

Applications of AI and ML in Food Process Engineering

State of the art



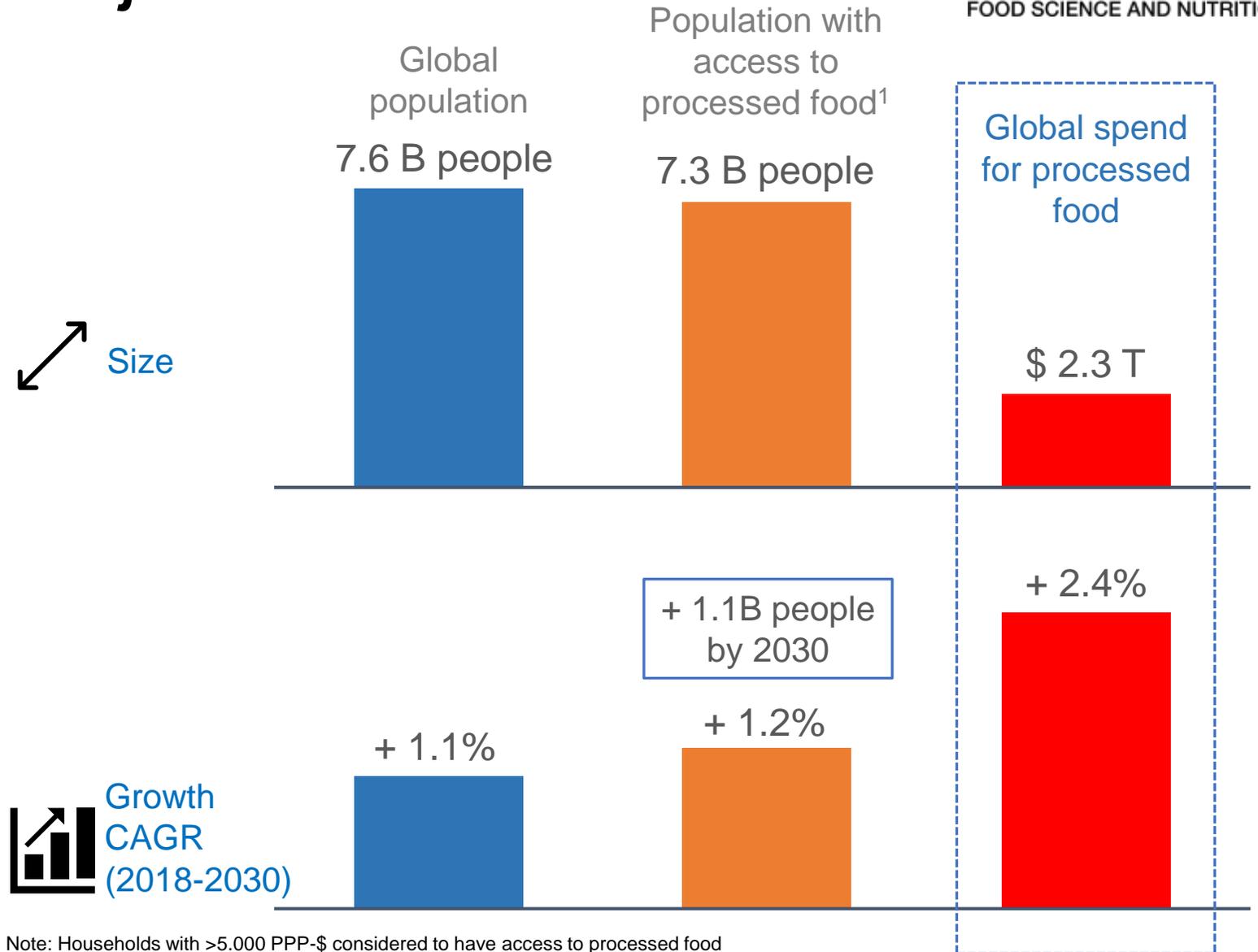
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Food security– a major concern

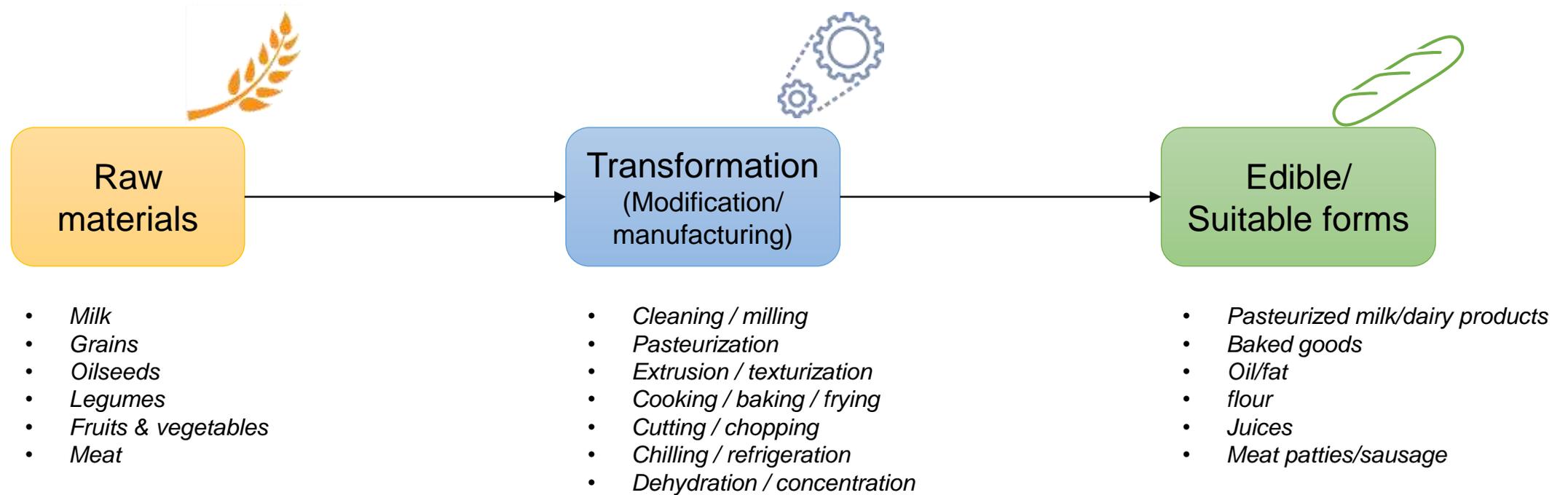


POPULATION GROWTH 1.1%, WHILE SPENDING TWICE AS FAST



¹Priddle (2022)

Food Process Engineering



Non-Uniform

Uniform / Homogeneous

Food characteristics
(weight/size/shape/color/
flavor profile)

AI/ML in food
processing

Process
control/automation

- *Enhance economic value*
- *Minimize labor intensive operations*
- *Reduce food wastage and cost*
- *High quality / uniformity*
- *Meet growing demand*
- *Process optimization*

AI/ML in Food Process Engineering

Food quality / safety / shelf life =

f (Temperature, time, RH, moisture content, pH, physico-chemical properties,...)

1.3 billion tons of food is lost annually due to the lack of proper processing; \$1 Trillion²

→ Environmental impact

→ Food scarcity

Food manufacturing
Complex process—
Many variables

...product flow rate, viscosity, pH, temperature profile, concentration, moisture content, storage conditions, aroma, flavor, texture...

Food and biological systems → non-homogeneous

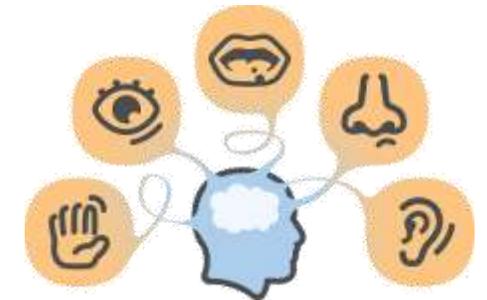
Foods processing → highly non-linear; Interactions b/w variables

ΔT during a heating/cooling → biochemical (nutrient, color, flavor, etc.) or microbial changes → should be considered

Moisture content constantly fluctuating → affect the flavor, texture, nutrients

Density, thermal and electrical conductivity, specific heat, viscosity, permeability, and effective moisture = f (composition, temperature, and moisture content,...) → vary during the process.

Irregular shapes are present.



Brain-Limited sensory perception

<https://www.pps.net/domain/2631>



<https://stock.adobe.com/>

AI/ML in Food Process Engineering

Role of AI/ML in food industry³

Food security management

- Image processing / recognition technologies.
- AI in fertilizer management for safe food
- Food inspection and grading using imaging
- Robotics for food warehouses
- Smart technologies; information sharing

Food quality management

- AI for improving food quality
- Mathematical modeling
- ML techniques for increasing the productivity
- Pesticide management using AI.

➤ Methods to analyze the Food Processing operations³

Machine vision

Artificial neural network

Genetic algorithm

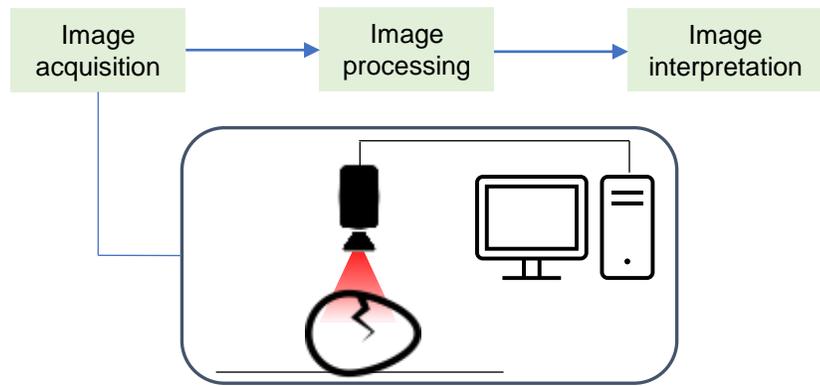
Fuzzy logic

Decision-tree

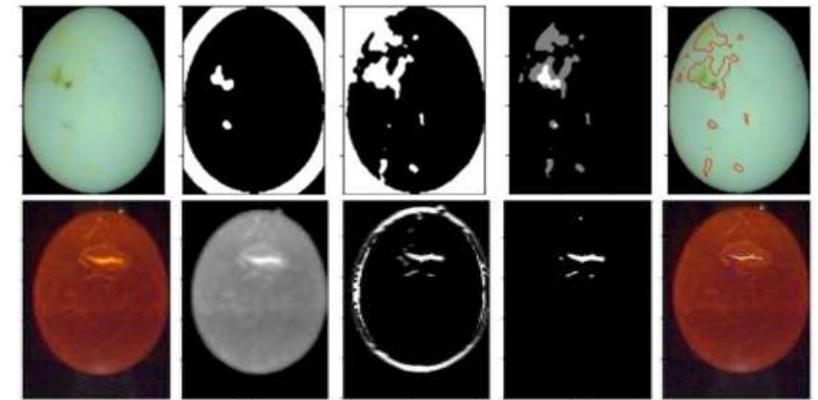
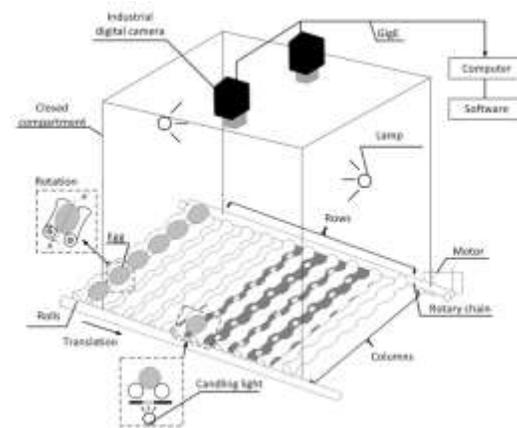
Support vector machines

Machine vision

- Using cameras to automatically observe, capture, evaluate, and recognize stationary/moving objects
- Image acquisition (Hyperspectral imaging, thermal imaging, NMR, MRI...); Image processing
- Non-destructive testing (grading, package quality, foreign object, debris detection,...)



Machine vision system⁴

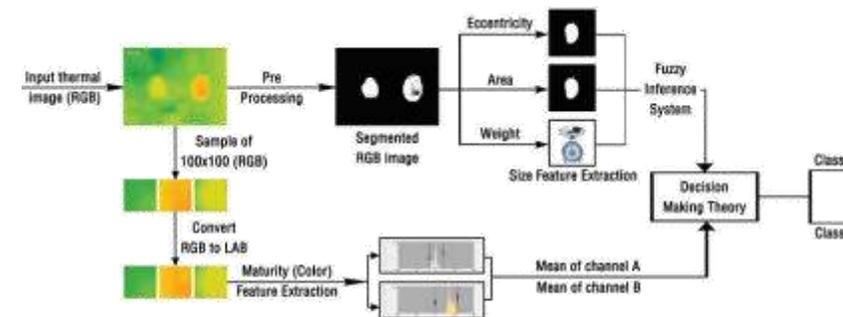
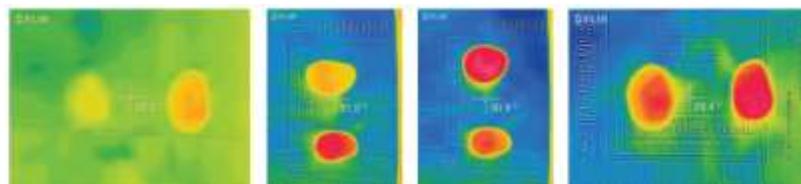


Dirt/crack detection in egg by image analyses and machine vision⁵

Grading mango by size and maturity (ripe/unripe)⁶

Maturity → mean intensity algorithm in L*a*b* color space

Size → Fuzzy classifier with parameters of weight, eccentricity, and area



Eccentricity - Distance from the center to a focus/ Distance from that focus to a vertex
 Area - Number of pixels
 Weight - Manual by weighting machine in grams
 Size Feature Extraction output - Small, Medium, Big
 Maturity (Color) Feature Extraction output - Unripe, Partially Ripe, ripe

Class I - Size(Small, Medium), Maturity(Unripe, Partially Ripe)
 Class II - Size(Medium, Big), Maturity(Partially Ripe, Ripe)

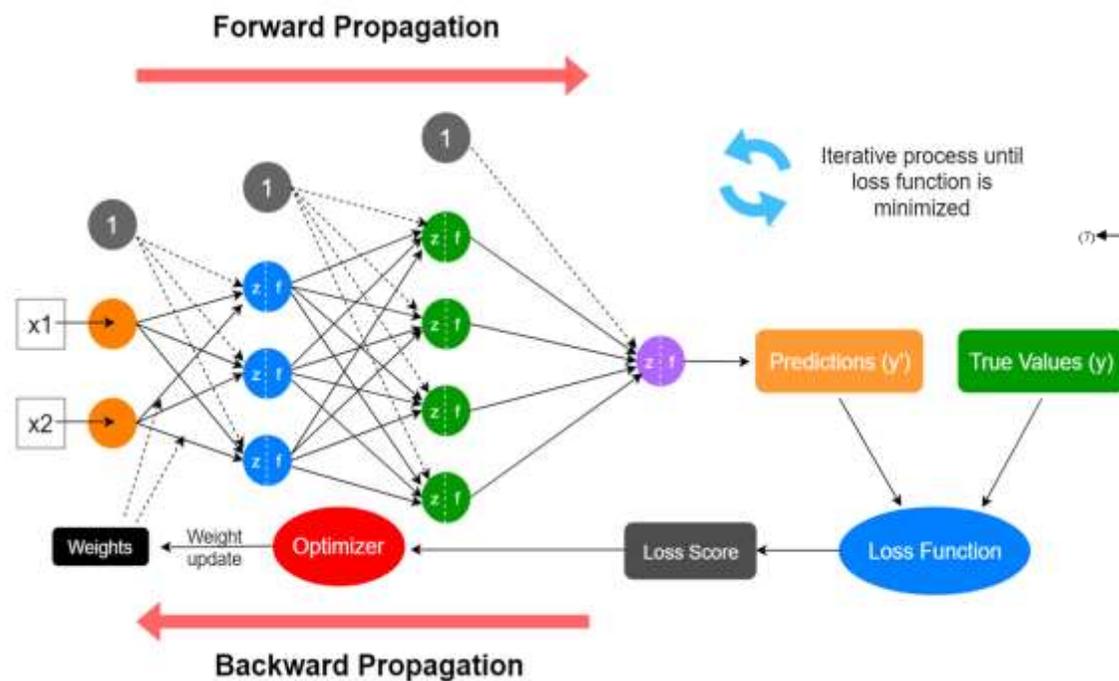
⁴Zhu et al. (2021)

⁵Valencia et al. (2021)

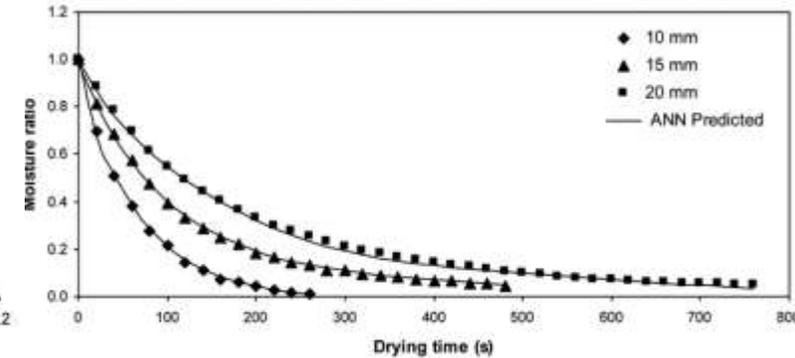
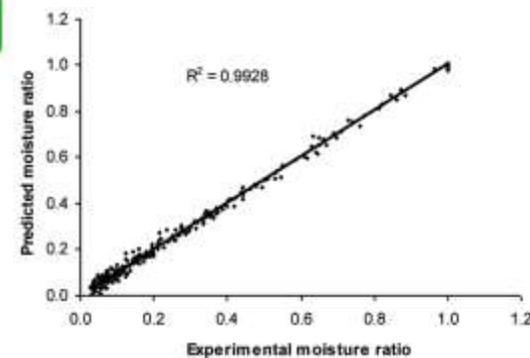
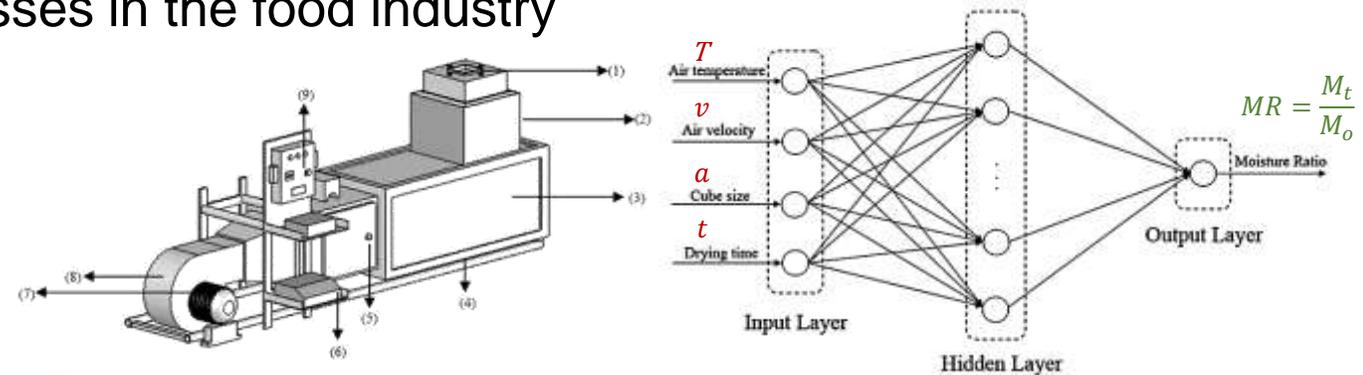
⁶Naik & Patel (2017)

Artificial Neural Networks

- Aims to solve problems of AI, by building a linked system; simulates human brain
- Trial and error learning; solve highly non-linear problems
- Used to model and predict different processes in the food industry



ANN architecture⁷



Carrot-cube hot air drying; predictive modeling of drying⁸

- Better predictive performance than conventional statistical and heat-diffusion models⁹

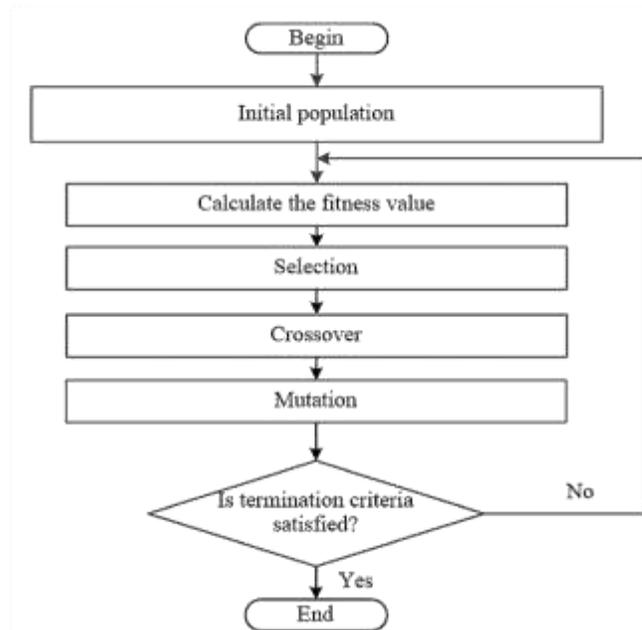
⁷Pramoditha (2022)

⁸Aghbashlo (2011)

⁹Tripathy and Kumar (2008)

Genetic algorithm

- Optimization of multi-dimensional non-linear complex problems; simulates natural evolution



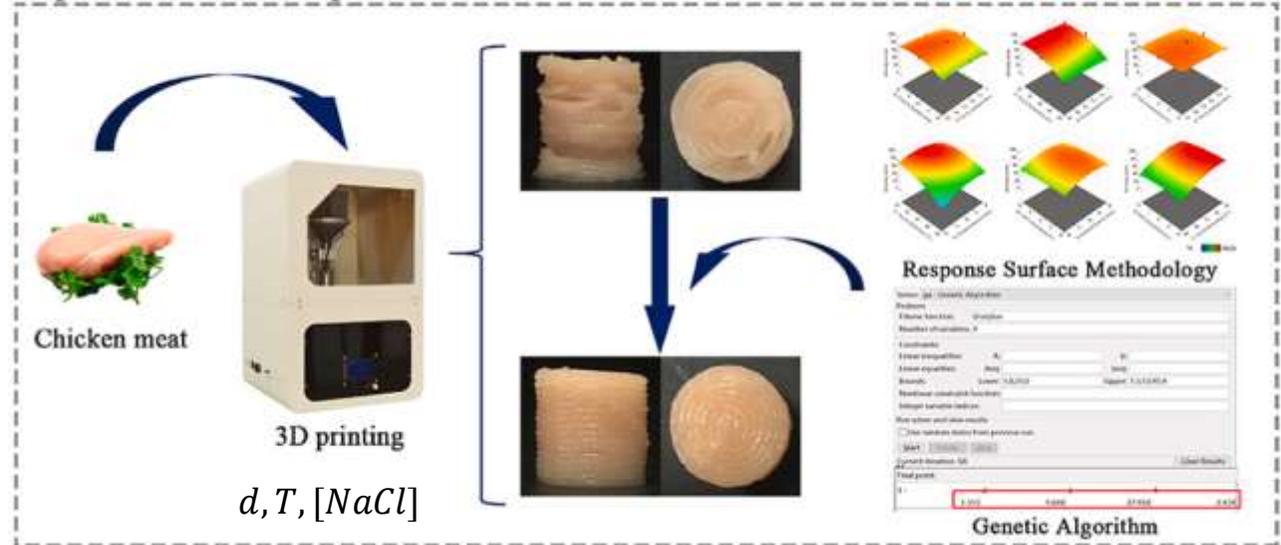
Flowchart of standard genetic algorithm¹⁰

Extrusion cooking

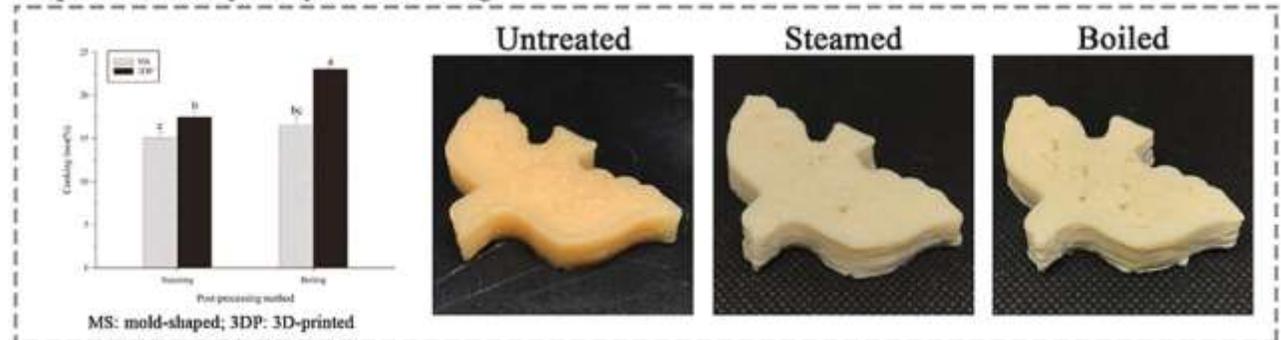
Temp	rpm	Additive%	Moisture%
100	80	10	20
150	120	30	60

Quality

Step 1. RSM-GA based optimization



Step 2. Feasibility analysis of cooking

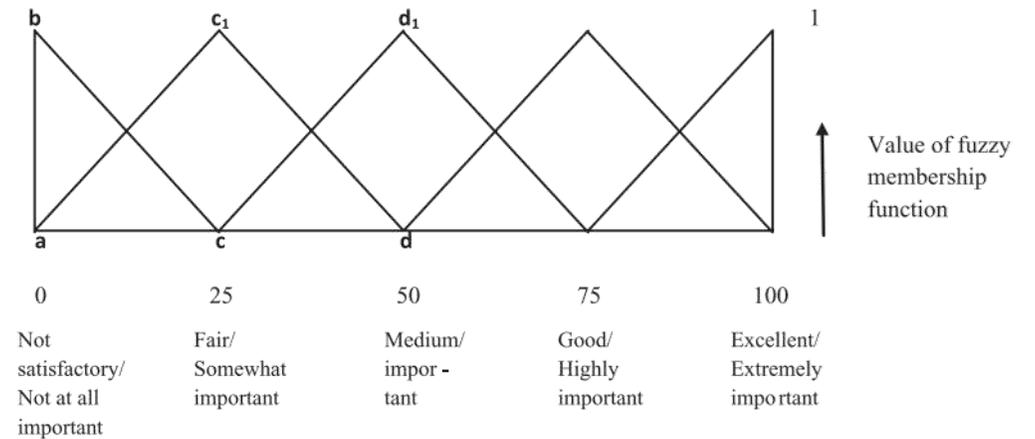
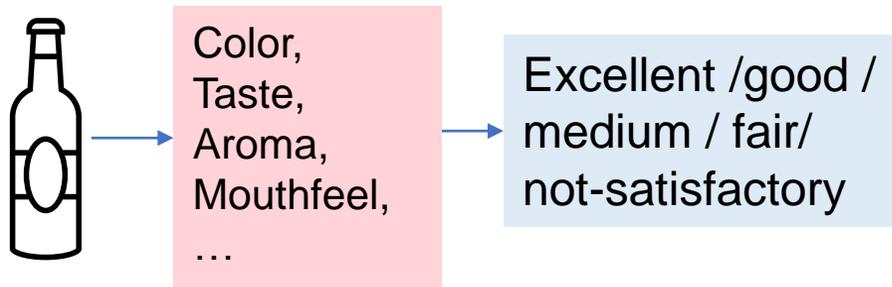


Optimizing 3D printing of chicken meat¹¹

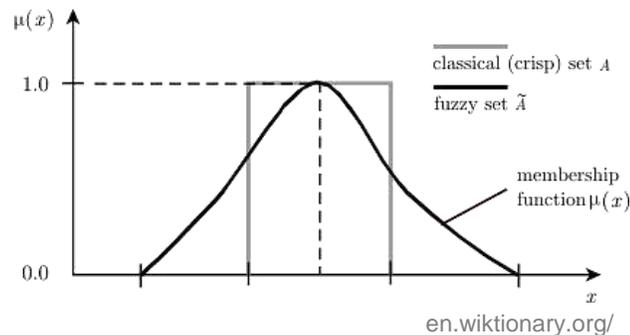
¹⁰Albadr et al. (2020) ¹¹Yang (2022)

Fuzzy logic

- Deals with uncertain, subjective, imprecise data to yield numerical data
- Liking/disliking of food products → sensory data → fuzzy



Membership function of fuzzy 5-point sensory scale¹²



Scale factors	Color	Flavor	Homogeneity	Taste
Not at all necessary	0	0	0	0
Somewhat necessary	0.239279	0	0.178571	0
Necessary	0.861405	0.294393	0.785714	0
Important	0.741765	0.930211	0.785725	0.287273
Highly important	0.136731	0.67136	0.178571	0.887273
Extremely important	0	0.075034	0	0.54053
Ranking	IV	II	III	I

Computational fluid dynamics

CFD simulation

Using numerical analysis and data structures to analyze and solve problems that involve fluid flows.

Initial conditions, $t = 0$

Initial temperatures, $T=25\text{ }^\circ\text{C}$
Initial velocity, $\vec{v}_z = \vec{v}$
turbulent flow conditions, 5%
 κ - ϵ turbulence model

Boundary conditions, $t = t_{end}$

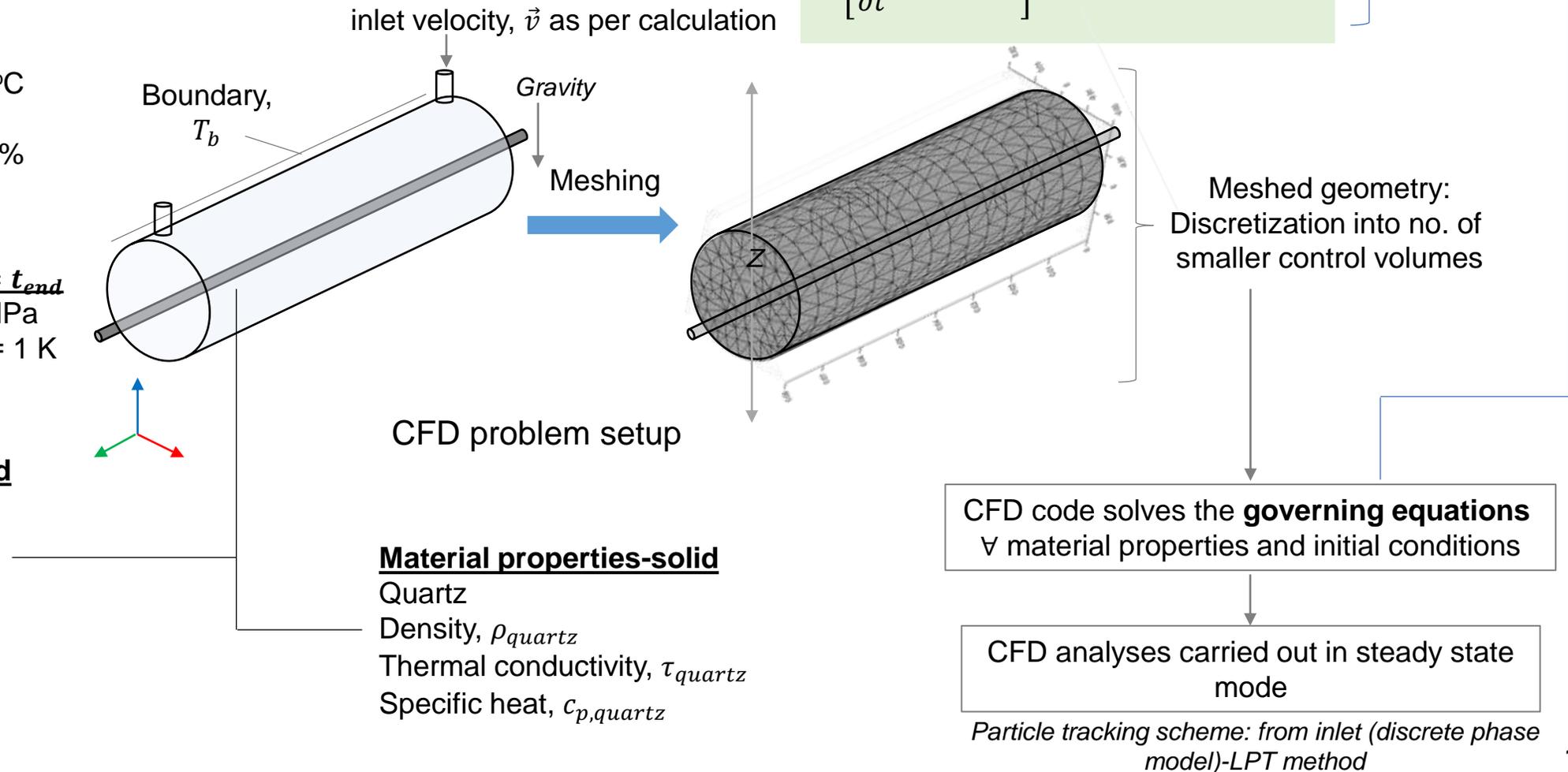
Outlet Pressure, $p = 0.01\text{ MPa}$
Boundary temperature, $T_b = 1\text{ K}$

Material properties-Liquid

Density, ρ
Specific heat, c_p
Viscosity, μ
Thermal conductivity, τ

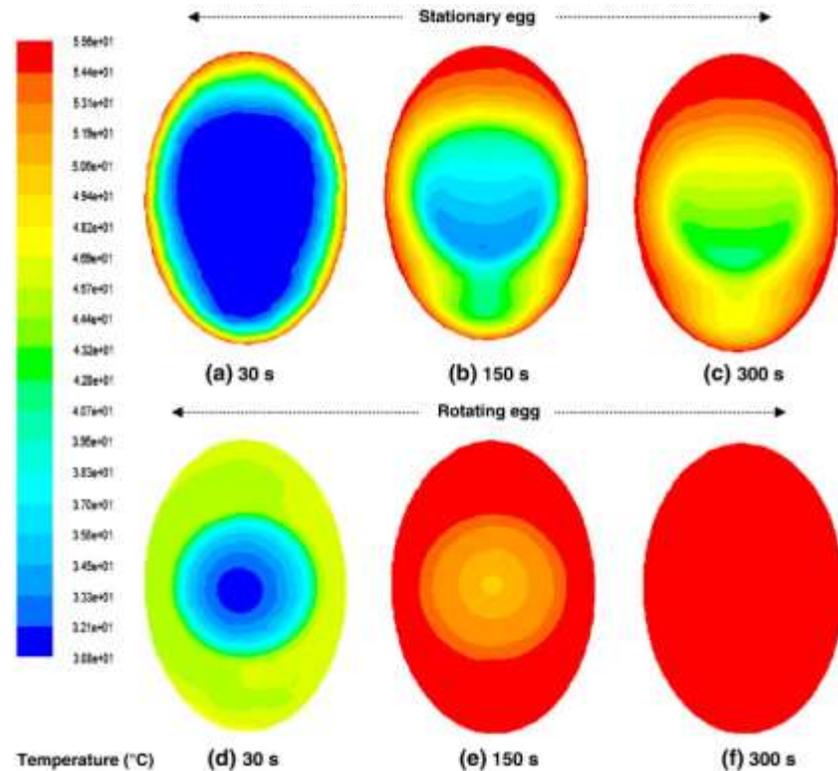
Material properties-solid

Quartz
Density, ρ_{quartz}
Thermal conductivity, τ_{quartz}
Specific heat, $c_{p,quartz}$

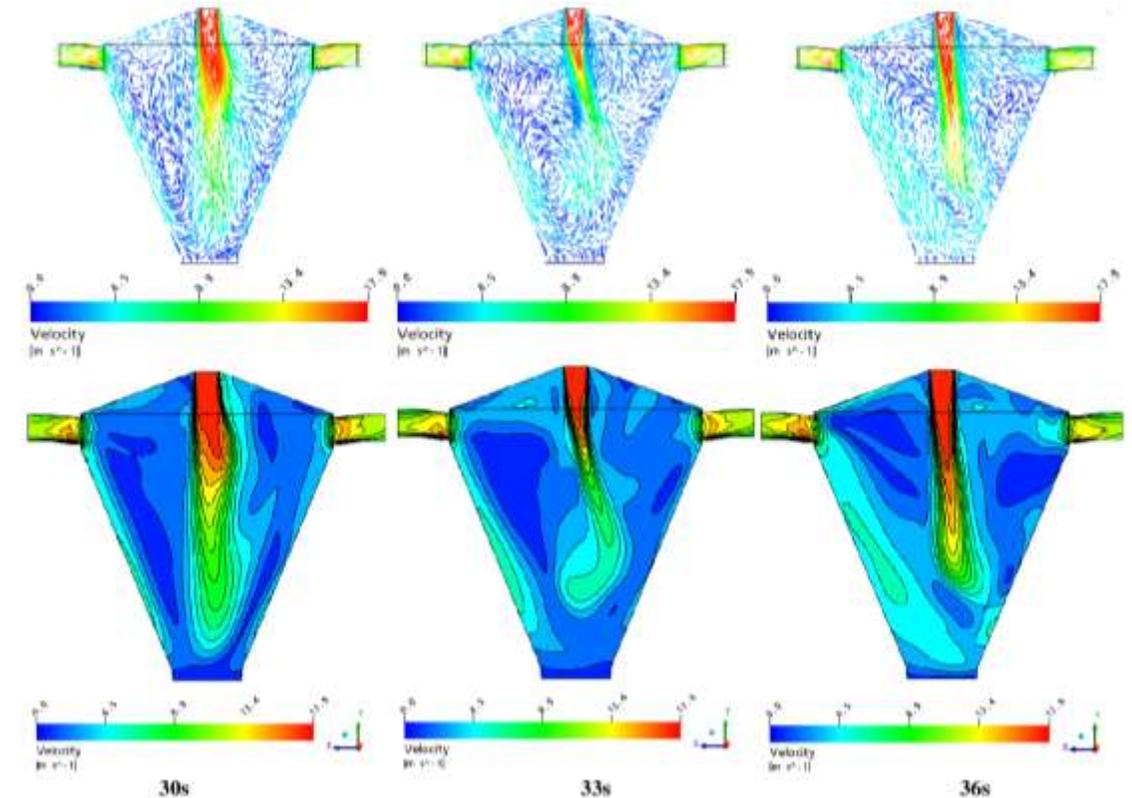


Computational fluid dynamics

- CFD numerical analysis helps in prediction of variables (T, v, []) at any point within the geometry
- Good comparison with experimental values



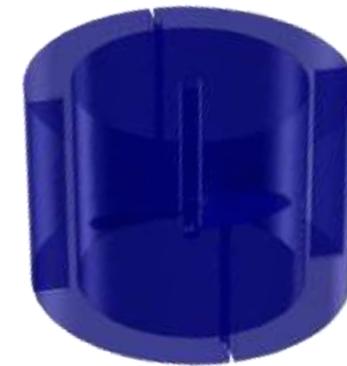
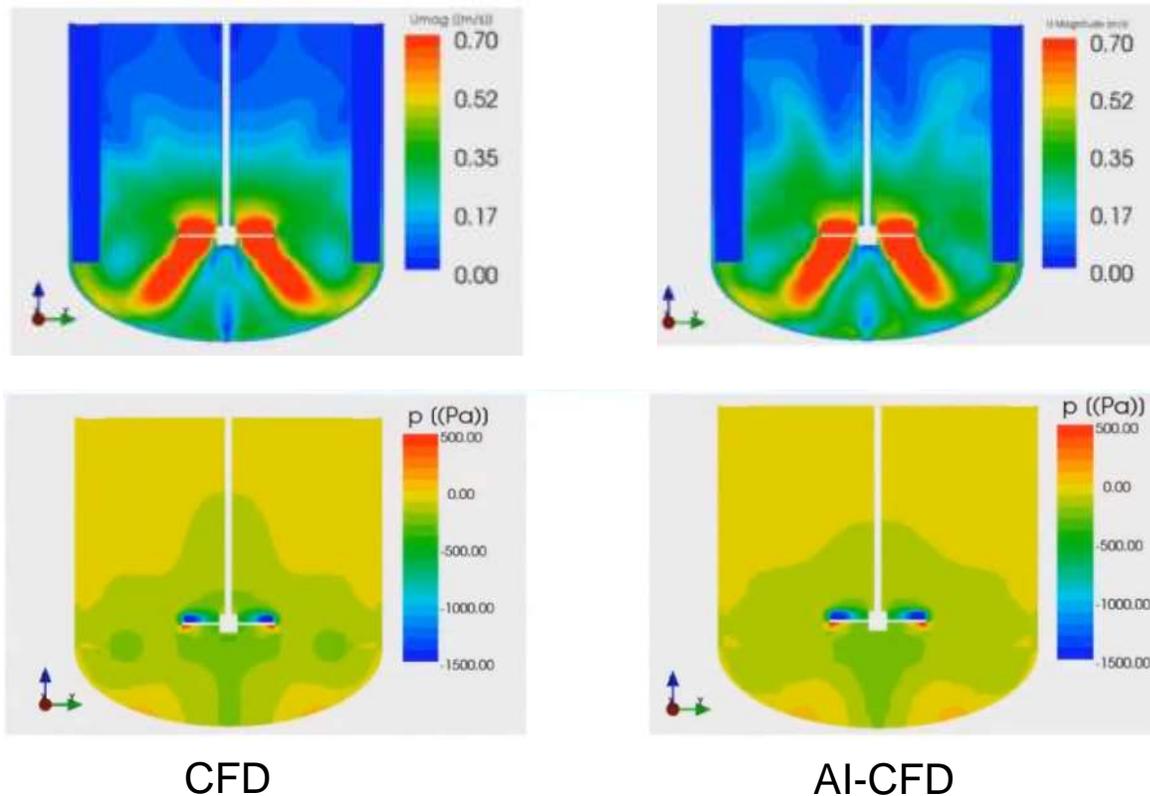
Egg heating up to 55.6 °C; stationary vs rotation at 5 rpm¹³; visualize the temperature contours



Velocity contours¹⁴ inside a spray dryer for producing milk powder; Interaction of milk particles with hot air

AI applications in CFD

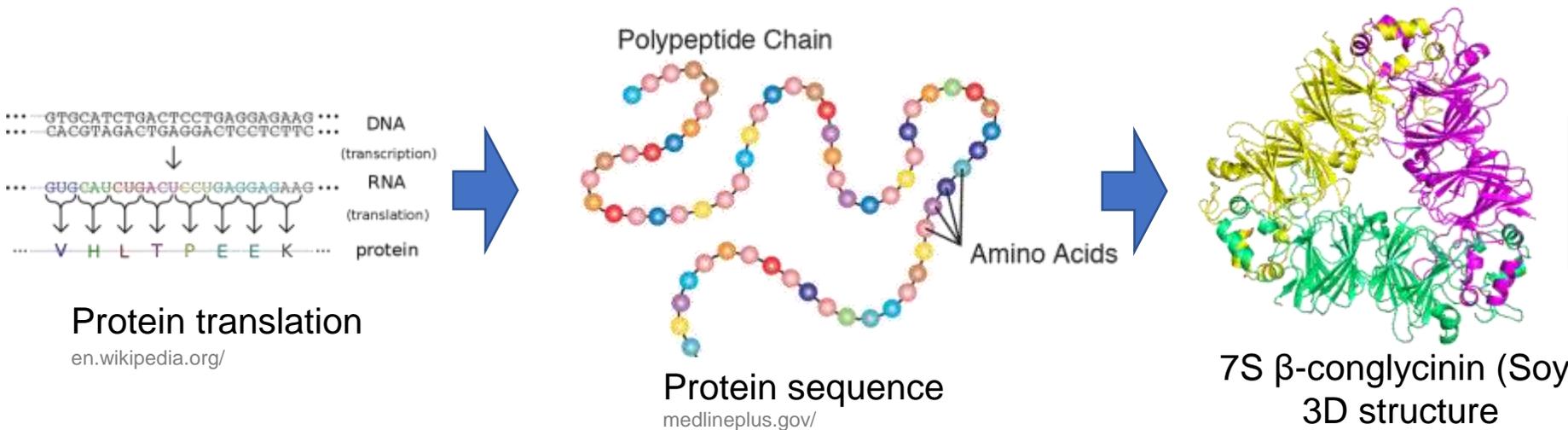
- AI augments the performance of CFD solvers
- Faster analyses; shorter run time; maintains accuracy¹⁵



CFD analysis of ST bioreactor¹⁶

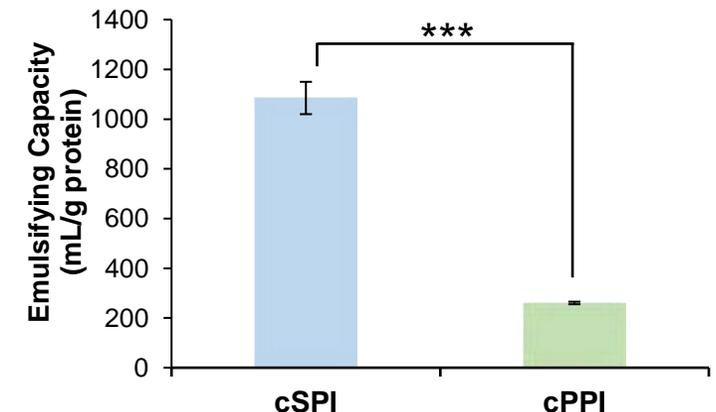
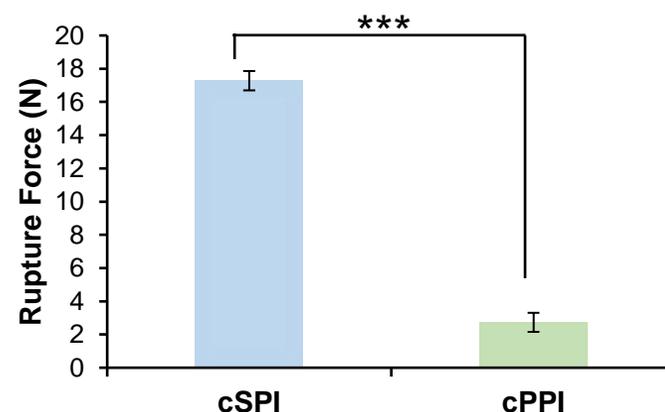
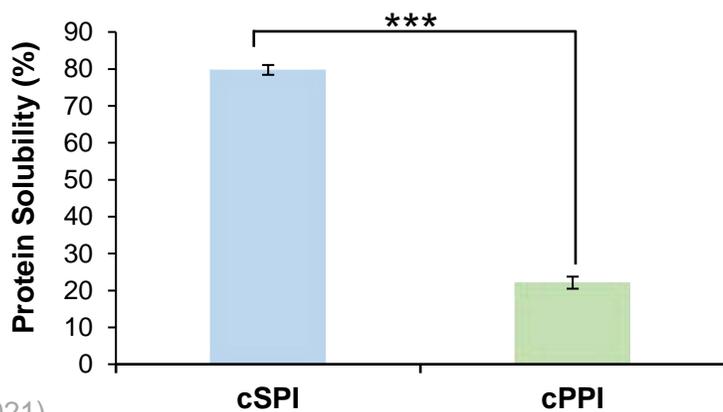
Plant Protein functionality prediction

- Plant protein → cater to the growing vegan population demand
- Applications → Protein functionality = f (protein structure, source)



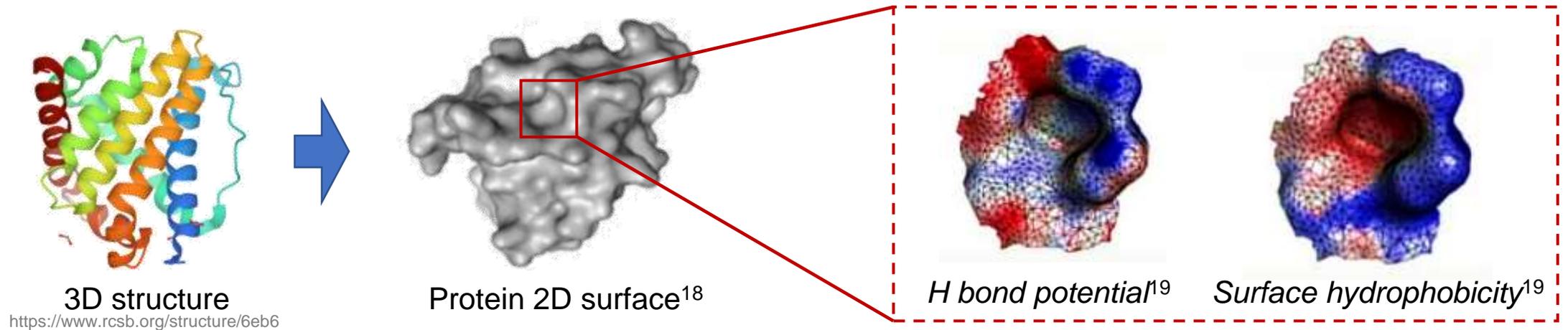
Soy vs pea protein¹⁷

- Soy has cysteine residues
- Better functionality



Plant Protein functionality prediction

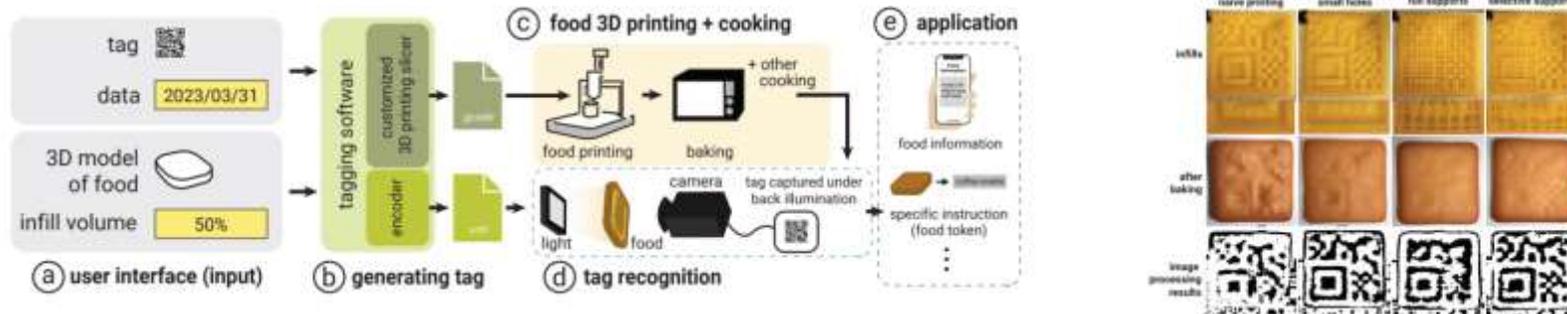
- Collaboration b/w PPIC and Microsoft
- Prediction of protein functionality → **ML application** (PPIC has a huge database of structure-function data for several plant protein)



- Develop predictive models from the data on the structure-function relationship → identify proteins for specific application
- Solubility, pH → beverage applications
- Good gelling → meat alternatives

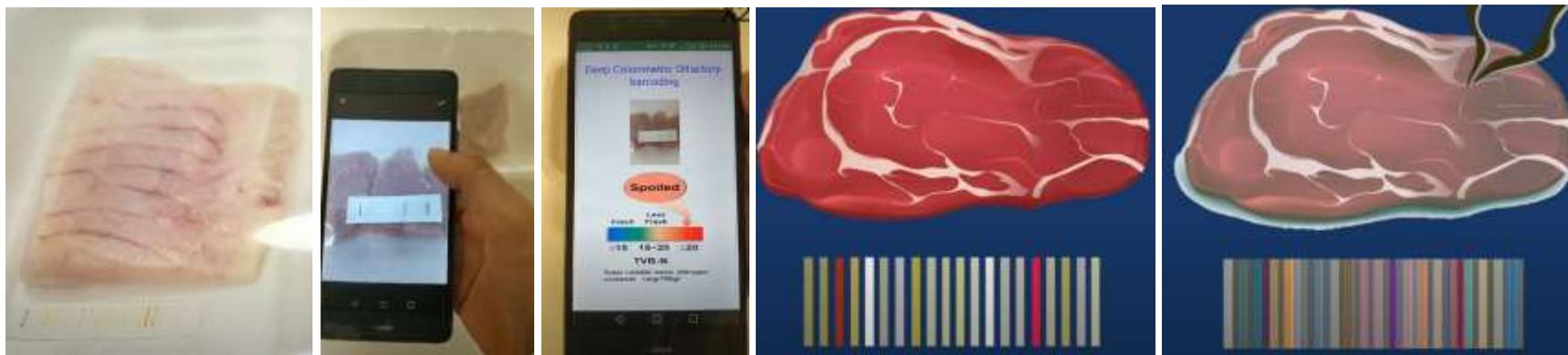
Other applications

- Interiqr – 3D printed cookie with embedded qr code → reduce waste generation due to packaging/labelling



3D printed cookies with qr code²⁰

- electronic nose (e-nose) barcode → changes color over time by gases produced by meat as it decays → barcode 'reader' smartphone app²¹



<https://scitechdaily.com/ai-powered-electronic-nose-sniffs-out-meat-freshness/>

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Thank you!



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