Survey of United States Commercial Ice Cream Products

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Complex Structure of Ice Cream

“Ice cream is a frozen food made from a mixture of dairy products, containing at least 10% milkfat.” – International Dairy Foods Association, FDA
Microstructure and Drip-through Rate

Increase (faster) drip-through rate

- Increase in ice crystal size (Muse & Hartel, 2004)
- Decrease in overrun (Sakurai et al., 1996)

Decrease (slower) drip-through rate

- Presence of added emulsifiers (Bolliger et al., 2000)
- Increase in fat destabilization (Muse and Hartel, 2003; Segall and Goff, 2002; Berger and White, 1971; Berger et al., 1972)
  - Minimal amount of destabilized fat (Koxholt et al., 2001)
- Increase in percent overrun (Sofjan and Hartel, 2004; Sakuai et al., 1996)
- Increase in total percent fat (Roland et al., 1999)
- Decrease in mean ice crystal size (Muse and Hartel, 2003)

No influence on drip-through rate

- Ice crystal size (Koxholt et al., 2001)
- Overrun (Muse & Hartel, 2004)
Microstructure and compositional effect on sensorial properties

- **Increase (faster) melt rate** - Increase perception of ice crystals (Stampanoni Koeferli et al., 1996)
- **Decrease (slower) melt rate** - Increase in fat (Guinard et al., 1997; Stampanoni Koeferli et al., 1996)
- **Decrease in percent fat** - Decrease in perception of creaminess (Morris, 1992; Roland et al., 1999),
- **Increase in percent fat** - increase in perceived mouth coating (Aime et al., 2001; Stampanoni Koeferli et al., 1996) and decrease in perception of ice crystals (Stampanoni Koeferli et al., 1996)
Background

• Much research has been done on the microstructure of ice cream products
• Many driving factors that influence drip-through rate but the complete interactions are not fully known.
• No published data on the microstructure, compositional, behavior, and sensorial properties of United States commercial ice cream products
• Survey the relationships between and influences on sensory, microstructure, behavior of US commercial ice cream products
Design of study

- 18 different vanilla ice cream products purchased
- Samples stored at -28.9°C until analysis (~1 week)
- Complete analysis on microstructure of ice cream products
- Statistical analysis performed
**Microstructure**

- **Ice Crystals** (Glovebox, -15°C, 40X)
  - Effected by:
    - Stabilizers
    - Freezing conditions
    - Percent total solids
  - 26.3 ± 1.59 μm – 67.1 ± 3.91 μm

- **Air Cells** (Glovebox, -6°C, 40X)
  - Effected by:
    - Percent Overrun
    - Shear stress from dasher
    - Residence time
    - Stabilizers
  - 17.1 ± 1.61 μm – 39.5 ± 1.80 μm

- **Destabilized Fat** (Mastersizer & Microscopy)
  - Effected by:
    - Emulsifiers
    - Shear stress from dasher
    - Type of fat
  - 2.60 ± 0.17% – 55.3 ± 5.94%

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**Particle Size Distribution**

- X-axis: Particle Size (micrometer)
- Y-axis: % Volume
• Drip-through Test
  • Drip-through Rate = Slope of linear portion of curve
    • $0.13 \pm 0.02 \text{ g/min}$ – $1.88 \pm 0.12 \text{ g/min}$
Additional measurements

- **Overrun**
  - Archimedes’ Principle
    \[ \left( \frac{V_{ic} \times \rho_{mix}}{m_1} - 1 \right) \times 100 \]
    - \( 21.7 \pm 1.12\% - 119 \pm 3.96\% \)

- **Percent total fat**
  - Mojonnier Test
    - \( 0.01 \pm 0.05\% - 14.3 \pm 0.58\% \)

- **Total solids**
  - CEM Microwave/Moisture Analyzer
    - \( 31.1 \pm 0.13\% - 42.6 \pm 3.15\% \)
Compositional & structural attributes of commercial ice cream samples

<table>
<thead>
<tr>
<th>Components</th>
<th>Average and Standard Error</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ice crystal size (mm)</td>
<td>48.1 ± 2.3</td>
<td>26.3 – 67.1</td>
</tr>
<tr>
<td>Mean air cell size (mm)</td>
<td>29.9 ± 1.5</td>
<td>17.1 – 39.5</td>
</tr>
<tr>
<td>Percent total fat (%)</td>
<td>8.6 ± 1.0</td>
<td>0.01 – 14.3</td>
</tr>
<tr>
<td>Percent fat destabilization (%)</td>
<td>21.9 ± 3.88</td>
<td>2.60 – 55.3</td>
</tr>
<tr>
<td>Overrun (%)</td>
<td>75.0 ± 6.5</td>
<td>21.7 – 119</td>
</tr>
<tr>
<td>Density of ice cream (g/L)</td>
<td>649 ± 0.03</td>
<td>509 – 904</td>
</tr>
<tr>
<td>Density of ice cream mix (kg/L)</td>
<td>1.10 ± 0.01</td>
<td>1.07 – 1.16</td>
</tr>
<tr>
<td>Drip-through rate (g/min)</td>
<td>1.07 ± 0.15</td>
<td>0.13 – 1.88</td>
</tr>
<tr>
<td>Total solids (%)</td>
<td>38.3 ± 0.67</td>
<td>31.1 – 42.6</td>
</tr>
</tbody>
</table>

Large range of commercial ice cream products on the market
Ice Crystals (26.3 – 67.1 μm)

Air Cells (17.1 – 39.5 μm)

Particle Size (2.60 – 55.3%)

Drip-through Rate (0.13 -1.88 g/min)
High Fat Destabilization, Minimal Collapse

- Ice crystals
- Free water
- Serum phase

- Fat/destabilized fat

- Air cells

$t = 0$ minutes
$t = 60$ minutes
$t = 120$ minutes
Low Fat Destabilization, Full Collapse and Drip-Through

- Ice crystals
- Free water
- Serum phase
- Fat/destabilized fat
- Air cells

\[
\begin{align*}
  t &= 0 \text{ minutes} \\
  t &= 60 \text{ minutes} \\
  t &= 70 \text{ minutes}
\end{align*}
\]
Sensory Analysis

• Trained sensory panel of 17 panelists from UW-Madison Food Science Department
• Spectrum™ Descriptive Analysis
  – Approximately 20 hours of training
• 6 key sensorial attributes
  – Melt rate, breakdown, ice crystal size, denseness, greasiness, and overall creaminess
• 15-point numeric scale (0 = lowest intensity, 15 = highest intensity)
• 17 ice cream products used in sensory analysis (sample 824 was not available for sensory analysis)
Sensory Attributes of Commercial Ice Cream Samples

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Mean and Standard Error</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakdown</td>
<td>4.63 ± 0.20</td>
<td>2.79 – 6.67</td>
</tr>
<tr>
<td>Creaminess</td>
<td>5.71 ± 0.31</td>
<td>2.42 – 7.32</td>
</tr>
<tr>
<td>Denseness</td>
<td>3.46 ± 0.13</td>
<td>2.24 – 4.59</td>
</tr>
<tr>
<td>Greasiness</td>
<td>2.95 ± 0.71</td>
<td>2.46 – 3.73</td>
</tr>
<tr>
<td>Melt rate</td>
<td>10.82 ± 0.27</td>
<td>7.17 – 12.40</td>
</tr>
<tr>
<td>Particle Size/Iciness</td>
<td>1.11 ± 0.08</td>
<td>0.59 – 2.12</td>
</tr>
</tbody>
</table>
Statistical Analysis

• JMP Statistical Software
  – Multivariate Pairwise correlation – determine correlations between microstructural/compositional and sensory attributes
  – $p < 0.05 = \text{statistically significant}$
  – Principle component analysis (PCA) used to determine interrelationships between and within the sensorial and microstructural data.
PCA Biplot of compositional and structure parameters

- Nonfat samples distinguished by percent fat and DT rates
- No key microstructure differences between full fat and reduced/light products (mainly differs by %fat)
- Full fat samples 880, 559, and 293 separated by %FD, %TS, and DT rate
- Samples with high %fat tend to have lower overrun (inverse, \( p < 0.05 \)) and larger ice crystals (positive, \( p < 0.0001 \))
- Ice crystals nor air cells are key drivers in ice cream DT rates

*Correlates with findings in literature*
PCA Biplot of compositional and structure parameters

= full fat
= reduced fat/light
= nonfat

Drip-through rate vs:

• Percent Fat Destabilization – Inverse, $p < 0.0001^*$
• Mean ice crystal size – inverse, $p < 0.01^*$
• *Percent total fat – inverse, $p < 0.0001^*$
• Overrun – positive, $p < 0.05$

* Correlates with findings in literature
Sensorial Correlations

- Ice crystal size distribution
- Degree of partial coalescence
- Overrun and mean air cell size
- Drip through, mean ice crystal size, overrun, air cell size

Iciness correlates to the size of ice particulates
Greasiness
Breakdown and Denseness
Melt Rate
Ice Cream Products Surveyed

• 17 commercial ice cream products were tested in duplicates
  – 11 full fat
  – 2 nonfat
  – 4 low fat/reduced fat
• 4 ice creams/panel
• Ice cream into 1x1 cm cubes
• References were provided each session
• Ice cream was distributed in three rounds
• Statistical Analysis – One-way ANOVA and Student t-Test, Multivariate Pairwise Correlation, PCA
PCA Biplot of the sensory parameters

- Wide range of sensorial attributes for all products
- Denseness (inverse, p < 0.0001) and breakdown (inverse, p < 0.0001) have an strong inverse relationship to melt rate
- Samples perceived as creamy were also greasy (positive, p < 0.0001)
- Melt rate is not distinguishable by %fat
- Size of ice particulate had no relationship with rate of melt (p = 0.34)
PCA biplot of microstructure and sensory analysis

- **DTR** does not predict melt rate in the mouth ($p = 0.14$)*
- Percent total fat correlates with creaminess*
- Creaminess (positive) and greasiness (positive) correlate with %FD with $p < 0.05$.*
- Mean ice crystal size had no correlation with size of ice particulates ($p = 0.60$)

The meaning of the abbreviations above are as follows: **MACS** = Mean Air Cell Size; **MICS** = Mean Ice Crystal Size, **FD** = Fat Destabilization; **DTR** = Drip-through Rate.

* Correlates with findings in literature
Conclusion

• There exist a wide range of compositional and structural attributes in United States commercial ice cream products.
• Microstructure properties do not necessarily predict sensory properties:
  – Drip-through vs Melt rate
  – Mean ice crystal size vs Iciness/Ice particle size
• Interdependent components within structural, compositional, and sensorial properties make it difficult to determine how ice cream products will behave, regardless of fat phase.
• Many complexities in understanding the influences on the behavior of ice cream products.
Frozen Dessert Center at Babcock Hall
Our Mission

The mission of the Frozen Dessert Center is to:

*Advance the art & science associated with the research & production of frozen desserts.*

We accomplish this mission through a coherent program that includes:

- **Services** focused in the areas of manufacturing, sensory and microstructure analyses, product development, and quality control.
- **Outreach** to promote our knowledge, skills and expertise to professionals in the frozen dessert industry and beyond
- **Educating** University of Wisconsin-Madison students to become the future leaders within the industry
About Us

- Founded in fall of 2012
- Combines the frozen dessert expertise and resources housed within the University of Wisconsin – Madison Food Science Department.

**Advisory Staff:**
- Dr. Richard Hartel – Microstructure analysis
- Dr. Scott Rankin - Sensory, flavor, batch production

- We assist a variety companies with various services:
  - **Comprehensively** – Assist companies to carryout projects from ideas to actual marketable products
  - **Development** - Work with companies to design trials
  - **Trials** - Small and large-scale mix and frozen product trials
  - **Reports/Data** - Microstructure and sensory analyses and reports
Services Provided

- **Ingredients & Flavors** – Analysis of new ingredients and flavors, sensory analyses, microstructure analyses, stability testing, and quality control

- **Mix and frozen dessert production** – small and large scale test runs with new ingredients or processing conditions

- **Equipment** – Testing the use of new equipment or new processes for frozen dessert manufacturing

- **Shipping** – Ship sample products overnight to a specified location
Available Equipment

- **Analytical**
  - Melt-down test, Ice crystal and Air cell Size and Distribution, Microscopy imaging, Stability testing

- **Freezers**
  - Batch
  - Continuous - small and large scale

- **Pasteurizers & Homogenizers**
  - Batch (LTST) and Large (HTST)

- Dairy plant scale-up equipment

- Sensory software
Example Projects

• Provide service in formulation analysis and production of product

• Analyze ice crystals during stability study for a new ingredient

• Process product and carry out sensory and microstructure analysis
FDC Technical Research Conference

- Technical Research Conference (Fall 2016)
  - Scope of the industry
  - New trends and Technology
  - Innovation
  - Technical and Processing research forum
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Thank you

- IDFA Ice Cream Technical Conference
- University of Wisconsin-Madison
  – Frozen Dessert Center at Babcock Hall
- Professors R.W. Hartel and S. A. Rankin
- Undergraduate Research Assistants
- Wisconsin Hatch Grant
Questions
References