leatherhead food research

3D printing and food manufacture

Gimmick or game-changer?

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3D printing is becoming increasingly mainstream, but there has been limited uptake in the food industry to date. This paper considers how the technology can be applied to food manufacture, and asks whether it can make the leap from gimmick to game-changer.

Advantages of 3D printing

For many industries, the benefits of 3D printing – also known as 'additive' manufacturing – are linked to improved efficiency and reduced waste. It involves atom-by-atom, or layer-by-layer, creation of an object based on a digital file. This differs from 'subtractive' manufacturing techniques which generally cut or mill items from materials such as plastic or metal.

Non-food sectors including aerospace and defence, healthcare, education and consumer goods are already embracing this technology. And with a recent MarketsandMarkets report suggesting the global 3D printing industry could grow to $32.78 billion by 2023, some experts predict that the food industry is set to follow.

So, could 3D printing unlock a new age of innovation for food manufacture? And if so, how?

Scientific and technical considerations

The American Society for Testing and Materials outlines seven categories of 3D printing:

- Vat photopolymersiation
- Material jetting
- Binder jetting
- Material extrusion
- Powder bed fusion
- Sheet lamination
- Directed energy deposition

Each involves different methods to lay down and 'set' layers of material, enabling the end-product to remain stable in 3D. The most appropriate category varies depending on the specific requirements of the given application. And the physical and chemical properties of the raw material must also be considered. In non-food sectors, materials such as polymers, metals, ceramics and paper are used to make objects ranging from car and engine parts to electronic components, as well as medical and dental products and toys.

The most appropriate techniques for 3D printing of food are dictated by the nature of the ingredients used. In a review on this topic, Sun *et al.* (2015) lists the applicable technologies as:

- Selective laser sintering / hot air sintering
- Hot melt / room temperature extrusion
- Binder jetting
- Ink jet printing

Sintering, for instance, allows complex structures to be built rapidly without the need for post-curing. But it's only of use for sugar and fat based materials with relatively low melting points.

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There is much diversity between and within food and non-food items in terms of 3D printing techniques. However, there are always three common elements to the process:

1. Software design of the object. This includes ‘slicing’ (the creation of the layers)
2. Printing the object in layers, using this designed software
3. Setting the layers as they are made, to ensure stability – also referred to as ‘post deposition fusing’

These steps are critical in defining the microstructure and properties of the end-product.

Food-based applications of 3D printing

Early adopters of 3D printing in the food sector have mainly experimented with chocolate or sugar to create unique shapes. Hershey’s partnership with 3D Systems to install a 3D chocolate printer at Hershey World has been widely covered in trade media. However, there is widespread interest in using the technology for general manufacture – possibly of multi-ingredient meals – as well as for entertainment.

Since 2015, Barilla has held an annual 3D printed pasta competition and chocolate company Barry-Callebaut recently announced it was partnering with byFlow to explore the manufacturing potential of 3D printing.

Yet 3D printing of food involves challenges that are not seen in other sectors. Ingredients have various melting points and physical properties that a printer needs to adapt to. The ingredients need to be stable to the process (usually heat) that fuses the material. There are also food safety implications to be considered. What’s more, reformulating products for 3D print production is likely to result in changes to textural and other sensory properties, which could be an issue with heritage products. And finally, each layer of the 3D structure needs to set quickly, but without preventing the integration of subsequent layers.

On the flip side, 3D printing unlocks a whole new world of possibility for product development and innovation. The potential for true personalisation of foods is immense, as well as the ability to manufacture on-demand, reducing food waste.

Potential food applications for 3D printers appear to fall into four categories:

- In-home
- Vending / point-of-sale
- Restaurant
- Full scale manufacturing

Initial trials have largely been aimed at the personalised gift market. More recently, the viability of kitchen printers and even full scale manufacturing is being explored.

Natural Machines has developed a 3D printer aimed at professional cooks. In the longer term, this could evolve into a kitchen product for the consumer, offering a new means of cooking and preparing food.

The technology also offers scope for on-demand customisation to meet nutritional or sensory preferences. Since manufacture is controlled by a software programme,

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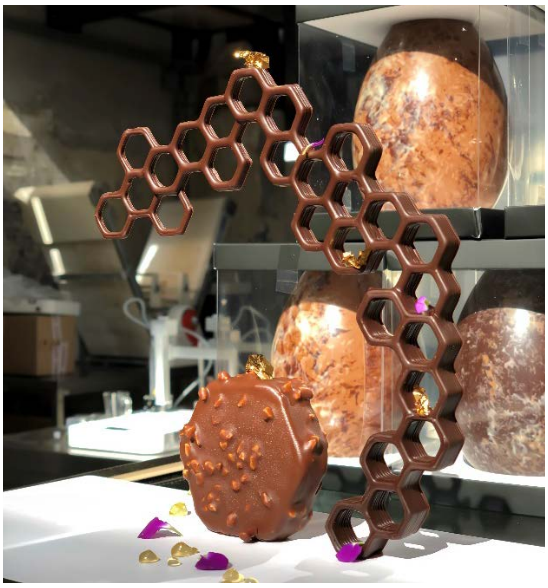
adaptations can be accommodated easily without the need to adjust machinery or overhaul production lines.



byFlow example of 3D printing capability. Image: byFlow

Some professional chefs are embracing the technology and high-end restaurants, such as Mélisse in Santa Monica and Enoteca Paco Pérez in Barcelona, are starting to include 3D printed dishes on their menu. London's Food Ink not only creates its entire menu using 3D printing, but everything in the restaurant is manufactured this way, including the furniture.

Recipe development for 3D printing
Not all foods can be 3D printed, and those that are suitable are likely to need reformulation to deliver good 3D structure. Sun *et al.*'s review of 3D food printing outlines three materials categories:

- **Natively printable materials**
  This covers multi-ingredient products such as chocolate, cheese, batters, starch or protein pastes, and other easily extrudable foods.
- **Non-printable traditional materials**
  Rice, meat, fruits and vegetables are considered non-printable.
- **Alternative ingredients**
  This category includes extracts from algae, fungi, insects and seaweed.

Reformulating products to enable 3D printing does pose a challenge. However, if the benefits are compelling enough, manufacturers will invest to overcome obstacles. Bazooka Candy Brands has developed a new 3D printed gummy confectionery. Each sweet interlocks with others so consumers can make their own flavour combinations. The gummy formulation had to be adapted to work with 3D technology, but the brand now anticipates extending its portfolio of 3D printed products.

The Foodini home version, from Natural Machines, enables consumers to 3D print from fresh ingredients. Image: Natural Machines

Consumer attitudes
Leatherhead Food Research surveyed a panel of 975 UK consumers to discover awareness of and attitudes towards 3D printing. We found that 87% of respondents had heard of it, but they mainly associated it with construction, automotive and engineering industries. They liked the idea of having a 3D printer in the

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kitchen, but men were keener on this than women. When asked about using it for food manufacture, more than half expressed concerns over food safety. However many felt it could have benefits such as convenience and the ability to personalise food products.

Future developments

Bioprinting

Tissue engineering, where cells are grown on a scaffold made from donor bio material or synthetic material, could be advanced with 3D printing. For instance, biological structures could be created using cells as the 'ink'. This concept is currently being explored by bio-tech company CELLINK to develop human tissues and organs. Another business, Modern Meadow, specialises in ethical products made from bio-fabricated leather using collagen grown in its laboratory.

In time, bioprinting technology could evolve to encompass the creation of meat. In fact, a patent describing such a process has already been filed by Forgacs *et al.* (2014).

4D printing

Some organisations have begun exploring the potential of 4D printing. This offers an exciting extra dimension, where layers of 3D printed objects incorporate additional materials that change shape when activated by an external stimulus such as water or temperature.

Researchers at the Massachusetts Institute of Technology (MIT) have developed gelatine-based pasta or noodle flat sheets which transform into 3D shapes according to a computer software design when water is added. This has been accomplished by incorporating thin layers of gelatine at various densities which swell to differing extents in water. On the surface, a patterned cellulose layer prevents areas of the gelatine surface from swelling before rehydration. This could underpin the development of 'flat-pack' pasta, reducing packaging costs by an estimated 50% as well as reducing storage and transport costs.

Conclusions

While 3D printing of food is still in its infancy, it clearly offers much potential in terms of efficiency, innovation and personalisation. The ability to create new sensory properties and health foods customised to individuals' needs is also on the table. We're unlikely to see 3D printing replacing traditional food manufacture in the short term, but it can certainly complement it. There are strong indications that this technology is set to make the leap from gimmick to game-changer as it becomes more mainstream, enabling brands to achieve that all-important competitive differentiation.

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How Leatherhead can help

Leatherhead has a team of experienced scientists who are capable of supporting the industry in all aspects of 3D printing, from design and preparation of prototypes to reformulation or product innovation.

About the authors

Professor Kathy Groves

Kathy has over 35 years' experience in food microscopy and product development where she has pioneered the use of microscopy for food structure analysis and quality assessment. She has applied her expertise across multiple categories including snacks, confectionery and beverages, and numerous research areas including protein functionality, starch and fat interactions, meat quality and emulsions.

Kathy has a degree in Biochemistry, is a Fellow of the Royal Microscopical Society and a member of IFST. She is also Visiting Professor at the University of Chester and has presented on nanotechnology and food to the Government's House of Lords Select Science Committee.

Rhys Watkins

Rhys is Principal Consumer Technician within the Consumer, Sensory & Market Insight team at Leatherhead Food Research. He organises and runs fieldwork on behalf of clients, then undertakes the subsequent analysis. A key part of Rhys' role is delivering online consumer surveys and analysis on behalf of the Science Group and clients. He holds a Certificate of Achievement in Sensory Evaluation at Foundation Level (IFST). Rhys graduated from Bangor University with a BA (Hons) in History and joined Leatherhead in 2010.

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