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3D Printing of Food

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Introduction and History

Three-dimensional (3D) printing is a process that creates 3D objects from a virtual model, usually designed through computer aided design (CAD) software. The principle of a 3D printer is analogous to that of a regular office printer, to which has been added a third dimension, giving the ability to print three-dimensional objects from a range of materials.

Charles W. Hull of 3D Systems Corporation created the first working 3D printer in 1984 (Hull, 1986). Since then, advancements in printing technology have widened the possibilities in terms of 3D-printed objects. A decade ago, 3D printers were an expensive hobby, costing about the same as a family car, but in more recent times, a basic printer is roughly the same cost as a low-end laptop (Miller, 2016).

3D printing has rapidly become a disruptive technology in many industrial areas around the globe, as seen in Figure 91.1 (Morris, 2014). Automotive, building construction, electronic manufacture, biomedical and aerospace are just a number of sectors where 3D printing has been implemented in order to increase automation and also decrease waste (Ngo et al., 2018).

However, in more recent times, 3D printing has progressively appeared in the realm of food manufacture. Confectionary, chocolate and even pizza can now be printed from a machine. 3D food printing is beginning to emerge into society, and the idea of having a 3D food printer at home as a method of food preparation doesn’t seem to be so unrealistic. Since 1988, various rapid prototyping techniques have emerged, which can be classified as liquid-based, solid-based and powder-based (Chua et al., 2010).

Possible End-Use Scenarios

3D food printing has been seen to be used in a variety of applications, ranging from home-cooking with families to professional chefs at Michelin star restaurants (Table 91.1). This section explores how 3D printing can benefit each of these key food-related areas and why 3D printing is set to become the technology of the future.

Food Applications

Currently, 3D food printing has been established in food areas as diverse as the military, meals for the elderly, confectionery and food designed for space missions. The list of food materials that can be utilised in such applications using the 3D food printing process is growing at an incredible rate and includes ingredients such as chocolate, sugar, fruit and vegetables. In this section, relevant applications for everyday food ingredients that can be 3D printed using commercially available printers will be discussed in detail.

Chocolate

Chocolate extrusion has been by far the most common material to be used in creating 3D food structures. The Choc Creator V1 and V2 (Plus) became the first commercially available 3D chocolate printer in 2012 (Choc Edge, 2018). The Choc Creator is...
TABLE 91.1 Examples of 3D Food Printing Applications in Different Use Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Examples of applications</th>
</tr>
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| Domestic kitchen        | • Enables creative, consistent designs to be created in bakery and/or decoration applications  
                           • Allows mass production for parties and large family events  
                           • Reduces food wastage by combining commonly discarded, but nutritious, parts of fruits and vegetables (e.g., stalks, skins, etc.) into purée to be used as sauce, topping, plate decoration, etc.  
                           • Allows control over portion size  
                           • Can encourage children to develop an interest in their own nutrition if allowed to create their own design  
                           • Can facilitate personal, precise and consistent nutrition   |
| Restaurant kitchen      | • Increases chef efficiency by delegating time-consuming and repetitive tasks to the printer  
                           • Produces consistent meals in terms of shape, portion size and precision placement  
                           • Creates shapes and structures that may be difficult or impossible to do by hand  
                           • Incorporates elements of 3D-printed foods into traditional dishes for a modern twist  
                           • Produces personalised cake toppers for special events  
                           • Creates unique and personalised culinary experiences (e.g., printing customers’ name or custom designs on the plate or dessert)   |
| Vending machines        | • Potentially offers healthier snacking option  
                           • Offers convenience; order in advance online or through phone application and collect when completed  
                           • Allows customised nutrition, flavours and texture to suit each individual user  
                           • Can be placed in high-flow areas such as airports, train stations, shopping centres, cinemas, universities/colleges, work places, fitness centres, etc., for healthy, personalised convenience options   |
| Nursing homes and hospitals | • Shearing effect of printing creates softer food material, which can be ingested more easily for individuals with swallowing difficulties (i.e., dysphagia)  
                           • Creates nutritious and attractive meals compared with traditional bland high-calorie pastes typically found in nursing homes to maintain weight  
                           • Nursing home residents can look forward to the nutritious and tasty meals that they used to enjoy pre-admittance. Encourages healthy appetite, which helps in maintaining muscle mass and weight  
                           • 3D-printed meals in hospitals might benefit patients who, due to surgery or treatment, might have a small appetite, be consuming strong medicines, and/or require high-calorie and nutrient-dense foods   |
| Food processors         | • Novel shapes can be created and changed as desired, with little or no changeover in equipment required  
                           • Only one production line is required for multiple products; changes to product design or size can be made immediately on the same production line, meaning that fewer lines are required, thereby saving factory floor space and capital cost on individual machines for individual products  
                           • Enables rapid in-house prototyping with minimal cost  
                           • Promotes production of mass customised products (i.e., personalised items have added value)   |
a three-axis Cartesian computer numerical control printer with a chocolate extruder head (Godoi et al., 2016). The innovation relies on an extrusion system capable of handling chocolate, which requires accurate control of viscosity and temperature conditions. The printer is composed of three components: the first is a heat-controlled chamber, and the second is a pump that pumps the melted chocolate into the third component, which is the extrusion head and nozzle (Hao et al., 2010).

Recently, on 7 July 2019, Cadbury launched the world’s first Cadbury Dairy Milk 3D printer in Melbourne, Australia, for World Chocolate Day. According to Kopp (2019), chocolate-lovers were offered the chance to be among the first to take away their very own personal selection of 3D-printed chocolate pieces built from layer upon layer of delicious Cadbury Dairy Milk chocolate.

**Confectionery**

In 2014, Print2Taste GmbH was established as a spin-off company from the University of Weihenstephan-Triesdorf in Freising (Germany). Procusini 3.0 was developed as an extrusion-based 3D printer that would be suitable for professionals in catering, event gastronomy and hotels, as well as bakery and confectionery. The company claims that the Procusini halves production time and can create 84 small structures in just 93 minutes, allowing professionals to complete other tasks whilst printing is in operation. The Procusini includes a temperature-controlled cartridge holder to maintain the temperature of food materials contained within. The printer can also operate through a Wi-Fi connection from an electronic device such as a tablet or phone. Procusini is a mobile printer with dimensions of $60 \times 60 \times 65$ cm and weighs only 9 kg.

Food materials that have been printed using the Procusini include pasta (four colours available), chocolate, marzipan (Figure 91.2), fondant (five colours), goat’s cheese, sausage meat, mashed potato and cassis (i.e., blackcurrant puree) (Procusini, 2018). In 2019, Procusini launched the Mycusini, which is a small, compact chocolate printer starting at €198; it will fit in any kitchen at $19 \times 19.5 \times 27$ cm, which is described as being ‘smaller than most coffee machines’.

In 2014, the American-based manufacturer 3D Systems developed Chefjet and Chefjet Pro, two NSF (National Sanitation Foundation) and UL (Underwriters Laboratory) certified kitchen-ready 3D food printers. The printer operates using liquid binding (LB) technology, which requires water and powder-based ingredients. A roller-component lays down a thin layer of powder (i.e., sugar) on the printing surface. A print head then sprays water or liquid binder in a pattern that draws a shape on the powder surface. The powder recrystallizes when in contact with the water or binder, which encourages a solidifying and binding process through the joining of adjacent particles. The piston supporting the print bed is progressively lowered at the completion of each layer until the object is completely formed. The process is repeated several times until the 3D structure is built (Figure 91.3) by cross-linking of the particle surfaces (Godoi et al., 2016).

**Pasta**

Extrusion-based processes have been employed by TNO (Netherlands Organisation for Applied Scientific Research) researchers to print a large variety of foods using sugars, proteins, meat purees and other nutrients extracted from alternative sources, such as algae and insects (Van der Linden, 2015).

In 2012, TNO researcher Kjeld van Bommel announced that, in partnership with Barilla (an Italian pasta company), they had developed a 3D pasta printer that can print customised pasta shapes and colour. Most recently, TNO and Barilla created 3D-printed pasta in the shape of roses, using classical pasta recipes (ingredients: durum wheat semolina and water, without additives) (Van der Linden, 2015).

Massachusetts Institute of Technology (MIT) has brought 3D food printing another step further in terms of innovation by introducing the concept of ‘4D printing’. Wang et al. (2017) introduced this term through their experiments with pasta, where the initially flat-shaped pasta will twist and curl up in a unique pattern when hydrated and/or heated. The 4D effect is caused by the addition of carefully placed edible films made of common food materials such as protein, cellulose or starch, which contract when water and/or heat is incorporated.

**FIGURE 91.2** Procusini Printer printing chocolate pieces and an example for a marzipan-printed car cake topping.

(Procusini, 2018)
The basic ChefJet printer can only print monochrome food decoration, whilst the ChefJet Pro prints in full colour and in a multitude of flavours, including sour cherry, chocolate, vanilla, mint and watermelon (Ngo, 2015). The ChefJet printer can print edible sculptures and confections of all shapes and sizes which were previously impossible to create by hand. An example of these complex and creative designs can be found in the collaboration between The Sugar Lab by 3D Systems and Modernist Cuisine, whereby, using the Chefjet Pro, a colourful and intricate swirling sugar sculpture (Figure 91.4) was 3D printed to balance across the rim of a cocktail glass for the 50th birthday celebration of renowned Spanish chef Ferran Adrià. The specially designed perforated shape of the sculpture allowed the absinthe to flow through the Gaudi-style structure while absorbing the sweetness of the sugar, creating a colourful, theatrical and sweet cocktail experience.

Meals

Natural Machines, a Barcelona-based start-up company, launched the Foodini food printer prototype in 2013. Foodini is a syringe-based deposition printer with a tactile user interface. The printer (10 kg) is a 43.8 × 43 × 43 cm cube with a touchscreen display powered by Android OS with Wi-Fi connection. The printer has a capsule receiver at the top where users can insert a cartridge with fresh pureed ingredients (Natural Machines, 2018).

The process proposed by Foodini is quite simple; users have to cook and prepare liquid-based food by mixing different kinds of ingredients. Then, they load the liquid-based mixture into capsules (five maximum). Each capsule can hold 123 mL of liquid, and the five combined can hold 615 mL. Users insert capsules in the Foodini and select printing programs through the touchscreen. The printer will then start extruding food one capsule at a time onto the print bed (Sevenson, 2014). Not all foods can be printed; however, the Foodini allows the user to print intricate designs that may not be possible to achieve by hand. This is accomplished through the use of a smaller nozzle diameter (0.5 mm) and computer-controlled print head. Different nozzles are also available to accommodate textural differences between food types (Chadwick, 2017).

The machine has successfully printed different kinds of food products, such as crackers, individually shaped cereal, gnocchi, ravioli, bread sticks, butter, pizza, cereal bars and biscuits (Figure 91.5). The machine is equipped with a heating element...
with a maximum temperature of 100 °C. The heating function can only keep food materials melted (like chocolate) or keep food warm. In some cases, where meals require cooking, users will have to cook the printed food in a separate process before eating (Hoopes, 2013).

The Foodini contains built-in 3D-scanner hardware capable of scanning an object, digitally saving the shape and then printing it. It can also scan an object such as a plate or a cupcake and print on top of this (Sevenson, 2014). The Wi-Fi connection allows users to share their recipes with the Foodini community. In addition, the founders of Foodini also propose to produce pre-prepared capsules and make them available in supermarkets. These capsules will contain all the ingredients required for a recipe pre-programmed by the printer (Natural Machines, 2018).

Netherlands-based company byFlow has specialised in 3D printing since 2009. The Portable ‘Focus’ 3D food printer, created by byFlow, is currently sold as a business-to-business (B2B) product, optimised for desserts, including chocolates and meringues (Figure 91.6). byFlow claims that chefs and patissiers use ‘Focus’ on a daily basis ‘to experiment with textures and shapes, save time and money, create new designs, and amaze their customers’ (Chadwick, 2017).

byFlow’s clients in the restaurants space so far include La Boscana in Barcelona. This restaurant uses both Focus and Natural Machines’ Foodini. The printer is not only based in the kitchen but placed in front of the customer’s table so that they can see their dishes coming to life. Focus printers also appeared at Food Ink’s 3D printing project in 2016 (Figure 91.7), a pop-up restaurant in London. Currently, the Focus printer has been used in printing applications such as marzipan, ganache, hummus, fondant, mango caviar, avocado, meringue, pureed tomato and mozzarella, and even pureed chicken and beef.
Specialist Nutritional Foods

One of the unique applications of 3D-printed food is producing foods with a soft texture for elderly customers who have difficulty swallowing (Deloitte, 2015). One in 25 adults is affected by chewing and swallowing difficulties, otherwise called dysphagia (Bhattacharyya, 2014).

The German company Biozoon launched the ‘3D Smoothfood Project’ in 2014, which aims to design and create individualised nutritious meals. The meals will have a jelly-like texture that resembles solid food when printed but dissolves easily when ingested and swallowed by the consumer (Deloitte, 2015).

Biozoon originally specialised in a range of texturisers that change the consistency of food. Their SeneoPro powder is combined with pureed ingredients to form a smooth paste or gel. The mixture is then inserted into a cartridge in the printer and printed to resemble the solid shape of that ingredient (Figure 91.8).

Mathias Kück, owner of Biozoon, claims that the look and taste of the end product match the original food item: ‘When eaten by a patient, the food can be destroyed without using the teeth and flow like a gel through the throat’ (Chadwick, 2017).

Fruit

Dovetailed is a design studio and innovation lab founded in 2011 in Cambridge, UK. In 2014, Dovetailed created their first 3D food printer, ‘nüfood’, which is controlled using an app on the user’s phone, allowing the user to design their own unique flavoured shape, which can be added to beverages, breakfasts and salads to provide added bursts of flavour. According to Vaiva Kahlkaïtè, creative director and founder, the printing process is based on the spherification technique, a well-known molecular-cooking method (Figure 91.9).

This method involves combining liquids such as fruit purée or juices with sodium alginate. The combination is then dropped in a controlled fashion by the 3D printer into a bowl of cold calcium-based food-grade liquid, where it forms tiny caviar-like spheres. Fruits and other shapes are formed by layering the tiny spheres of juice until the desired shape is built. For example, nüfood explored unique flavour pairings such as balsamic and raspberries, which they combined in a 3D-printed cube and added to a whiskey sour cocktail.

Culinary Applications

Bakeries

The adoption of 3D printing is evolving rapidly in the baking scene (Duchêne et al., 2016; Deloitte, 2018). For example, a large international company, CSM Bakery Solutions, which produces a broad range of products for customers in more than 100 countries (CSM Bakery Solutions, 2018), has entered into partnership with The Sugar Lab by 3D Systems to enable collaborative research and development, engineering, design and printer development, which will be focused on specific sourcing, food product development and go-to-market plans (Unrein, 2017). Initially, CSM Bakery Solutions will target how 3D printing may assist chefs creating high culinary art in venues such as casinos and cruise liners (CSM Bakery Solutions, 2018).

The artisanal field of confectionery that produces decorative bakery products (Figure 91.10), chocolates and other types of sweets is one of the food industry fields that can benefit from the dimensions that 3D printing can offer. However, 3D-printed chocolates and other decorations should not be confused with moulding, which has already been developed in the confectionery sector (Duchêne et al., 2016).
FIGURE 91.8  Examples of entire meals printed by Biozoon.
(Biozoon, 2018)

FIGURE 91.9  Dovetailed’s 3D printer nūfood – printing a strawberry.
(nūfood, 2014)
Restaurants and Chefs Serving 3D-Printed Foods

Many smaller R&D service-focused companies are developing innovative concepts, such as 3D-printed dinner at pop-up restaurants. Additionally, pop-up fine dining concepts have been tested in Europe and the US (Duchêne et al., 2016). In 2016, diners at the pop-up restaurant Food Ink were served a nine-course meal in which all the food was fabricated using 3D printing technology (Lupton, 2017). The dishes were made from pizza dough, hummus, mushy peas, chocolate mousse and goat’s cheese (Figure 91.11). Two chefs of elBulli and La Boscana, Joel Castanye and Mateu Blanch, were behind the menu. The utensils and even the chairs were 3D printed (Hartman, 2016).

3D Printing and Fine Dining

One of the emerging regional areas for 3D printing of food is Barcelona. Here, restaurants such as Dos Cielos and La Boscana have been actively involved in experimenting (Duchêne et al., 2016; Ahmed, 2017). At La Enoteca in the Hotel Arts in Barcelona, chef Paco Perez, who has won several Michelin stars for his restaurants, has created a new dish entitled ‘Sea Coral’, which is a 3D-printed ‘coral’ shape made of seafood purée (Figure 91.12). A report for the BBC website showed how Perez and his co-workers constructed this dish in one of his restaurants (Koenig, 2016).

Also in Catalonia is Reimagine Food, a research and design group who develop digital gastronomy ecosystems and robots in cooking (Duchêne et al., 2016) and use disruptive technology, such as drones, artificial intelligence, robotics, wearable devices and big data, adapting them to the needs of consumers and the food industry (Reimagine Food, 2014). In 2018, chef Jan Smink opened the first full-time 3D-printed food restaurant in the town of Wolvega in the Netherlands. Smink previously worked for De Librije, a triple Michelin star-winning restaurant. Now, after creating new recipes (Figure 91.13) and aiding in R&D, he is ready to provide a unique dining experience that takes advantage of 3D printing technology. Chef Jan Smink has stated: ‘By using the Focus 3D Printer I’m able to make forms and shapes that would otherwise not be possible. I can surprise...’

Figure 91.11 shows, on the left, ‘Caesar’s Flower of Life’ (seasoned bread, assorted flowers and vegetables) and, on the right, ‘3D Boscana’ (nocilla, chocolate cream, hazelnut polvoron, milk ice cream, Dutch chocolate leaves and 3D-printed centre spiral.

**Figure 91.10** A ChefJet Pro 3-D printer from 3D Systems uses powdered sugar and hydrated food colouring to create products like cake decorations. (The Sugar Lab by 3D Systems, 2020)

**Figure 91.11** 3D-printed meals served at the pop-up restaurant Food Ink in London in 2016. (Mendoza, 2016)
my guests with a unique experience that is very tasty as well. 3D Printing is the future!' (Smink, 2018).

In the United States, Melisse is a Michelin 2-star restaurant in Santa Monica, run by chef Josiah Citrin. The restaurant partnered with 3D systems and has, for example, developed a dish where the 3D printer crafted a fresh crouton using an aromatic onion powder, as seen in Figure 91.14 (Ahmed, 2017).

Collaborative Projects and Applications

The 3DS Culinary Lab in Los Angeles brings together 3D food printing technology developers with chefs and food industry representatives (Lupton, 2017). One such example is the dish created by Mei Lin, the winner of Bravo’s Top Chef Season 12, which was based entirely on the flavours of Hawaii and inspired by the beauty of a passion fruit flower (Duchêne et al., 2016; Lupton, 2017; The Sugar Lab by 3D Systems, 2020). The dish contained cylinders of passion fruit curd, caramelised banana crème anglaise chilled to a gelato consistency by liquid nitrogen, freeze-dried strawberry powder, bee pollen crumble, toasted yogurt, and sliced fresh bananas and strawberries (Figure 91.15a). A delicate, perforated 3D-printed interpretation of the passion fruit flower, flavoured with actual passion fruit, crowned each plating. Mei invited guests to shatter the delicate sugar passion
fruit flower with their spoons (Figure 91.15b) to incorporate the flavour and texture of the piece into each bite (The Sugar Lab by 3D Systems, 2020).

TNO has been involved in an interesting gastronomy project with food designer Marijn Roovers and chef Wouter van Laarhoven, who together created a chocolate shell just 0.8 millimetres thick using the Focus Printer. The chocolate’s continent of origin is embossed in gold, whilst inside, it holds delicacies that symbolise that region (Figure 91.16). Roovers mentions that the chocolate globes take an hour to print and claims that they have the texture of aerated chocolate bars as a result of printing the globe in 200 layers of chocolate. The North America globe contains segments of crème of sweetened corn and bourbon whiskey. Meanwhile, the South America globe is filled with chocolate with allspice and popped corn. The African globe consists of portions of ras el hanout with cumin and yoghurt (TNO, 2015).

In Silicon Valley, a team of over 30 people, including 3D artists, designers, food scientists, chefs and engineers, created a way for people to immerse themselves in a new reality in which they enjoy different meals (The Project Nourished Initiative). All participants need is a VR headset (for stimulating vision), an aromatic diffuser (for smell), 3D-printed cubes (for texture), a bone conduction transducer (for chewing), a gyroscopic utensil (fork for the virtual and physical food), and a virtual cocktail glass (for intoxication). The 3D-printed cube is made of algae, which adds taste and texture. The texture of the cube, the aromatic diffuser and the sounds produced by the bone conduction transducer trick the consumer’s mind into believing they are eating actual sushi (The Sensorama, 2017).

In 2014, Dutch industrial design student Chloé Rutzerveld presented her Edible Growth project in collaboration with Eindhoven University of Technology and TNO. For this project, she 3D printed an edible ecosystem made up of a carbohydrate matrix containing miniature plants and mushrooms. At the start, Chloé created the design for the carbohydrate structural matrix on a 3D modelling program, printed it out and then printed a combination of seeds, spores and yeast embedded in agar-agar into it. Agar-agar is a gelatinous paste, which functioned as a soil for the seeds and yeast to grow and feed on. After about five days, the plants had grown sufficiently, and the product was ready to be eaten (Figure 91.17). However, waiting a little longer gives the plants some more time to grow, and the taste of the food intensifies (Rutzerveld, 2014).

Applications of Molecular Gastronomy
In recent years, applications of molecular gastronomy such as ‘molecular cooking’ and ‘note-by-note cooking’ have emerged (This, 2008, 2013, 2014). Molecular cooking is defined as producing food in kitchens using ‘new’ tools, ingredients and methods (ttz-Bremerhaven, 2018); examples of this could include use of equipment such as siphons, ingredients such as sodium alginate, and methods such as sous-vide cooking. In the case of ‘note by note cooking’, meat, fish, vegetables or fruits are not used to make dishes, but instead compounds, either pure or in mixtures, are assembled by the chef to design the shapes, colours, tastes, odours, temperatures, trigeminal stimulation, textures, nutritional aspects and more of the desired dish (This, 2013).

In many instances, the ingredients used in these molecular gastronomy applications, e.g., hydrocolloids, including gelling agents such as agar-agar and gelatine, are suitable for 3D printing. This will allow freedom of design in terms of not only composition, structure and texture but also taste (Duchêne et al., 2016). In particular, it is possible to design and print customised note-by-note foods. An example of a 3D-printed note-by-note prototype recipe can be found in Part III of this book. It is suitable for vegans and/or those who are lactose-intolerant.

Specialised Stores and Personalised Products
Specialised shops that offer 3D-printed products include the Amsterdam-based MELT Ice pops, which has offered custom-made ice pops since 2012 (Melpops, 2018) and uses 3D-printed moulds that are printed using domestic 3D printer manufacturer Ultimaker’s printers (Duchêne et al., 2016). The Magic
Candy Factory also specialises in personalised products and is the world’s first 3D gummy candy printer, allowing anyone to create shapes, write messages and draw their own custom candies (Magic Candy Factory, 2017).

Limitations
Major challenges still to be solved relate to the need for multi-material printing systems and integration with traditional cooking processes, like baking or boiling. One of the major hindrances is the low printing speed (Duchêne et al., 2016).

The cost of home food-printing machines has also been noted in some media reports as a potential barrier to consumer interest, as was the problem that these devices were still in development, so that people who might be interested in purchasing them would have to wait until they came onto the market (Lupton, 2017).

The expensive nature of the gourmet printed food featured in restaurants has also received attention, as in the following headline in an online newspaper article about the Food Ink pop-up restaurant: ‘Is this the future of fine dining? Restaurant where all the food and even the table is 3D printed – but it will cost you £250 a head’ (Best, 2016).

Some media reports also quoted experts in the food industry as voicing some reservations about whether 3D-printed food would be widely accepted by consumers. This was usually in response to the more speculative uses of the technology, as in the virtual reality meals served through the Project Nourished initiative or the use of cultured meat (Lupton, 2017).

Future Speculations
The global 3D printing food market is expected to expand during the period 2017–2024 and to reach USD 400 million by 2024. The market growth is driven by factors such as the growing demand for customised food (Researchnester, 2018). Richard Watson, futurist, writer and founder, predicted in The Telegraph’s feature on ‘back to the future’ that ‘By 2045 many kitchens will feature a 3D Printer … a fun kitchen gadget to sit alongside the Soda stream and waffle maker’ (Titcomb and Murgia, 2015).
Companies like Natural Machines see the future of 3D printing food as a faster and more precise operation, possibly even including more textures. A US startup called Modern Meadow is working on a technique to 3D print meat without having to slaughter an animal at all. The process includes using stem cells to create what they call ‘bio-ink’, which is then inserted into a nozzle similar to that of a 2D inkjet printer. The ‘live’ bio-ink is then extruded into an agarose gel mould. After that, it matures in a ‘bioreactor’, resulting in organ tissue. The agarose gel is then removed, leaving the end product (Houser, 2017).

Production capacity can be increased through the use of a well-managed print farm or print cell of multiple 3D printers, allowing simultaneous production in multiple materials (Formlabs, 2017).

**Conclusions**

In recent times, the users of 3D-printed foods have become many and varied, ranging from domestic to professional kitchens to retailers and large food manufacturers. The use of this technology has opened up an array of applications allowing personalised food design and nutritional meal formulation. In the last few years, more and more companies have been developing 3D food printers that have specific design features, e.g., for printing doughs or even complete meals. As a result, it has become possible to diversify ingredients beyond those used by the pioneering confectioners. A number of collaborative 3D food printing projects are currently underway, involving multi-disciplinary teams (e.g., chefs, scientists, engineers and artists), who aim to
further improve our eating experiences. While there are some limitations to 3D printing technology, the pace of developments, together with the economic forecast for 3D food printing, signals a positive future ahead.

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