Engineering Meat-like Texture in Plant-Based Proteins

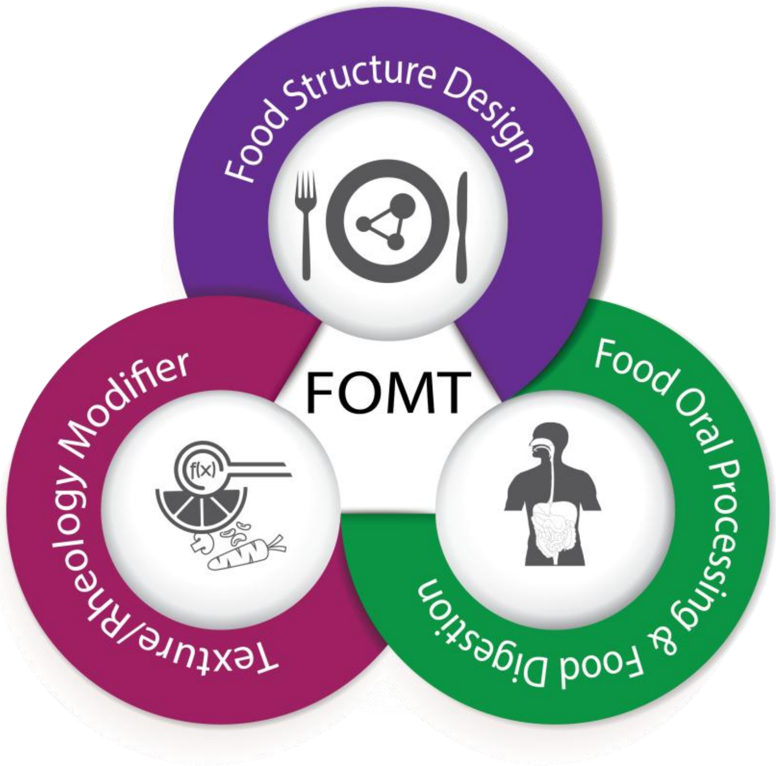
การออกแบบเนื้อสัมผัสสำหรับโปรตีนทางเลือก สู่ประสบการณ์เสมือนจริง

Kamolwan Israkarn

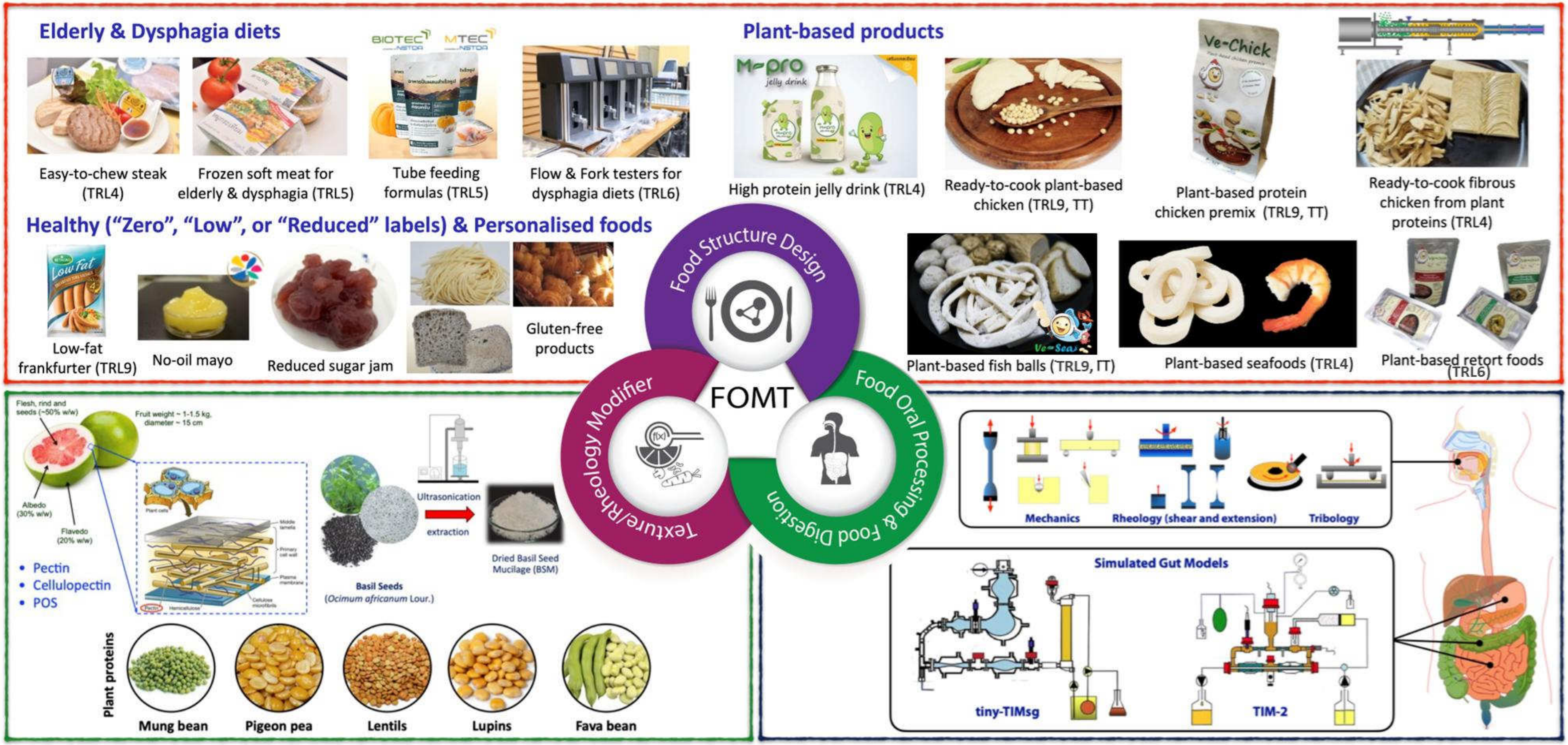
Food Materials Research Team
National Metal and Materials Technology Center (MTEC),
National Science and Technology Development Agency (NSTDA)

Food Materials Research Team

is under Advanced Polymer Technology Research Group of the National Metal and Materials Technology Center (MTEC), National Science and Technology Development Agency (NSTDA).



Core technologies


Elderly & Dysphagia diets
Easy-to-chew steak (TRL4)
Frozen soft meat for elderly & dysphagia (TRL5)
Tube feeding formulas (TRL5)
Flow & Fork testers for dysphagia diets (TRL6)
Plant-based products
High protein jelly drink (TRL4)
Ready-to-cook plant-based chicken (TRL9, TT)
Plant-based protein chicken premix (TRL9, TT)
Ready-to-cook fibrous chicken from plant proteins (TRL4)
Healthy ("Zero", "Low", or "Reduced" labels) & Personalised foods
Low-fat frankfurter (TRL9)
No-oil mayo
Reduced sugar jam
Gluten-free products
Plant-based fish balls (TRL9, TT)
Plant-based seafoods (TRL4)
Plant-based retort foods (TRL6)
Food Structure Design
FOMT
Texture/Rheology Modifier
Food Oral Processing & Food Digestion
Flesh, rind and seeds (~50% w/w)
Fruit weight ~ 1-1.5 kg, diameter ~ 15 cm
Albedo (30% w/w)
Flavedo (20% w/w)
Pectin
Cellulopectin
POS
Ultrasonication
extraction
Basil Seeds (Ocimum africanum Lour.)
Dried Basil Seed Mucilage (BSM)
Plant proteins
Mung bean
Pigeon pea
Lentils
Lupins
Fava bean
Mechanics
Rheology (shear and extension)
Tribology
Simulated Gut Models
tiny-TIMsg
TIM-2

Outline

Engineering Meat-like Texture in Plant-Based Proteins

การออกแบบเนื้อสัมผัสสำหรับโปรตีนทางเลือกสู่ประสบการณ์เสมือนจริง

- ***Technology in Structural and Textural Design for Plant-Based Meat Products***

  เทคนิคการออกแบบโครงสร้างและเนื้อสัมผัสของผลิตภัณฑ์เนื้อเทียม

- ***The Potential of High-Temperature Shearing technology in the Plant-Based Meat Industry***

  เทคโนโลยีเฉือนด้วยอุณหภูมิสูงและความเป็นไปได้ในเชิงอุตสาหกรรม

- ***3D-Printing: Precise technology for the meat analogue industry***

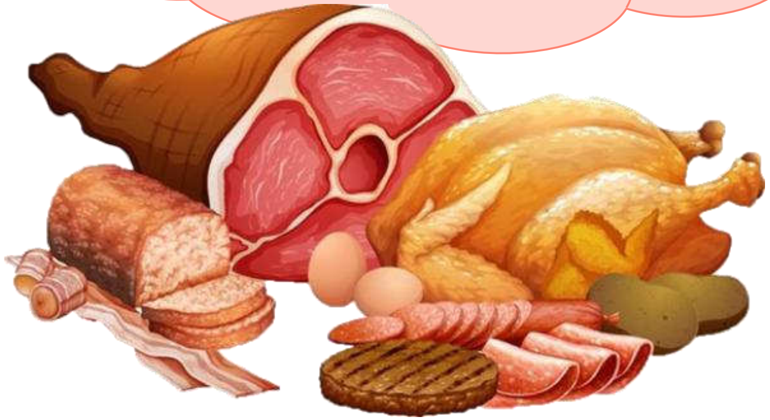
  3D-Printing: เทคโนโลยีจำลองเนื้อสัตว์เทียมอย่างแม่นยำ

Technology in structural and textural design for plant-based meat products
เทคนิคการออกแบบโครงสร้างและเนื้อสัมผัสของผลิตภัณฑ์เนื้อเทียม

Innovation and technology for plant-based food structuring

Traditional plant-based meat alternative products

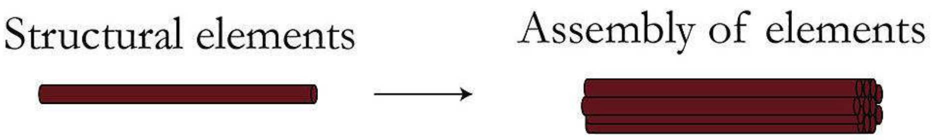
Organoleptic properties similar to animal meat products

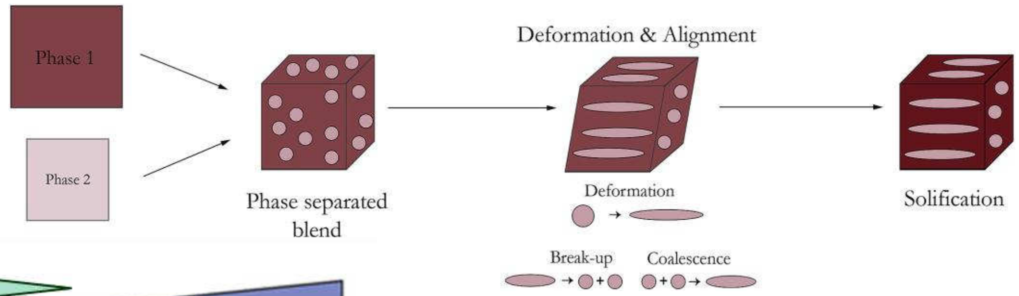


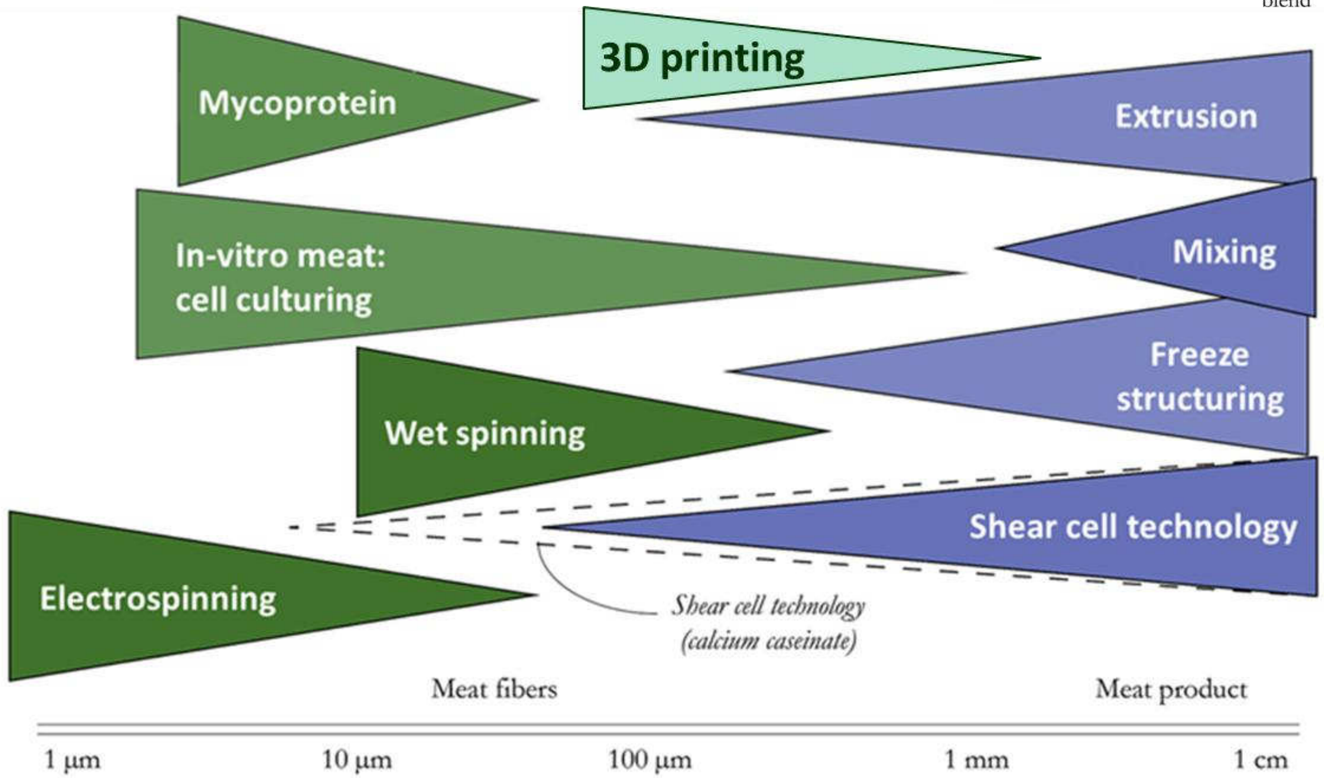
Fibrous meat-like structuring processes

1. **Bottom-up strategy**

2. **Top-down strategy**







(modified from Dekkers et al., 2018)

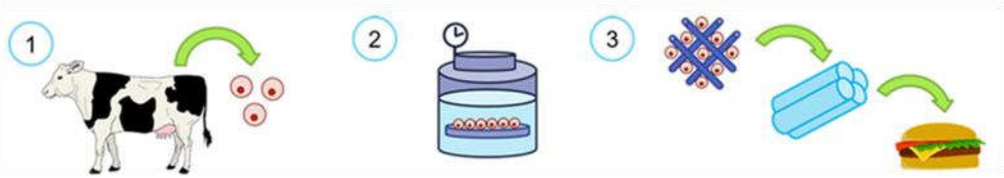
Bottom-up strategy

a) Mycoprotein (fungi protein)

โปรตีนแผ่นกรอบจากมัยคอโปรตีน (25-27% protein)

อนุสิทธิบัตร เลขที่คำขอ 2303000864

b) *In-vitro* meat: cell culturing

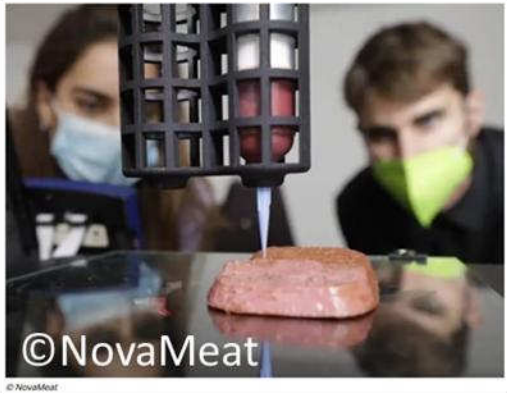


The cultured meat industry is growing rapidly. IDTechEx forecasts the cultured meat market to be worth $11.13 billion by 2041

https://www.idtechex.com/th/research-report/cultured-meat-2021-2041-technologies-markets-forecasts/815

- สิงคโปร์ ถือเป็นประเทศแรกของโลกที่อนุญาตให้ขายเนื้อสัตว์จากห้องทดลองเพื่อการพาณิชย์ได้ โดยอนุมัติให้มีการขายนักเก็ตไก่ที่ทำจากไก่สังเคราะห์ จากบริษัท Eat Just

c) 3D food printing



Mostly driven by start-ups!

www.mtec.or.th

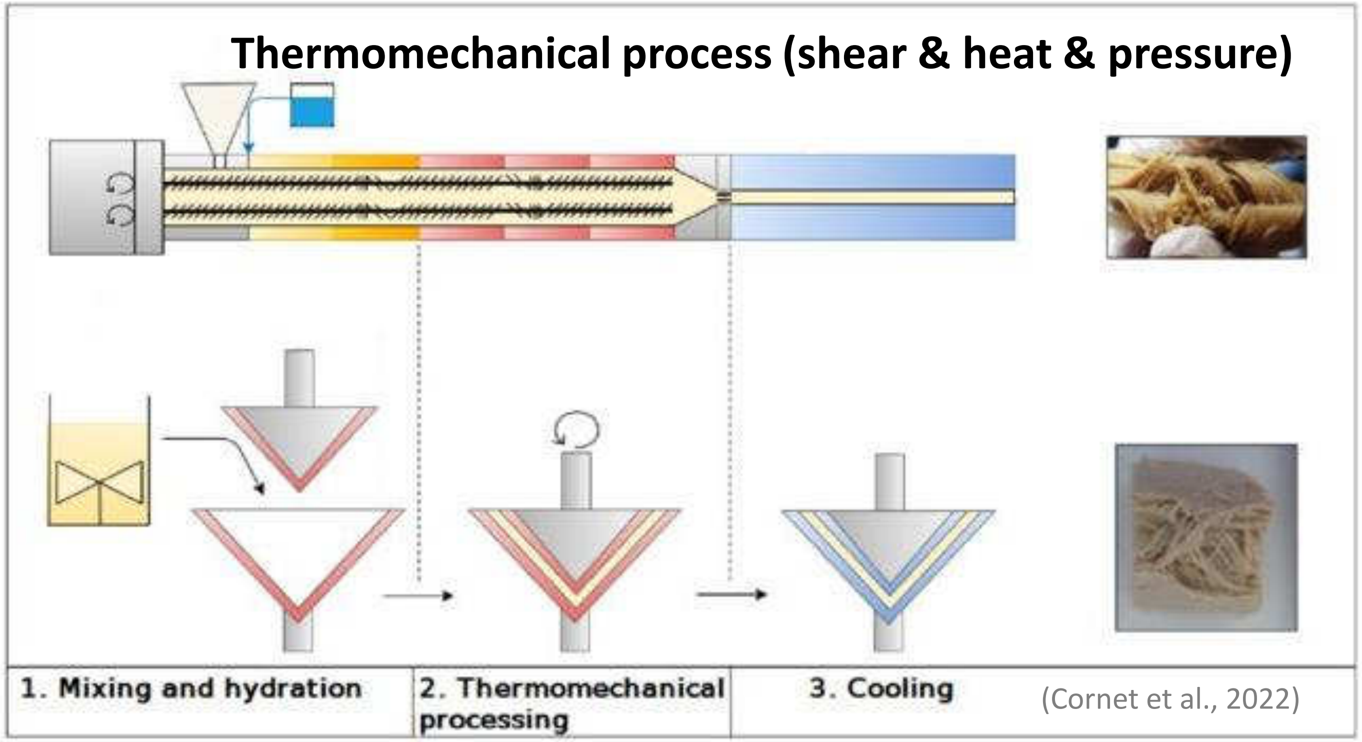
FOMT Food Materials Research Team
MTEC NSTDA
สวทช NSTDA

Top-down strategy

- **Processing approach**

  ❑ Extrusion technology

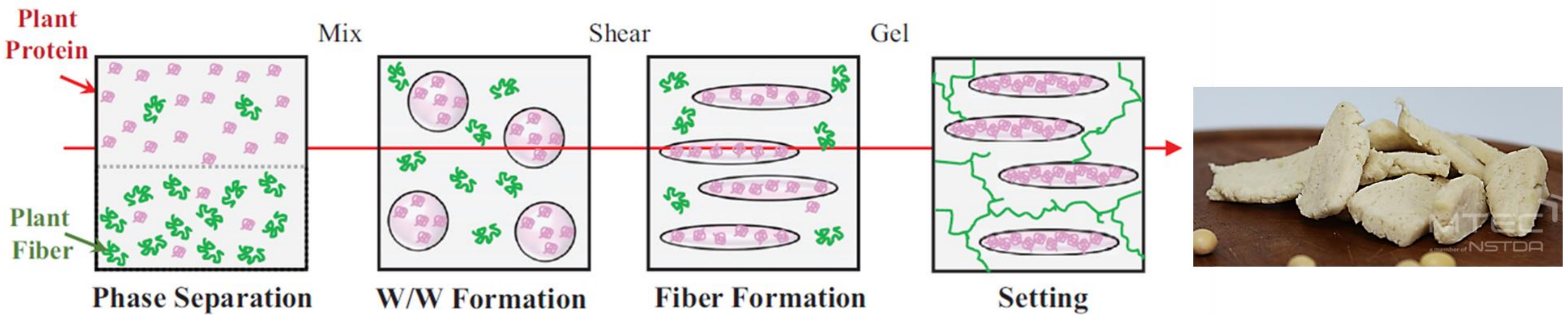
  ❑ Shear cell technology



- **Physicochemical approach**

Physicochemical operations involve controlled phase separation, structuring, and gelation of biopolymer mixtures

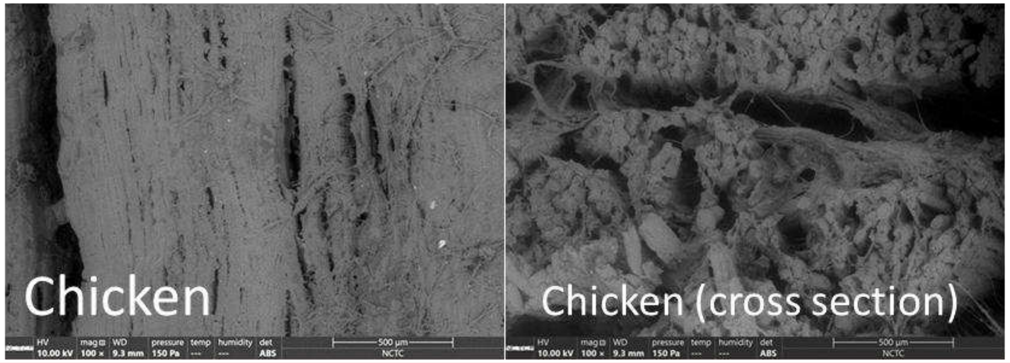
❑ Mixing/blending technology



(McClements & Grossmann, 2021)

MTEC
a member of NSTDA
FOMT
Plant-based meat technologies
Mixing/Blending
Extrusion
Extruder
Low moisture meat analogue (LMMA) หรือ โปรตีนเกษตร
High moisture meat analogue (HMMA) หรือ เนื้อเทียมความชื้นสูง
Ve-Chick
No cholesterol
Contain fiber
RTC or Frozen RTE
Gluten-free premix
Shelf-stable RTE
NEW LAUNCH
Ve-Sea
Gluten-free seafood products (fish balls, shrimp balls, squid balls, fish noodles and fish rolls)
Gluten-free shrimp
Gluten-free squid
NEW LAUNCH
Contact:
นายชนิต วานิกานุกูล
งานประสานธุรกิจและอุตสาหกรรม
อีเมล chanitw@mtec.or.th

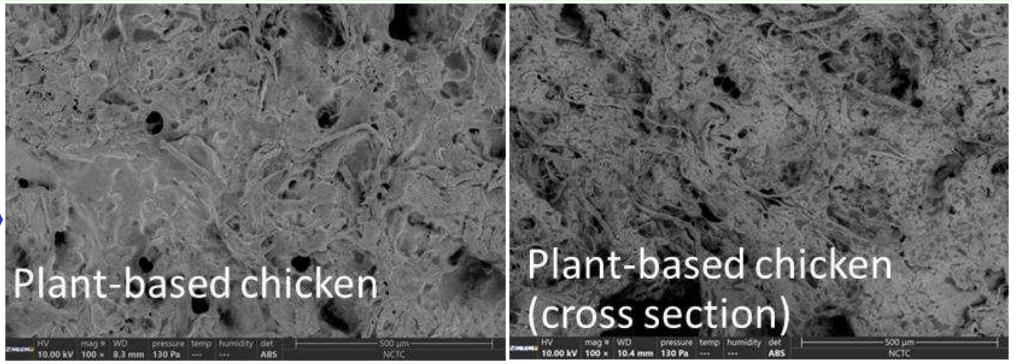
Chicken



Plant-based Chicken

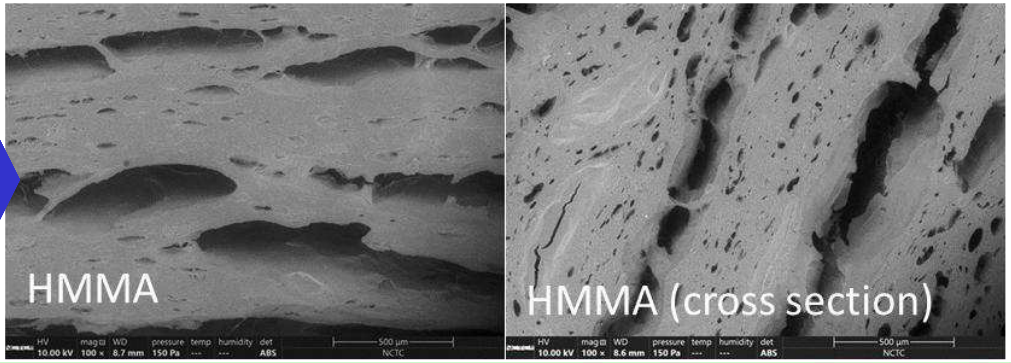
Mixing

Blender



Extrusion

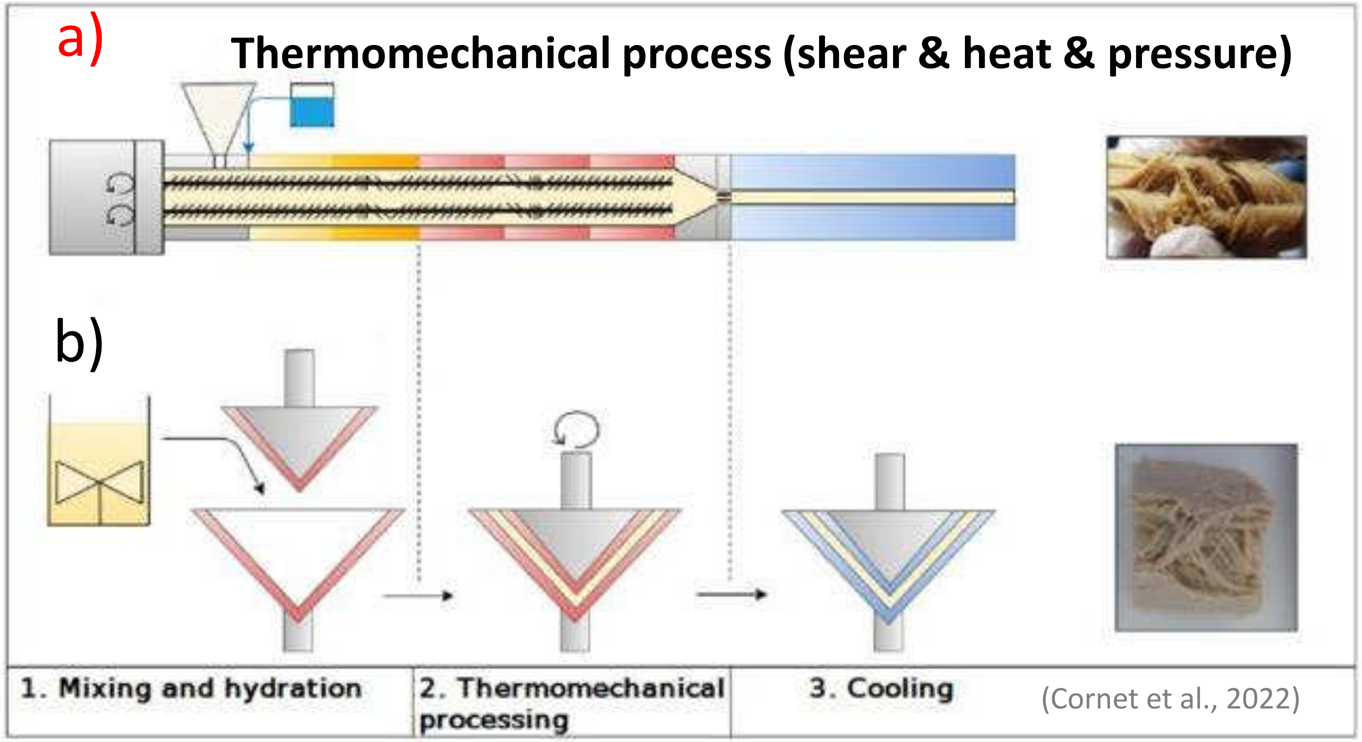
High Moisture Extruder



The potential of high-temperature shearing technology in the plant-based meat industry
เทคโนโลยีเฉือนด้วยอุณหภูมิสูงและความเป็นไปได้ในเชิงอุตสาหกรรม

a) **Extrusion technology**

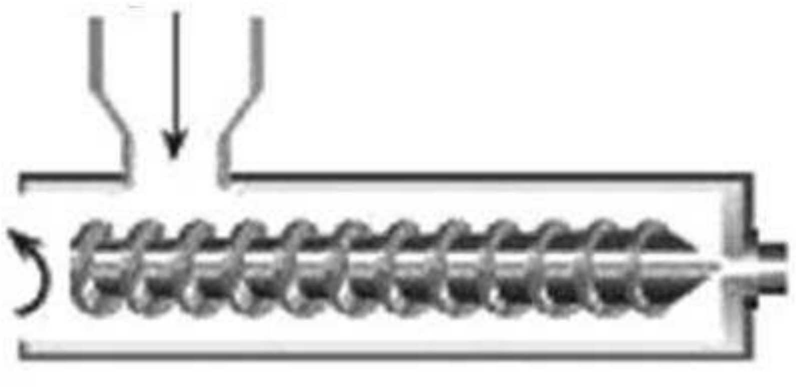
b) Shear cell technology



(Cornet et al., 2022)

Extrusion technology

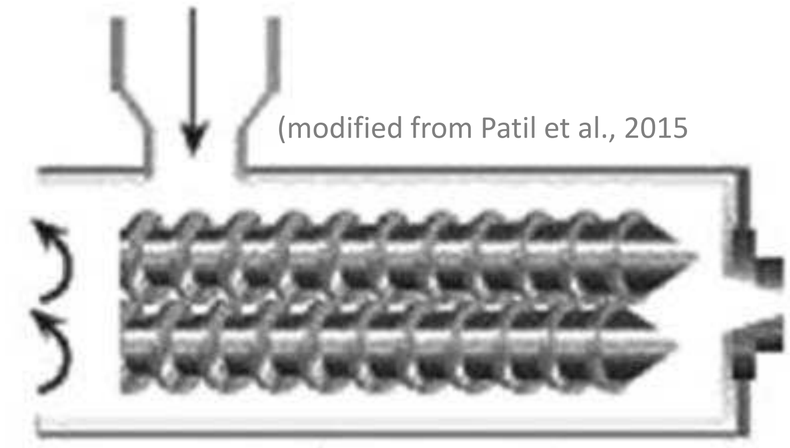
Single-screw extruder



Low moisture extrusion

Twin-screw extruder

(modified from Patil et al., 2015



Low moisture extrusion (water content in feed formulation < 40%)
High moisture extrusion (water content in feed formulation > 40%)

Low moisture meat analogue (LMMA)
Or Texturized vegetable protein (TVP)

- ❑ Sponge-like structure
- ❑ Need rehydration

https://entrepreneurview.in/tag/textured-soy-protein/

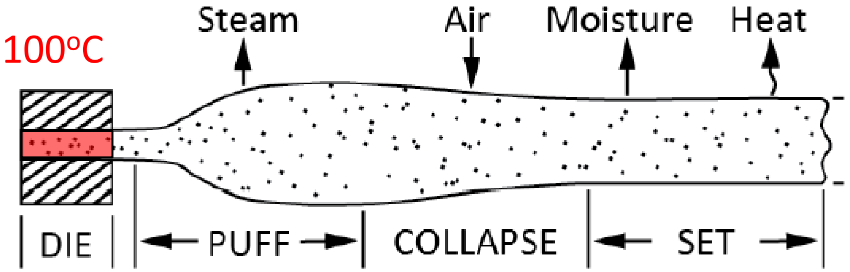
(Wang et al., 2023; Zhang et al., 2019)

Extrusion technology

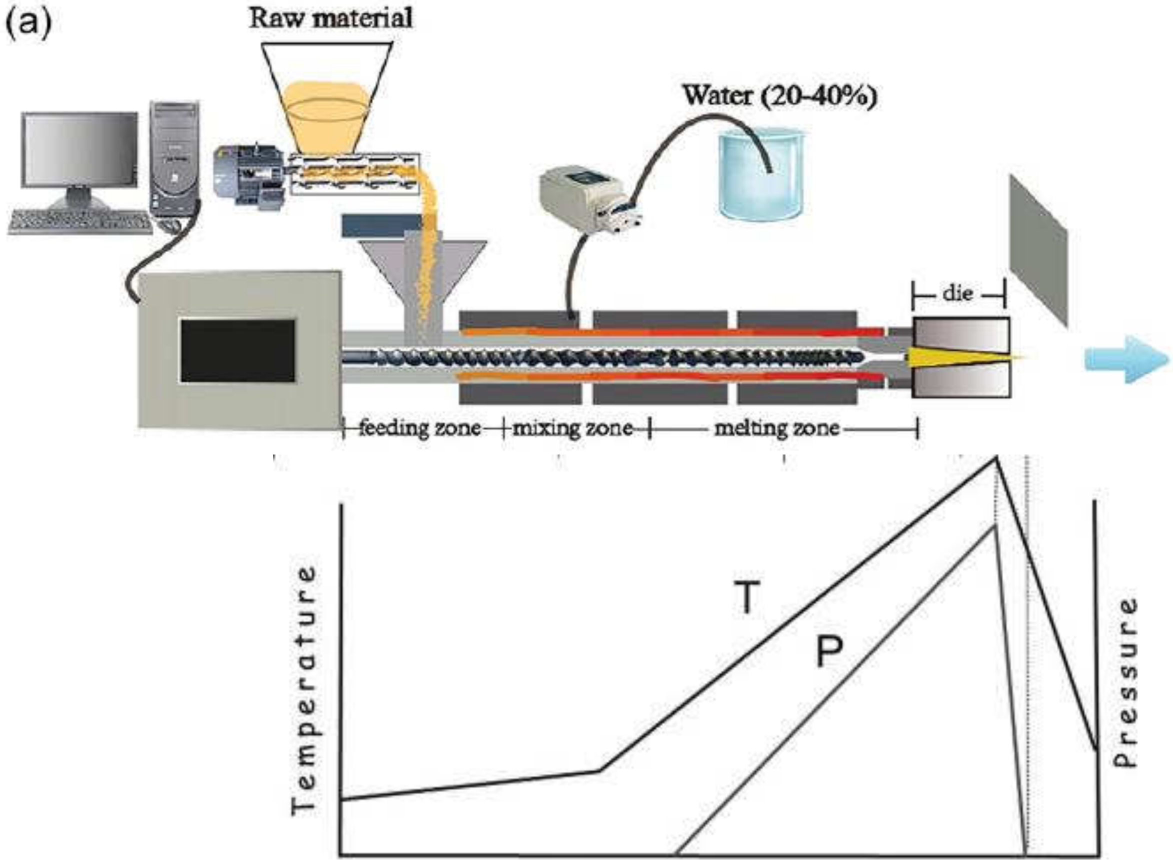
Low moisture extrusion

(water content in feed formulation **< 40%**)

> 100°C

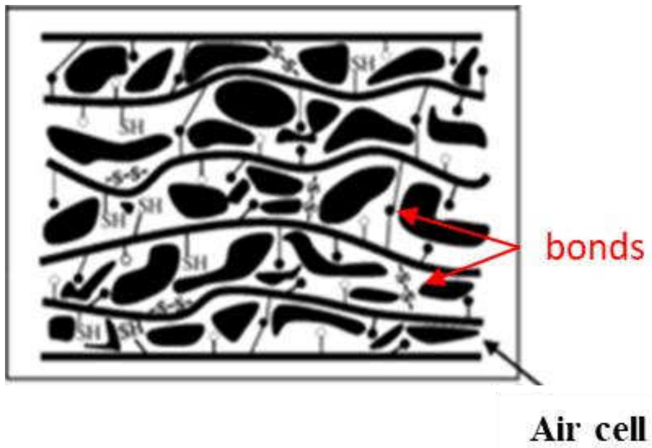


The expansion process



https://entrepreneurview.in/tag/textured-soy-protein/

TVP or LMMA



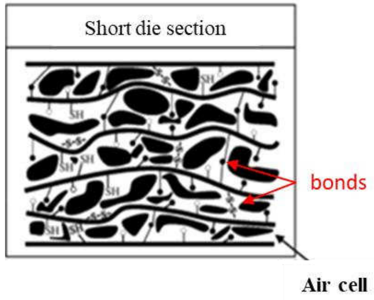
- ❑ Rapid drop in temperature and pressure
- ❑ Superheated water inside the mixture converts to steam and evaporates
- ❑ Formed porous structure and dry texture

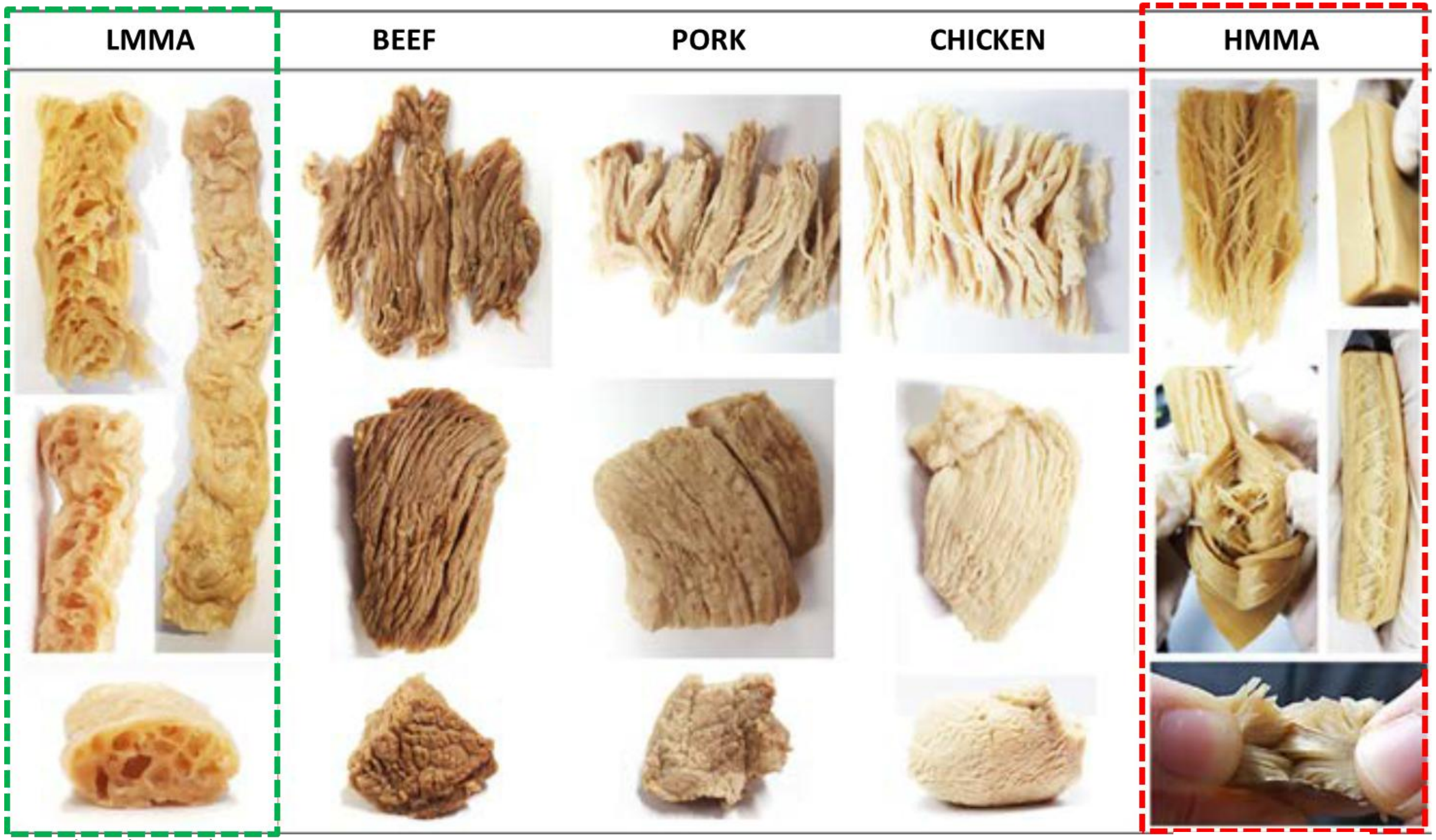
(modified from Zhang et al., 2019; Young and Forte, 2018; Samard et al., 2019)

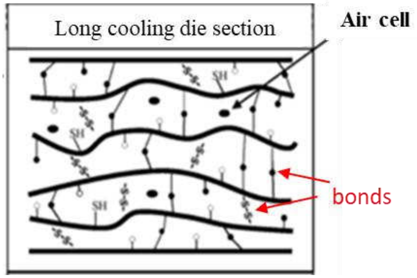
Extrusion technology

LMMA (low moisture meat analogue)

HMMA (high moisture meat analogue)





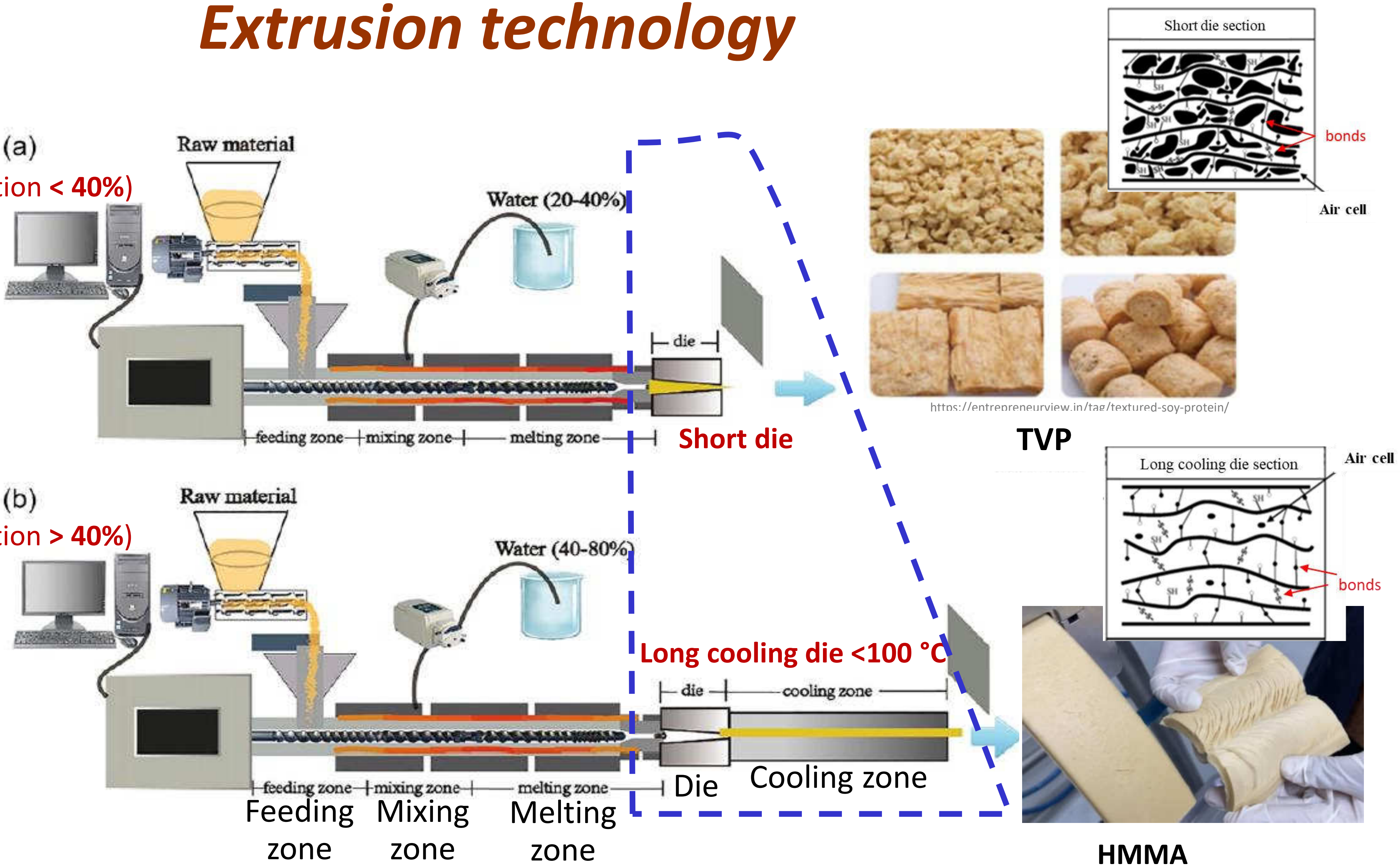


(modified from Samard, 2019; Samard et al., 2019)

Extrusion technology

Low moisture extrusion (a)
(water content in feed formulation **< 40%**)

High moisture extrusion (b)
(water content in feed formulation **> 40%**)

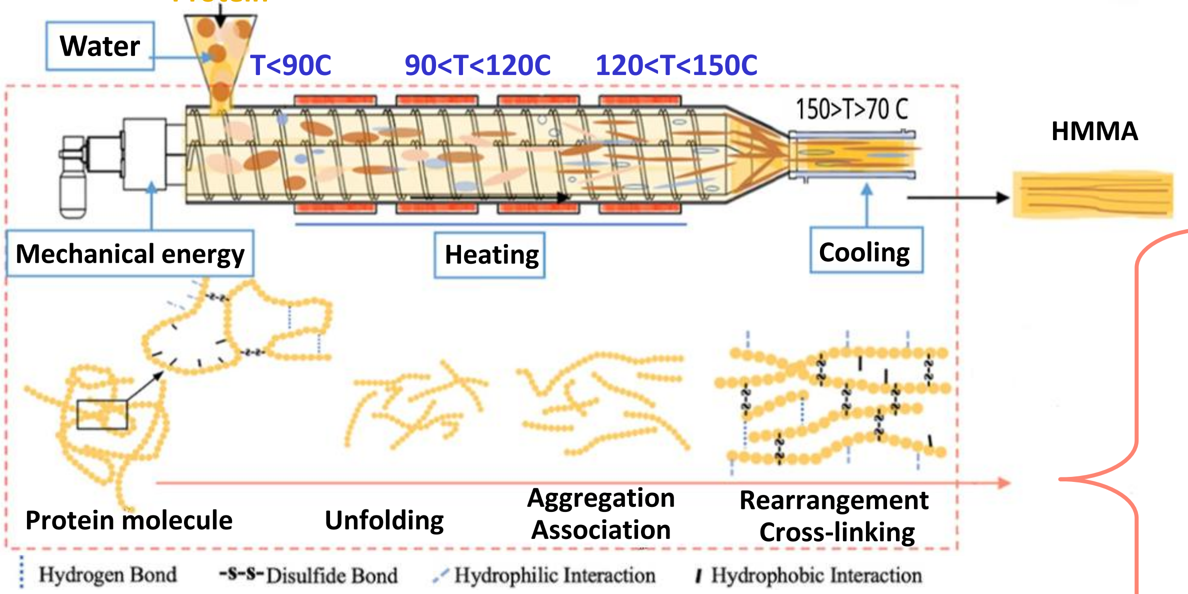


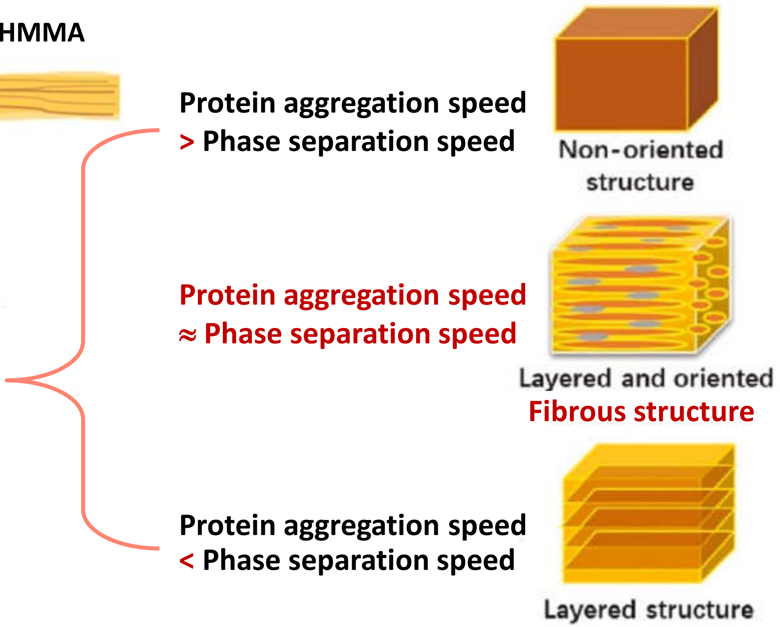
(modified from Zhang et al., 2019)

Extrusion technology

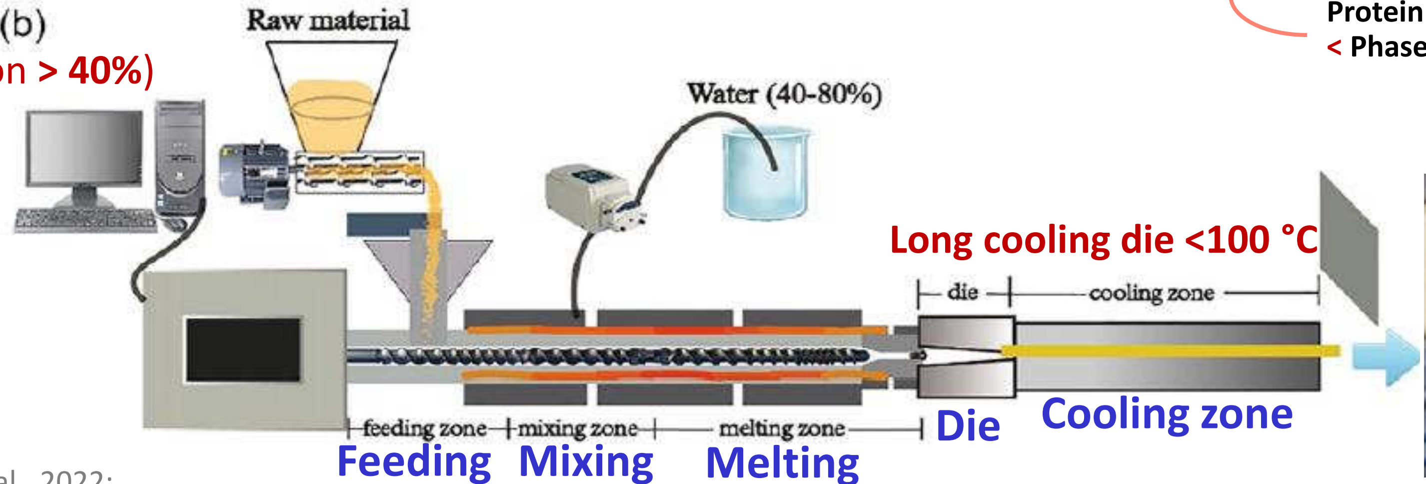
During extrusion:

- **Conformation of protein changes**





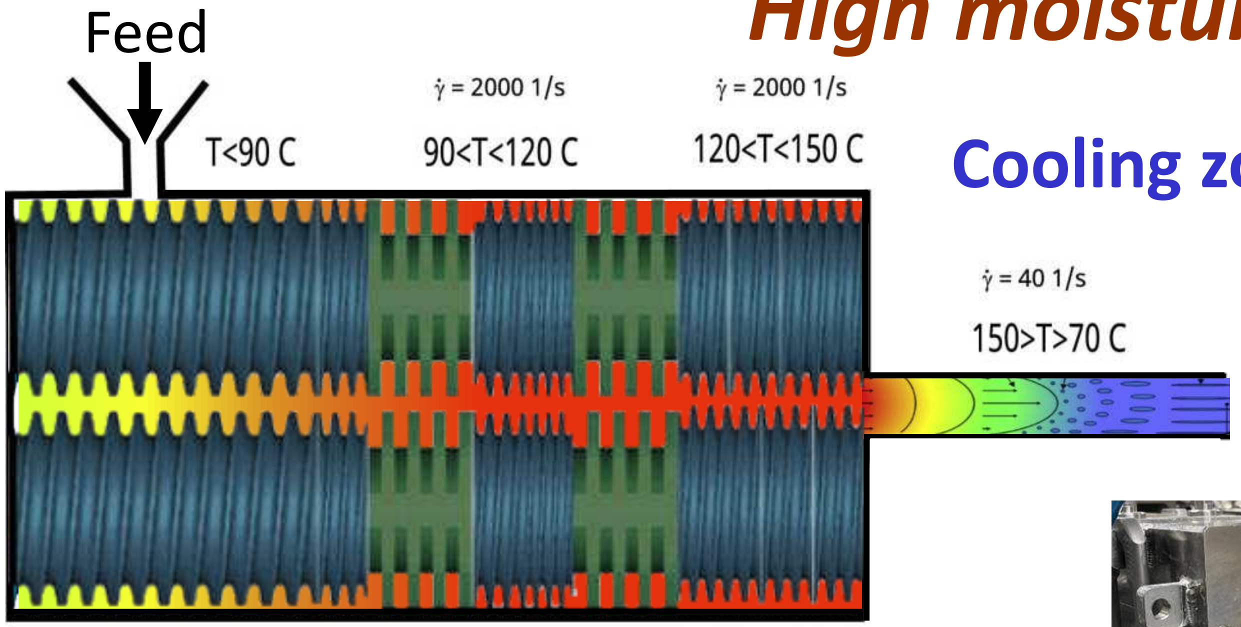
High moisture extrusion
(water content in feed formulation **> 40%**)

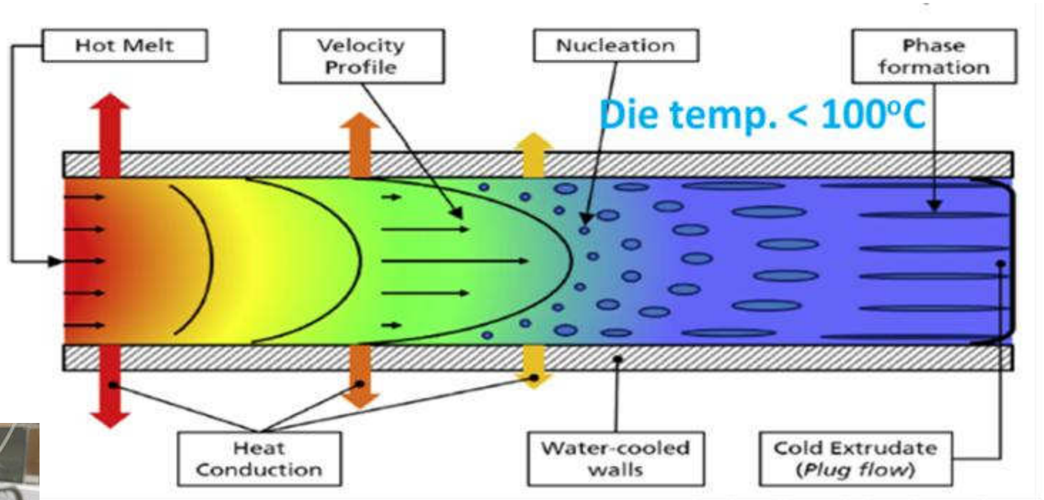


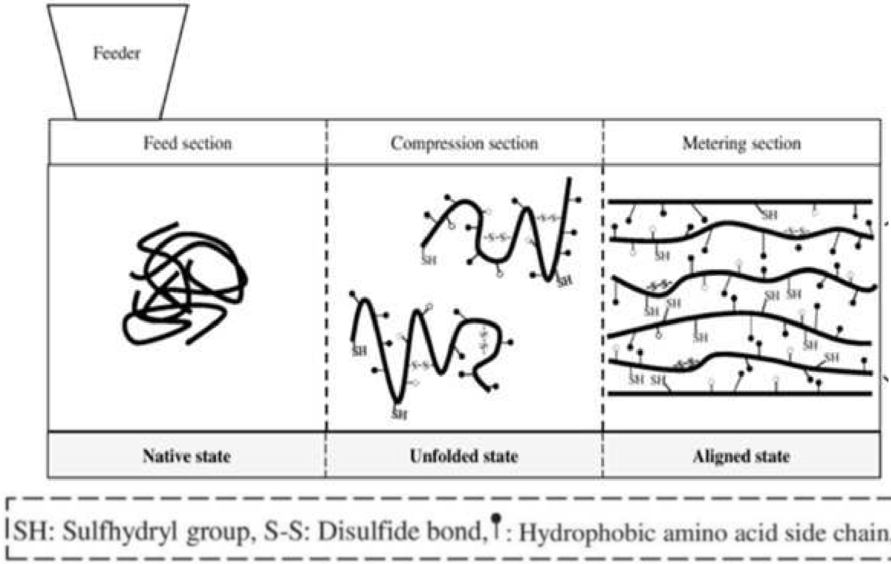
HMMA

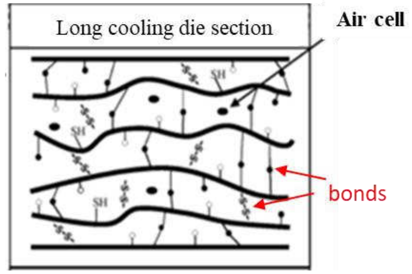
(modified from Zhang et al., 2019; Zhang et al., 2022; Zhang et al., 2023; van der Sman and van der Goot, 2023)

High moisture extrusion







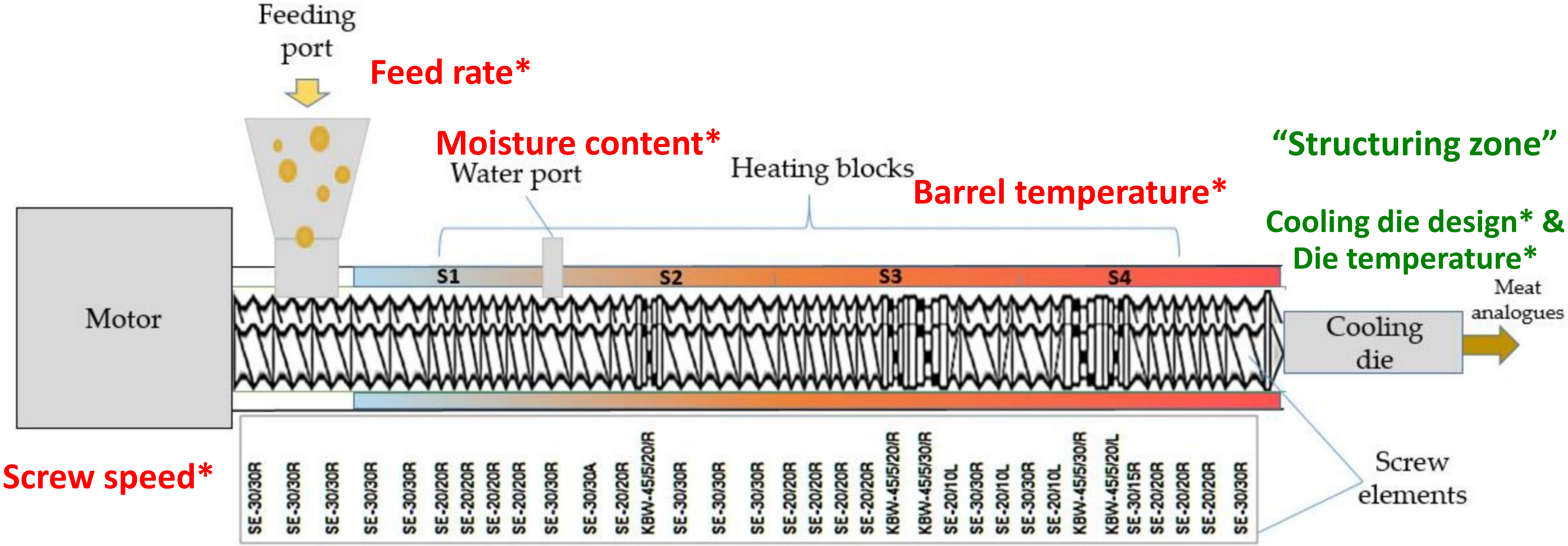


- ❑ Cooling of the protein melt from the wall to the center of the die
- ❑ Laminar flow in the cooling die
- ❑ Flowing along the die and further solidification of the protein melt cause formation of anisotropic structure

(modified from van der Sman and van der Goot, 2023; Samard et al., 2019; Sandoval Murillo et al., 2019)

Extrusion technology: *Factors affecting characteristics of HMMA*

to form fibrous structure, protein need to have fully denaturation



Feed rate*

Moisture content*

Barrel temperature*

Screw speed*

Screw configuration*

"Structuring zone"

Cooling die design* & Die temperature*

***relate to degree of denaturation of protein**

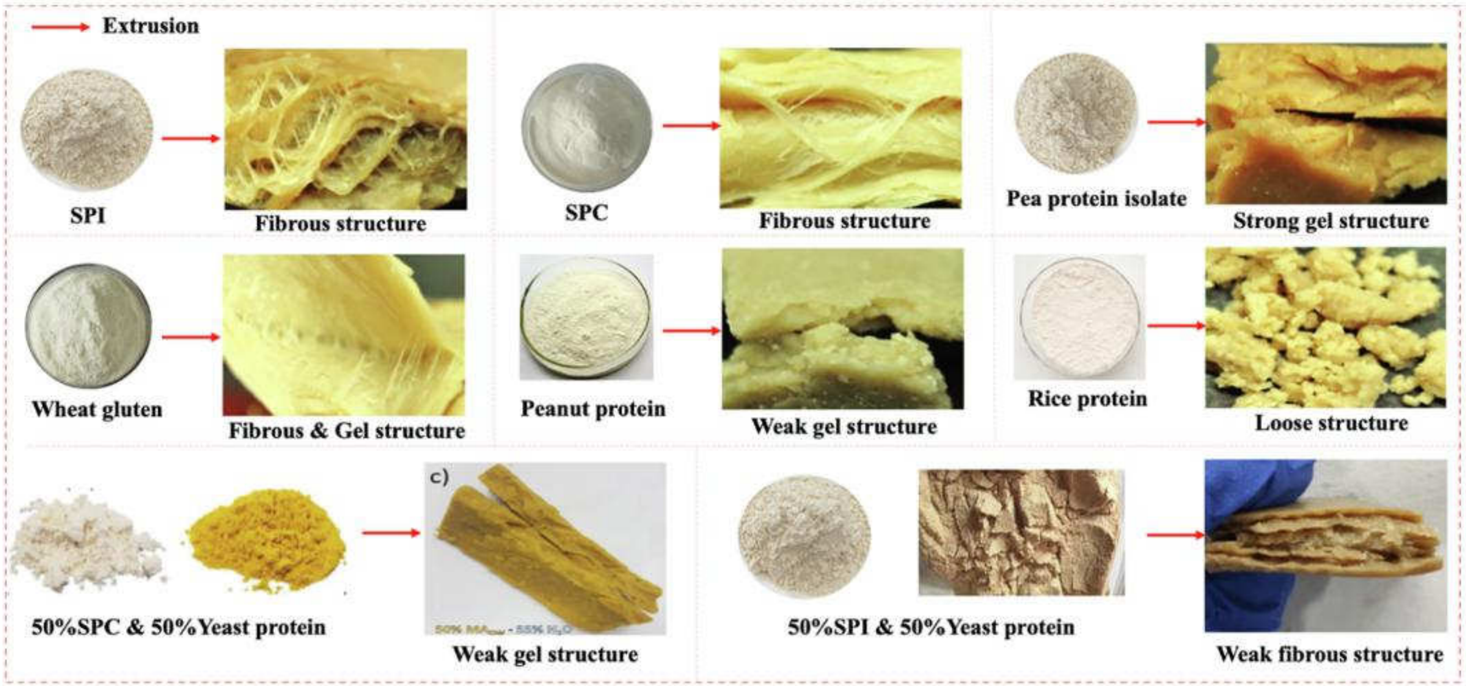
***relate to fibrous formation of HMMA**

Foods **2021**, *10*, 843. https://doi.org/10.3390/foods10040843

Extrusion technology: *Factors affecting characteristics of HMMA*

Feed formulation:

- ❑ Types of protein
- ❑ Oil content
- ❑ Polysaccharides
  - Soluble fiber
  - Insoluble fiber
  - Starch



(van der Sman and van der Goot, 2023; Zhang et al., 2023)

Fibrous chicken analogue
HMMA
(High Moisture Extrusion Meat Analogue)

Cooling die exit

- Protein content ~ 20-30%
- Moisture content ~ 60-65%

Commercial food products from HMMA

KASETSART UNIVERSITY
IFRPD

Twin Screw Extruder

Co-rotating Twin Screw Extruder
(ZSK 18MEGAlab, Coperion, Germany)

Extrusion (max. 10 – 15 kg/h)

Co-rotating Twin Screw Extruder
- 9 segmented barrels
- Screw diameter: 18 mm
- Barrel length: 72 mm
- L/D: 36
- Max. temp: 300°C
- Max. screw speed: 1000 rpm

Ancillary units
- Solid gravimetric feeder
- Liquid volumetric feeder
- Liquid gravimetric feeder
- Long cooling die
- Circular die (2, 3, 4 mm diameter)
- Pelletizer
- Belt conveyor

Applications
- High moisture meat analogues
- Texturized vegetable protein
- Physically modified starch and protein (clean label)
- Snacks
- Flavoring agents
- Pet food products

Please contact:
BD team (Mr. Chanit Wanikanukul)
e-mail: chanitw@mtec.or.th

3D-printing: precise technology for the meat analogue industry
3D printing: เทคโนโลยีจำลองเนื้อสัตว์เทียมอย่างแม่นยำ

Design
- CAD design
- STL files
- G-code

Pre-printing
- Formulation of the inks

3D printing
- Parameters
- Performance
- Rheological properties
- Binding mechanisms

Post-printing
- Baking
- Frying
- Cooking
- Boiling
- Drying
- ...

(Caron et al., 2024)

CAD (Computer-Aided Design)

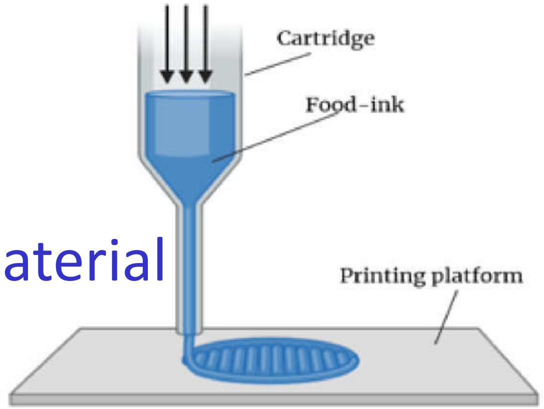
STL (Standard Triangle Language)

G-code: printing region, speed, and axis of the motors

M-code: auxiliary commands

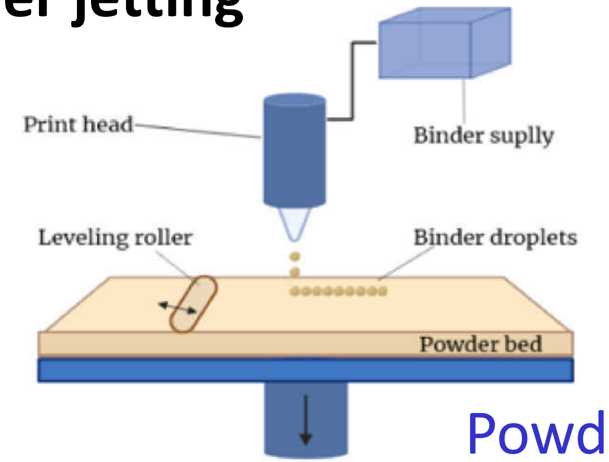
Four types of 3D food printers

Extrusion-based printing

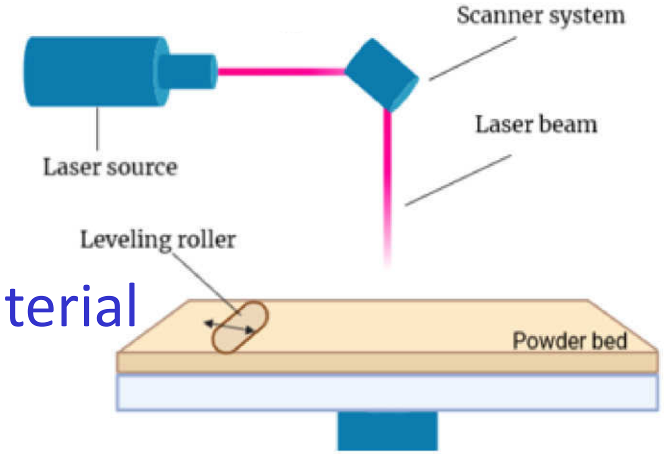


Viscous, paste-like material

Binder jetting

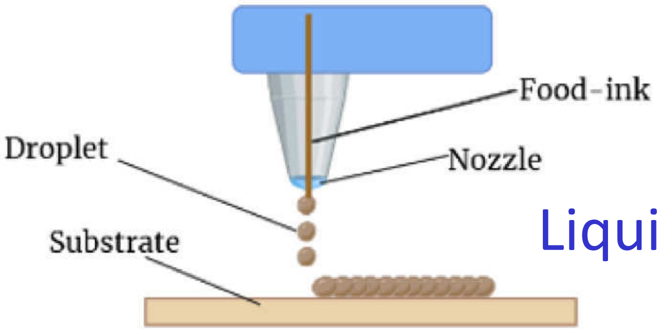


Powdered food material



Powdered food material

Selective laser sintering
Selective hot air sintering



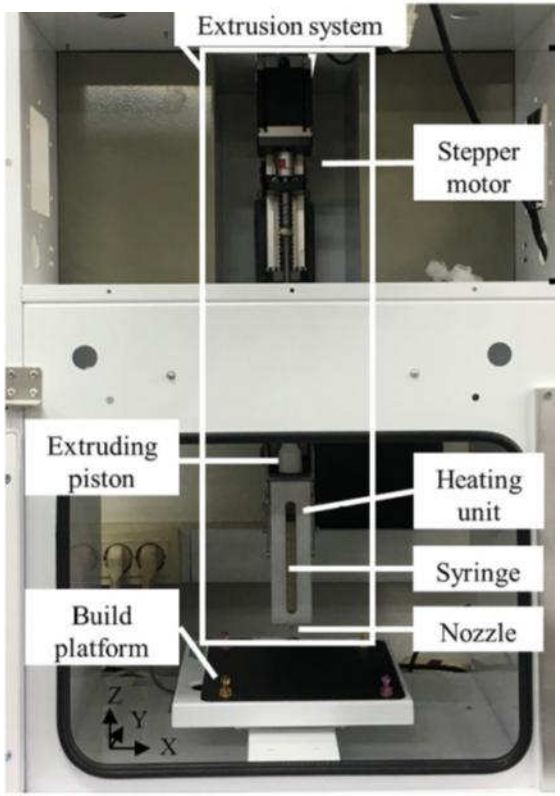
Liquid-based material

Inkjet printing

(Varvara et al., 2021)

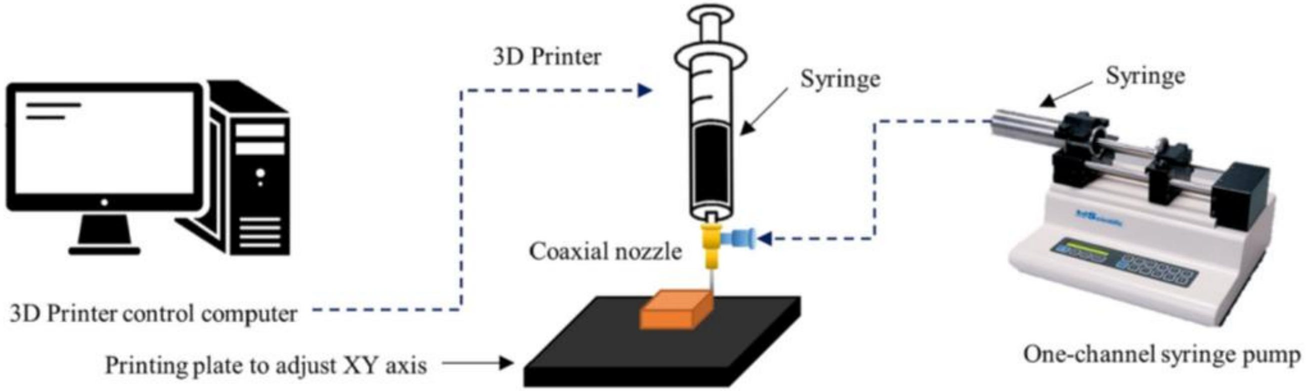
Single extrusion 3D printer

Outlook

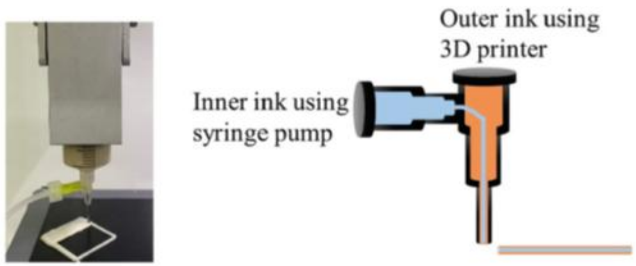


Internal components

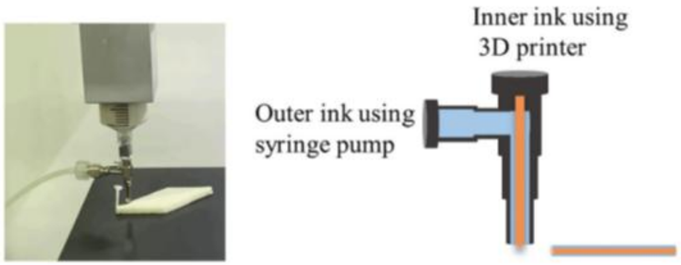
Coaxial extrusion 3D printer



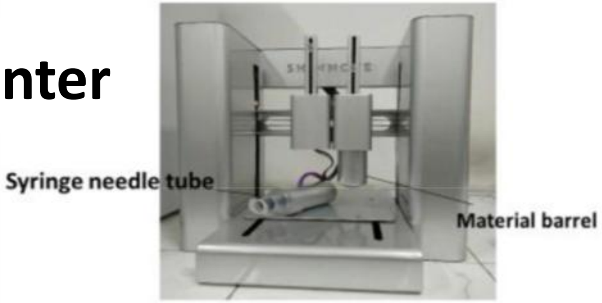
(i) Type A coaxial nozzle

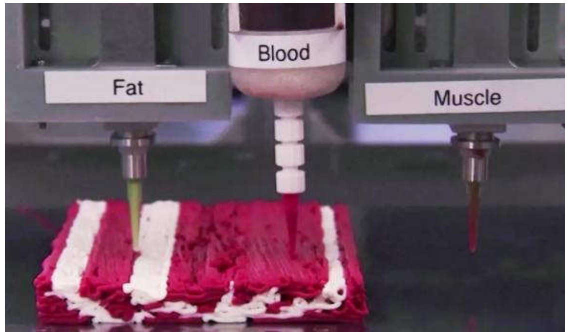


(ii) Type B coaxial nozzle



Dual/multi-head extrusion 3D printer

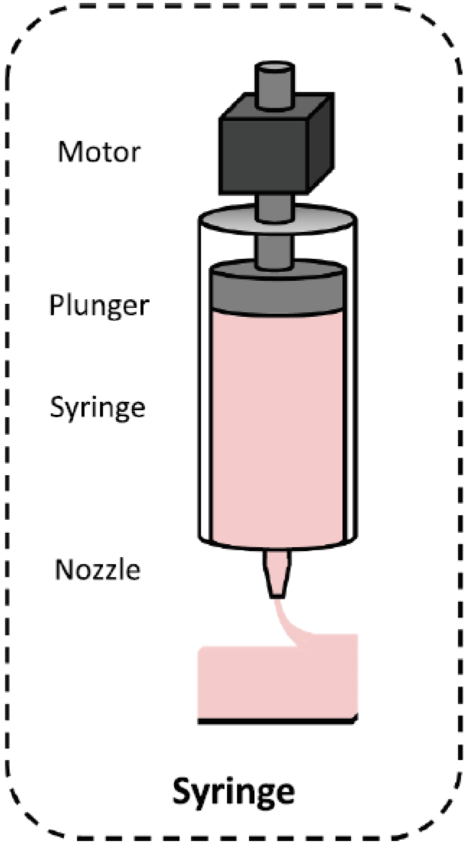




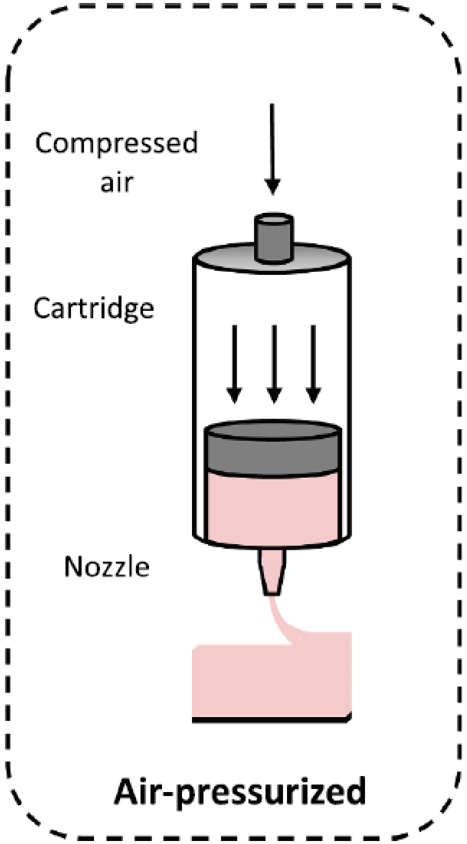
https://www.dw.com/en/3d-printed-steaks-and-fish-fillets-a-meat-revolution/video-70793715

(Wen et al., 2023)

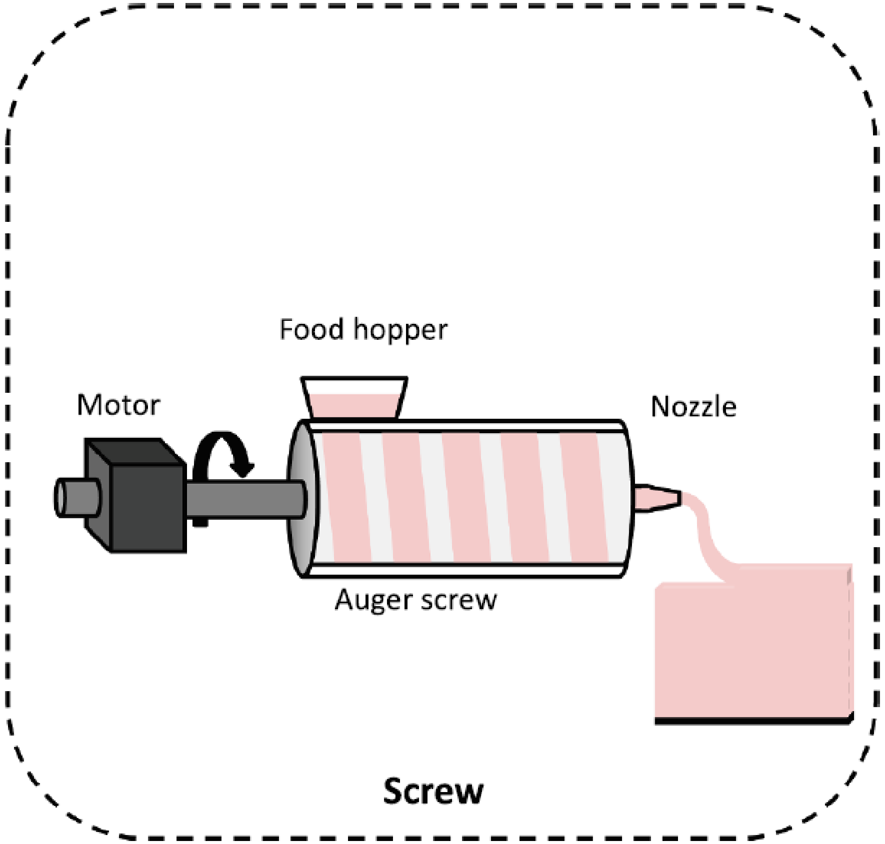
Three working principles of extrusion 3D printing (Caron et al., 2024)



- Semi-solid or solid food inks with high viscosity and high mechanical strength

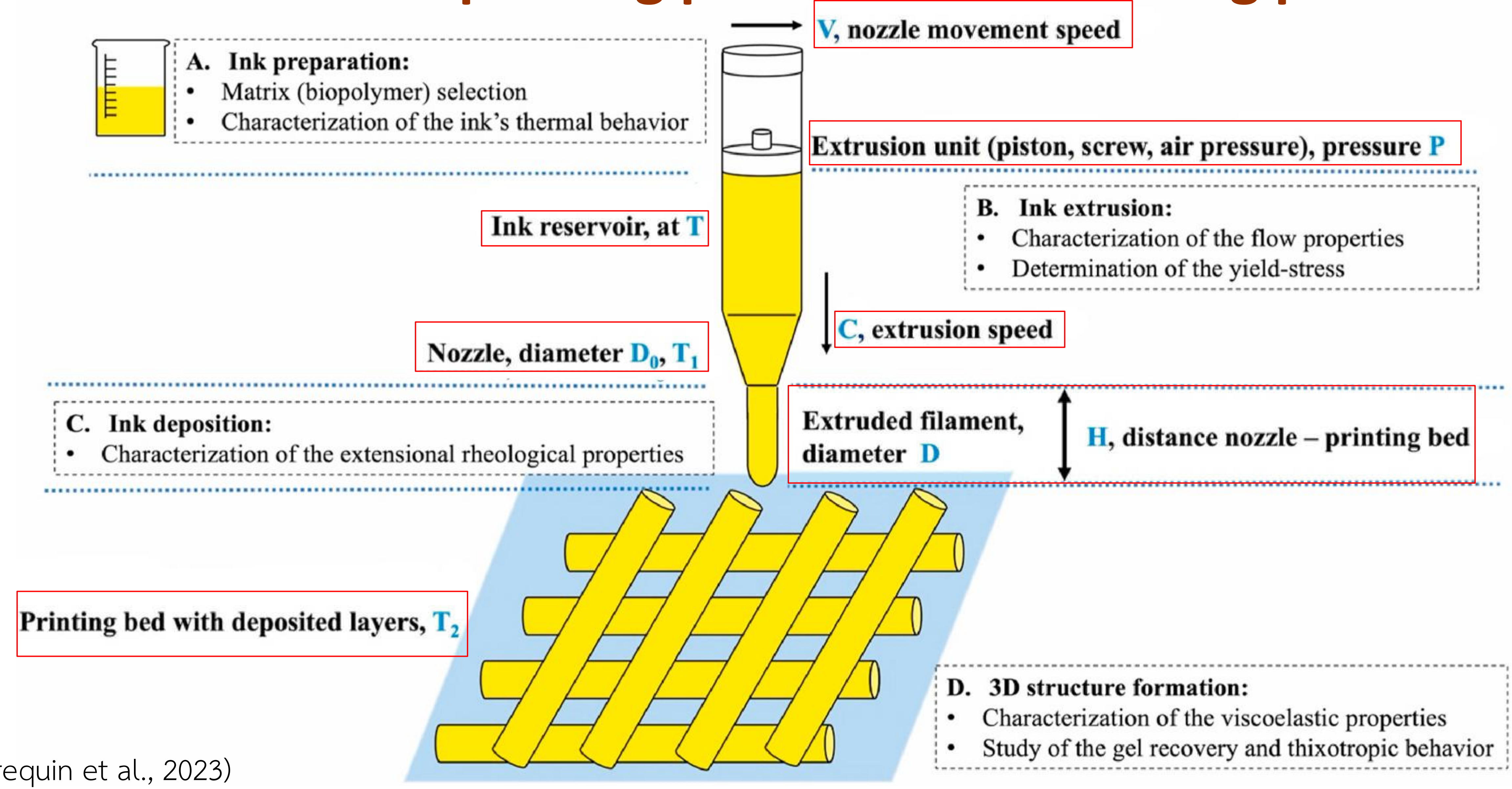


- Liquid or low-viscosity food inks



- Not suitable for food inks with high viscosity and high mechanical strength
- Pellets or granular forms can be printed after being heated and softened

Extrusion-based 3D printing process and operating parameters



(Outrequin et al., 2023)

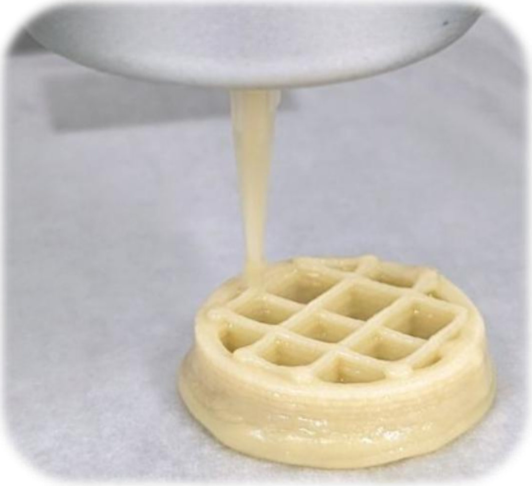
Food Materials Research Team

"Printability" of food inks

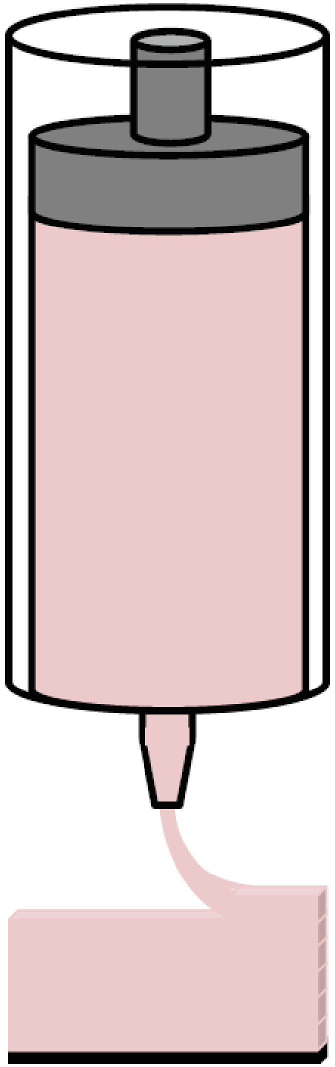
✓ **Extrudability**: the material must be able to flow continuously through the print nozzle (or print head)

✓ **Shape Holding / Shape Fidelity**: After extrusion, the built-up structure must not collapse and must be able to retain the desired shape

Ink rheological properties at each stage of printing are essential to ensure an ideal printability with excellent reproducibility.



Four rheological stages of the printing process :
key rheological properties of the food ink and printer parameters



Stage 1: Flow initiation

Stage 2: Flow through a nozzle

Stage 3: Deposition

Stage 4: Layer support

1st

Ink : ***yield stress*** = minimum pressure required to make an ink flow through a nozzle

Printer : ***maximum pressure*** provided by printer > minimum pressure
nozzle length, nozzle diameter

2nd

Ink : ***viscosity, shear thinning behavior, consistency index***

Printer : ***temperature*** *(> melting temperature)*, ***pressure, speed/flow rate, nozzle size***

3rd

Ink : ***thixotropic behavior, gelling properties***

Printer : ***temperature of bed*** *(< gelling temperature of ink)*, ***distance between nozzle and bed***

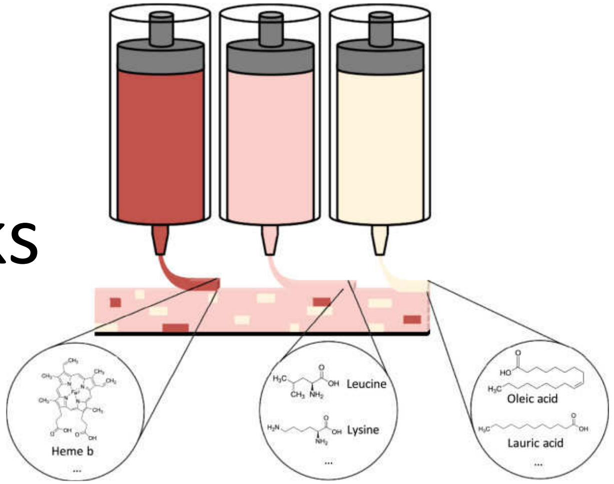
4th

Ink : ***storage modulus (G')*** $\Rightarrow$ *G'>G"* $\Rightarrow$ *solid like*, ***tan****δ < 1*

Printer : ***infill design, infill density***

(Outrequin et al., 2023; Caron et al., 2024)

Food inks



Protein-rich inks, Lipid-rich inks, Blood-mimicking inks

Ink components

- Proteins
- Fat/oil
- Starch/Flour
- Hydrocolloids
- Enzyme
- Colors, flavors, nutritional component
- Water

Selected based on

✓ **Tissue-mimicking characteristics**

✓ **Rheological properties**

⬇

Extrudability, Printability & Self-supporting ability

(Outrequin et al., 2023; Caron et al., 2024)

Post-printing

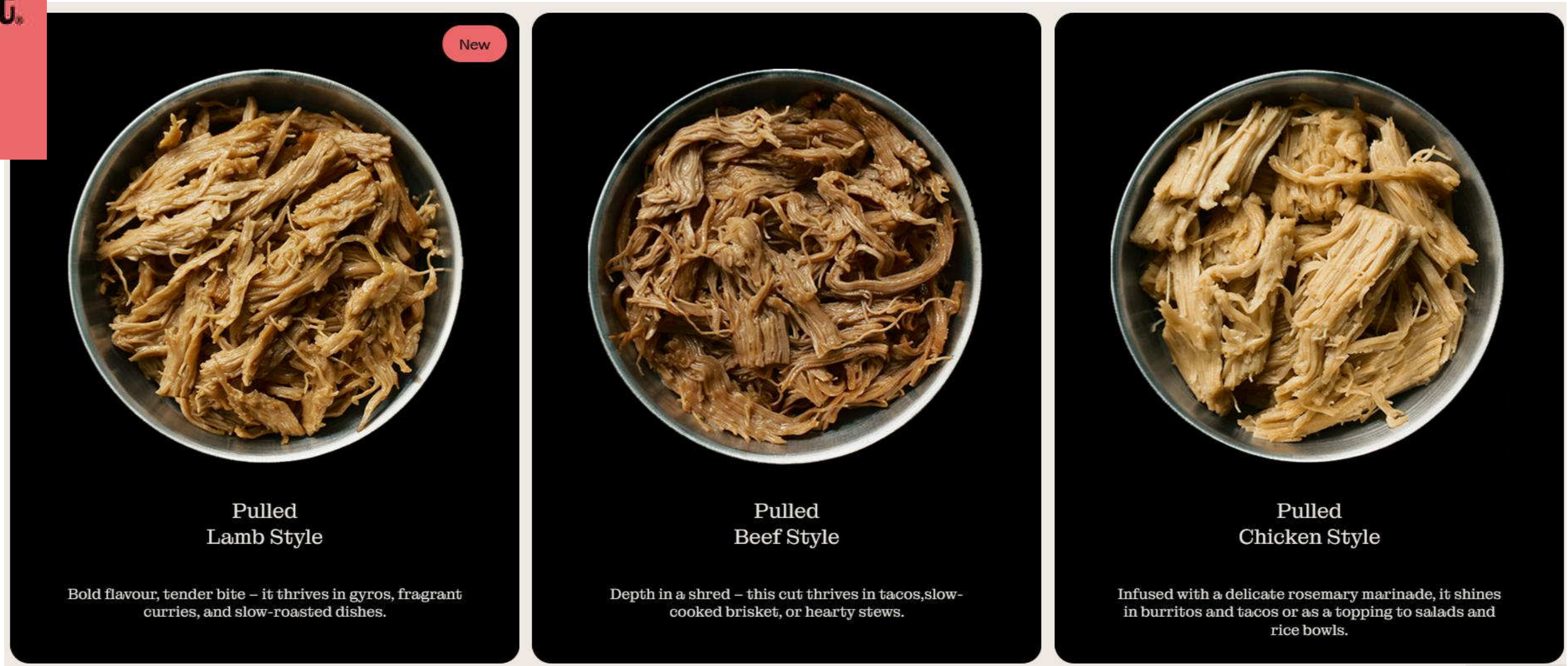
The post-printing treatments include storage, baking, steaming, drying, frying, boiling, and microwaving, etc.

- enhance food safety
- improve shelf-life
- be integrated into traditional cuisine

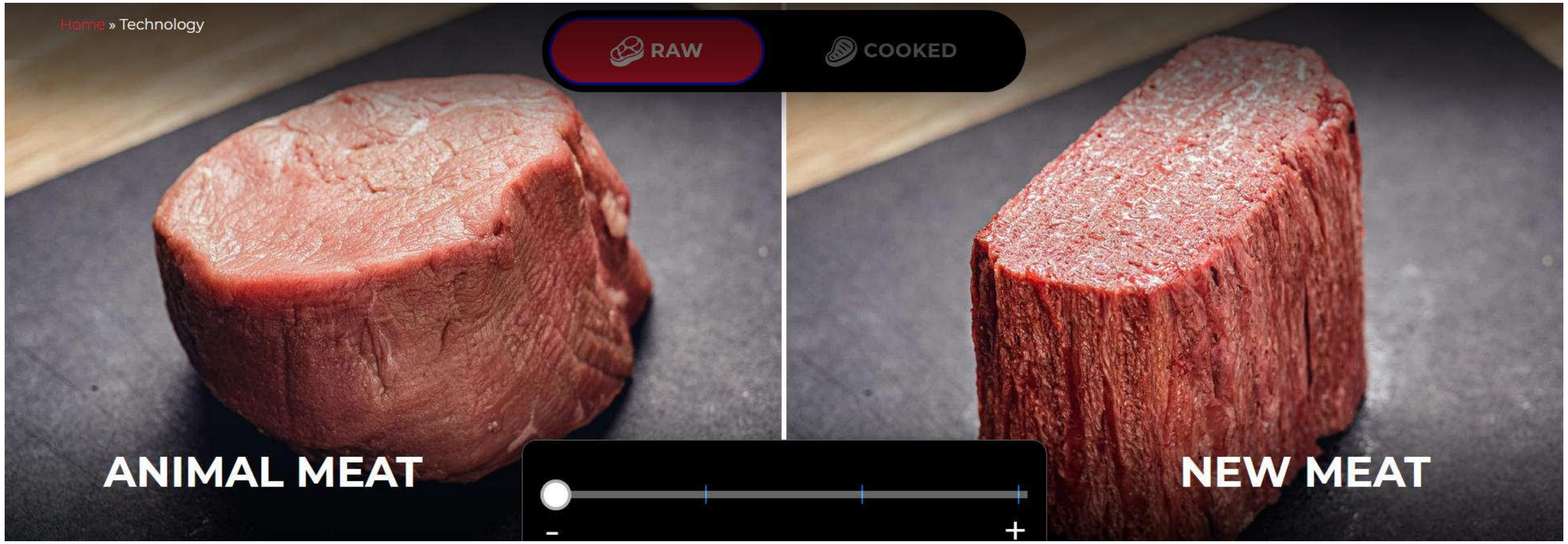
(Caron et al., 2024)

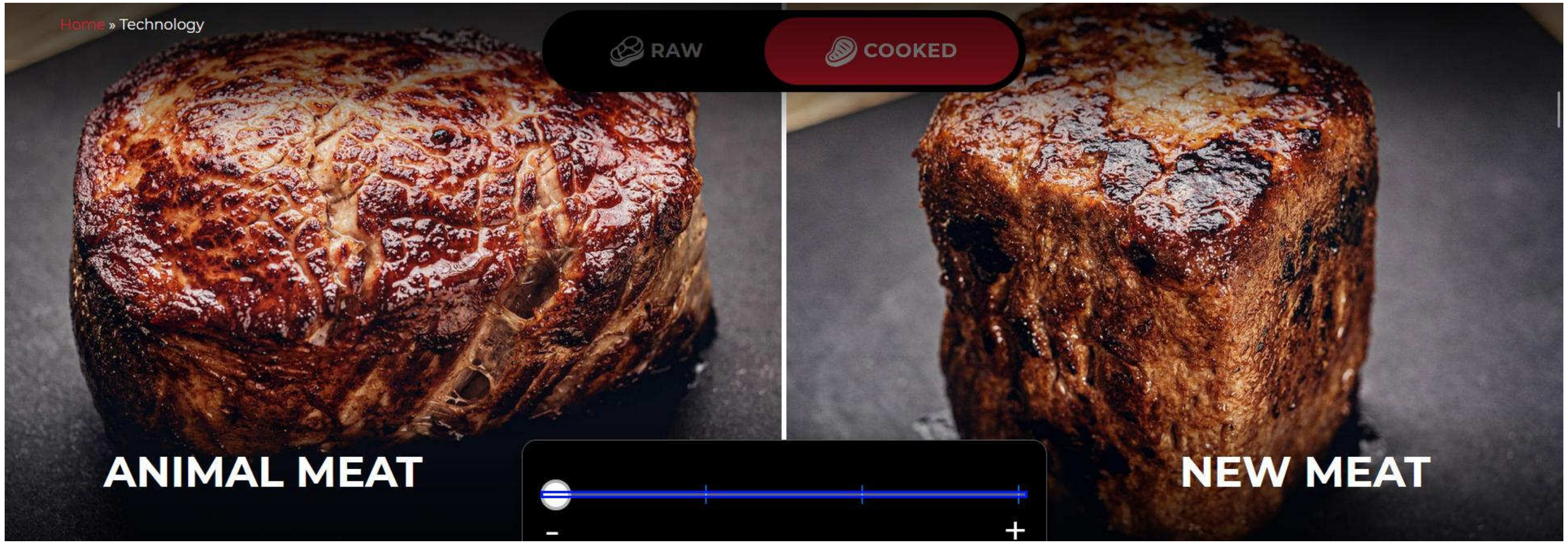
Commercial 3D-meat analogue products

Novameat



Commercial 3D-meat analogue products





Commercial scale 3D-printers

Steakholder

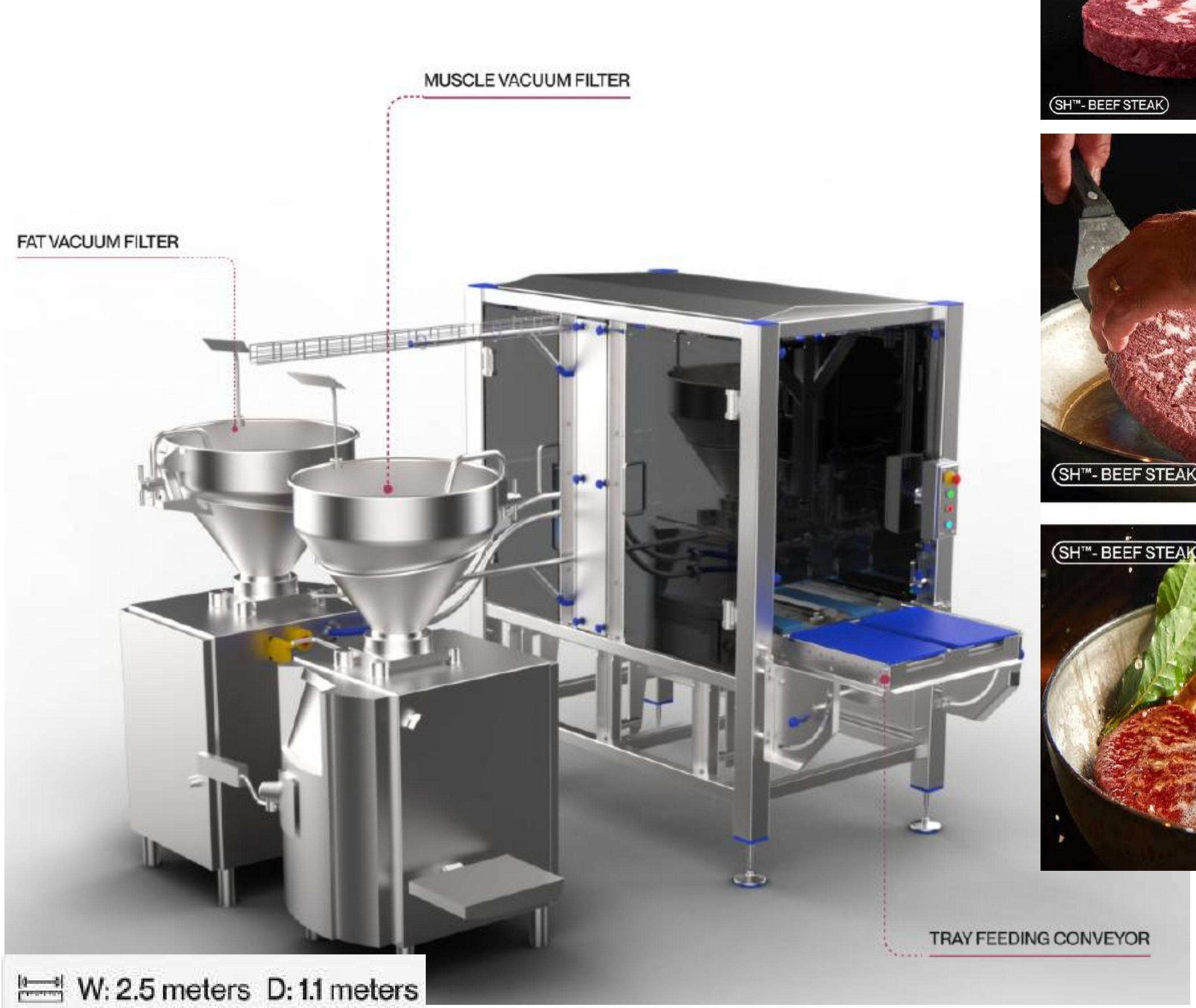
PLANT-BASED MEAT PRODUCTION

MX200

TECHNOLOGY

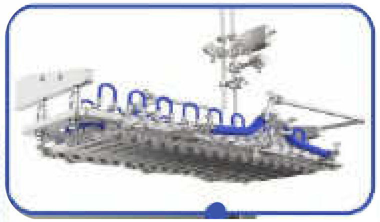
Introduction to Fused Paste Layering (FPL®) Technology

- Production output: Up to 420 kg/hour
- Layered Printing Production
- Fiber Alignment Technique
- CIP Ready
- Anti Clogging Technology
- Hygienic Cleaning Design
- Shaping options: Rib-eye, Chicken filet, Tenderloin, Sirloins



Commercial scale 3D-printers

Steakholder



TECHNOLOGY

Introduction to Drop Location in Space (DLS®) Technology

- Production output: Up to 100 kg/hour
- Printing Process with Zero Waste
- Modular Configuration Layout
- CIP Capability
- Anti Clogging Technology
- Endless Shaping Possibilities
- Layered Printing Production
- Hygienic Cleaning Design

FOMT Facilities/Equipment

Rheology and texture analysis:

Rheometers (rotational (controlled-strain & controlled-stress), extensional, interfacial, capillary) and a **Universal testing machine**

Food processing:

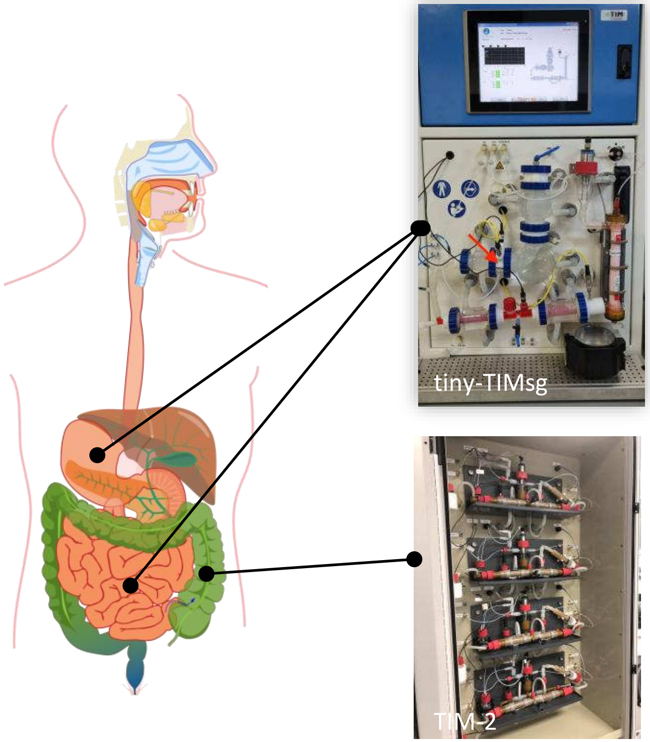
Blast Chillers
Shock Freezers

Twin screw extruder with long cooling die & TVP dies & liquid feeders

Dual-head extrusion 3D printer (syringe)

3D-food printers

Food digestion:



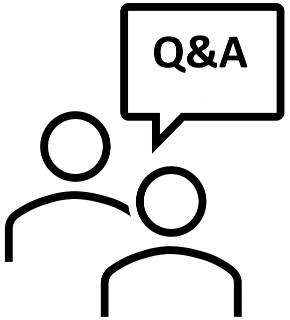
Simulated Gut Model

- tiny-TIMsg (stomach + small intestine)
- TIM-2 (large intestine)

Other facilities: High pressure homogenizer, High-Performance Anion-Exchange Chromatography System (HPAEC-DIONEX), High shear dispenser, Sous-vide machine, Twin drum dryer, Ultrasonic probe.

Acknowledgements

Food Materials Research Team
Advanced Polymer Technology Research Group
National Metal and Materials Technology Center (MTEC)
National Science and Technology Development Agency (NSTDA)



For more information about FOMT