Process induced structural features of solid cereal foams - in relation to oral processing

PhD thesis
Syed Ariful Alam
VTT Technical Research Centre of Finland
Ariful’s dissertation:
Process induced structural features of solid cereal foams

- Work started in 2014
- Research at VTT Espoo
- Studies at the University of Helsinki, Department of Food and Environmental Sciences.
- Supervisors:
  - Docent Nesli Sozer (Senior Scientist at VTT)
  - Assist. Prof. Kati Katina (UH)
  - Academy Prof. Kaisa Poutanen (VTT)
- Funded by: Academy of Finland, VTT & Raisio Plc. Research Foundation

Objective: Understand the main structural and mechanical features of healthy solid foams. Elucidate mechanism of structural disintegration of healthy solid foams in mouth and stomach phase.
Overview of the PhD thesis & publications

- Influence of particle size reduction on structural & mechanical properties of extruded rye bran
  - Published at Food and Bioprocess Technology, 2014

- Effects of rye bran particle size reduction on *in vitro* starch digestibility and structural & textural properties of high-fibre extrudates
  - Submitted to Food and Bioprocess Technology, 2015

- Structural and mechanical properties of brittle cereal foams affecting disintegration in mouth during *in vivo* mastication
  - On-going study

- Disintegration of high fibre solid cereal foams in mouth (*in vivo*) & in stomach (*in vitro*) & their positive impact on physiological responses
  - Funding: 2016-2017 (to be applied)
Why RYE?

- **90%** of world rye production is in Europe
- **30%** is consumed as food
- Traditional use as whole grain breads, often produced by sour dough fermentation
- Health effects of rye bread increasingly demonstrated
- Development of new types of rye products & ingredients for the modern consumer is important

**Beneficial physiological effects in humans**

**RYE BRAN**
- 40-45% dietary fibre
- 15-20% protein
- 13-20% starch
- 4-5% fat
Background

- Extrusion processing can be used for production of a wide range of solid cereal foams e.g., puffed snacks, flakes etc.
- Addition of DF into extruded product improve the nutritional quality
- Bran addition → product quality (e.g., expansion, hardness & crispiness) attributes reduced
- Addition of DF into extruded product improve the nutritional quality
- Breakdown in mouth by mastication inversely related to food hardness and thus affects hydrolysis rate
- Prediction of the disintegration pattern of solid cereal foams → Mathematical modelling
Importance of structure and texture formation in food design

- Increased demand for high quality healthy food products.
- Technological and physical challenges in high fibre food matrices.
- Adverse affect on sensory texture and flavor/taste.
- Important to understand the physical basis of texture in order to be able to design palatable and healthy foods.
Objectives

- Understand the main structural and mechanical features of healthy solid foams e.g., puffs and flakes

- Assessing the effect of structural and mechanical properties of high fibre extruded puffs & flakes on disintegration in mouth (*in vitro*) and in bolus formation

- Elucidate mechanism of structural disintegration of healthy puffs and flakes (*in vivo* mouth and *in vitro* stomach phase) in comparison to regular wheat based foams
Flow chart of 4-year work

Extrusion

- Open cereal matrices
  - Microstructure
    - WAI & WSI
  - Macrostructure
    - Texture
    - Starch HI

- Open & closed cereal matrices
  - In vivo mastication
    - Particle size
    - Bolus
      - In vitro stomach
        - Viscosity

Hierarchical model
Psychophysical model
Experimental design paper 1 & 2/4

Publication 1:
100 % rye bran
3-particle sizes of rye bran:
- Coarse (440 µm)
- Medium (143 µm)
- Fine (28 µm)
- Screw speed: 300/500rpm
- Feed Moisture: 17/ 19 %
- Barrel T profile: low (110°C) / high (130°C)
- Hydration regimen: In-barrel/Preconditioning

Publication 2:
Rye endosperm flour + 15/30% rye bran
- 2-particle size (Coarse vs. Fine)
- Screw speed: 500 rpm
- Feed moisture: 17%
- Barrel T profile: low (110°C)
- Hydration regimen: In-barrel/Preconditioning

Raw material:
RYE BRAN
Partile size reduction and effect on rye bran quality and on extrudates

Commercial | Coarse | Medium | Fine
---|---|---|---
Starch: black
Lignified cells: yellowish brown
Protein: red/brown
β-glucan: light blue

Rye bran extrudates
Structural & textural parameters

- Macro-structural vs. Textural parameters
  - Expansion
  - Piece density
  - Crispiness

- Microstructure
  - Effect of particle size and extrusion on microstructure (LM)
  - X-ray microtomography (XMT)

- Texture Analysis: Uni-axial compression test for puffs & crammer shear compression for flakes

- Micro-structural vs. Textural parameters
  - Porosity, air cell diameter
  - Cell wall thickness, crispiness
Crispiness index

Mechanical properties of the extrudates were analysed using a texture analyzer (TAXT2i) and the Texture Exponent software (v5.1.2.0) (both from Stable Micro Systems, UK).

- A 36 mm Al cylindrical compression plate was used to compress the samples to 70% of their original diameter (test speed of 1 mm/s).

- **Crispiness index** \((CI) = \frac{\text{Curve length (N)}}{A \times F_{\text{mean}}}

\)

\[
A = \text{Area under the f-d curve}
\]

\[
F_{\text{mean}} = \text{Average force of the \# peaks from the F-d curve}
\]

\[
\text{Curve length} = \sum |\Delta \text{Force}|
\]
Particle size reduction gives lower thickness to radius ratio; less thick and more expanded cells

Representative XMT images of
a) Coarse
b) Medium
c) Fine particle-sized extruded rye bran samples

In barrel

Pre-conditioned
Macro-structural vs. Textural parameters

- High screw speed and small particle size
  - good expansion
  - low density

- High expansion and low density
  - More crispy
  - less hard texture

---

In-barrel water

Preconditioning

COARSE 440 μm

MEDIUM 143 μm

FINE 28 μm
Particle size reduction to 28 μm gave extrudates with crispy texture. Pre-conditioning had an adverse affect on crispiness.

- Fine particle increased the crispiness for both in-barrel and preconditioned extrudates.
- In-barrel water feed in combination with high screw gave crispiest puffs.

IB = In-barrel water feed; PC = Preconditioning; Screw speed = 300 & 500 rpm
In general particle size reduction reduced $F_{\text{max}}$. Pre-conditioning before extrusion reduced hardness ($F_{\text{max}}$) values.

- Higher screw speed reduced the hardness.
- Preconditioning reduced the hardness for all particle size.

**F$_{\text{max}}$ of extrudates reduced with particle size reduction**

IB= In-barrel water feed; PC= Preconditioning; Screw speed = 300 & 500 rpm
Fibre modification

- Coarse rye bran
  - No significant effect

- Medium and fine rye bran:
  - Increase in IDF and TDF
  - SDF increased only in few samples

- Extrusion had only limited effect on DF composition
- The effect was more pronounced with medium and fine rye bran
Micro-structural vs. Textural parameters

- Particle size reduction to 28 µm
  - Porosity ↑
  - Air cell diameter ↑
  - t/D ratio ↓
  - more expanded air cells in relation to cell wall thickness
- Energy required to fracture big air cells with thin cell walls is lower than that required for small air cells with thick cell walls
- Less hard, more crispy extrudates
Crispiness increases with increased expansion and decreased piece density for fine particle sized rye bran extrudates.

- Higher expansion tends to give crispy puffs
- Higher density reduces crispiness
2nd paper: Effects of rye bran particle size reduction on in vitro starch digestibility and structural and textural properties of starch-based high-fibre extrudates (submitted)

Fine IB 30:
High cell wall thickness & Large cell wall area
Effect of particle size on in vitro starch digestibility

In-barrel water feed extrudates

<table>
<thead>
<tr>
<th>t (mm)</th>
<th>C_wA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.14 ± 0.01 a</td>
<td>1.55 ± 0.15 ab</td>
</tr>
<tr>
<td>0.16 ± 0.01 ab</td>
<td>1.02 ± 0.11 ab</td>
</tr>
<tr>
<td>0.14 ± 0.01 a</td>
<td>1.36 ± 0.44 ab</td>
</tr>
<tr>
<td>0.14 ± 0.00 ab</td>
<td>1.12 ± 0.12 ab</td>
</tr>
<tr>
<td>0.17 ± 0.01 bc</td>
<td>1.73 ± 0.40 ab</td>
</tr>
</tbody>
</table>

- 15% bran addition: Fibre: 8.2%
- 30% bran addition: Fibre: 12.6%
Experimental design 3/4

Publication 3:

100% Rye flour & Rye flour + 10% rye bran

- Screw speed: 250 (F) & 345 (P)
- Feed moisture: 4.5 (P) & 12 (F) In-barrel
- Barrel T profile: low (80-95-110-120°C)

- Interidividual variance due to chewing pattern
- Effect of fibre: 7 vs. 9%
- Structure/texture effect on mastication: puffs vs. flakes

EMG: EMG activity time -> Chewing time -> Number of bites -> Duty cycle -> Total work -> Work/bite
3rd paper outline

100% Rye flour & 90% Rye flour + 10% Rye bran

Extruded puffs and flakes

Mastication & EMG

Fibre: 7 & 9%

15 female volunteer

Bolus

Starch digestibility

Image analysis

Microscopy

Saliva impregnation

X-ray Microtomography

Starch HI

Viscosity

Microscopy

Texture

Microscopy & particle area distribution of masticated bread sample
Mastication trial/Electromyography

- 15 participants
- Bipolar electrodes on the **masseter** and **temporal** muscles on both sides of the face
- 3 portions
  - control bread: (2x2x2) cm cube
  - Puffs: (2x3.5) cm ribbon
  - Flakes: 1 table spoon
- Masticated until subjective swallowing point and the bolus was then expectorated
- EMG activity measured continuously
- Onset, duration and amplitude of each bite event were extracted from EMG time series
HIGH FIBRE (RYE) FOODS ARE HAVE GOOD POTENTIAL TO ASSIST IN REDUCTION OF RISK OF CHRONIC DISEASES.

UNDERSTANDING THEIR STRUCTURE FORMATION AND ORAL DISINTEGRATION - THE CONNECTION BETWEEN FOOD PROCESSING AND EATING – HELPS TO DEVELOP BETTER FOODS.
THANK YOU!

ariful.alam@vtt.fi
VTT - 70 years of technology for business and society