Food 3D Printing for Personalized Nutrition

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Food 3D Printing

CONCEPTS

- Additive manufacturing
- Layer-by-layer fabrication
- Constructs complex structures at ease
- Sustainability & minimal wastage

APPROACHES & MATERIAL SUPPLIES

- Extrusion-type food 3DP – most popular
- 3 classes of printing inks:
  - ✓ Natively printable foods
  - ✓ Non-printable foods
  - ✓ Alternative food sources

For further reading:

Nachal, N., Moses, J. A., Karthik, P., & Anandharamakrishnan, C. (2019). Applications of 3D printing in food processing. Food Engineering Reviews, 11(3), 123-141.

3D printing in the food industry

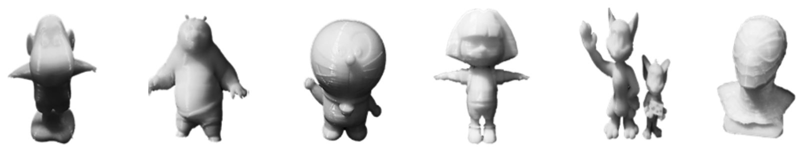
- Customized food & package designs – enhanced preferences & food model prototyping
- Nutrient enrichment – focusing on health status improvement
- Cost reduction in food preparation & transport
- Food waste reduction & utilization
- Process digitalization & versatility for domestic, retail and bulk manufacturing processes
- Personalized nutrition

3D Food Printing

For Personalized Nutrition

Nutritious 3D-printed foods for children with asthetic improvement

- School surveys - shape & flavor preferences
- Millet-pulse indigenous composite flour
- 3DP snacks
- Rich in fiber (~17.79%), protein (~10.41%) & minerals

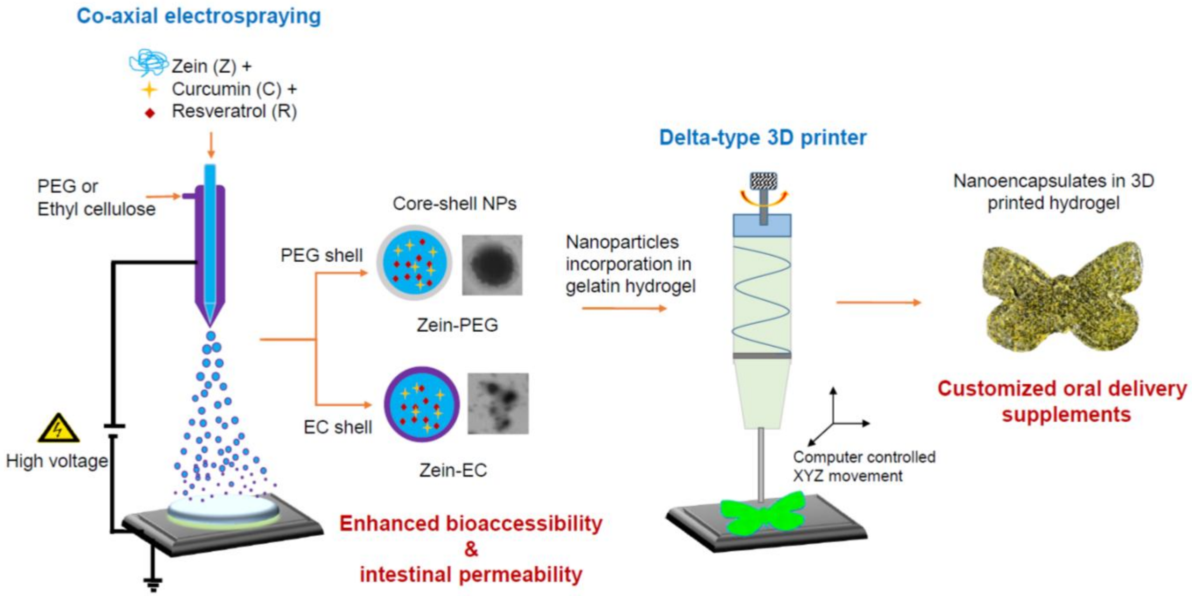


- Customized shapes
- Egg yolk and egg white fractions
- Solves storage, handling and transportation challenges

Krishnaraj, P., Anukiruthika, T., Choudhary, P., Moses, J. A., & Anandharamakrishnan, C. (2019). 3D extrusion printing and post-processing of fibre-rich snack from indigenous composite flour. Food and Bioprocess Technology, 12(10), 1776-1786.

Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2020). 3D printing of egg yolk and white with rice flour blends. Journal of Food Engineering, 265, 109691.

Nutraceutical-loaded & functional 3D-printed foods

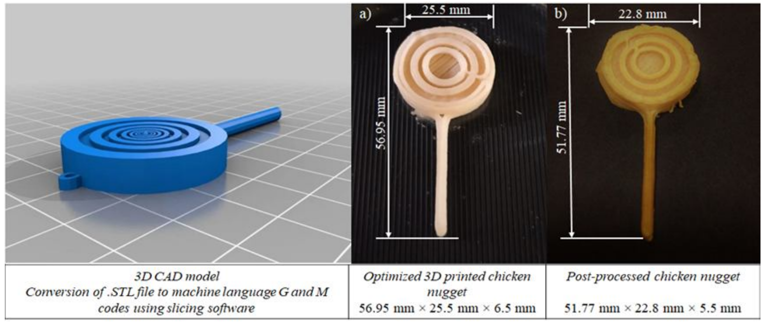


Leena, M. M., Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2022). Co-delivery of curcumin and resveratrol through electrosprayed core-shell nanoparticles in 3D printed hydrogel. Food Hydrocolloids, 124, 107200.

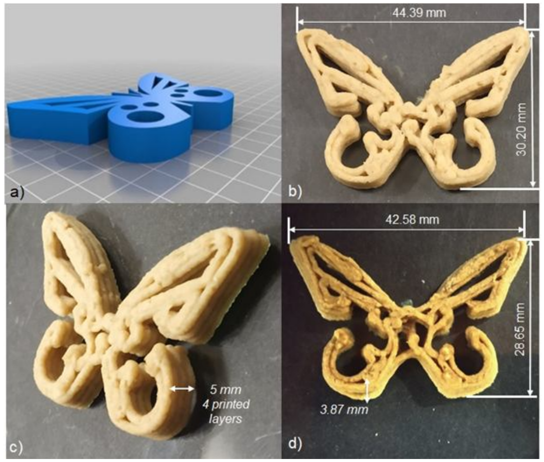
High-protein 3D-printed foods

3D printed plant-based meat analog

Pulse-millet-oilseed based gluten-free, soy-free product with 27% protein



3D printed chicken nugget & fiber-enriched nugget

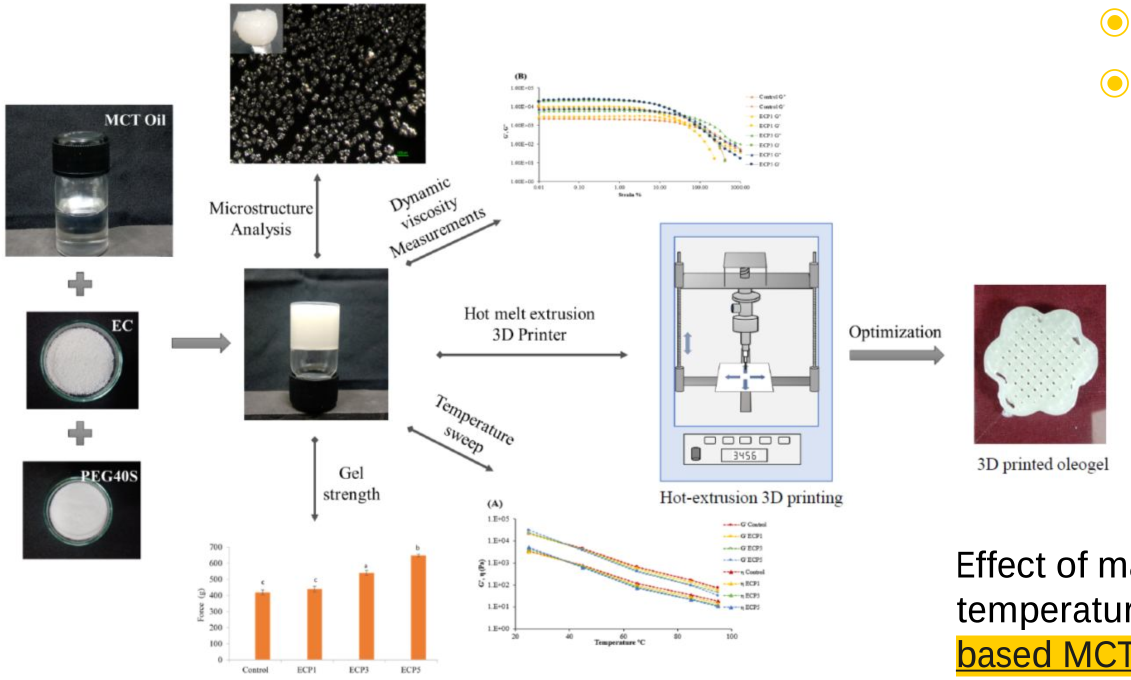


3D printed mushroom – based snack

Wilson, A., Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2020). Customized shapes for chicken meat–based products: feasibility study on 3D-printed nuggets. Food and bioprocess technology, 13(11), 1968-1983.

Keerthana, K., Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2020). Development of fiber-enriched 3D printed snacks from alternative foods: A study on button mushroom. Journal of Food Engineering, 287, 110116.

3DFP as a drug vehicle



- Most common 3DP dosage form – tablets
- Most used – soft materials with biological applications

Effect of material composition and 3D printing temperature on hot-melt extrusion of ethyl cellulose based MCT oil oleogel

Kavimughil, Maria L., Moses, J.A., & Anandharamakrishnan, C. Effect of material composition and 3D printing temperature on hot-melt extrusion of ethyl cellulose based MCT oil oleogel.

Personalized foods for astronauts (space) and soldiers (military)

Why?

Long-duration missions

Reduce downtime in refilling supplies

Boredom – the need for variety!

What?

Creating foods faster and safe than a chef

Print on demand (real time monitoring of nutritional needs using biosensors)

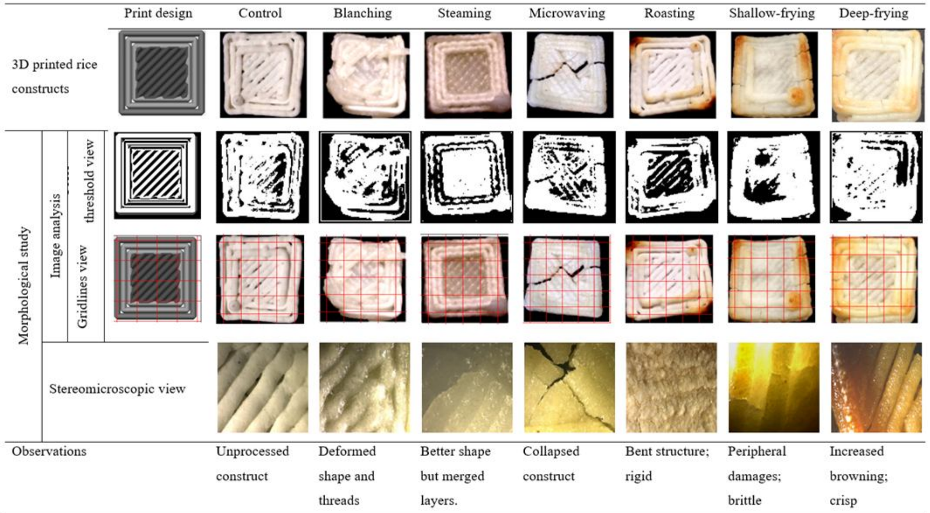
How?

Print and eat on site

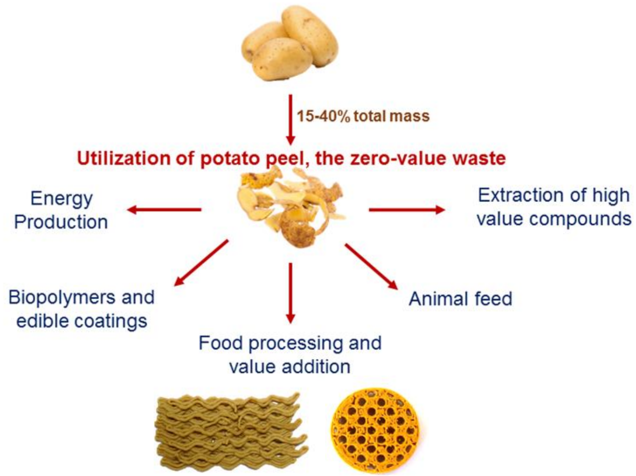
Zero waste

Digitally controlled tailor-made meals

- 3D printed rice starch constructs & the impact of post-processing



- Noodles from potato peel waste



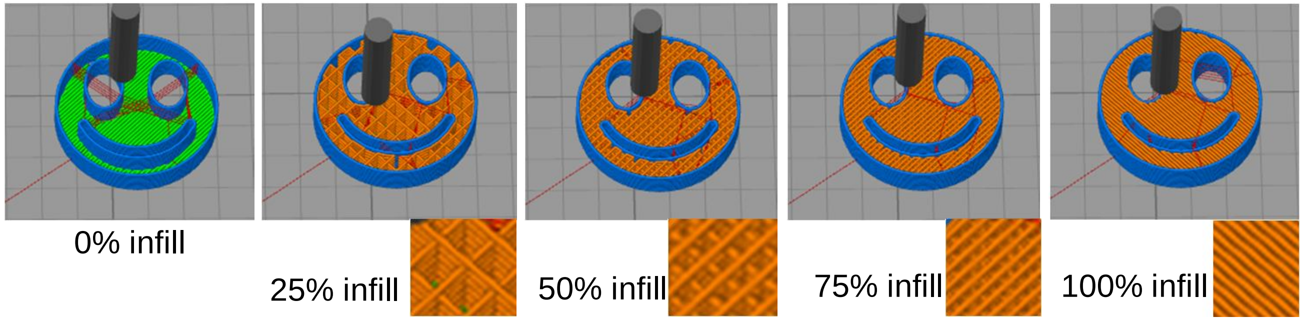
Theagarajan, R., Moses, J. A., & Anandharamakrishnan, C. (2020). 3D extrusion printability of rice starch and optimization of process variables. Food and Bioprocess Technology, 13(6), 1048-1062.

Theagarajan, R., Nimbkar, S., Moses, J. A., & Anandharamakrishnan, C. (2021). Effect of post-processing treatments on the quality of three-dimensional printed rice starch constructs. Journal of Food Process Engineering, 44(9), e13772.

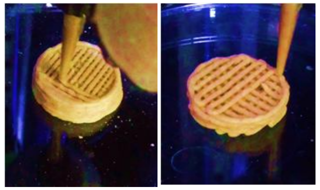
Muthurajan, M., Veeramani, A., Rahul, T., Gupta, R. K., Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2021). Valorization of Food Industry Waste Streams Using 3D Food Printing: A Study on Noodles Prepared from Potato Peel Waste. Food and Bioprocess Technology, 14(10), 1817-1834.

3D-printed texture modified foods for those with swallowing diorders

- Modifying texture and consistency
- To meet Int. Dysphagia Diet Standardization Initative Categories



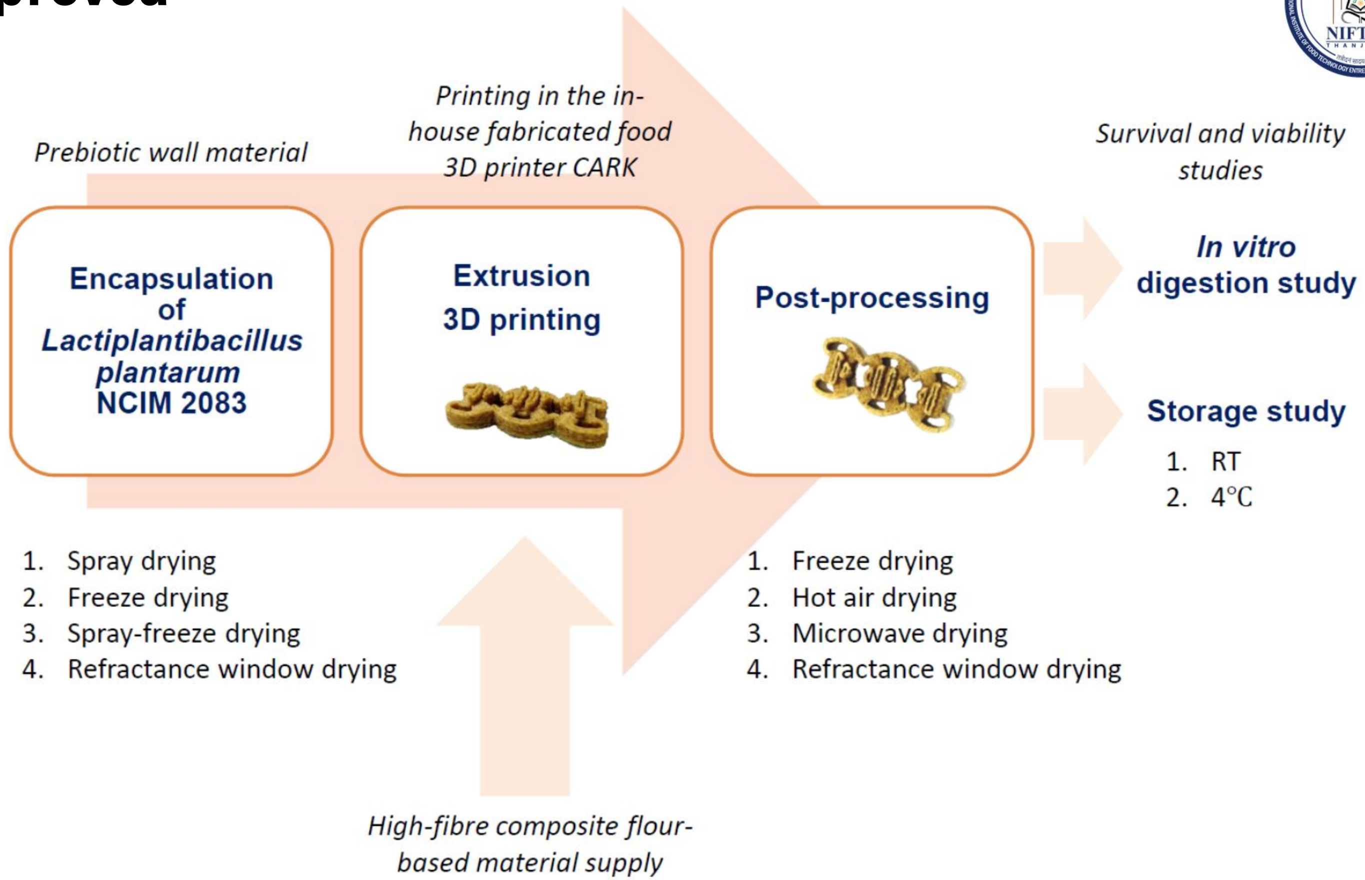
- Structured foods with controlled glycemic responses



Pearl millet fortified idli batter, 3D printed with different infill levels and fermented

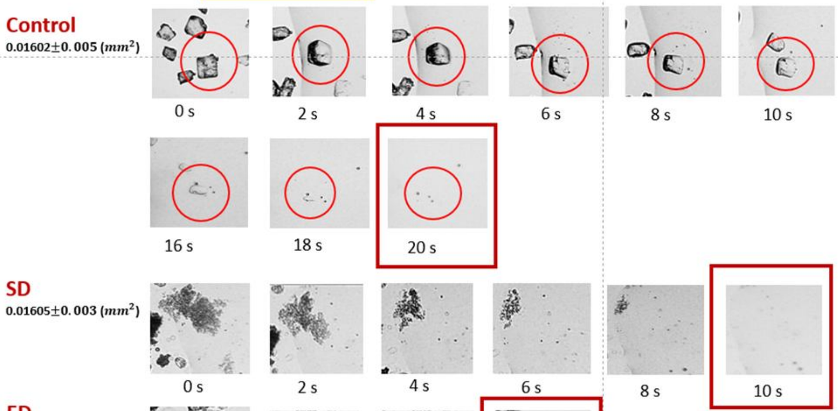
Vijayakumar Raja, Moses JA, Anandharamakrishnan C. 3D printing of pearl millet fortified idli batter: Study on the effect of fermentation on the shape of printed constructs.

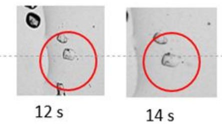
Probiotics for improved digestive health

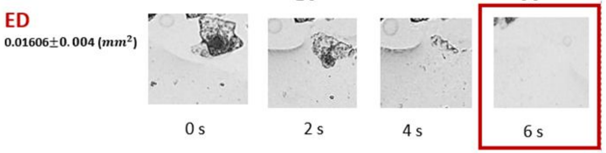


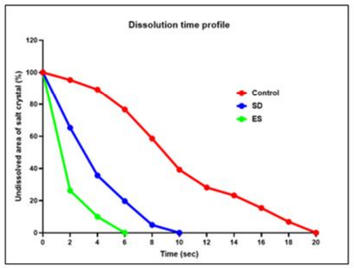
Yoha, K. S., Anukiruthika, T., Anila, W., Moses, J. A., & Anandharamakrishnan, C. (2021). 3D printing of encapsulated probiotics: Effect of different post-processing methods on the stability of Lactiplantibacillus plantarum (NCIM 2083) under static in vitro digestion conditions and during storage. LWT, 146, 111461.

Hybrid technologies for reducing dietary sodium intake

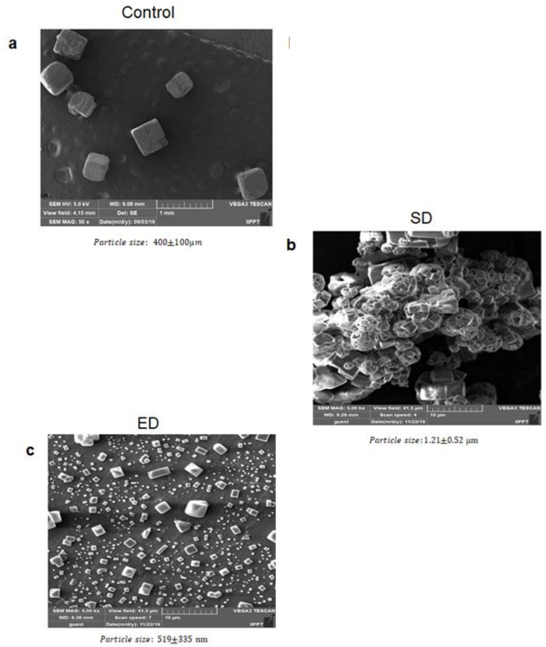








Sample	Dissolution kinetics model	Dissolution rate constant (s^{-1})
Control	Zero-order	K_0 = 5.91±0.46
SD	First-order	K_1 = 0.44±0.007
ED	First- order	K_1 = 0.75±0.03



Vinitha, K., Leena, M. M., Moses, J. A., & Anandharamakrishnan, C. (2021). Size-dependent enhancement in salt perception: Spraying approaches to reduce sodium content in foods. Powder Technology, 378, 237-245.

Vinitha, K., Sethupathy, P., Moses, J. A., & Anandharamakrishnan, C. (2022). Conventional and Emerging Approaches for Reducing Dietary Intake of Salt. Food Research International, 110933.0

3D printing of **polymeric materials that act as a supporting structure** for the growth of cells & tissues

Self-assembly of small micro-sized **smart particles that change patterns** when acted upon by stimuli

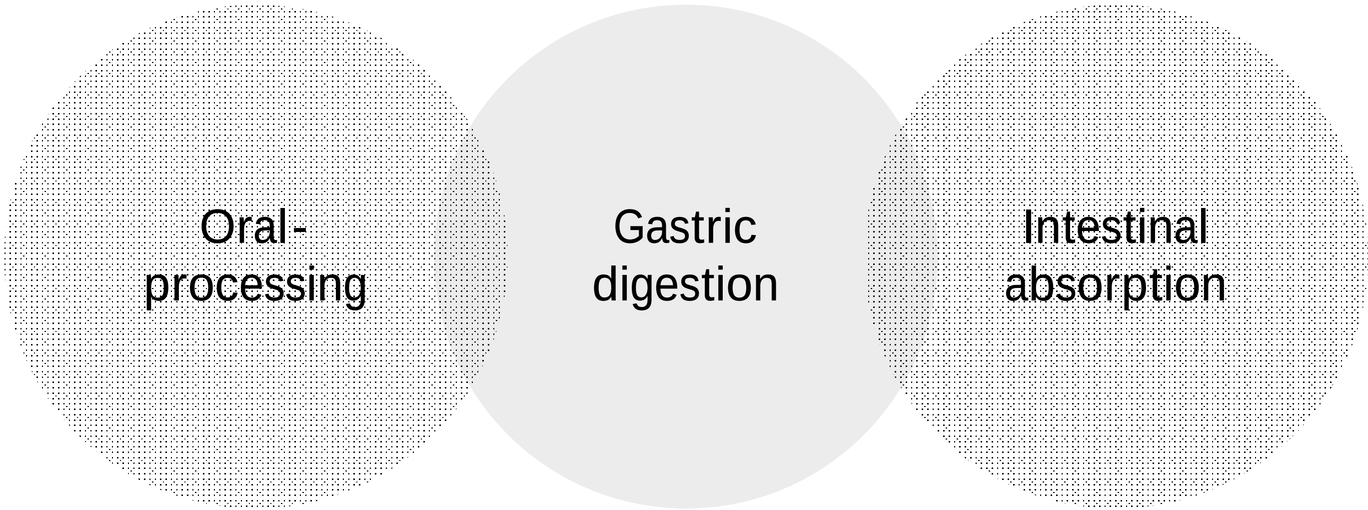
The fascinating science of

4D Printing

Smart material changes its shape / colour / flavour / nutrition when acted upon by stimuli

Shanthamma, S., Preethi, R., Moses, J. A., & Anandharamakrishnan, C. (2021). 4D printing of sago starch with turmeric blends: A study on pH-triggered spontaneous color transformation. ACS Food Science & Technology, 1(4), 669-679

Understanding food destructuring, nutrient absorption & GI @ NIFTEM - T



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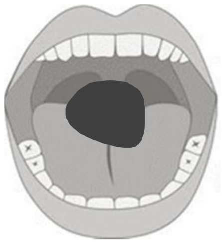
(1)
Oral-processing



Sethupathy, P., Priyadarshini, S. R., Moses, J. A., & Anandharamakrishnan, C. (2021). Matrix-dependent oral processing, oro-sensory perception, and glycemic index of chocolate bars. Journal of Food Processing and Preservation, 45(12), e16067.

Sethupathy, P., Sivakamasundari, S. K., Moses, J. A., & Anandharamakrishnan, C. (2021). Effect of varietal differences on the oral processing behavior and bolus properties of cooked rice. International Journal of Food Engineering, 17(3), 177-188.

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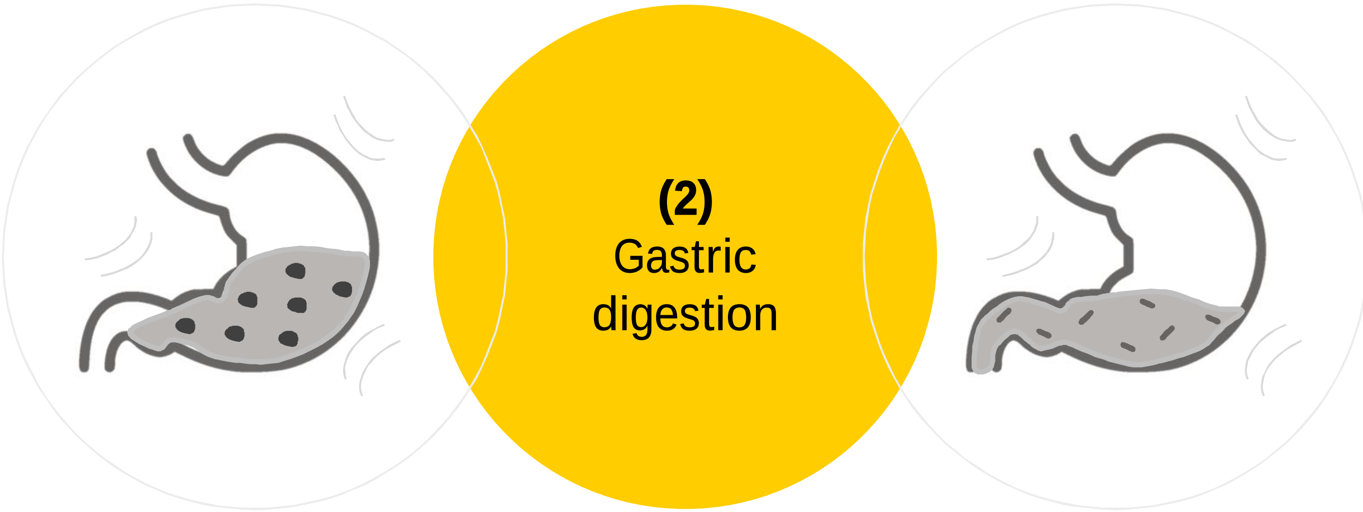

Payal, A., Elumalai, A., Moses, J. A., & Anandharamakrishnan, C. (2021). An investigation on gastric emptying behavior of apple in the dynamic digestion model ARK® and its validation using MRI of human subjects–A pilot study. Biochemical Engineering Journal, 175, 108134.

Ranganathan, S., Vasikaran, E. M., Elumalai, A., Moses, J. A., & Anandharamakrishnan, C. (2021). Gastric emptying pattern and disintegration kinetics of cooked rice in a 3D printed in vitro dynamic digestion model ARK®. International Journal of Food Engineering, 17(5), 385-393.

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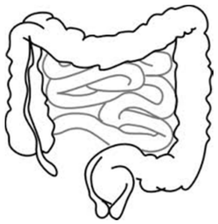

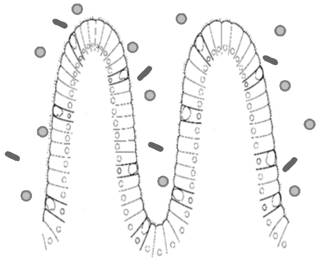

(3)
Intestinal absorption

Priyadarshini, S. R., Moses, J. A., & Anandharamakrishnan, C. (2021). Prediction of in-vitro glycemic responses of biscuits in an engineered small intestine system. Food Research International, 147, 110459.

Jayan, H., Leena, M. M., Sundari, S. S., Moses, J. A., & Anandharamakrishnan, C. (2019). Improvement of bioavailability for resveratrol through encapsulation in zein using electrospraying technique. Journal of Functional Foods, 57, 417-424.

Challenges & the future

x

Batch consistency

x

Consumer awareness & acceptance

x

Speed & capacities

x

Digital piracy & ethics

+

Novel range of products & new manufacturing practices

++

IoT integrated smart 3DFP & position in the digital food & nutrition market

+++

3D food printers in every kitchen?

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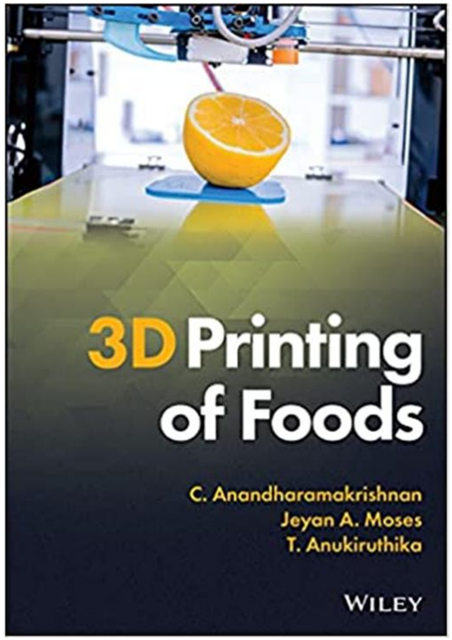
Data analytics linked individual preference databases



Thank you!

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Further reading

Our other recent publications in this field

Nida, S., Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2021). 3D printing of grinding and milling fractions of rice husk. Waste and Biomass Valorization, 12(1), 81-90.

Wilson, A., Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2021). Preparation of fiber-enriched chicken meat constructs using 3D printing. Journal of Culinary Science & Technology, 1-12.

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Conflict of Interest

None