Modulate infant microbiota
- Stimulate the immune systems
- Used in infant formula to mimic functions of HMO

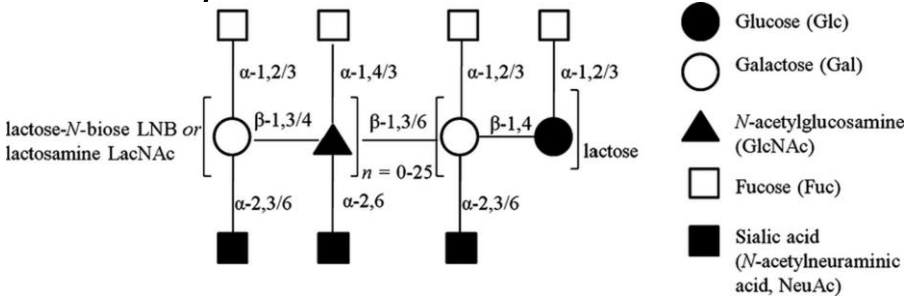
GOS

- Prebiotic health benefits are increasingly thought to relate to the function rather than the composition of intestinal microbiota
- Lactose and GOS are metabolized to short chain fatty acids, which are major mediators of physiological benefits of dietary fibre and non-digestible oligosaccharides
- Health claims for prebiotic carbohydrates are not approved in the U.S., Canada, or the EU



Hetero-oligosaccharides

- Structural and/or functional similarity to human milk oligosaccharides
- Transglycosylation of lactose with enzymes other than β-Gal
- Sialidase, glucansucrase, fructansucrase or α-fucosidase
- N-Acetlyglucosaminidases can transfer a GlcNAc residue onto lactose, to build the core structure of HMOs

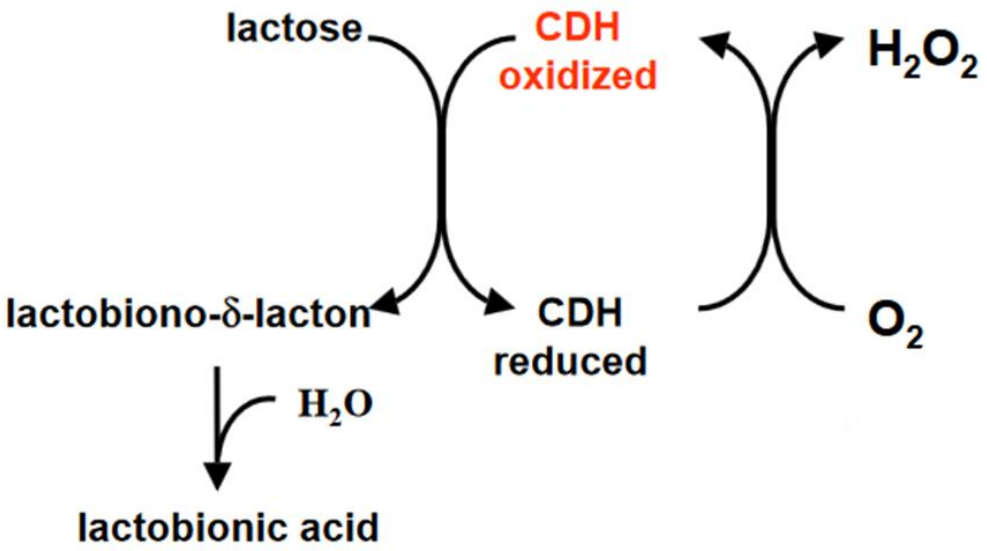


Hetero-oligosaccharides

- Prebiotic effects
- Fermentation to short-chain fatty acids by intestinal microbiota confers health benefits
- Other potent biological activities
- Direct immunomodulation
- Prevent binding of bacterial toxins or adhesins (*in vivo* studies)

Lactobionic acid

- C1 oxidation of lactose



- Skin care, pharmaceuticals, sport drinks, detergents

Table 3
Some options for lactose utilisation

Product	Applications
Acetic acid	Foods
Acetone	Various
Alcohol	Foods, energy
Amino acids	Various
Antibiotics	Medical
Butanol	Various
Citric acid	Foods
Food oils	Animal feeds
Fuel gas	Energy
Galactaric acid	Various
Galatonic acid	Various
Gibberellic acid	Plant hormones
Glucaric acid	Various
Gluconic acid	Various
Hydrolysed lactose	Sweetener, lactose malabsorbers
Itaconic acid	Various
Lactase	Enzyme applications
Lactic acid	Foods
Lactic polymers	Biodegradable plastics, prosthetics
Lactitol	Non-nutritional sweetener
Lactobionic acid	Chelating
Lactose crystals	Food, tablet binder
Lactose foams	Insulation
Lactose polymers	*Surfactants*
Lactosyl urea	Ruminant feeding
Lactulose	Infant nutrition
Malic acid	Various
Oligosaccharides	Medical
Polysaccharides	Food gums
Single cell protein	Various
Vitamins	Food fortiflcation

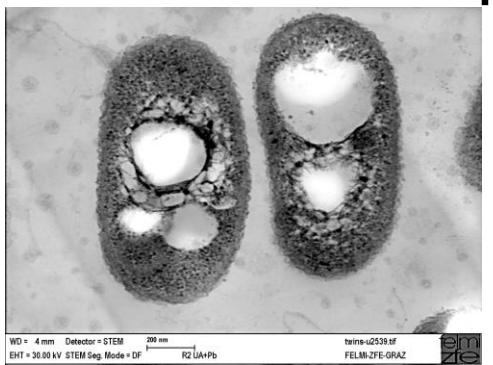
Zadow 1991 Food Research Quarterly, 51, 99-106

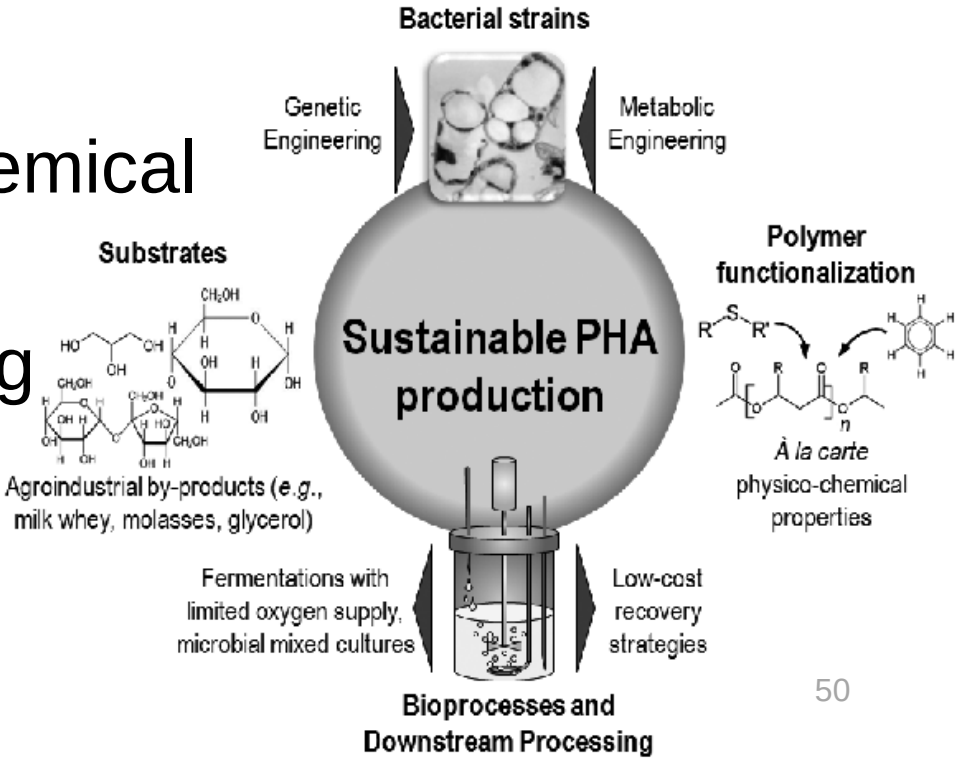
Green plastics

- Polyhydroxyalkanoate (PHA) biopolymers
- Bio-compatible
- Compostable
- Industrial applications:
  - Packaging (high O_2 barrier)
  - Paper coating
  - Medical applications
  - Vitamins, antibiotics
  - Biofuels

Green plastics

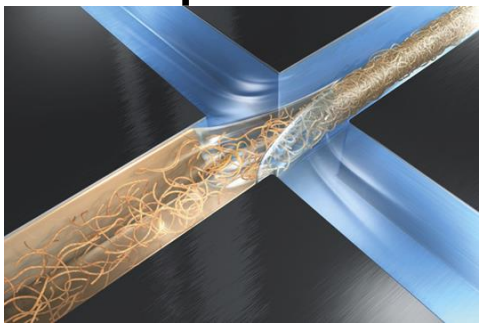
- Carbon feed stock for various microbial species
- Substitute for polyethylene (PE), polypropylene (PP), poly(ethylene terephthalate) (PET)
- GMO bacteria
- Competitive to petrochemical plastics(?)
- Downstream processing





Swedes spin silk from whey protein

- Or perhaps, like Rumpelstiltskin, we can spin whey into gold (or silk)
- Use whey protein nanostructures to form artificial silk



- Closely resembles the lightweight and elastic properties of silk.
- Uses include: biosensors or self-dissolving wound dressings.

https://phys.org/news/2017-01-scientists-artificial-silk-whey-protein.html#jCp

Will We Make $1 Billion?

- No shortage of new ideas, processes and products
- How do we make money from them?
- Technology push vs market pull
- Story to tell
- Economics
- Clinical trials
- Clean label

Thank you – any questions