The use of nitrogen gas as a physical blowing agent to produce puffed snacks made from yellow pea flour

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Food legumes

- High quality proteins
- Low in calories & glycemic index

Food industry & consumers

- New food processes
- Protein-rich ingredients from plants

Image: http://www.lightomega.org/

Food security & sustainability

Global food demand

Image: http://www.fitnflexed.com/

Aerated foods

- Trends of healthy snacking and convenience foods
- The continuous quest for novelty & new products with superb palatability
- Unique textures and structures → Great opportunities to manufacture nutritionally dense (e.g., plant protein-rich) foods!

Image: http://www.21food.com

Image: http://www.healthylifetricks.com

Image: http://www.thishonestfood.com

Extrusion

- A high throughput process and flexibility to control food design
- An effective means of engineering bubbles and to load plant protein-rich ingredients into foods
  - Converts dense, hard materials into lighter, more palatable and appealing forms
- Significantly enhances food quality

Image: http://foodprocessing.wsu.edu/research/extrusion-processing/

Image: https://www.generalmillscf.com/products/category/cereal/bulk/reeses-puffs

Extrusion

- Multiple unit process operations:
  - Mixing, shearing, cooking…

bubble dynamics: nucleation, growth, coalescence, collapse, setting ⟶ extrudate structure

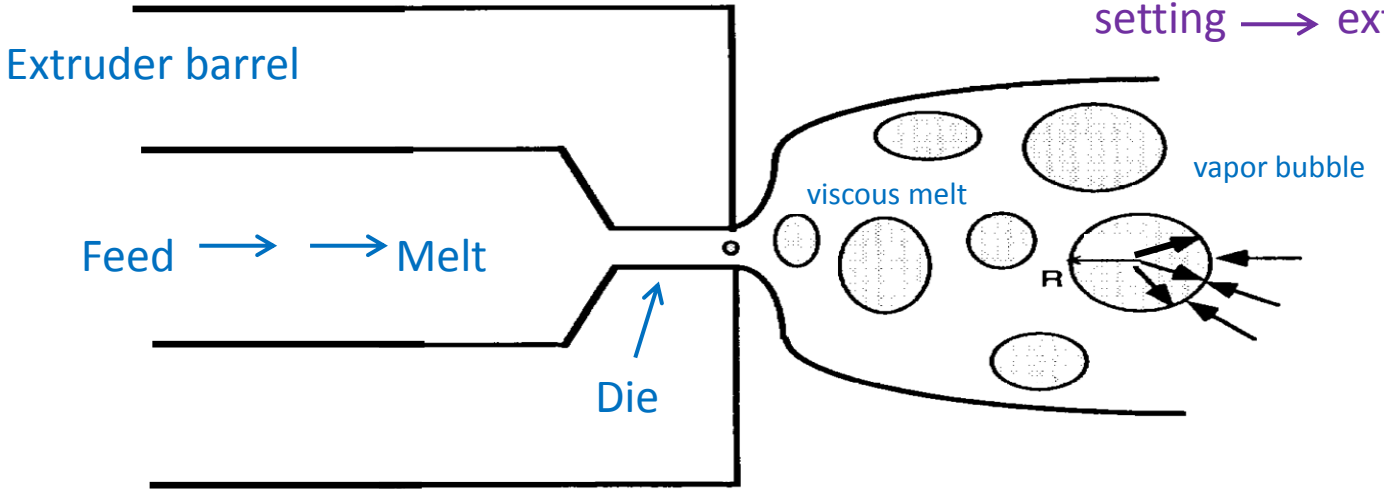


Image: Della Valle et al. 1997. J Food Eng. 31: 277.

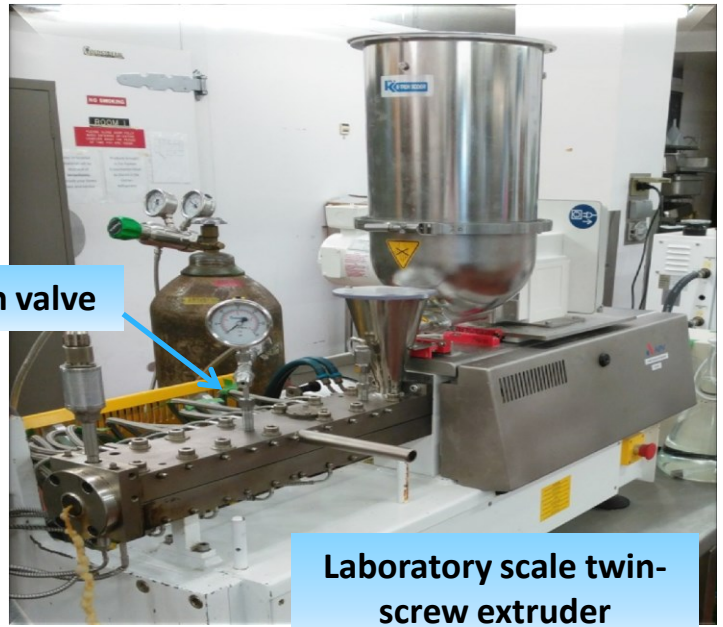
Background

- Why aren't protein-rich aerated foods as common as the starch-based ones in supermarkets?
  - Failure in generating extrudates with structural and sensory quality
    - Resistance to expansion
    - Collapse before solidification
    - Harder and denser extrudates
- How can we manipulate the structure of aerated foods?
  - Physical blowing agents

Image: https://www.flickr.com/photos/kpat/4126435982/

Physical blowing agents

- In polymer industry – foaming:
  - To generate cellular structures and to reduce material weight and cost
- In extrusion of foods:
  - Limited to starch-rich systems
  - To manipulate aerated structure of extruded products.
- The most common physical blowing agent for food extrusion is SC- CO_2
  - More homogeneous aerated structure
  - Can mitigate quality issues due to protein enrichment



Rationale

- Physical blowing agent solubility
- Gases with different solubility values, and at different concentrations, substantially influence aerated foam structure
- Melt composition, extrusion pressure and temperature → cellular structure
- Food extrusion to date → exclusively subcritical and supercritical CO_2

Objective

To manipulate the physical, textural and microstructural properties of extrudates made from yellow pea flour (~20% protein) using gas (N_2) assisted extrusion.

Experimental Design

- A lab-scale, co-rotating twin screw extruder (2.3 mm diameter circular die)

- 3 feed moisture contents:
  - Low (14%)
  - Medium (16%)
  - High (18%)

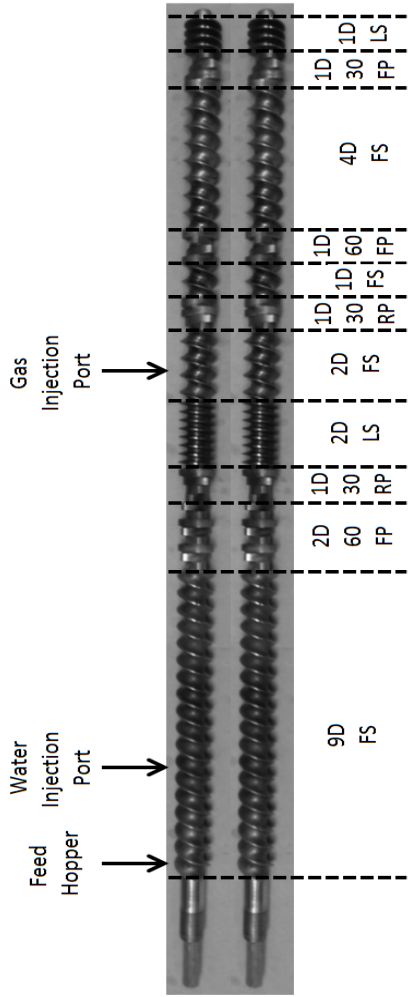
- N_2 gas was injected into the extruder barrel as a physical blowing agent.
  - 1-5 bar (0.1-0.5 kPa)

Image: http://promociones.praxair.com.mx

- Constant screw speed → 200 rpm
- Constant die temperature → 150°C

Experimental Design

- Extrudate expansion:
  - Bulk density, expansion index
- Extrudate microstructure and color:
  - Scanning Electron Microscopy (SEM)
  - Color meter
- Extrudate textural properties:
  - Hardness, crunchiness, crispiness



Experimental design and dependent extrusion variables

Feed moisture content (%)	N_2 pressure (bar)	Torque (Nm)	Die pressure (bar)	SME (Wh/kg)
14	0	38	54	230
	1	38	54	230
	2	37	56	219
	3	33	59	200
	4	32	58	192
	5	32	60	190
16	0	33	45	195
	2	30	52	181
	4	29	49	171
18	0	26	41	157
	2	25	41	147
	4	25	43	149

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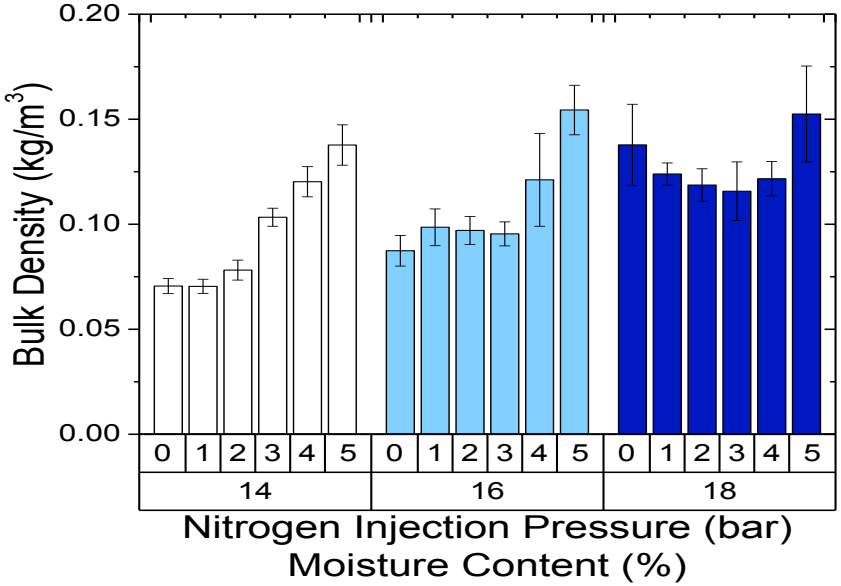
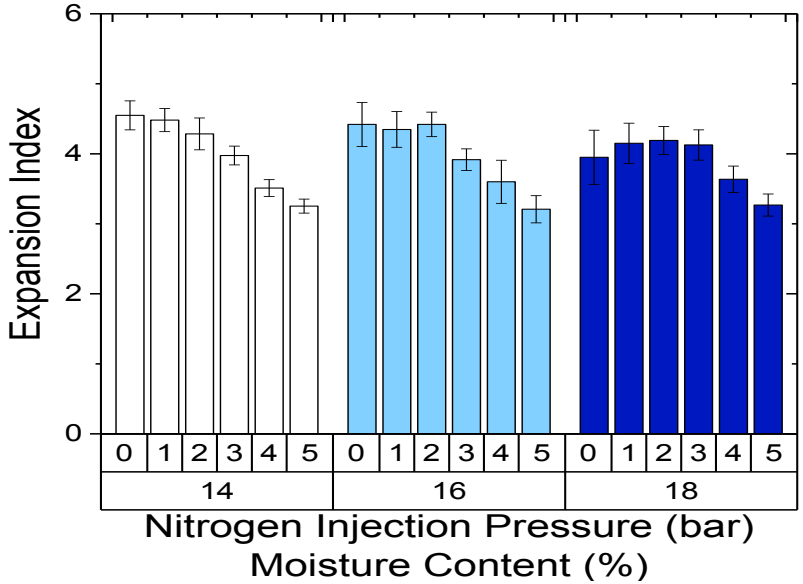
Extrudate expansion





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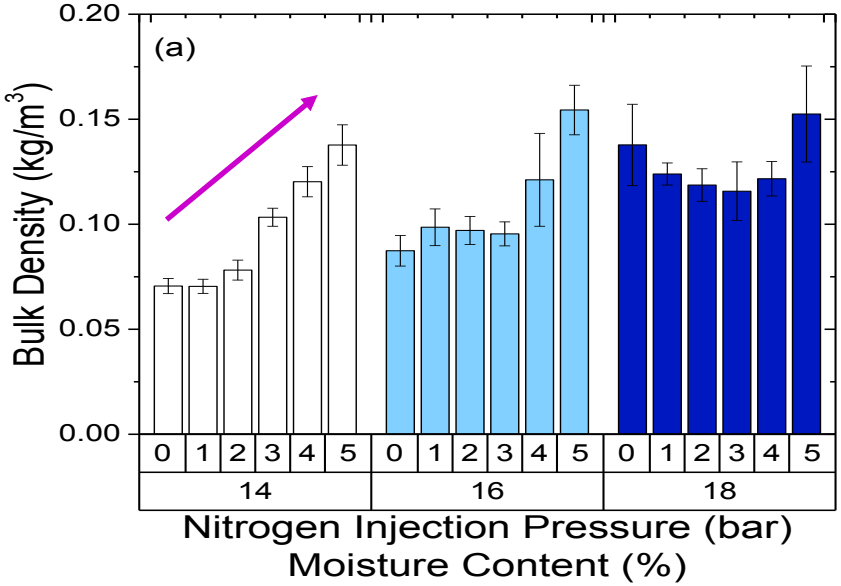
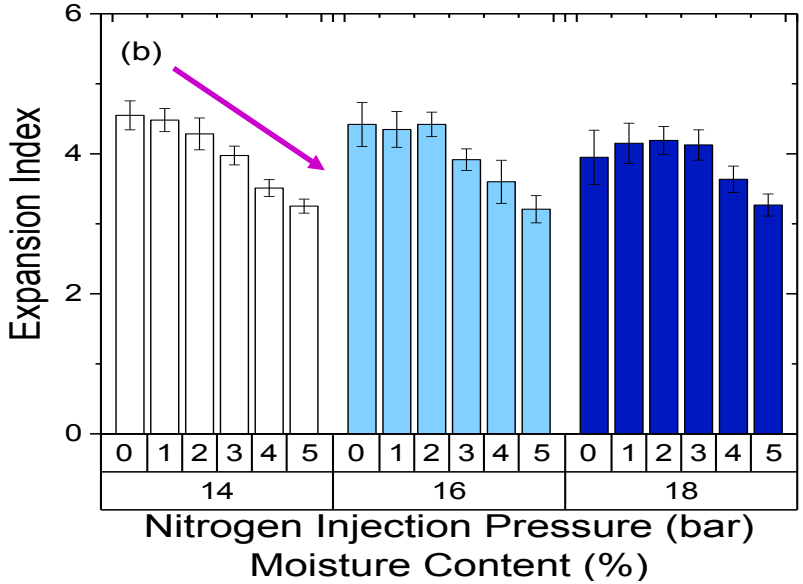
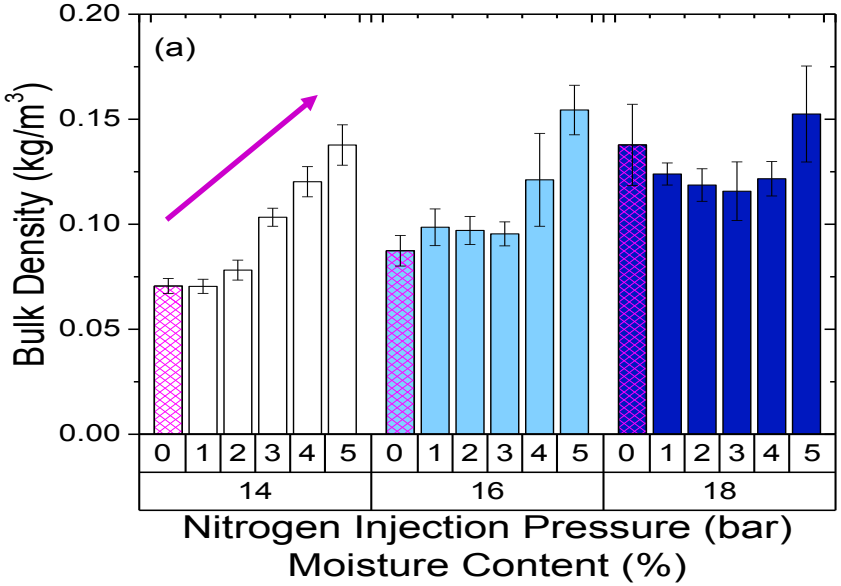
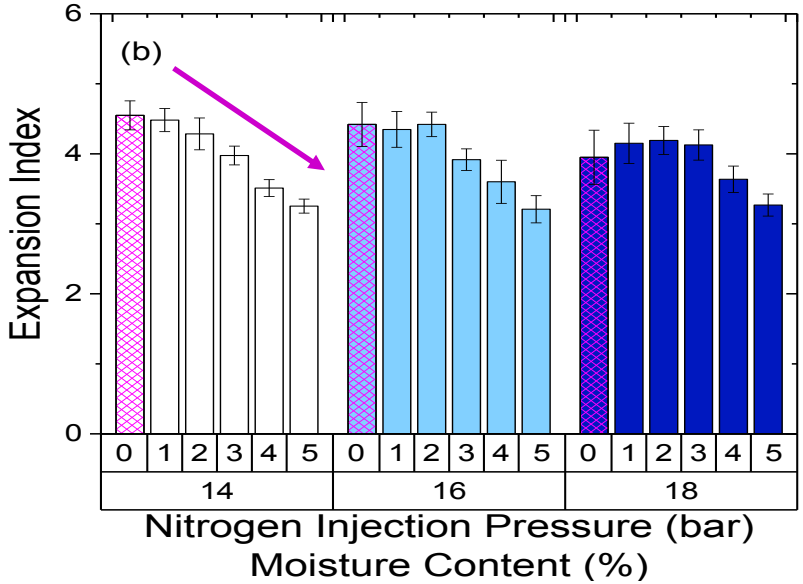


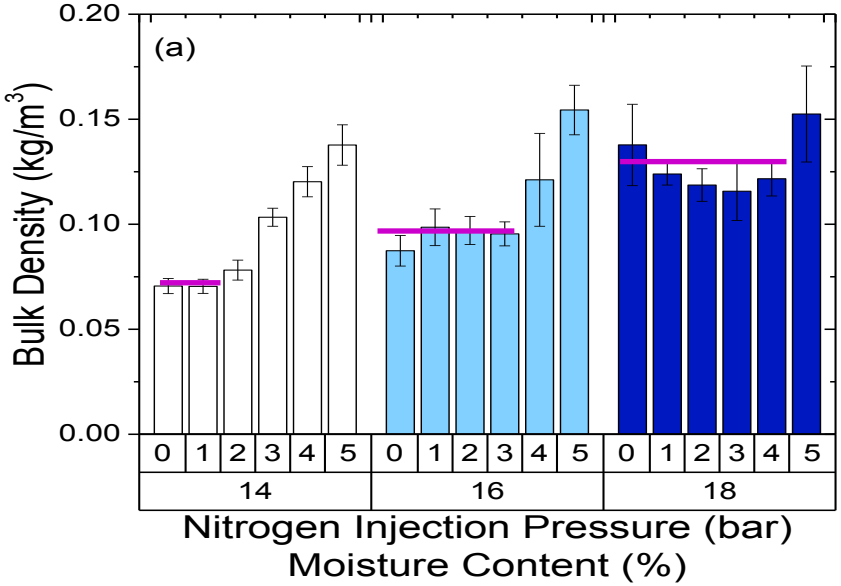


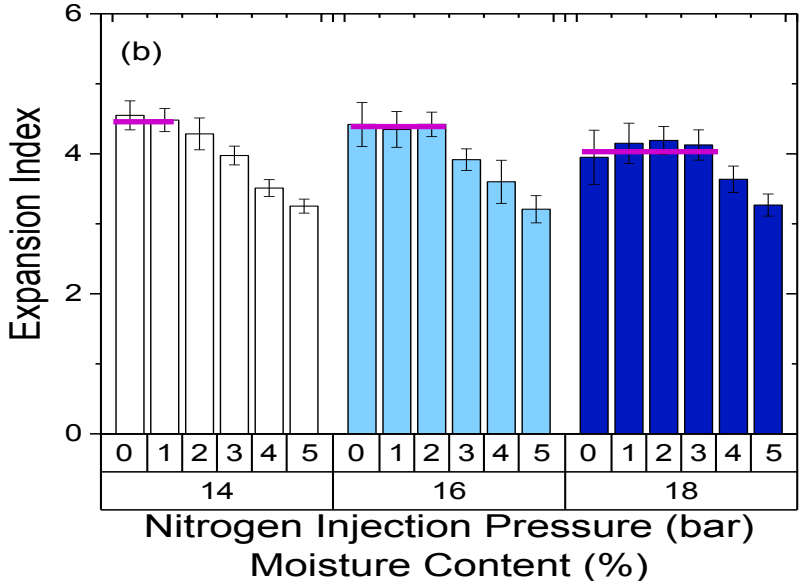
Extrudate expansion



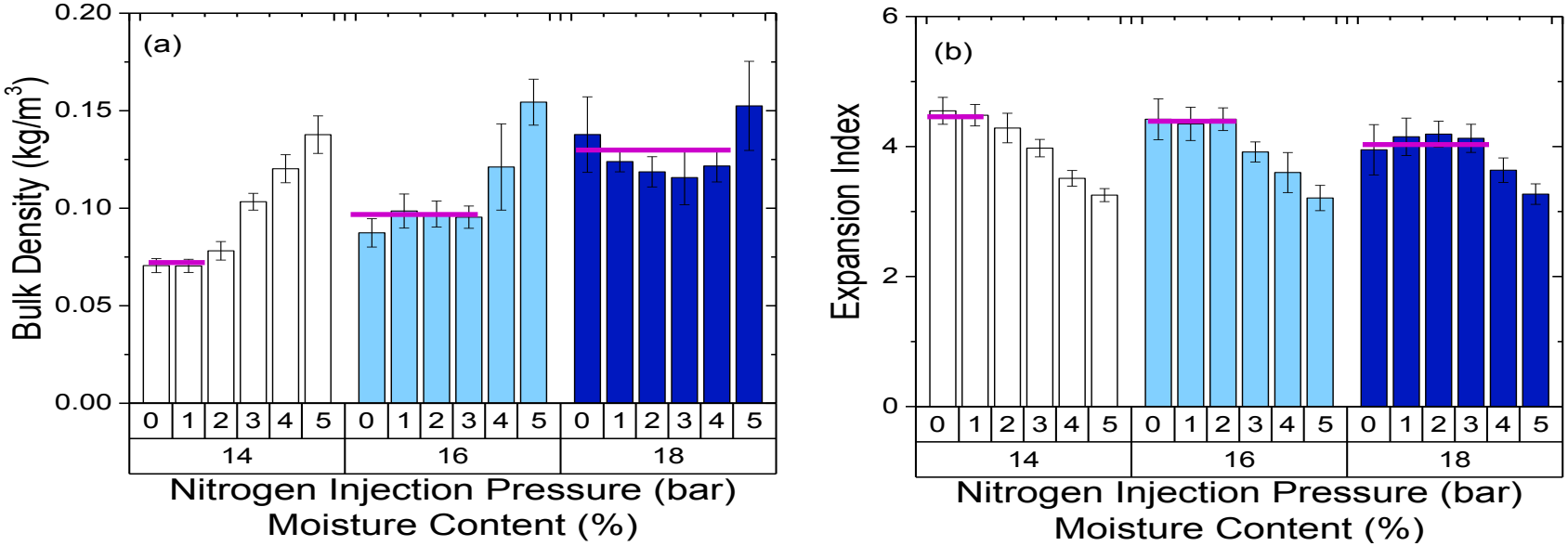


Extrudate expansion





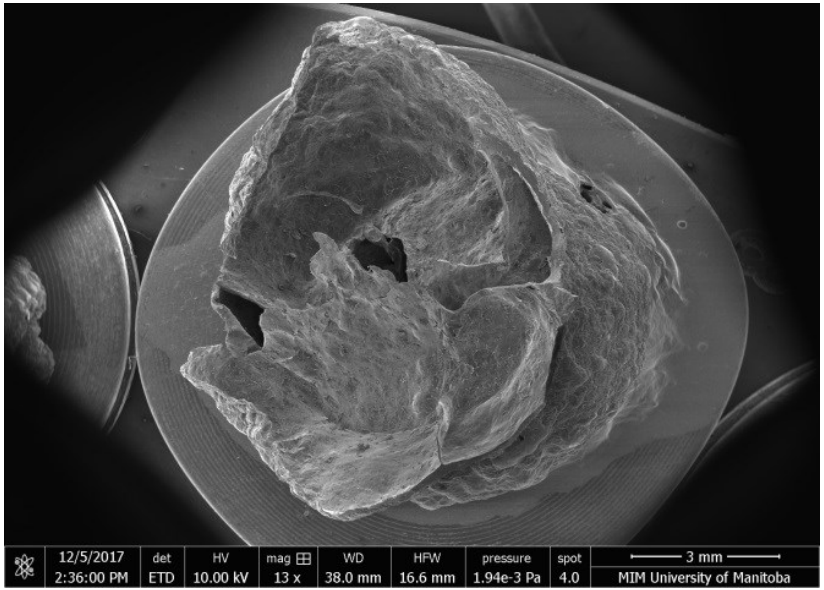
Extrudate expansion



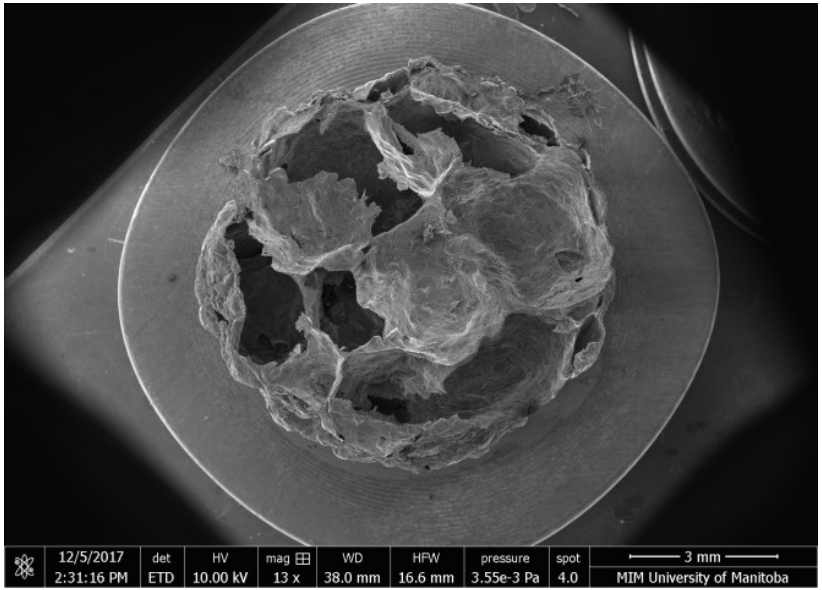
A decrease in overall expansion at high P observed for SC-CO_2 assisted extrusion for corn starch and corn starch-whey protein isolate extrudates.

Alavi et al., 1999. Food Res. Int.
Cho and Rizvi, 2009. Food Res. Int.

Cross sectional microstructure

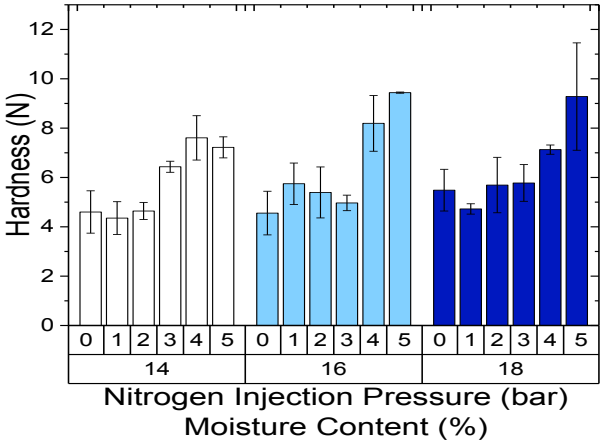


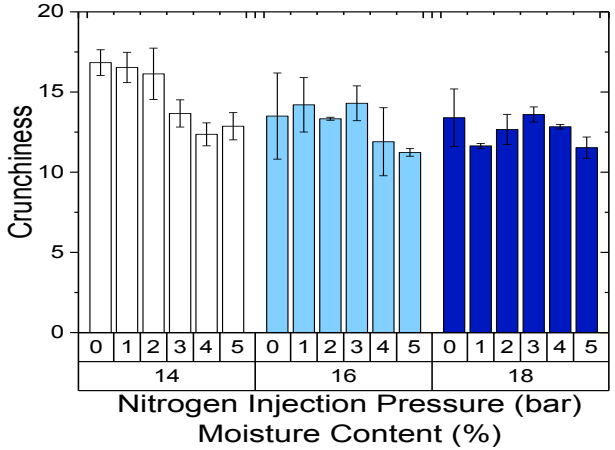
18% moisture – No N_2

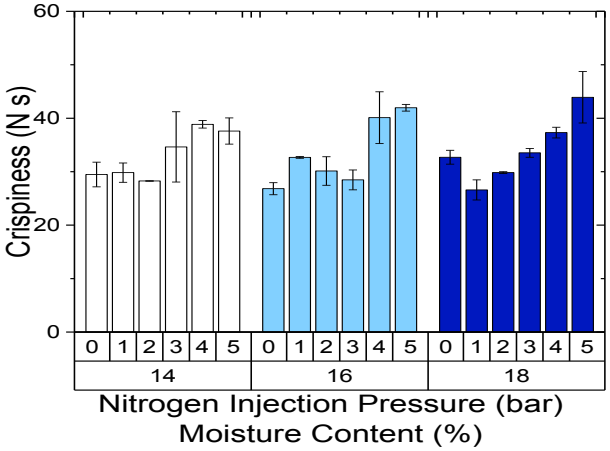


18% moisture – 5 bar N_2

Extrudate texture







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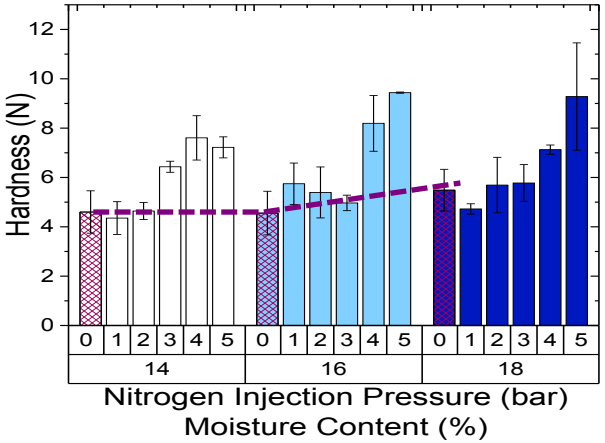

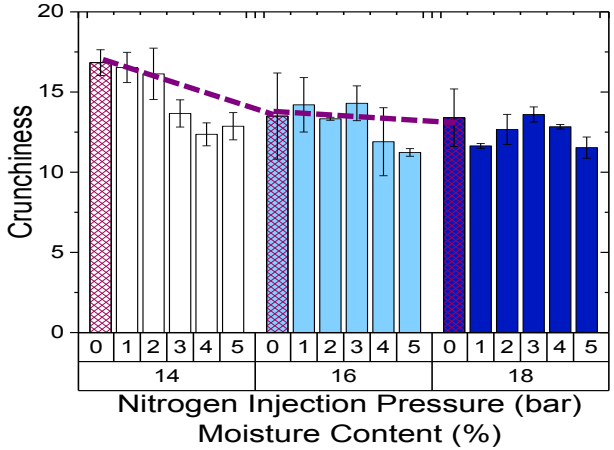

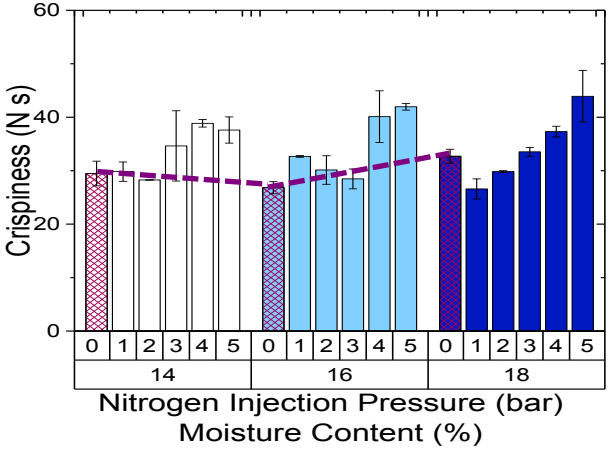

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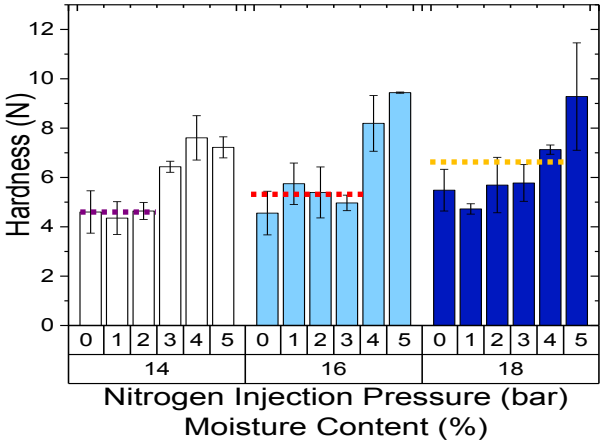

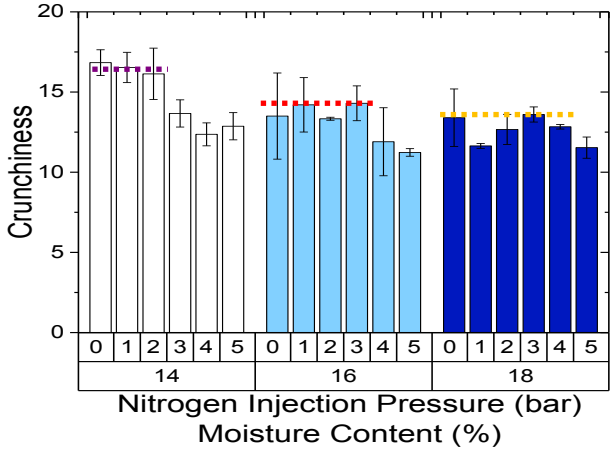

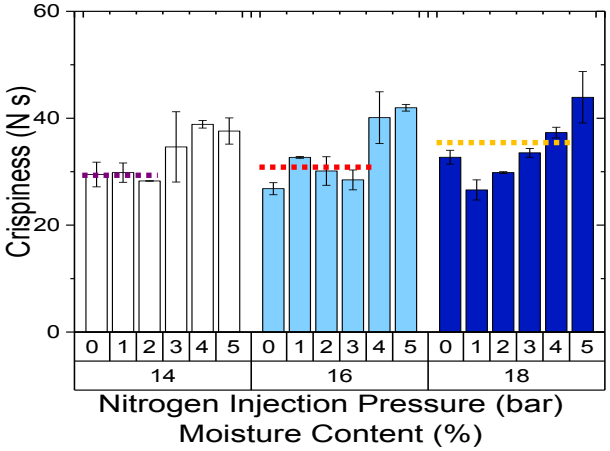

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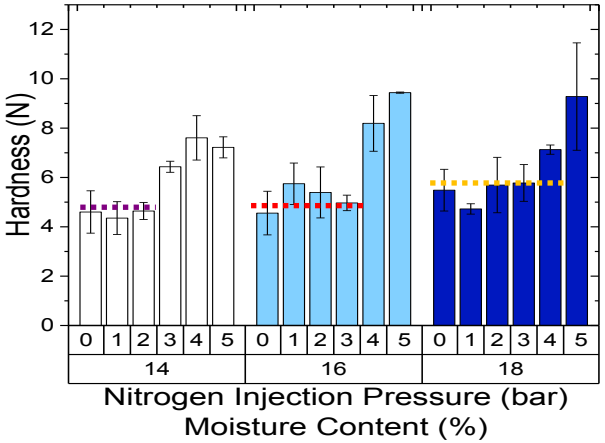
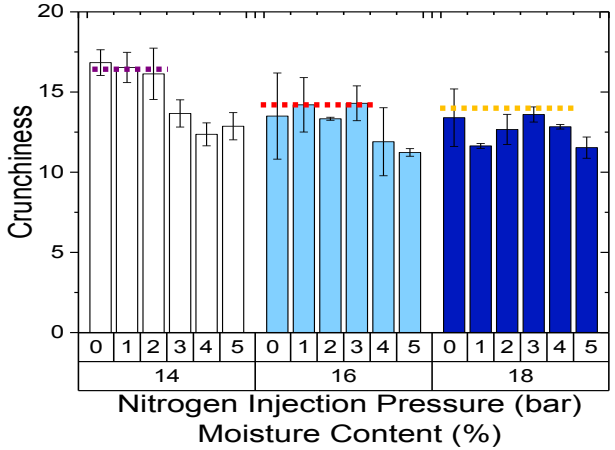
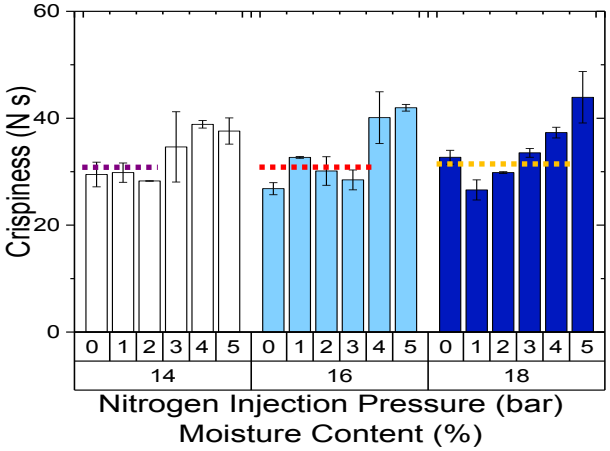
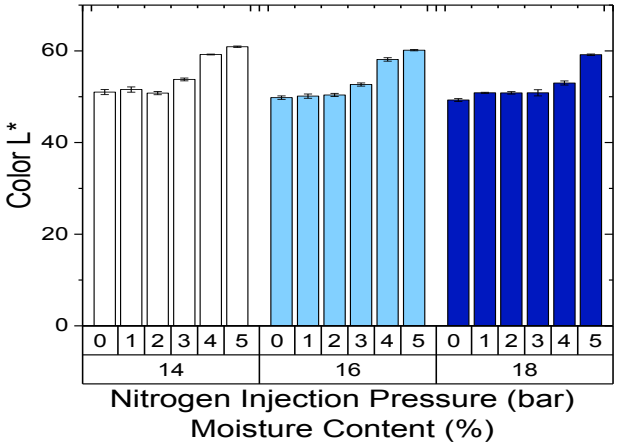


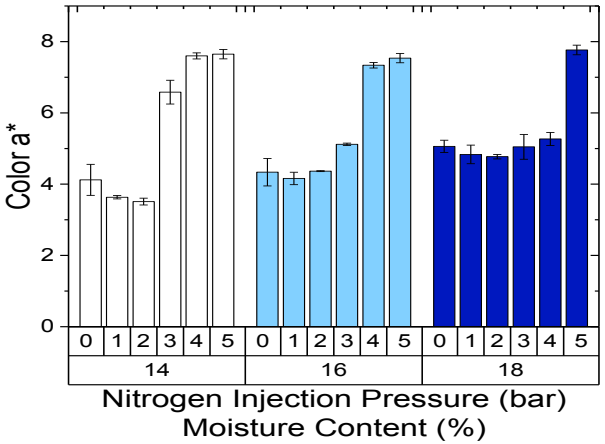


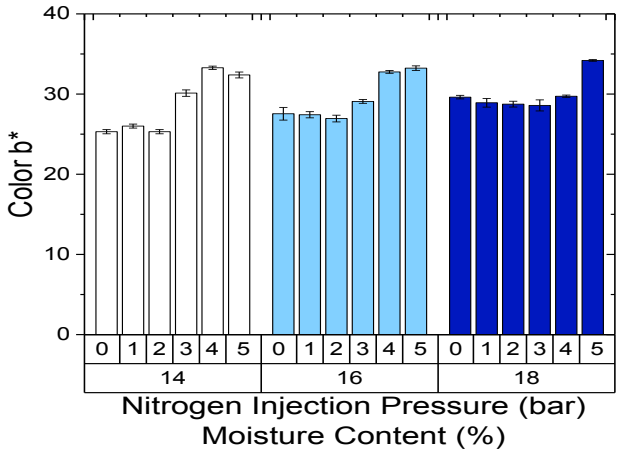


- Expansion index and hardness → r=-0.899
- Bulk density and crunchiness → r=-0.874
- N_2 pressure and crispiness → r=0.822

Extrudate color







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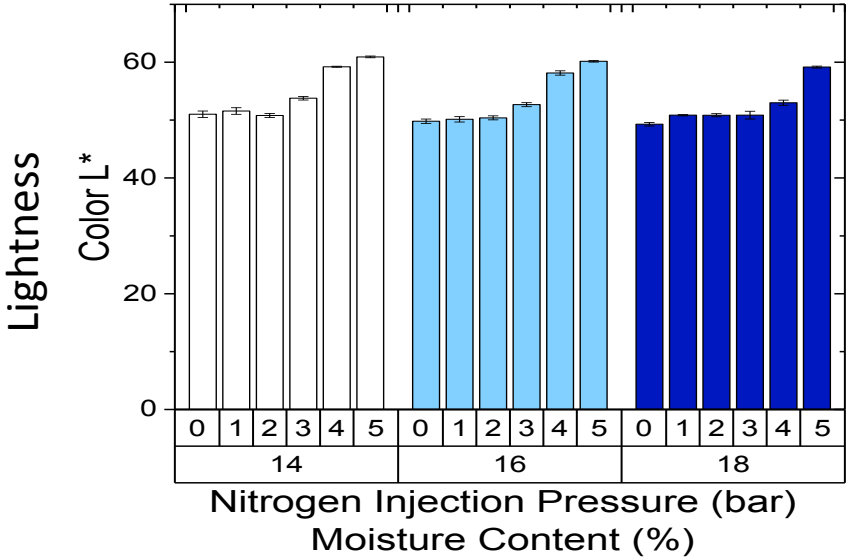

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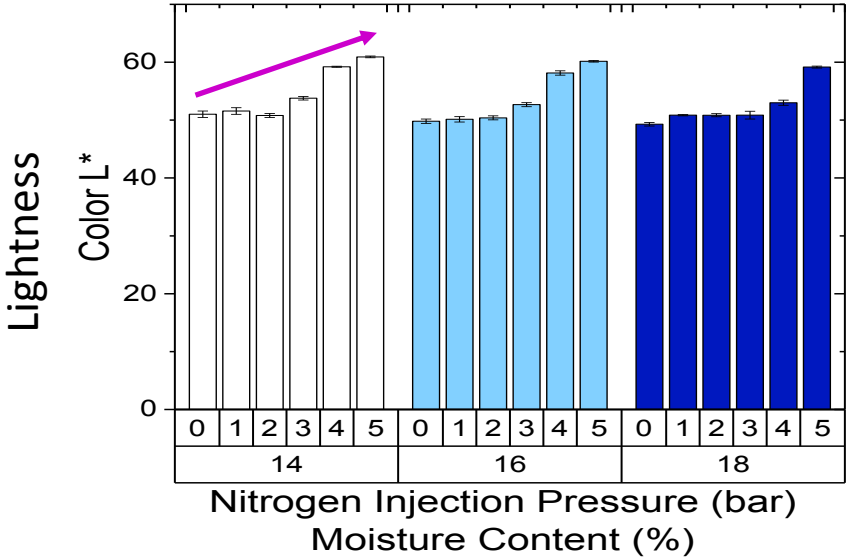
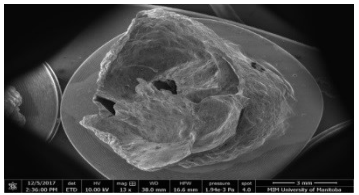
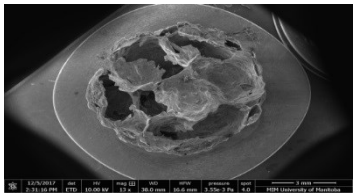




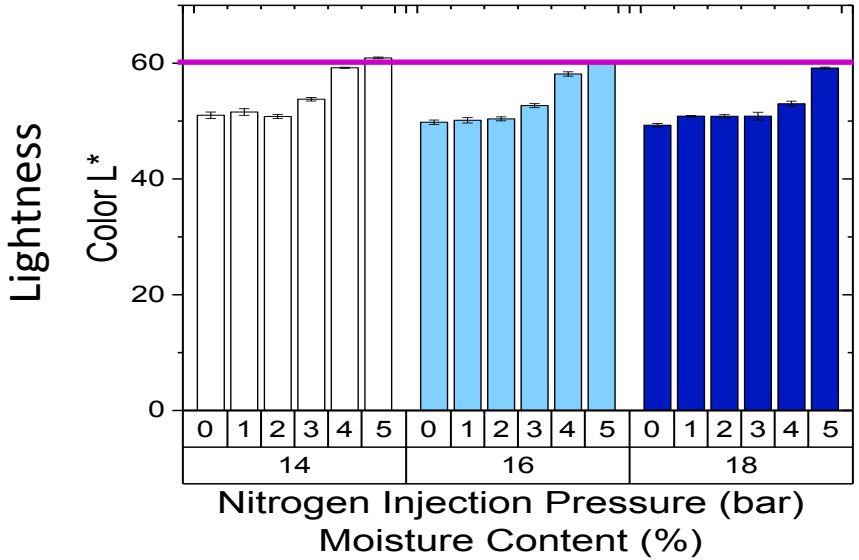
18% mc, no N_2

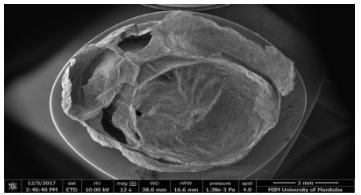


18% mc, 5 bar N_2

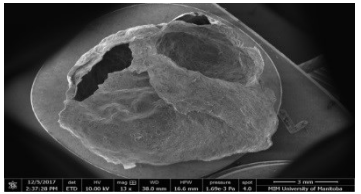
- Diffused reflection + specular reflection of the incident light in the presence of N_2.
  - Higher number of bubbles nucleated during N_2 assisted extrusion leading to serial reflections of light at cell-cell wall interfaces

Extrudate color





14% mc, no N_2



16% mc, no N_2

- Diffused reflection + specular reflection of the incident light in the presence of N_2.
  - Higher number of bubbles nucleated during N_2 assisted extrusion leading to serial reflections of light at cell-cell wall interfaces

Conclusions

- Extrudate expansion was feed moisture content and N_2 pressure dependent.
- Microstructure, texture and color were not substantially influenced by feed moisture content.
- Physical blowing agent assisted extrusion can potentially improve extrudate physical, textural and microstructural properties.

- Future work: Maintaining the homogeneous cell structures obtained by physical blowing agent assisted extrusion while at the same time increasing the overall extrudate expansion.

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University of Manitoba

Faculty of Agricultural and Food Sciences

MIM

Manitoba Institute for Materials

Ingredion

LACC IGW

Opportunities at the University of Manitoba

- Food and Human Nutritional Sciences Dept.
- Graduate Studies
  - MSc or PhD
- Background in food engineering and/or processing

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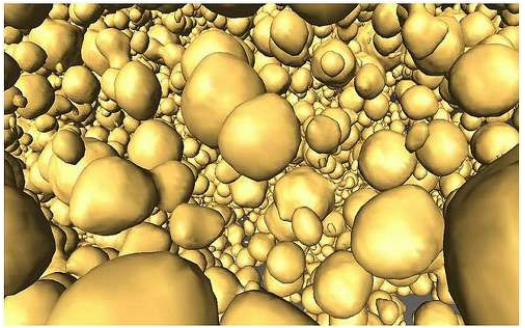
For more info, visit: http://www.filizkoksel.ca/

- Other aerated foods:
  - Bubbles in bread dough
  - Bubbles in noodles
    - Microstructural quality
    - Mechanical properties
    - Ultrasound waves
    - X-ray microtomography




Muchas
Gracias