Application of Additive Manufacturing for Processed Cheese

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Overview

- Introduction
  - Background information and context
  - Aims and objectives

- Materials and methods
  - Development of 3D printing configuration

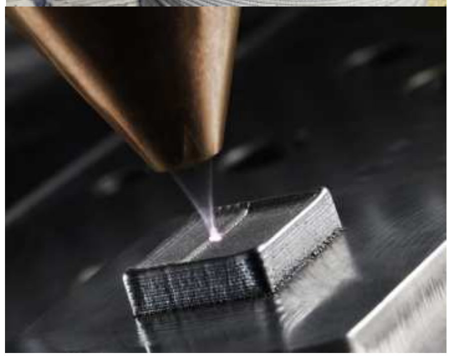
- Results and discussions
  - Effect of additive manufacturing process upon processed cheese microstructure

- Conclusions

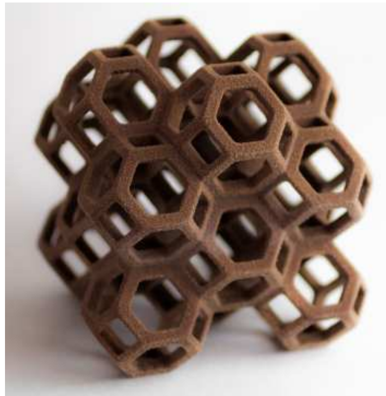
Additive Manufacturing

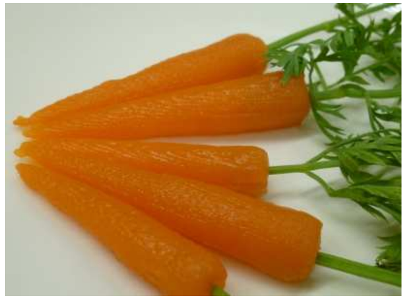
- Additive manufacturing, more commonly know as 3D printing, was first developed in the 1980s.

- Additive manufacturing is a process by which 3D structures are generated, has numerous applications in areas such as:
  - Construction
  - Fabrication of specialised components
  - Medical
  - Automotive
  - Food



3D Printing of Food



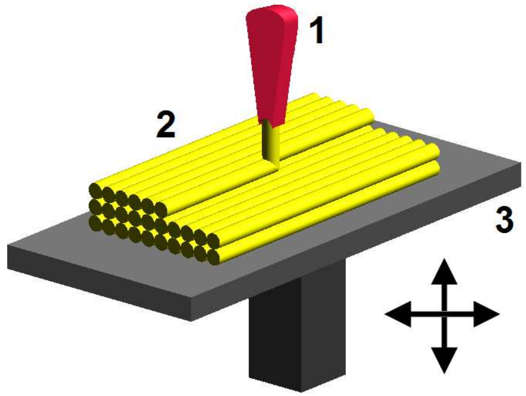


- Over the past decade, 3D printing of food has garnered significant interest.

- The key applications of 3D printing of food include:
    - Personalised food opportunities in the home.
    - Novelty food products.
    - Specialised stage nutrition
    - Encapsulation of bioactives or pharmaceutics for specific nutrition needs.

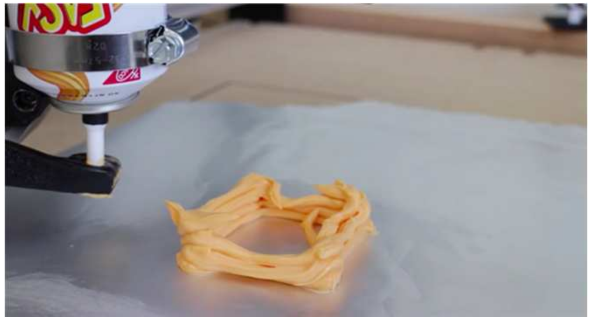
Methods of 3D Printing of Food

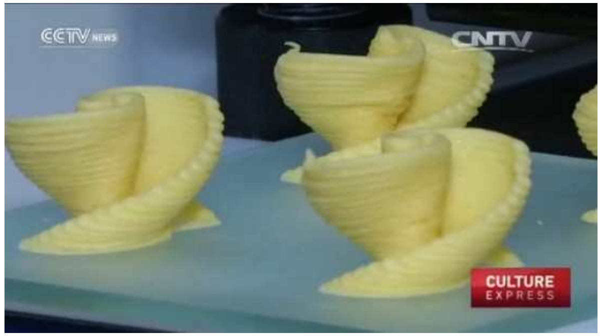
- There are broadly 2 main methods for the 3D printing of food:
  - Controlled fusion:
    - Uses solids or powders as the printing medium melting them at controlled temperatures on the printer to develop 3D food geometries.
  - **Controlled deposition:**
    - Consists of the extrusion of a molten food product to generate 3D food structures.



Examples of 3D Printing with Food

- Numerous examples of 3D printing of food are currently available.
- Nevertheless, the effects of 3D printing on the physical properties and microstructure of food is not fully understood.





Stresses Associated with 3D Printing

- 3D printing typically applies 2 stresses to a food system:
  - A heating step (*i.e.*, melting)
  - A shearing step (*i.e.*, extrusion through a nozzle)

- Both of these stresses will alter the microstructure of a food product.

- However little research has been conducted to date investigating these effects upon the physical properties and microstructure of food.

Processed Cheese

- Processed cheese is manufactured by heating, mixing and emulsifying a blend of natural cheese with other dairy products, water, vegetable fats, proteins, emulsifying salts and additives.

- Effectively, processed cheese is a solid emulsion system.

Aims & Objectives

- Develop a syringe based additive manufacturing approach for cheese applications
- Understand the effects of the additive manufacturing upon processed cheese microstructure
  - Dual melting and extrusion steps.

Materials and Methodology

Materials

- The printing material used in this study was a commercially available processed cheese.
  - 3 different batches (B1, B2, and B3) were investigated in order to understand the effect batch-to-batch variation.

- The composition of the cheese was:
  - 25% fat
  - 3% carbohydrate
  - 18% protein
  - 3% salt

Cheese Samples

- As part of this study 4 cheese samples were employed:
  - Fresh cheese (FC)
  - Melted cheese (MC) – melted at 75 ^{o}C for 15 min
  - Low speed printed cheese (LSPC)
  - High speed printed cheese (HSPC)

- Low speed and high speed are in reference to the rate of extrusion from the syringe, 4 or 12 mL/min, yielding shear rates of 201 and 604 s^{-1}, respectively.

$$\dot{\gamma} = \frac{8v}{d}$$

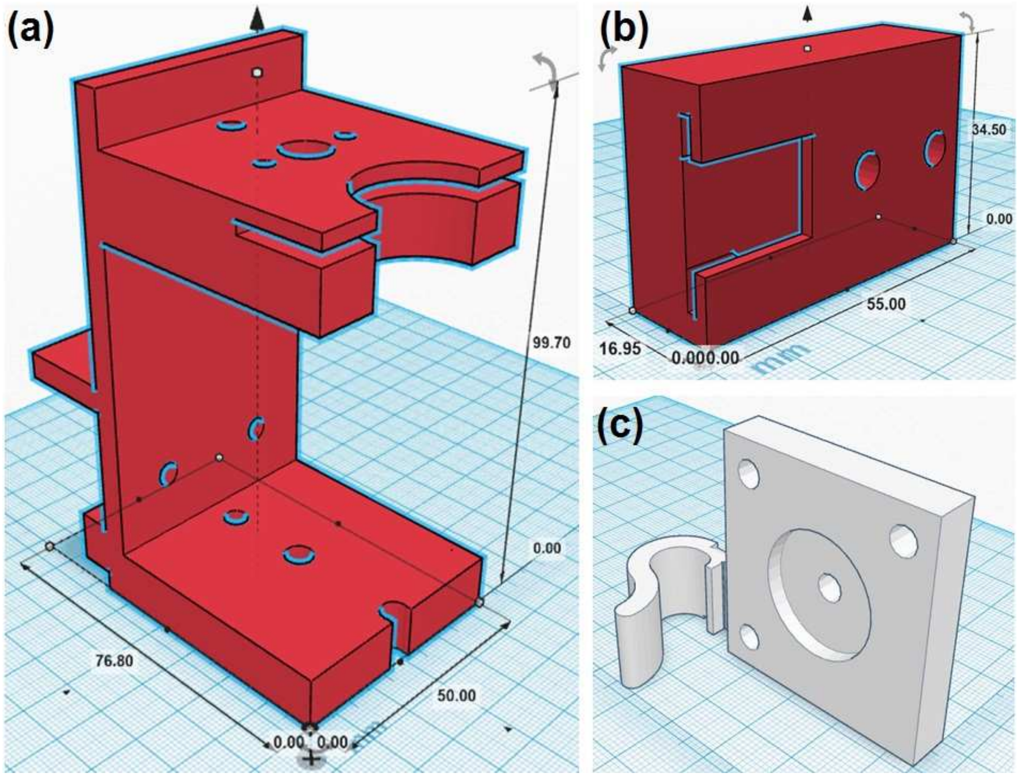
Printer Configuration

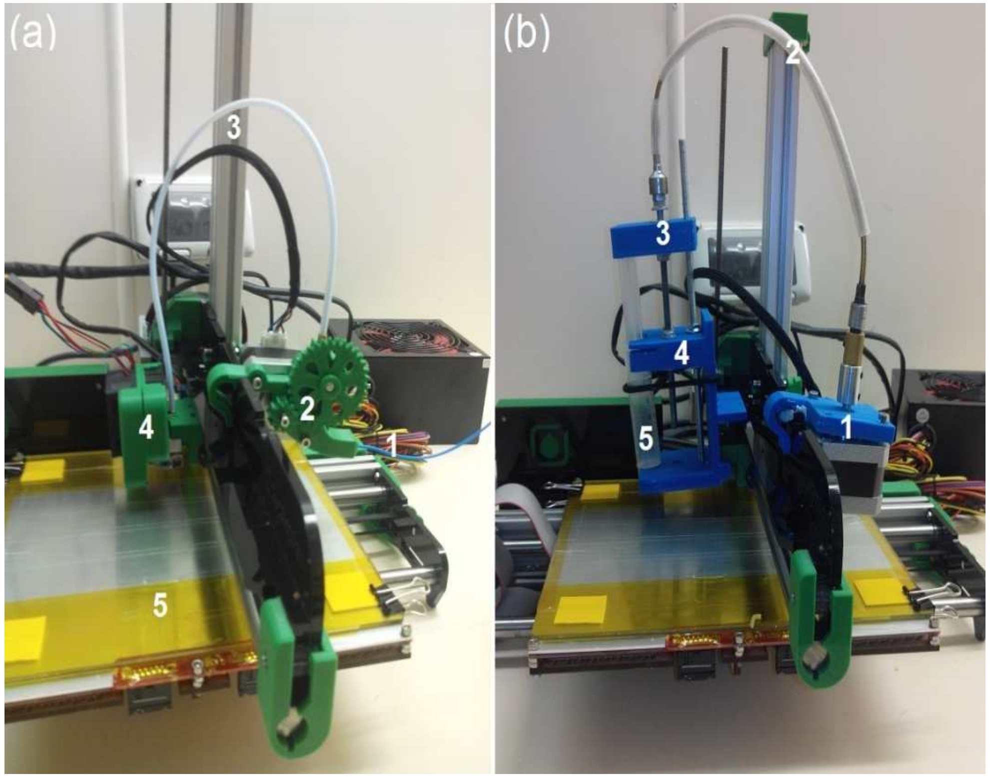
- A plastic printer was modified to print for food systems.

- Special components were printed with a polylactic acid (PLA) filament to facilitate:
  - Mounting a loaded syringe.
  - Transmitting power from the motor into a downward pumping action.

- In addition, components were designed to be lightweight.

Printer Configuration





Characterisation Methods

- 4 processed cheeses were characterised:
  - Fresh cheese (FC)
  - Melted cheese (MC)
  - Low speed printed cheese (LSPC)
  - High speed printed cheese (HSPC)

- Analytical approaches:
  - Textural profile analysis (TPA)
  - Oscillatory rheology
  - Confocal laser scanning microscopy (CLSM)
  - Colourimetry

Results and Discussions

Batch-to-Batch Variation

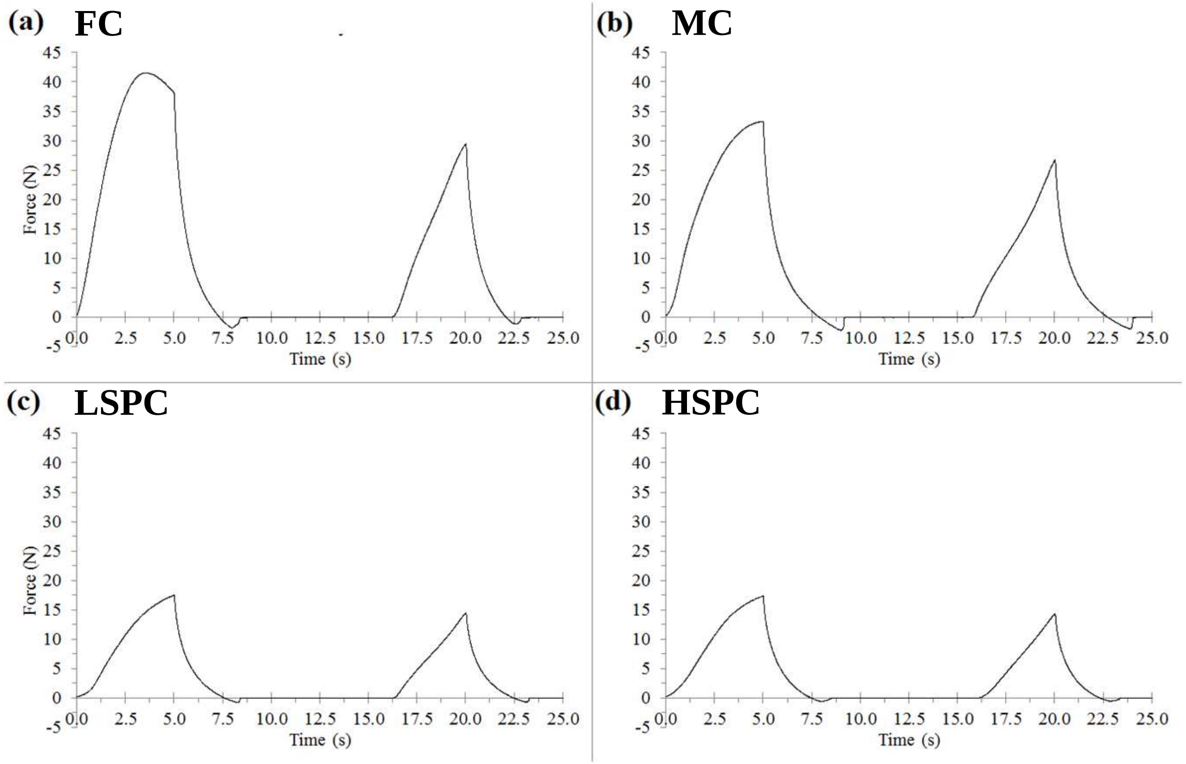
- The following table compares the batch-to-batch variability of the input printing material, using TPA indicators.

	Hardness (N)	Adhesiveness (N.s)	Cohesiveness	Springiness	Resilience
B1	41.71 ± 1.33	-1.96 ± 0.23	0.45 ± 0.03	0.77 ± 0.02	0.17 ± 0.02
B2	36.42 ± 1.87	-1.9 ± 0.11	0.47 ± 0.01	0.79 ± 0.01	0.18 ± 0.01
B3	28.7 ± 0.17	-1.9 ± 0.72	0.63 ± 0.02	0.86 ± 0.01	0.28 ± 0.01

- Significant differences were seen between the 3 batches, with respect to hardness, cohesiveness and resilience in particular.

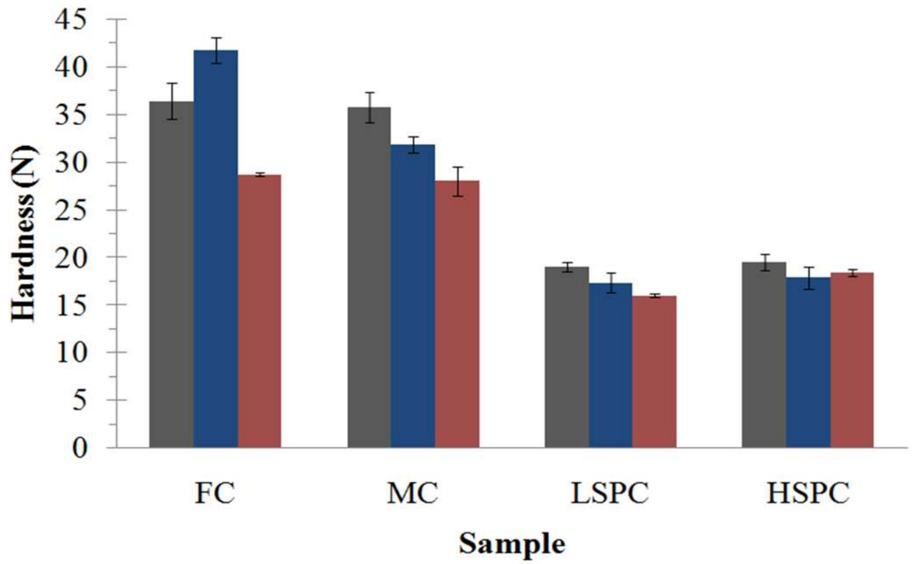
Textural Profile Analysis

- Comparison of the a TPA sweep for the four studied cheeses: FC, MC, LSPC and HSPC.



Effect of Printing and Batch on Hardness

- Comparison of the TPA indicator of hardness with respect to the 3 studied batches, and 4 cheese samples: FC, MC, LSPC and HSPC.



- Irrespective of initial cheese structure, after printing, hardness was the same between the 3 batches, and significantly lower.

Stiffness Loss of Cheese after Printing

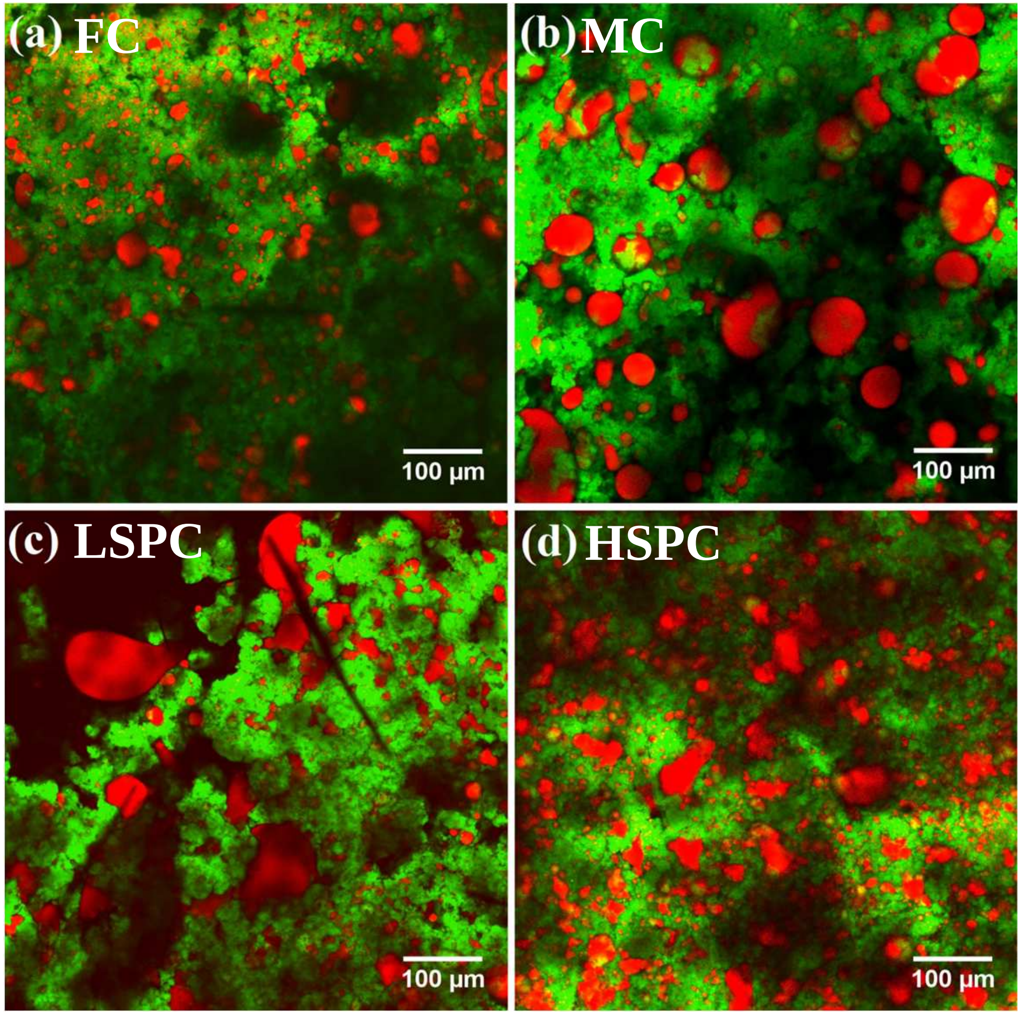
- Comparison of the rheology indicators 4 cheese samples: FC, MC, LSPC and HSPC.

	G*(30) (10^4 Pa)	tan(δ)max (-)	Stiffness loss (%)
FC	9.23 ± 0.68	0.26 ± 0.01	58.79 ± 4.46
MC	4.38 ± 1.04	0.31 ± 0.01	62.55 ± 4.84
LSPC	3.28 ± 0.33	0.33 ± 0.01	68.41 ± 2.16
HSPC	3.38 ± 0.28	0.32 ± 0.01	67.02 ± 2.20

$$Stiffness\ loss = \frac{G^*_{30} - G^*_{\tan(\delta)\max}}{G^*_{30}}$$

- These results further confirm the previously shown TPA indicators, that melted and printed cheeses are softer than fresh cheese.

Microstructure Visualisation



- FC has a uniform fat globule size.
- MC has an increase in fat globule size distribution.
- LSPC has large, irregularly shaped fat globules.
- HSPC has smaller, irregularly shaped fat globules.

Colour Analysis

- Colour analysis was conducted used L* (lightness), a* (green to magenta) and b* (blue to yellow) values.

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

ΔE (-)	Visual difference
0 – 0.2	Imperceptible
0.2 – 0.5	Very small
0.5 – 1.5	Small
1.5 – 3	Distinct
3 – 6	Very Distinct
6 – 12	Great
> 12	Very Great

Colour Analysis

- Colour differences were observed after each of the processing stages. The following differences are with respect to FC.

Sample	ΔL	Δa	Δb	ΔE	Visual difference
MC	-0.63 ±0.21	+0.30 ±0.04	-0.23 ±0.17	0.73	Small
LSPC	-0.62 ±0.88	+0.34 ±0.04	+1.80 ±0.70	1.93	Distinct
HSPC	-2.50 ±0.20	+0.20 ±0.09	-1.00 ±0.19	2.70	Distinct

- Distinct colour changes were observed for the printed samples, attributed to microstructural changes.
- In addition, significant differences were observed between printed cheese with respect to L* values.

Conclusions

- A plastic printer was successfully retrofitted with a syringe based food printing mechanism capable of printing processed cheese.
- Melting of the cheese (MC) resulted in a softer cheese in comparison to fresh cheese (FC), as the emulsion drop size increases.
- Both printed cheeses demonstrated comparable properties, both softer than FC and MC, due to the irregular shape of the fat droplets.
- Printing of the cheeses removed the effect of initial batch-to-batch variation.
- However differences were observed in L* values, attributed to different size of the fat globules between LSPC and HSPC.

Acknowledgements

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  - School of Food and Nutritional Sciences
  - School of Pharmacy
  - Department of Electrical and Electronic Engineering

- Thank you all for your attention

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