Buttermilk: the valuable, yet overlooked food ingredient

David W. Everett, PhD
Leprino Foods Professor in Dairy Science
Director, Dairy Innovation Institute
California Polytechnic State University, San Luis Obispo
City of San Luis Obispo
Population 47,000
First settled by Chumash nation
Spanish mission settlers in 1772

Mission San Luis Obispo de Tolosa
(St. Louis, the Bishop of Toulouse)
Factors that affect milk composition

- Age of cow
- Breed of cow
- Stage of lactation
- Bacteriological state of milk
- Seasonality
- Diet of cow
- Milking frequency
- Processing effects: homogenization, storage temperature
What is buttermilk?

- High in lactose
- About ~1% fat, of which 1/5 are phospholipids
- Secondary product with low value (due to microbial counts)
- Good emulsifier (primarily due to casein contamination)
- May improve the flavour of low fat cheese
- Key ingredient: the milk fat globule membrane (MFGM)

**Table 17.1 Approximate Composition (% w/w) of Some Types of Powder**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Whole milk</th>
<th>Skim milk</th>
<th>Whey</th>
<th>Sweet cream buttermilk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>26</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Lactose</td>
<td>38</td>
<td>51</td>
<td>72</td>
<td>48</td>
</tr>
<tr>
<td>Casein</td>
<td>19.5</td>
<td>27</td>
<td>0.6</td>
<td>26</td>
</tr>
<tr>
<td>Serum protein</td>
<td>4.8</td>
<td>6.6</td>
<td>8.5</td>
<td>6.2</td>
</tr>
<tr>
<td>“Ash”</td>
<td>6.3</td>
<td>8.5</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>—</td>
<td>—</td>
<td>0.2–2</td>
<td>—</td>
</tr>
<tr>
<td>Water</td>
<td>2.5</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Market price of butter

US market price per lb

Global Dairy Auction

All prices in USD
Buttermilk powder market price

Results from the latest Trading Event
Event 197 / 3 October 2017

Change in GDT Price Index from previous event
-10.3%

Average price (USD/MT, FAS)
$1,804

Butter Milk Powder Prices

Global Dairy Auction prices

Product usage:
- Bakery products
- Frozen desserts
- Prepared dry mixes
- Beverages
- Frozen foods
- Dairy products
- Salad dressings
- Snack foods
- Cheese products

All prices in USD
U.S. regulations

• Dry buttermilk (DBM) is light cream in colour with a clean, pleasing, sweet dairy taste.
• Typically, dry buttermilk is obtained by drying liquid buttermilk that was derived from the churning of butter and pasteurized prior to condensing.
• DBM has a protein content not less than 30% (dry buttermilk product can be <30%)
• It may not contain, or be derived from, non-fat dry milk, dry whey or products other than buttermilk and contains no added preservative, neutralising agent or other chemical.
• By removing moisture to the greatest extent possible, microbial growth is prevented.
• Product should be stored and shipped in a cool, dry environment with temperatures below 27°C and relative humidity below 65%.
• Stocks should be rotated and utilized within 8-9 months.
• Applications include bakery products, frozen desserts, dry mixes, beverages, dairy products, frozen foods, salad dressings and snack foods.
# U.S. Extra Grade Dry Buttermilk (DBM)

**American Dairy Products Institute**

<table>
<thead>
<tr>
<th>Classifications</th>
<th>Fat</th>
<th>Moisture</th>
<th>Protein</th>
<th>Titratable Acidity</th>
<th>Solubility Index</th>
<th>Scorched Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spray Dried Extra Grade DBM</td>
<td>Min 4.5%</td>
<td>Max 4.0%</td>
<td>Min 30.0%</td>
<td>Min 0.10%</td>
<td>Max 1.25 mL</td>
<td>Max 15.0 mg Disc B</td>
</tr>
<tr>
<td>Atmospheric Roller Dried Extra Grade DBM</td>
<td>Min 4.5%</td>
<td>Max 4.0%</td>
<td>Min 30.0%</td>
<td>Min 0.1%</td>
<td>Max 15.0 mL</td>
<td>Max 22.5 mg Disc C</td>
</tr>
</tbody>
</table>

Standard Plate Count 75,000 cfu/g; Coliforms ≤ 10 cfu/g

Salmonella negative
Listeria negative
Coagulase positive Staphylococci <10 cfu/g
Yeast & Mold ≤ 100 cfu/g
U.S. **standard** grade dry buttermilk (DBM)

American Dairy Products Institute

<table>
<thead>
<tr>
<th>Classifications</th>
<th>Fat</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Spray Dried Standard Grade DBM</td>
<td>Min 4.5%</td>
<td>Max 5.0%</td>
<td>Min 30.0%</td>
<td>Min 0.10% Max 0.20%</td>
<td>Max 2.0 mL</td>
<td>Max 22.5 mg Disc C</td>
</tr>
<tr>
<td>Atmospheric Roller Dried Standard Grade DBM</td>
<td>Min 4.5%</td>
<td>Max 5.0%</td>
<td>Min 30.0%</td>
<td>Min 0.1% Max 0.20%</td>
<td>Max 15.0 mL</td>
<td>Max 32.5 mg Disc D</td>
</tr>
</tbody>
</table>

Standard Plate Count 75,000 cfu/g; Coliforms ≤ 10 cfu/g

- Salmonella: negative
- Listeria: negative
- Coagulase positive Staphylococci: <10 cfu/g
- Yeast & Mold: ≤ 100 cfu/g
Butter and buttermilk manufacture

**Figure 19.1** Example of butter making from ripened cream.

- **Figure 19.11** Butter microstructure at room temperature. Liquid fat is white. Membrane thickness is much (about 10 times) exaggerated. After H. Mulder and P. Walstra, *The Milk Fat Globule* (Wageningen: Pudoc, 1974).
Butter and buttermilk manufacture

Buttermilk powder available on a large scale, is inexpensive, but has functional problems.

Commercial cream separation

Microfiltration of skimmed buttermilk can be employed to reduce microbial counts.
Cream churning

**Figure 19.2** Stages in the formation of butter. Greatly simplified, not to scale. Black is the aqueous phase; white is fat. From H. Mulder and P. Walstra, *The Milk Fat Globule* (Wageningen: Pudoc, 1974).
Cream churning

t = turning time to produce butter from cream
Gb = efficiency of churning (% fat in buttermilk)

Fritz butter churning process

Developed from the traditional batch churning process of crystallised cream
About half of New Zealand butter manufacturing uses the Fritz process

![Diagram of Fritz butter churning process]

- **Concentration** of the milk to cream (40% fat)
- **Crystallisation** of the fat in the cream
- **Phase inversion** of the cream (and further concentration by buttermilk draining)
- **Working** of butter to achieve fine moisture dispersion
Ammix butter churning process

Fresh milk fat is mixed with cream and salt and shock cooled to give rapid crystallisation

**Concentration** of the milk to cream (75% fat)
**Phase inversion** of the cream (and further concentration to fresh milkfat)
**Crystallisation** of fat in milkfat/serum mixture
**Working** of butter to achieve fine moisture dispersion
Types of liquid buttermilk

- Produced from the churning and separation of butter or cultured butter
- Mostly a consumer drinking product in Europe, and an ingredient in the United States
- Cultured buttermilk containing *L. lactis* ssp. *lactis* and ssp. *cremoris* (ingredient and digestive aid); also can use *Lb. delbrueckii* ssp. *bulgaricus*
- *L. lactis* ssp. *lactis* biovar *diacetylactic* or *Lc. mesenteroides* ssp. *cremoris* sometimes used to impart a more buttery flavour from the chemical compound, diacetyl
- Buttermilk (cultured or otherwise) now more commonly made from skim milk with < 1% fat; *traditional buttermilk* is made from churning cream
- Acidity in cultured buttermilk due to lactic acid (transformed from lactose in the milk)
- Slight curdling of casein proteins makes this thicker than skim milk
- Sensitive to oxidation – metallic off-flavour

* Bulgarian buttermilk is thicker and more acidic, incubated 38° - 42°C for 10-12 h (popular only in Bulgaria!)
Manufacture of cultured buttermilk

- Pasteurised skim milk or homogenised pasteurised low-fat (< 1%) milk
- Cooled to 22°C
- Inoculated with 1 - 3% mesophilic starter bacterial cultures
- Fermented 19° - 22°C for 15-20 h until pH 4.6 - 4.7
- Break up coagulum
- Cooled and packaged
- Shelf-life 2-3 weeks
## Composition of buttermilk (g /100g)

<table>
<thead>
<tr>
<th>Component</th>
<th>Conventional</th>
<th>Cultured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids</td>
<td>9.5 – 10.6</td>
<td>9.0 – 10.6</td>
</tr>
<tr>
<td>Fat</td>
<td>0.3 – 0.7</td>
<td>0.1 – 1.0</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>0.07 – 0.18</td>
<td>~0.02</td>
</tr>
<tr>
<td>Protein</td>
<td>3.3 – 3.9</td>
<td>3.1 – 3.5</td>
</tr>
<tr>
<td>Lactose</td>
<td>3.6 – 4.3</td>
<td>3.6 – 4.3</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>0.55 – 0.9</td>
<td>0.55 – 0.9</td>
</tr>
</tbody>
</table>

Conventional: made from buttermilk  
Cultured: made from skim milk
Other types of liquid buttermilk

- Dhallë, a type of buttermilk from Albania
- Chaas, a buttermilk drink native to the Rajasthan region
- Clabber, a Southern United States soured milk drink
- Doogh, a yogurt drink from Iran
- Filmjölk (Swedish)/Kulturmelk (Norwegian), a type of buttermilk from Scandinavia
- Ghol, an Indian buttermilk drink
- Kefir, a fermented milk drink from the Caucasus
- Lassi, a yogurt drink native to the Punjab region
- Mala or Maziwa lala, a type of buttermilk in Kenya
- Mattha, an Indian buttermilk drink
- Mor Kuzhambu, a buttermilk and curry dish native to the Tamil Nadu region
- Pomazánkové máslo, from the Czech Republic
- Žinčica, sheep milk whey from Slovakia

Consider the probiotic effect of drinking fermented dairy products

https://en.wikipedia.org/wiki/Buttermilk
Buttermilk powder isolation

- Removal of caseins by dissociation with citrate
- Rennet to remove casein aggregates
- Aggregation of MFGM fragments at low pH
- Ultracentrifugation, dialysis, microfiltration
- Super-critical fluid extraction of non-polar lipids

Butter

Churn cream into butter

Washing of cream

Wash with water, simulated milk ultrafiltrate, dissociating agents, or surfactants

Buttermilk

Lyophilisation or heat drying

Cool temperatures ~15°C

U.S. buttermilk powder prices US$2000 - $2200 per ton, October 13, 2017

Cold-drying retains functionality of labile components
Buttermilk and serum

Buttermilk and serum

An additional stream, α-serum, is a by-product of concentrating milk to form cream

Buttermilk functionality

- Comprises most of the milk fat globule membrane (MFGM) layer that protects fat globules in milk
- Biologically relevant membrane with multitude of components
- Functional flavour and texture properties
  - Emulsification
  - Liposomes as carriers and flavour masking agents
  - Impact of isolation procedure
  - Improves heat-stability of recombined evaporated milk\(^1\)
  - Improves whipping properties of recombined cream\(^2\)
  - Increases water-holding capacity and firmness of yoghurt\(^3\)

\(^1\) Kasinos, M., Tran Le, T., & Van der Meeren, P. (2014). *Food Hydrocolloids*, 34, 112-118.
Emulsifying efficacy

Buttermilk (BM) milk fat globule membrane (BM-MFGM100; ····], microfiltered BM whey (whey-MFGM100; —), Lacprodan PL-20 (Lac100; Arla Foods Ingredients Group P/S, Viby, Denmark; ----), mixture of microfiltered BM and BM powder (4:6, wt/wt; BM-MFGM40; – · –), mixture of microfiltered BM whey and BM powder (4:6, wt/wt; whey-MFGM40; · · ), and mixture of Lacprodan PL-20 and BM powder (4:6, wt/wt; Lac40; – – –).

Buttermilk functionality

- Impact on cheese (added as buttermilk)
  - Increases moisture content and yield\(^1\)
  - Impairs casein aggregation during curd cooking
  - Decreases free oil in pizza cheese\(^2\)
  - Improves flavour (bacteria congregate near fat globule interface, and MFGM components may provide a carbon source), particularly reduced-fat cheese\(^3,4,5\)
  - Increases pizza cheese moisture and decreases melt and stretch\(^6\)

MFGM topological model

Asymmetrical location of membrane proteins far from certain

The phospholipid tri-layer, 4-10 nm thick

Surface chemistry and structure – the milk fat globule

Liquid ordered L_0 regions rich in sphingomyelin (highly saturated, longer chain) and cholesterol

Liquid disordered region

Two-dimensional reactions on emulsion and other colloidal surfaces to generate texture and flavour reactions

Purported health benefits of the dairy matrix

- Cholesterol and sphingomyelin in close association in the MFGM
- Raw cream buttermilk treated with pepsin and microfiltered lowered cholesterol micelle solubility by 57%, but only 17% with pasteurised cream¹
- Superior antioxidant activity from MFGM peptides²
- Slight in vivo lowering of cholesterol absorption through intestinal epithelial cell layer by consumption of 45 g/day of buttermilk³
- Implicated inhibition of infectivity by rotavirus activity, attributed to the glycoprotein and carbohydrate components⁴

Giant unilamellar vesicle model systems

GUV generated from electroformation.

Non-fluorescent lipid domains formed with DPPC/DOPE 3/7 mol/mol in a GUV system.

Model milk fat globule vesicles to examine surface structures

Fat globule surface structure

Liquid-ordered domains are thicker by approximately 1 nm compared to liquid disordered domains.

Buttermilk powders

Valio sweet butter milk powder

Historically considered a low-value product…but huge potential!

Current global market (3-10-2017) price US$1840 per ton

Global prices dropped 30% over last 12 months

Compare with SMP US$1895; WMP US$3037; rennet casein US$6123 per ton

Fonterra butter milk powder

Products usually promoted for their good solubility, clean flavor, and emulsifying efficacy.

Fonterra

Dairy for life

High heat butter milk powder
MFGM health claims

Functional health properties* of MFGM phospholipids

– Sphingolipids, including sphingomyelin and metabolites (ceramide, sphingosine, sphingosine-1-phosphate, ceramide-1-phosphate)
  • colon anti-carcinogenic properties
  • cholesterol and LDL adsorption lowering effects by lowering liposome membrane fluidity, raises HDL levels (milk more potent than egg sphingomyelin)
  • trans-membrane signal transduction and regulation of immune cell development
  • cell growth and apoptosis
  • lipoprotein formation
  • mucosal growth in the gut
  • associated with age-related diseases, such as Alzheimer’s
  • ameliorate inflammatory processes in atherosclerosis
  • treatment for insulin resistance, dyslipidemia, cardiovascular diseases
  • protection against bacterial and virus infections

– Fatty acid binding protein
  • anti-carcinogenic properties (colon, breast)

* Scientific literature reports - evidence in some cases is weak, and in some cases insufficient
MFGM health claims

Functional health properties* of MFGM phospholipids

- **Phosphatidylserine**
  - positive effects on Alzheimer’s patients
  - restoration of memory
  - alleviate muscular soreness

- **Phosphatidylcholine**
  - support liver recovery
  - protect human gastrointestinal mucosa against toxic attack
  - reduced life-threatening necrotizing enterocolitis

- **Lactadherin**
  - protection against gut viral infection

- **Butyrophilin**
  - suppression of multiple sclerosis

- **Lyso-phosphatidylcholine and xanthine oxidase**
  - bacteriocidal and bacteriostatic properties (S. *aureus*, *E. coli*, *Sal. enteritidis*)

* Scientific literature reports - evidence in some cases is weak, and in some cases insufficient
Snow Brand

Neo Kid-Plus

Sphingolipids
Gangliosides
Arachidonic acid
Nucleotides
Galactosyllactose

Sialic acid
Docosahexaenoic acid
Choline
Phospholipids

snowbrand.com.my
**Phospholipid concentrates:** sphingomyelin
Cell growth and regulation

**Gangliosides:** mono-sialo ganglioside 3 (GM3), di-sialo ganglioside (GD3) and phosphatidylserine
Infant learning and development, maintain gut health and balancing the immune system
Nutritional milk powders for children
5x Docosahexaenoic acid
Sialic acid

Dutch Lady Growing Up Milk 123 for ages 1+
Dutch Lady Growing Up Milk 456 for ages 3+
Dutch Lady Growing Up Milk 6+ for ages 6+
Arla Foods

Lacprodan® PL-20
Phosphatidylserine and sphingomyelin
Performance boost, contributes to healthy ageing, promotes cognitive development in infancy

Lacprodan® MFGM-10 for infant nutrition.
Lactoferrin, IgG, sialic acid, phospholipids and gangliosides
Neonatal gut maturation and myelination of the central nervous system
Gangliosides for beneficial gut microflora, and intestinal maturation and cognitive development
MFGM components for anti-pathogenic effects
Lactoferrin protects against microbial infections

www.arlafoodsingredients.com
Meiji – Global Brands Marketing

Meiji FM-T
Meiji mamilac
Meiji Fu

Fortified with docosahexaenoic acid
Cerebral and retinal development
Novel ingredients from milk
Case study: the milk fat globule membrane (MFGM)

Originates from lipid droplet extrusion from the mammary epithelial cells

Protects milk fat globule from lipolysis and coalescence

Contains components with bioactive functionality

Major component of buttermilk

Emulsification, carriers of flavour compounds

Implicated inhibition of infectivity by rotavirus activity, attributed to the glycoprotein and carbohydrate components

## Composition of the MFGM

<table>
<thead>
<tr>
<th>Component</th>
<th>mg/100g fat</th>
<th>mg/100mg MFGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteins</td>
<td>1800</td>
<td>70</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>650</td>
<td>25</td>
</tr>
<tr>
<td>Cerebrosides</td>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>Monoacylglycerides</td>
<td>Present</td>
<td>Unknown</td>
</tr>
<tr>
<td>Water</td>
<td>Present</td>
<td>0</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>0.04</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>&gt;2570</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Composition depends upon the method of extraction
Proteins in MFGM extractions

XO accounts for around 20% of membrane proteins

Heat treatment can cause association of whey proteins with MFGM surface layers

Note the large amount of caseins and whey proteins in the extractions

Compartmentalisation of enzymes

Milk fat globule membrane

Redox enzymes
- Xanthine oxidase
- Cytochrome C reductase

Hydrolases
- Acetylcholine esterase
- Alkaline phosphatase
- Acid phosphatase
- 5’-Nucleotidase
- Glucose-6-phosphatase
- Phosphodiesterase
- Adenosine triphosphatase

Lyases
- Aldolase

Transferases
- γ-Glutamyl transferase
- Galactosyl transferase

Sulfhydryl oxidase
Lactoperoxidase
Superoxide dismutase
Ribonuclease

Serum phase
- Lipoprotein lipase
- Plasmin (lower pH)


Polar lipids in MFGM

<table>
<thead>
<tr>
<th>Polar lipid class</th>
<th>% of total polar lipids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphatidylcholine (PC)</td>
<td>36</td>
</tr>
<tr>
<td>Phosphatidylethanolamine (PE)</td>
<td>27</td>
</tr>
<tr>
<td>Sphingomyelin (SM)</td>
<td>22</td>
</tr>
<tr>
<td>Phosphatidylinositol (PI)</td>
<td>11</td>
</tr>
<tr>
<td>Phosphatidylserine (PS)</td>
<td>4</td>
</tr>
<tr>
<td>Lysophosphatidylcholine (LysoPC)</td>
<td>2</td>
</tr>
</tbody>
</table>

Composition depends upon the method of extraction
Seemingly minor processing steps can affect lipid composition—

Cooling
Heating
Churning
Homogenization

RM: Raw milk
RC: Recombined cream
BP: Buttermilk powder
PM: Processed milk (homogenized and pasteurised)
Selective enrichment of polar complex lipids

In bovine milk, xanthine oxi-do-reductase is in the XO form
Capable of oxidising a wide range of aldehydes
Oxidises retinol to retinal, then to retinoic acid which is responsible for most of the activity of vitamin A

XO has both bacteriocidal and bacteriostatic properties brought about by—

1. Production of reactive superoxide and hydrogen peroxide in the gut
2. Reduction of nitrite to nitric oxide, and to peroxynitrite
3. Stimulating lactoperoxidase system in milk (reductant + H₂O₂ → oxidant + H₂O)

Oxidation reactions of XO

Hypoxanthine $\xrightarrow{O_2, H_2O_2} Xanthine $\xrightarrow{O_2, H_2O_2} Uric acid

Uric acid elevated in blood; crystals implicated in gout*.

XO is the target of the widely used anti-gout drug, Allopurinol, an isomer of hypoxanthine and a xanthine oxidase inhibitor.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Reaction</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xanthine oxidase</td>
<td>$XH + H_2O + O_2 \rightarrow X=O + H_2O_2$</td>
<td></td>
</tr>
<tr>
<td>Xanthine dehydrogenase</td>
<td>$XH + H_2O + NAD^+ \rightarrow X=O + NADH$</td>
<td></td>
</tr>
<tr>
<td>Aldehyde oxidase*</td>
<td>$RCHO + H_2O + O_2 \rightarrow RCOOH + H_2O_2$</td>
<td></td>
</tr>
</tbody>
</table>

*Found mainly in liver

*Genetic, diet, and lifestyle causes
Consumption of alcohol, fructose-sweetened drinks, meat, seafood
Known as “rich man’s disease, or “the disease of kings”
Dairy matrix effect on XO activity

XO in solution and in buttermilk

Effect of heating at 65°C

Effect of heating at 75°C
Xanthine oxidase activity in processed milk

\[ \text{XH} + \text{H}_2\text{O} + \text{O}_2 \rightarrow \text{X}=\text{O} + \text{H}_2\text{O}_2 \]

Located in the cytoplasmic region of the MFGM
Oxidation of aldehydes to acids
Increase in n-fatty acids leading to methyl ketones, \( \gamma \)- and \( \delta \)-lactones.

Washing cream with either simulated milk ultrafiltrate (SMUF) or water

Raw cream

Non MFGM proteins

Fat globules

Dilution

Washed cream

Attachment of non-MFGM proteins

Releasing of MFGM

Washing of fat globules

Diluted cream

Centrifugation

Outer PL bilayer

Triacylglycerol core

XO

Washing & recombination

Outer PL bilayer

Triacylglycerol core
Washing fat globules

Scale bars: 5 µm

Native fat globule

Fat globule washed with simulated milk ultrafiltrate (SMUF)

Fat globule washed with water
Xanthine oxidase activity on emulsion surfaces

* Specific activity of XO (mU mg⁻¹ of protein)

The importance of dairy food structure

- Texture
- Flavor
- Digestibility
- Appearance
- Shelf-life
- Health
- Food microenvironment and safety
- Release of nutrients and bioactive components
Conclusions

• Milk has a complex native structure that impacts upon release of nutrients and, therefore, human health

• Extraction of MFGM components must take into account the impact of heat treatments

• Processing of milk can have a profound effect on dairy product flavor, release of nutrients, and health:
  – Location of complex lipids and enzymes on the milk fat globule surface

• Appropriate extraction methods can add value to buttermilk and buttermilk powders

• Understanding the structure-induced functionality of dairy products is a relatively new field that requires interdisciplinary research by food physicists, manufacturing technologists, and gastrointestinal physiologists
Time for questions