Applications of nanosciences to nutrients and foods

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Outline

• Brief introduction: food industry and role of nanosciences.
• The two axes of the food industry of today
• Food nanotech by nature and man
• The scales of foods
• How are foods structured today and how they should be structured
• Reducing the scale for food design
• Food microstructure and the health/nutrition interface
• Food microstructure and the gastronomy/pleasure interface
• Conclusions
Introduction

- Food industry is the largest manufacturing sector worldwide: ca. US$ 4 trillion annual turnover.
- Globally, a large proportion of foods are consumed after minimal processing and postharvest losses are high. In most places (urban centers) food is abundant and relatively cheap.
- Except for large multinationals, most food companies are relatively low-tech SME’s where traditional technologies are geared to local tastes and traditions. Recently, difficulties in adopting emerging processing technologies (HPP, ohmic heating, etc). Difference with the chemical and pharma industries.
- It appears that the smallest food structure effectively controlled by present industrial technology is ~ 5-10 μm. This is 100x larger than the upper limit of nanotechnology.
- Objectives:
  - Provide a vision of how food structures are built and breakdown.
  - Present examples of the unique added value for a technology that reduces the level by which we intervene food microstructures.
The dimensions of the food industry of the future

JMA (2008)
Where is the nano in foods?

Nature

Molecules
Ingredients
Processing

Digestion

Fresh foods
Processed foods

Molecules

Ingredients:
Molecules, macromolecules, (biopolymers) & water

Structures:
Cells, fibers, gels, emulsions, foams, structured, liquids

Properties:
Texture, flavor, shelf-life, bioavailability

1987: The first book on food microstructure

JMA (2008)
Things natural

- Ant ~ 5 mm
- Dust mite ~ 200 μm
- Fly ash ~ 10-20 μm
- Human hair ~ 60-120 μm wide
- Red blood cells with white cell ~ 2-5 μm
- ~ 10 nm diameter
- DNA ~ 2-12 nm diameter
- Atoms of silicon spacing ~ tens of nm

Things in foods

- Sugar crystal ~ 20 μm
- Plant cell ~ 100 μm
- Starch granules ~ 5-50 μm
- Meat fiber ~ 1-2 μm diam.
- Chloroplast ~ 300-400 nm
- Cluster
- Paraphyrin ring

JMA (2008)
Milk production in the cow’s udder cell

A “natural” microdevice

Fat globule

Cow’s udder cell

Milk fat globule membrane

From

JMA (2008)
Food microtechnology: Micro- and nanosized elements in structured dairy products

Aguilera and Stanley, 1999
The scales of food microstructures (approx.) and related sciences

- Chemistry
  - Water (0.3 nm)
  - Flavors
  - CHO polymers
  - Proteins
  - Emulsifiers
  - Network gels
  - Casein micelles

- Polymer science
  - Microbial cells
  - Gluten network
  - Lipid micelles
  - Plant cell walls
  - Microbubbles

- Colloidal science
  - Particle gels
  - Fat droplets
  - Plant cells
  - Starch
  - Cooked starch

- Food product physics
  - Powder particles
  - Crystals
  - Bubbles
  - Grains
  - Ice crystals in ice cream
  - Fat droplets
  - Plant cells

- Resolution of the eye
  - Detection in the mouth
  - Microbubbles
  - Digesta
  - Micro droplets

- "Nano" sciences
  - Casein nanoparticles
  - Microbubbles

JMA (2008)
Microstructural changes of food components during processing

PROTEINS
- Native β-Lg
- Denatured β-Lg
- Fibrils
- Aggregates
- Gel network

STARCH
- Recrystallized amylose
- Dextrins and degradation products from extrusion
- Encapsulating matrices
- Swollen starch

FATS
- TAGs
- Monoglycerides
- Crystallite
- Cluster
- Fat crystal network

Scales:
- 10 nm
- 100 nm
- 1 μm
- 10 μm
Interactions at molecular and nano-levels

At one stage or another, food are dispersions of multicomponents
Time- and length-scales in foaming

- Matrix fixation
- Disproportionation
- Drainage of lamella
- Constriction
- Diffusion of surfactant
- Conformational changes and diffusion of proteins

Solid foams (stable)
Liquid foams (unstable)

Time:
- hours
- min
- sec
- msec

Length:
- nm
- μm
- mm
Food structure formation: A change in paradigm

**Traditional**

- **Formulation** (recipe)
  - Structure formation
    - Biopolymer transform.
    - Phase creation
    - Reactions
  - Structure stabilization
    - Vitrification
    - Crystallization
    - Network formation

- Metastable structure

**Future**

- **Molecules**
- **Assemblies**
- **Interactions**
- **External variables** (shear, heat, pressure, etc)

- **Matrix precursors**
- **Structural elements**
- **Architecture**
- **Functional structure**
### Scale of intervention: Traditional food processing

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>SIZE OF DEVICE</th>
<th>SIZE OF STRUCTURAL ELEMENT</th>
<th>FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emulsification</td>
<td>1 mm</td>
<td>10 μm</td>
<td>$10^2$</td>
</tr>
<tr>
<td>Shaping (moulding)</td>
<td>10 cm</td>
<td>20–30 μm</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Spray drying</td>
<td>~1 mm</td>
<td>10–50 μm</td>
<td>~$10^2$</td>
</tr>
<tr>
<td>Crystallization (ice)</td>
<td>~1 mm</td>
<td>20–30 μm</td>
<td>~$10^2$</td>
</tr>
<tr>
<td>Extrusion</td>
<td>1–10 mm</td>
<td>nm → μm</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Gelation</td>
<td>10 cm</td>
<td>nm - μm → ∞</td>
<td>?</td>
</tr>
<tr>
<td>Frying (crust)</td>
<td>10 cm</td>
<td>1 mm</td>
<td>$10^2$</td>
</tr>
<tr>
<td>Baking</td>
<td>100 cm</td>
<td>mm</td>
<td>$10^3$</td>
</tr>
</tbody>
</table>
Controlled structuring of air, oil, water and ice

Architectures of foams made in a 250 μm coaxial capillary tube by varying the ratio gas/liquid flow rates (from Skurtys, Bouchon and Aguilera, 2007).

Oil droplets in an O/W emulsion after passage through a stack of layers of etched channels of a microfluidic device made from a silicon chip (from van der Zwan et al., 2006).

Evolution of a 2% potassium kappa-carrageenan particle subjected to capillary shearing flow during gelation (from Walther et al., 2004).

Different shapes of ice crystals made in: (A) Tris buffer; (B) Buffer and 400 mM of a polypeptide of an ice nucleating protein, and (C) Buffer and 50 mM of an anti-freeze protein (from Kobashigawa et al., 2005).
Foods, health and well-being

Scientific evidence + epidemiological studies relate diets with incidence of nutrition-related diseases (e.g., Mediterranean diet)

• Some nutrients and bioactive compounds show beneficial health-related effects – Specific effects (e.g., isolated and in vitro)
  • Foods with the same basic composition have different metabolic effects in vivo depending on their structures – Matrix effect (e.g., glycemic response, bioavailability of carotenoids)
  • Foods not nutrients are key to understand the nutrition-health interface in the body – Interaction effects

Opportunities to design new foods or modify existing ones

JMA (2008)
“Food matrix” and bioavailability of carotenoids

![Diagram showing the effect of food matrix and processing on bioavailability of carotenoids.](image)

**Very high bioavailability**

<table>
<thead>
<tr>
<th>Examples of Specific Components or Foods</th>
<th>Food Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulated natural or synthetic carotenoids</td>
<td>Formulated carotenoids in water-dispersible beaullets</td>
</tr>
<tr>
<td>Natural or synthetic Carotenoids—oil form</td>
<td></td>
</tr>
<tr>
<td>Papaya, peach, melon</td>
<td>Fruits</td>
</tr>
<tr>
<td>Squash, yam, sweet potato</td>
<td>Tubers</td>
</tr>
<tr>
<td>Tomato juice</td>
<td>Processed juice with fat containing meal</td>
</tr>
<tr>
<td>Carrots, peppers</td>
<td>Mildly cooked yellow/orange vegetables</td>
</tr>
<tr>
<td>Tomato</td>
<td>Raw juice without fat</td>
</tr>
<tr>
<td>Carrots, peppers</td>
<td>Raw yellow/orange vegetables</td>
</tr>
<tr>
<td>Spinach</td>
<td>Raw green leafy vegetables</td>
</tr>
</tbody>
</table>

**Very low bioavailability (<10%)**

**FIGURE 8.3** Effect of food matrix and processing on bioavailability of carotenoids. SOURCE: Adapted from Boileau et al (1999).
Structure and bioavailability of nutrients

Why don’t we get 100% of what we eat?

Modulating glycemic response by structuring


Structuring for pleasure and luxury

• Food away from home is 1/3 of the food business. Expenses on fine dining on the rise. Just in Paris there are over 500 restaurants with Michelin stars.

• Top chefs are to be taken seriously; they are the most innovative and credible people in the food industry.

• Example: they are not afraid of science and technology: 7 of the 10 top chefs in the world have their own laboratories and are into molecular gastronomy.

• They love to experience with new food structures and techniques. Most famous food structures are young: less than 200 years old.
Adding value to consumers: Impacts and needs of nanosciences in foods and food processing

Food safety
- Nano-biosensors for pathogens and contaminants
- Traceability

Tools
- Microscopy probes
- Advanced sensorial equipment
- Analytical
- Hi-resolution imaging

Protection/convenience
- Intelligent packaging
- Better barriers

Food processing
- Micro/nanoencapsulation
- Nanofiltration
- Membrane emulsification
- Microdevices

Health & wellbeing
- Delivery of bioactives
- Improved bioavailability of nutrients
- Weight control

Food design
- Microdispersions of air and water
- Novel and new/old structures
- Top gastronomy

Eco-friendly processes
- Water: self-cleaning surfaces
- Energy: nanocomposite insulation
- Waste: biodegradable packaging

Added nanostructures

Impact
- High
- Low

Need
- Low
- High

JMA (2008)
Conclusions

• If nanoscience and nanotechnology are manipulating and assembling structures at the 1 -100 nm level, food processing has done it for centuries using many types of molecules, although largely in an uncontrolled way.

• Thus, applications of micro- and nanotechnologies to food structuring are likely to bring large benefits to the food/ health-food industry. Examples: development of novel (micro)processes, creation of new textures and tastes, design of less calorie-dense foods, increased nutritional value and targeted nutrition for different lifestyles and conditions (obesity).

• As we increase our understanding of how present food structures are formed and broken-down, digested and absorbed, specific opportunities for nanosciences and nanotechnology will become more apparent. Gaps in knowledge may lead to the delayed adoption of technologies and/or inability to deal with uncertainties.