Development of Nutrient Delivery Systems

David Julian McClements and Hang Xiao
Department of Food Science
University of Massachusetts
Development of Nutrient Delivery Systems: Ingredients & Challenges

Challenges:
- Low water solubility
- Crystalline
- Chemical instability
- Enzyme digestibility
- Low bioavailability
- Flavor modulation
- Matrix incompatibility
- Targeted Delivery

Nutraceuticals
- Peptides & Proteins
- Probiotics
- Functional Foods

Vitamins
- Minerals

Functional Foods
Nutrient Delivery System Design: Performance Criteria

Matrix Compatibility
- Optical
- Rheological
- Stability
- Flavor

Processing
- Heating
- Cooling
- Drying
- Shearing

Storage
- Temperature
- Mechanical stress
- Light
- Oxygen
- Time

Consumption
- Appearance
- Texture
- Taste and Aroma
- Convenience

Ingestion
- Digestion
- Absorption
- Toxicity

Stable

DELIVERY SYSTEM CRITERIA:
- Fabricated from food grade ingredients using economic processing operations.
- Designed to function over wide range of conditions in food product and human body.
- Sensory acceptance

Controlled Instability
Enhancing Bioavailability: Designing Food Matrices to Control GIT Fate of Nutrients

Bioavailability & Targeted Delivery
- Ensure nutrients remain stable within the product during storage
- Create molecular environment in GIT that increases bioavailability
- Deliver bioactive components to site of action within GIT: mouth, stomach, small intestine or colon

Mouth, Stomach, Small Intestine

Engineered Lipid Nanoparticles

Digestion

Mixed Micelles

Colon

Chylomicrons
Improving Nutraceutical Bioactivity: Major Factors Limiting Bioavailability

\[ BA = B^* \times A^* \times T^* \]

- \( B^* = \) Bioaccessibility
- \( A^* = \) Absorption
- \( T^* = \) Transformation

Bioaccessibility: Liberation & Solubilization
Absorption: Transport across Mucus Layer & Epithelium Cells
Transformation: Chemical or Biochemical Changes
Food Design to Improve Bioavailability: Delivery Systems versus Excipient Foods

Nutrients

Dispersed within

Delivery Systems

Food Matrix Design

Composition & Structure

Physicochemical Properties

Sensory Attributes

GIT Fate

Bioavailability

Nutrient-Rich Food

Consumed with

Excipient Food

Emulsion-based Delivery

An emulsion consists of two immiscible liquids (usually oil and water), with one liquid being dispersed as very small spherical droplets in the other liquid.

Potential Advantages:

• Incorporating Hydrophobic Nutrients & Nutraceuticals into Broad Range of Foods and Beverages
• Increased Bioavailability

Nanoemulsion  Emulsion

High energy methods

Low energy methods
Emulsion Design for Bioavailability Improvement: Tailoring Functionality

- Particle Size
- Composition
- Interfacial Properties
- Aggregation State
- Lipid Droplet
- Oil Type

Lipid Droplet

Particle Size

Aggregation State

Composition

Interfacial Properties

Oil Type

Lipid Droplet

Negative
Neutral
Positive
Emulsion Design for Bioavailability Improvement: Liquid and Powdered Forms

Microencapsulation of nutrients by spray drying
Emulsion Design for Bioavailability Improvement: Effect of Particle Size

Coenzyme Q10 nanoemulsions made from digestible or indigestible oils

Droplet Properties

Heptadecanoic Acid (mg/g tissue)

- Coarse (CO)
- Medium (CO)
- Fine (CO)
- Fine (MO)

Duodenum
Jejunum
Ileum
Emulsion Design for Bioavailability Improvement: Effect of Particle Composition

- **Effect of Particle Composition**
- **Small Mixed Micelles (MCT)**
  - Too large to fit inside micelle
- **Larger Mixed Micelles (Corn Oil)**
  - Fits in micelle

β-carotene nanoemulsions made from LCT (corn oil), MCT or indigestible oil (orange oil).
Food Design to Improve Bioavailability: Delivery Systems versus Excipient Foods

Excipient Emulsions: Impact of Lipid Content & Type on Carotenoid Bioaccessibility from Carrots
Exciipient Emulsions: Enhanced Carotenoid Bioaccessibility in Supplements

Enhanced Bioaccessibility

Laura Salvia-Trujillo
Conclusions

- **Structural design principles** are being developed to create food-grade delivery systems with improved efficacy.
- These structurally designed systems can be fabricated from food grade ingredients using simple processing operations.
- These systems can be designed to improve food performance:
  - Digestibility
  - Controlled and Targeted Release
  - Increased Bioavailability
  - Modulate Satiety
- **Economics and robustness of new functional foods** needs to be assessed.
**Mechanism: Effect of Lipid Composition on Carotenoid Bioaccessibility**

- **Digestion**: Lipase acts on fat droplets.
- **Micellization**: Does not fit.
- **Solubilization**: Fits well.
- **Bioaccessible**: Mixed micelles.
Testing Bioavailability & Bioactivity: 
*In Vitro & In Vivo* Methods

- Encapsulated Bioactive
- Simulated Oral & Gastric Fluids
- Simulated Intestinal Fluid
- Digestion Rate & Extent
- pH-Stat Titration
- Centrifugation
- Sediment phase
- Micelle phase
- Lipid phase
- Fraction Released
- Time (s)
- Concentration Analysis
- Absorption ($F_A$)
- Bioaccessibility ($F_B$)
- Cell Culture
- Establish Physicochemical Mechanisms
Excipient Emulsion Design: Boosting Bioavailability

Fat Droplet Size

Fat Droplet Composition

Aqueous Phase Composition

Interfacial Properties

- Proteins
- Carbohydrates
- Acids, Bases, Buffers
- Chelating Agents
- Surfactants
- Antioxidants, Minerals

Phospholipids

Surfactants

Polysaccharides & Proteins