3D Printing: Printing Future Food

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The early origin of 3D printing technique was limited to develop photo-hardened polymers for manufacturing metal and ceramic parts. It was in 2007, when researchers at Cornell University developed an extrusion-based printer named Fab@home for printing food (Malone and Lipson, 2007). Three-dimensional printing or 3D printing is the 'additive manufacturing' technique used to create three-dimensional items by application of consecutive layers of materials (Waseem et al., 2023). This method allows the industries to formulate customised products based on the needs of target population. Food industries can now produce customised meals with specific nutrient content and can tailor meals with specific dietary supplements through 3D printing (Varvara et al., 2021). 3D printing is the amalgamation of material science, culinary art and engineering. With the use of this technology, food industry can be transformed through efficient food manufacturing, customized nutrition and distinctive culinary experience (Waseem et al., 2023). This technology also can help in the waste reduction and food contamination. The first 3D printer was developed by Hull in 1986 (Hull, 1986). Typically, there are seven techniques of 3D printing as per American Society of Testing and Materials (ASTM) which are for non-food materials (Standard ASTM, 2012):

1. Power bed fusion
2. Directed energy deposition
3. Material extrusion
4. Binder jetting
5. Material jetting
6. Sheet lamination
7. Vat polymerization

Following are different categories of 3D printing for food applications which are briefed further. Out of these four techniques, extrusion printing is the most common one.

1. Selective sintering
2. Extrusion method
3. Inkjet printing
4. Binder jetting

Selective sintering

In this process, powdered materials are bonded together forming a solid 3D structure with the help of laser or hot air as power source. Powdered material like starch, sugar and fat is used for sintering process and the unfused powder can be reused. The powder bed principle is used for selective sintering where solid powdered particles are consolidated selectively in a specific area as per the design to construct a finished 3D product (Andharamakrishnan et al., 2022). The laser scans the cross-sections and selectively fuses the powder. After scanning, the powder bed is dropped and a fresh layer of powder is applied on top. Until the final desired structure is achieved, this process is repeated while the unfused powder is restored and re-used (Liu et al., 2017). The process is affected by different parameters like particle size, melting temperature, flowability, glass transition temperature, bulk density, wettability, type of laser, power, energy, etc. (Sandhu and Singh, 2022). Figure 1. shows the selective sintering technique.

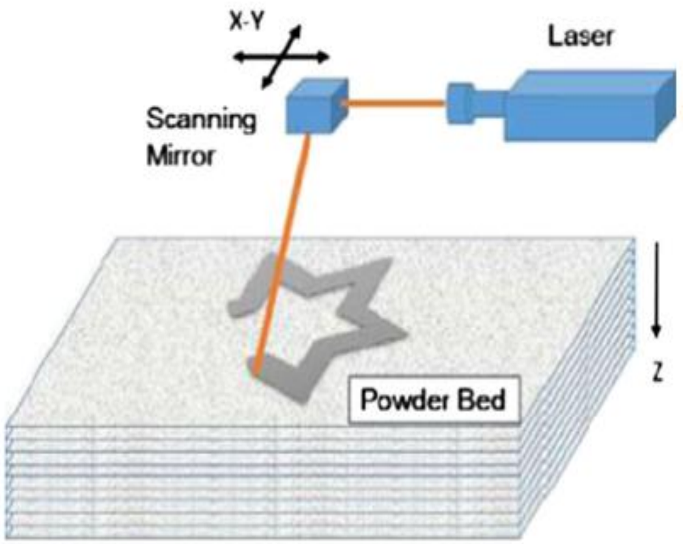

Fig. 1. Selective sintering printing (Sun et al., 2015)

Extrusion printing

This method is based on extruding the food through a nozzle under a constant pressure where the raw material could be either solid or liquid having low consistency or viscosity. The material is loaded into the extruder cartridge and then drawn through the nozzle with the help of ram pressure, layer-by-layer shape of food is created (Pitayachaval et al., 2018). During extrusion, the raw material can be heated before being depositing into layers onto platform of printer. The shape is made by horizontal movement of nozzle and vertical movement of platform. Optimum heating of the material is required to control the final viscosity (Varvara et al., 2021). Extrusion 3D printing has various applications in food, pharma, plastic and medical industries. Pre-tempering of chocolate, puree of food and its by-products, meat purees, cheese and dough have been commonly employed for extrusion process (Liu Z et al., 2017). In some cases, like meat or sea food extrusion, temperature needs to be maintained below 4°C to prevent microbial growth through all phases. Food additives like starch, xanthan gum, pectin etc. are added in purees to help sustain the shape of extruded product and improve printability, flowability and solidification (Mantilal S et al., 2020). The characteristics of end product is dependent upon nozzle diameter and pressure. The stable range of pressure inside nozzle ranges between 20-50 KPa for soft foods (fish, egg white foam, etc.) 100-170 KPa for stiffer pastes (Marmite, Vegemite, etc.), 300-600 KPa for thicker consistency foods (protein rich foods, fibres, multicomponent foods, etc.) (Varvara et al., 2021). Figure 2. depicts the hot-melt extrusion printing technique.

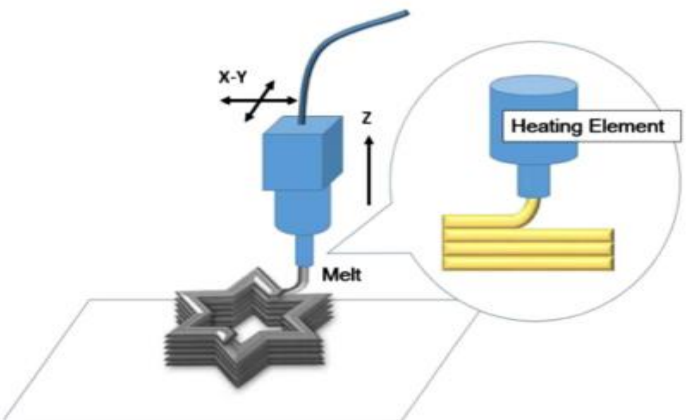

Fig. 2 Extrusion printing (Sun et al., 2015)

Inkjet printing

This technique uses the conventional inkjet technique where edible materials in liquid form are used instead of inks (Waseem et al., 2023). Stream of droplets of material is dispensed form a thermal or piezoelectric head to specific areas where thermal head is heated electrically to generate pulses that force droplets out of the nozzle (Pitayachaval et al., 2018). This method is commonly used for decorating or surface filling operations in cake, cookie, or candy. The process is completely non-contact method and thus prevents the contamination of food (Varvara et al., 2021). The surface tension and wettability of printing substrate regulates the droplet placement and spreading (Waseem et al., 2023). There are usually two types on inkjet printing, namely, continuous and drop-on-demand printing. In continuous type, the printer injects ink from a piezoelectric crystal at a constant frequency. While in drop-on-demand printer, the ink is released from the head by means of a valve that applies pressure. Despite being slower process than continuous method, it gives higher resolution and precision of final product. This method is used for low-viscosity materials for surface filling or image decoration (Godoi et al., 2018). Figure 3. shows the inkjet printing technique.

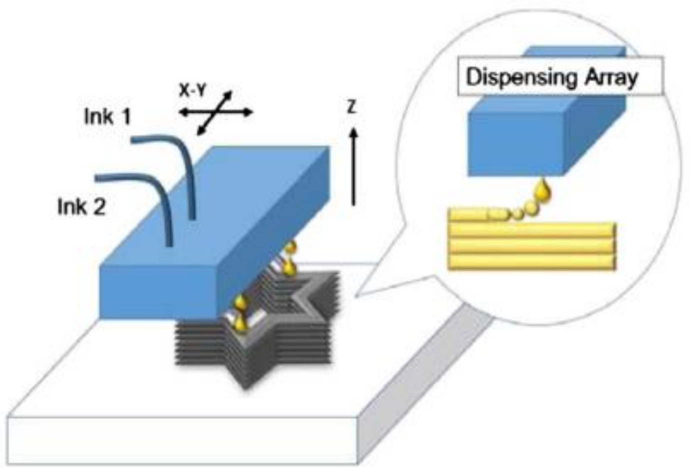

Fig. 3. Inkjet printing (Sun et al., 2015)

Binder jetting

This process, also known as liquid binding, involves layer-by-layer deposition of powdered material and selective liquid binder dispensing according to a 3D data file. This technique aids in the creation of many colourful structures. The build plate is sprayed with a mist of water onto which powdered material of appropriate thickness is sprayed. To this, liquid binder is ejected followed by next layer of powder. This process is repeated until a pre-determined structure is produced. Due to spray of liquid binder over food substrate, the created 3D build would require an extra drying process for removing the leftover moisture. Drying enhances mechanical integrity and structural stability. limited to materials that are powdered (Anandharamakrishnan et al., 2022). To ensure strong bonding and structural integrity various binders are examined for their interactions with food powders (Waseem et al., 2023). The properties of binder and powdered material decide the processing factors. Binder should have suitable viscosity, surface tensions, density etc. Powder should be flowable i.e. angle of repose should be less than 30 degrees. Also, it should have good wettability to promote interactions with binder (Godoi et al., 2018). Figure 4. shows the binder jetting printing technique.

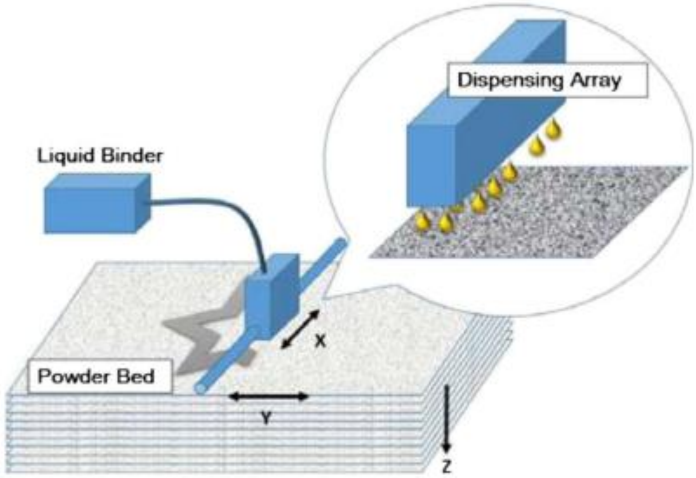

Fig. 4. Binder jetting printing (Sun et al., 2015)

Recent applications of 3D printing in food industry

3D printing is nowadays being by NASA for allowing astronauts to create their own space foods. Hershey, a chocolate company, collaborated with 3D printing company to develop 3D printing product (ChocoJet 3D) that allows astronauts to print their own customized chocolates in space (Kim et al., 2017). A German venture, Biozoon, developed 'Smoothfood' in form of jelly and sauce like grilled chicken which enhance the texture of dish for people with dysphagia or elder people having reduced masticatory function. This is serving as a 'Personalized Nutrition for Elderly' in Europe (Kim et al., 2017). London based students invented GumJet 3D printer which prints gum resin with flavouring layer by layer. Wacker, designed chewing gum 3D printer to create gums with coconut, fruit juice and plant extracts. They also invented Candy2Gum to convert candy into gum which handles water-based and fat-based ingredients (Liu et al., 2017). Barcelona based startup 'Novameat' has been printing plant-based meat analogue to combat unsustainable and insufficient global agricultural system to solve world's food supply problem. An American start-up, Modern Meadow, is working on 3D printing of stem cells that can mitigate meat-like matrix which will be identical to 'conventional-meat'. US Army is also interested in printing need-based foods depending on soldier's nutrition at the battlefield. They are working on ultrasonic agglomeration technology to offer variety of meals to soldiers (Davide and Xavier, 2015). Hans Fouche developed Cheetah Chocolate 3D printer with 8 nozzles which is based on extrusion printing to make different kinds of chocolates (Victor, 2015). ChefJet Pro 3D System prints visually appealing sweets and food decorations which are made from sugar, chocolate, cheese and other food materials. Interlocking sweets, wedding cakes and multi-colour cocktail decorations and sugar sculptures are being developed using ChefJet Pro (iReviews, 2014).

Conclusion

3D printing has evolved to a vast extent with its applications in military foods, space foods, customized foods for special dietary needs for elderly and people with dysphagia, confectionary, sweets, gums and chocolates. Though its application has been expanding in food sector, there are still some challenges regarding the printing precision and accuracy, printing speed, quality food production and nutritional requirements. Also, the composition of raw material, its properties, process parameters and post-processing treatments will also decide the printed structure's precision and accuracy. A lot of work is to be done on the limited addition of additives in food material, selecting those materials which give more cohesion in between layers. The need to ensuring food safety by considering the microbiological quality is also needed. Despite these challenges, the progressive innovative research in 3D printing technology will bring new solutions for food industries that will help in producing customized health foods which will be much more attractive and appealing to consumers. We can push the boundaries of food and design a future where precision, personalisation, and sustainability are key components of our eating experiences by utilising the most recent technological developments.

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