Rheology of Digestion
Simulation of the fate of meat and meat substitutes in the gastrointestinal tract

U.S. van der Schaaf[1], C. Küchenmeister-Lehrheuer[2], Gabriela I. Saavedra Isusi[2]
[1] Karlsruhe Institute of Technology, Institute of Process Engineering in Life Sciences, Karlsruhe, Germany
[2]Thermo Fisher Scientific, Pfannkuchstr. 10-12, 76185 Karlsruhe, Germany

INTRODUCTION

More people are adopting a plant-based diet for health benefits, ethical and environmental considerations, among other reasons. Nowadays, meat substitutes not only convince with their taste but also with their structure, thanks to the latest extrusion technology and structural characterization by means of rheology or tribo-rheology. Although consumer acceptance has increased, it is still unclear how these products compare to real meat in the digestive tract. Rheology offers simpler experimental designs to assess the digestibility of plant-based alternatives than conventional, complex in vivo studies.

Learn from selected examples how digestibility can be predicted using a classic rotational rheometer and a suitable measuring cell.

Digestion in the Human Body and Rheological Simulation

The digestion process is complex, involving various enzymes in different pH environments. Using rheological measurements, the process in the stomach and small intestine is simulated with the goal to clearly differentiate between different products.

Mouth
- Mechanical breakdown of food
- Enzymatic digestion of carbohydrates by amylase

Esophagus:
- Peristaltic transport of food to stomach

Stomach
- Mechanical mixing of food
- Protein denaturation by hydrochloric acid.
- Proteolysis by pepsin.

Small Intestine
- Enzymatic digestion of proteins, carbohydrates, and fats by pancreatic enzymes (trypsin, chymotrypsin, amylase, lipase) and bile
- Absorption of nutrients.

Large Intestine
- Water and electrolyte absorption.
- Fermentation of fibers by gut microbiota.
- Stool formation and excretion.

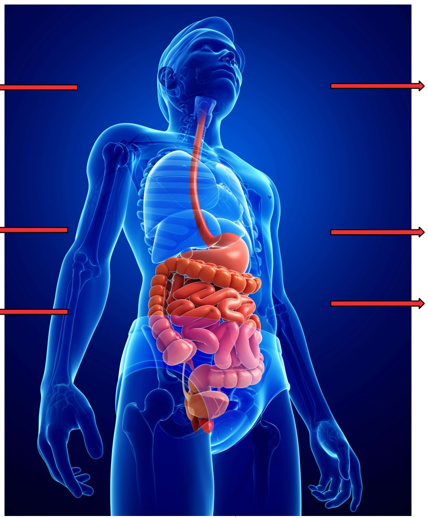

Fig.1 Human digestive tract

Material, Sample Preparation and Measurements

The following samples were used:
Beef, Chicken, Commercially available soy-based chicken alternative, Soy-based extrudates

Sample Preparation and Placement in Measuring Cell
- Meat and meat alternative chunks were sous-vide cooked
- Simulated mastication: grinding and meatball formation (2.5 g)
- Prepared meatball is placed in the measuring cell of the rheometer.
- Normal force - controlled lift movement into measuring position (measuring gap ~ 1,3 mm)
- Measuring cell is flooded with simulated salivary fluid without amylase

Stomach Phase (approx. 2 hours)
- Changing the rinsing medium to simulated gastric fluid
- pH value reduced to approx. 3
- Add digestive enzymes (pepsin).
- Observe the denaturation of proteins in the samples.

Small Intestine Phase (approx. 2 hours)
- Changing the rinsing medium to simulated intestinal fluid
- pH value increased to approx. 8
- Add digestive enzymes (pancreatin and bile salts).
- Observe the denaturation of proteins in the samples.

→ Digestion conducted according to Infogest 2.0 protocol[2]

Production of Meat like Extrudates

Extrusion is considered a key technology for imparting different textures to plant-based ingredients.

The Thermo Scientific™ Process™ 16 Hygienic Twin-Screw Extruder, equipped with a modular cooled slit die, produces samples for sensory evaluations, such as texture analysis [1].

In the screw section, shear and thermal energy alter the material properties of plant protein ingredients. In the die section, the process creates an anisotropic, fibrous protein matrix that resembles the texture of muscle meat, depending on the flow profile and heat transfer.

Meat alternatives taste good. How well can they be digested?

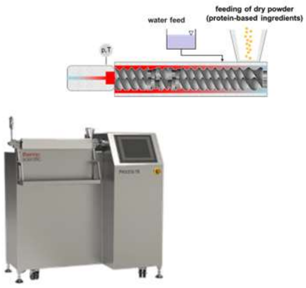

Fig. 2 Thermo Scientific™ Process™ 16 Hygienic Twin-Screw Extruder, detailed view: screw and die section

''Digestive Rheometer''

Rheological measurements were performed on a Thermo Scientific™ HAAKE™ MARS™ 60 Rheometer with submersion flow cell equipped with a serrated plate-plate geometry designed with an inlet and outlet so that the liquid can be varied to simulate the gastric or intestinal fluids. This allows pH alterations and enzymatic digestion to be observed in situ while assessing changes in the viscoelastic properties of the samples.

Fig.3 Submersion flow cell

Fig.4 Thermo Scientific™ HAAKE™ MARS™ 60 Rheometer

Results

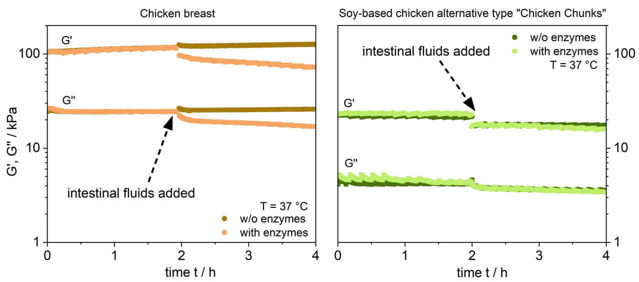

Fig.5 Results of rheological characterization (CD Mode: 1% Deformation, Temperature 37 °C): Addition of simulated gastric fluid (with or without respective enzymes) after 2 min; addition of simulated intestinal fluid (with or without respective enzymes) after 2 hours

Conclusions

- Conducting Infogest 2.0 protocol experiments is possible within the novel submersion flow cell
- No effect of pepsin on G' or G'' visible
- In chicken breast, G' and G'' decrease significantly upon addition of pancreatin and bile salts
- No effect of pancreatin and bile salts on G' and G'' of chicken alternative

→ Reduced structural breakdown in meat alternatives upon digestion

References

[1]Cheftel, J.C.; Kitagawa, M.; Quéguiner, C. New protein texturization processes by extrusion cooking at high moisture levels. Food Rev. Int. 1992, 8, 235–275
[2]NATURE PROTOCOLS |VOL 14 | APRIL 2019 | 991–1014 | www.nature.com/nprot

Karlsruhe Institute of Technology
ThermoFisher SCIENTIFIC