Executive summary: 3D printing technologies in the food system for food production and packaging

3D printing, also called additive manufacturing, represents a range of technologies that create 3D objects through a layer-by-layer deposition process using digital image files. 3D printing evolved over the past four decades from a prototyping tool to a manufacturing method in its own right in a number of industries and several additive manufacturing processes have matured into robust production technologies for highly customised and bespoke products when produced in small numbers. However, 3D printing technologies at their current stage of evolution are usually not considered commercially viable for mass production applications.

3D printing of food

3D printing of food emerged around 15 years ago promoted by 3D technology enthusiasts and academic engineering departments experimenting with foodstuffs, mostly chocolate or sugar-based, that could be printed at the time with generic 3D printers. Over the past decade a number of startups, have developed 3D printers optimised for some food ingredients, and at present a small number (globally fewer than 10) of different 3D food printers are commercially available for consumers. In addition, a limited B2B market for printers is emerging for use mainly in the confectionery and fine dining sector for the production of foodstuffs with personalised or customised shapes. At present a small number of startups (globally less than 20) are offering 3D food printing services, either through the sales of customised 3D printed food items or by offering these as part of a dining experience either in a restaurant or at events. In addition, a handful of large international food processing companies or kitchen appliance manufacturers have shown some limited engagement with the technology for around a decade, either through in-house R&D or patenting activity, or by entering collaborations with academic research departments or food printer manufacturing startups.

Over the past five years, academic research into the technical possibilities and challenges of food 3D and 4D printing, as well as media reporting on the technology has rapidly increased. In addition, several emerging niche applications for 3D food printing (3DFP) are currently tested and promoted by a few commercial players, such as 3D printed personalised nutrition or texturising of foods for patients with difficulties eating regular food in hospitals and care homes. Adaptations of the technology to such specific sub-niches indicate that 3D printing might act as an enabling or supporting technology for other technology-enabled trends in the food system, such as personalised nutrition, use of alternative proteins or food side- or waste streams, plant-based meat and cultured meat analogues, functional foods and health nutrition. Moreover, food printing currently appears to evolve from a focus on the shape aspect of printed foods towards exploring solutions for food processing challenges and novel ways to modify textures and the sensory experience of certain foodstuffs in an area that could be described as food product prototyping. Very recent innovations, such as 4D printing applications for food in which the texture, colour, taste, or shape of the printed item change over time, or upon external stimuli, are at an early stage and need to become still more robust and cost effective before they might add value to products and enter wider consumer markets.

Despite increasing research and exploration of such potential application areas, 3D and 4D printing of food is at present still a curiosity niche phenomenon, most advanced possibly in the fine dining and confectionery segment for the production of edible and personalised decorative food items, mostly chocolate- or sugar-based. However, current maturity levels of the few commercially available food printers, some service offerings on the market, and continuous low-level engagement of large food producers with the technology, are indicative of the potential of 3D food printing to be able to reach wider consumer markets via different channels in the next five to ten years.

Selected key findings

- Despite increasing R&D activity and the development of specific food printers optimised for a limited number of foodstuffs, such as chocolate, sugar, dough-based, fruit gels, or cheese, commercial viability of the technology still needs to be proven. Globally a very low number of commercially active 3DFP operators exist currently (< 20).
- Peak academic research and patenting was observed over the past five years with a total number of publications directly related to 3DFP of around 150 and a small number of relevant patents over the past decade with few patent holders holding more than one patent.
- Most of the academic literature is concerned with the technical aspects of formulating printable food inks and with optimising printing conditions using various additives such as hydrocolloids, indicating that additives are essential for 3DFP to enable the technical printing process.
- Existing food printers are using mainly extrusion-based printing technology and physical and chemical characterisation of viscosity and rheology of food inks is a major technical research concern as most food ingredient mixtures are still difficult to print.
- Trends in R&D indicate that healthy and functional foodstuffs, such as fruit- and vegetable-based as well as various proteins, including novel sources of proteins such as from plants, insects or algae, are currently explored for their suitability to be 3D printed at scale.
- Modified 3D printing technology is currently applied in the plant-based and cultured meat alternatives sectors to improve texture of products.
- Consumer knowledge of and interest in 3DFP is very limited at present.
- Despite discussion in the academic literature of potential wider impacts of the technology on the food system, for example through more localised supply chains, or claims to be able to contribute to sustainability, it is recognised that these claims are at the present stage of technology readiness and commercial maturation highly speculative and at least 5-10 years away from realisation.
- Future evolution of the 3DFP field is expected to be slow due to technical challenges, such as slow printing speeds and technical issues around print quality and the requirement of expert pre-processing of ingredients and optimisation of printer settings. Hence, the B2B printer and services market may evolve quicker than the B2C market.
- At present 3DFP is not directly regulated anywhere in the world and food safety issues around the technology are not well understood beyond common sense arguments, such as that printer parts need to be easy to clean and cleaned regularly etc.
- Potential regulatory aspects of 3DFP technology are discussed in the academic literature and highlight a possible labelling requirement of 3D printed food as novel foods, or as highly processed foods depending on food type printed.

3D printing of food packaging

Use of 3D printing technologies for the production of (primary) food packaging is at present very limited and available information on the subject indicates a role mainly in prototyping of food packaging, such as for containers, bottles, boxes, etc, while final food packaging is still produced via cheaper existing mass production technologies. Small startups occasionally use 3D printing to demonstrate functionality of novel packaging materials or concepts, and large packaging manufacturers occasionally 3D-print moulds for the mass production processes of some packaging to save engineering costs. In the academic literature 3D printing of novel, for example sustainable, packaging materials is explored and the possibility to use 3D printing to manufacture elements for smart packaging sensors has been discussed. However, at present 3D printing technology is not robust enough and commercially not competitive compared to other existing mass production technologies for food packaging.

Selected recommendations for the FSA

Short-term FSA priorities (within 3 years)

- Identify hubs and nodes of the emerging 3DFP ecosystem.
- Set standards for labelling early in the technology evolution, as different printing technologies subject foodstuffs to different physical and chemical parameters as well as additives. This may impact the nature and nutritional properties of the end product.
- Develop safety and hygiene standards for the emerging categories of printing processes.
- Engage with academia and research institutions that work on 3DFP technology to understand impacts of pre- and post-processing of printed foodstuffs and respective printing processes on FSA remit areas.

Medium term FSA priorities (3-5 years)

- Continue research on the impact of pre-processing, printing and post-processing on natural and nutritional properties of 3D printed food.
- Consider assessment frameworks for the validity of claims made by 3DFP actors, such as on nutritional quality, health, sustainability, and if necessary devise relevant regulation.

Long-term FSA priorities (5-10+ years)

- Continue research on health impact of long-term consumption of 3D printed foods.
- Establish standards of what printable foodstuff formulations (inks/pastes) are permitted with their longer-term impacts on health/consumers in mind.