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Application of 3D Food Printing in Food Industry Development

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Summary

Food industry is craving to develop new technologies and processes which will satisfy customers' ambiguous wishes but also specific dietary needs. In 21st century, food allergies or food intolerances are affecting population from nurseries up to elderly stages while causing people, not only health issues but also making their nutrition plans and grocery shopping challenging and expensive. Three dimensional (3DP) food printing is a potential solution to advance current food processing techniques, but also to integrate 3DP and digital gastronomy technique to customize food products. If applied in domestic cooking or catering services, 3DP can provide an engineering solution for customized food design and personalized nutrition control, but also has the potential to redefine food supply chains. Still, people might be doubtful to eat 3D printed food due to their perception that it does not taste as good as traditional food and it appeals almost over-processed and artificial. This paper gives the short overview on 3DP techniques, devices and ingredients used for 3DP, as well as the possible future application in food manufacturing.

Keywords: *3D food printing, additive technology, food manufacturing, ingredients for 3DP*

Introduction

People are now following trends more than ever, so even in food consumption there are leading trends of coming back to organic and wholesome food, but also trying new techniques and food processing techniques. So where does 3D printing (3DP) belong in food processing? By definition additive manufacturing is a new technology focused on the computer navigated layer-by-layer deposition of materials to build up 3D objects (Hao, 2010). All these requirements make food more and more expensive and exclusive. However, an important advantage of 3DP includes minimal manual labor and the capacity to manufacture extremely complex shapes, making it appropriate for a wide range of applications, especially in a fast-increasing consumer goods industry such as the food industry (Drury, 2003; Galantucci, 2009; Godoi, 2016; Li, 2015; Tumbleston, 2015; Khalil, 2007; Sun, 2015; Zoran, 2011).

Currently food manufacturing is oriented to serial production which is not only convenient but also considerably cheaper per product unit compared to manually manufactured products. 3D food printing revolution can also radically change the way we think about food manufacturing and preparation. This process can eliminate grocery shopping for ingredients to pre-paring the ingredients and cooking, and lead to an instant readymade meal (Tran, 2011). But like any other novelty, it takes time to be accepted by wider consumers, but it can also find a niche for people with specific dietary needs.

3D food printing – 3DP

Up to now there are several food printing techniques (Table 1.), such as selective laser sintering/hot air sintering, hot-melt extrusion/room temperature extrusion, binder jetting, and inkjet printing, but the extrusion-based 3D food printing is the most commonly implemented method (Sun, 2015). This is a digitally controlled, robot-assisted manufacturing process that allows complex 3D food products (made of liquid/semi-solid/solid material) to be built layer by layer (Huang, 2013).

a) Hot-melt extrusion – FDM

This process originates from fused deposition modelling (FDM), and describes the extrusion process of melted semi-solid thermoplastic material from stationary FDM head and deposited onto a substrate. In food processing it is mostly used for 3D chocolate products which are slightly heated above its melting point and solidified almost immediately after extrusion (Hao, 2010). FDM food printer includes compact size and low cost of maintenance, but cons such as long production time and delays caused by temperature fluctuation.

b) Sintering technology

Also known as powder bed binder jetting, each powder layer is distributed evenly across the fabrication plat- form, and liquid binder sprays to bind two consecutive layers of powder (Sachs, 1990). The powder material is usually stabilized by spraying water mist to minimize the disturbance caused by a binder dispensing. Sugars and starch mixtures can be used as a powder material and binders could be liquids mostly based on high sugar content, which also presents cons of this technique as well as high machine costs, but this technology offers faster fabrication and the possibility to build complex structures.

Table 1. Comparison of 3DP technologies in food printing (Sun, 2015)

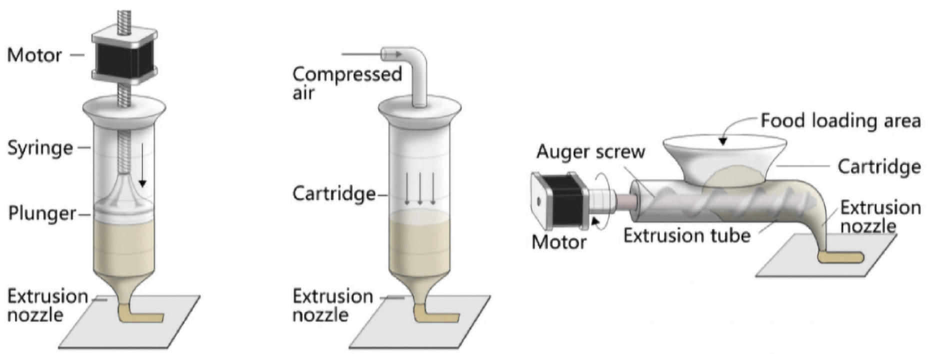
	Hot-melt extrusion	Sintering technology	Inkjet powder printing	Inkjet printing
Materials	Food polymers such as chocolate	Low melting powder such as sugar, NesQuik, or fat	Powder such as sugars, starch, corn flour, flavours, and liquid binder	Low viscosity materials such as paste or puree
Viscosity	$10^3 \sim 10^5$ cP	Not applicable	$1 \sim 10$ cP (binder)	$5\times10^2 \sim 5\times10^3$ cP
Platform	• Motorized stage • Heating unit • Extrusion device	• Motorized stage • Sintering source (laser or hot air) • Powder bed	• Motorized stage • Powder bed • Inkjet printhead for binder printing	• Motorized stage • Inkjet printhead • Thermal control unit
Printing Resolution	Nozzle diameter: $0.5 \sim 1.5$ mm	powder size:100 μm	nozzle diameter $\leq$ 50 μm Powder particle $\leq$100 μm	nozzle diameter $\leq$ 50 μm
Fabricated Products	Customized chocolates	Food-grade art objects, toffee shapes	Sugar cube in full color	Customized cookies, Bench-top food paste shaping
Pros	• Cost effective • Fast fabrication	• Better printing quality • Complex design	• More material choices • Better printing quality • Full colour potential • Complex design	• Better printing quality
Cons	• Low printing quality	• Expensive platform • High power consumption • Limited materials	• Slow fabrication • Expensive platform	• Slow fabrication • Expensive printhead • Expensive platform • Limited materials
Machine & Company	Choc Creator by Choc Edge	Food Jetting Printer by TNO	Chefjet by 3D Systems	Foodjet by De Grood Innovations

c) Inkjet printing

Inkjet food printing releases multi-material streams/droplets from a syringe-type multi-channel print head in a drop-on-demand way under gravity and creates 3D edible food products such as cookies, cakes or pastries. This process can be used to drop on-demand materials onto pizza bases, biscuits, and cupcakes and dry them by solvent evaporation.

d) Extrusion-based 3D printing (E3DP)

E3DP is an additive manufacturing technique, where the material is pushed in a melted, slurry or paste form, through a nozzle to build up an object layer by layer (Wolfs, 2019). In the pre-extrusion phase, as shown in Fig.1, the food formulation must remain fluid which is achieved by ensuring that the used food materials have a small particle size. The result of extrusion-based 3D food printing is achieving a comparable geometric product obtained through digitalized design while allowing personalized nutritional control (Sun, 2018). Single or multi nozzles can be used one by one or simultaneously to print products according to consumer demands producing unique tastes, and customized nutritional profiles. This 3D printing technique is suitable for producing carbohydrate based food, such as bread, pizza and cookies, etc, due to the potential of high precision and industrialization in carbohydrate based 3D food.



(a) Syringe-Based Extrusion (b) Air Pressure Driven Extrusion (c) Screw-Based Extrusion

Fig. 1. Extrusion mechanisms a) syringe-based; b) air pressure driven; c) screw-based (Sun, 2018)

Ingredient formulations

3D printing trials were conducted with ingredients commonly found in foods, which contained components from all main groups of nutrients, i.e. carbohydrates, protein, fat and dietary fiber, either alone or in combination with other ingredients (Lille, 2018).

Various food formulations and food recipes can be tested in order to maintain not only nutritional value but also to preserve the sensorial characteristic like texture in cookies. This simple but widely appreciated treat contains fat to provide lubricity or mouth coating, starch to provide viscosity and proteins to provide a range of textures and nutrition. Acknowledging the major health problems of modern society, obesity and chronic diseases digitized food printing offers the key to upgrade the recipe of existing food products' nutritional profile by reducing or eliminating undesirable ingredients, or replacing them with healthy ingredients (i.e. fiber and micronutrients such as vitamins and minerals) (Wolfs, 2019). The most successful materials for 3D food printing are dough (with or without additives) due to its consistency, rheology and ability to solidify after printing. Additives like starches, polysaccharides or proteins have a positive effect on melting behaviour, glassy state and plasticization of 3D pastes during liquid- and powder-based 3D printing (Bhandari, 1999). The flow behaviour and viscous modulus of a dough affect its extruding action, while its elastic modulus, gel strength, rupture strength and adhesiveness influence its ability to support the 3D structures. The dough can be easily extruded because of its pseudoplastic behavior with its viscosity decreasing as the shear rate increases. Various starch types have specific shear-stability and a yield stress which helps in retaining the shape after deposition. But starch paste concentration will define printing technology, mostly the extrusion of the material through the syringe tip and final shape, precision and stability of 3D printed objects. The starch is used in 3D paste as a thickening agent due to its ability to gelatinise by heat in the aqueous suspension.

Apart from some gum-like protein (e.g. gelatin), most proteins cannot be used directly as a 3D printing raw material. Denaturation of proteins under external stress (temperature or mechanical strength) or compounds (e.g. strong acid or base) is a good way to prepare raw material adapted to 3D printing. Proteins can be deposited with polysaccharide materials (e.g. alginate) in a layered structure under the defined conditions. Regarding proteins isoelectric points and possible aggregation, protein based gelation and hydrogel forming mechanism can be widely used in 3D food printing. Due to various external effects like, pH and temperature variations, proteins can be transformed in easy to print pastes in mixture with fibres and various sources of carbohydrates. Plant proteins and soluble fibres (from oats and barley) can be used as flour replacements, sugar can be replaced by natural sweeteners, fats could be enriched trough addition of Chia and flax seeds or its oils rich in omega-3 fatty acids. 3DP offers great insight to every ingredient segment which also offers possibility to develop recipes for people with severe allergies, like dairy products, nut products, gluten intolerance, etc.

But what about minor ingredients? How can we add vitamins, natural colorants and bioactive compounds like anthocyanins, carotenoids, betanidins, plant polyphenolic compounds, or essential fatty acids?

By combining established techniques like electrospinning and microencapsulation in addition to 3D printing technologies. These technologies can be directly integrated into the food printing process through multi-print head platform, to control ingredients dispensing. Micro- encapsulation can pack minerals, vitamins, flavors and essential oils within another material for the purpose of protecting active ingredients from the close environment. Electrospinning can produce food materials with preferred size and structure (lower fat and lower salt) with appropriate sensory properties and novel ingredi- ents (Neethirajan, 2011).

Chemical and physical changes that are developed during food processing may not occur during the 3D printing

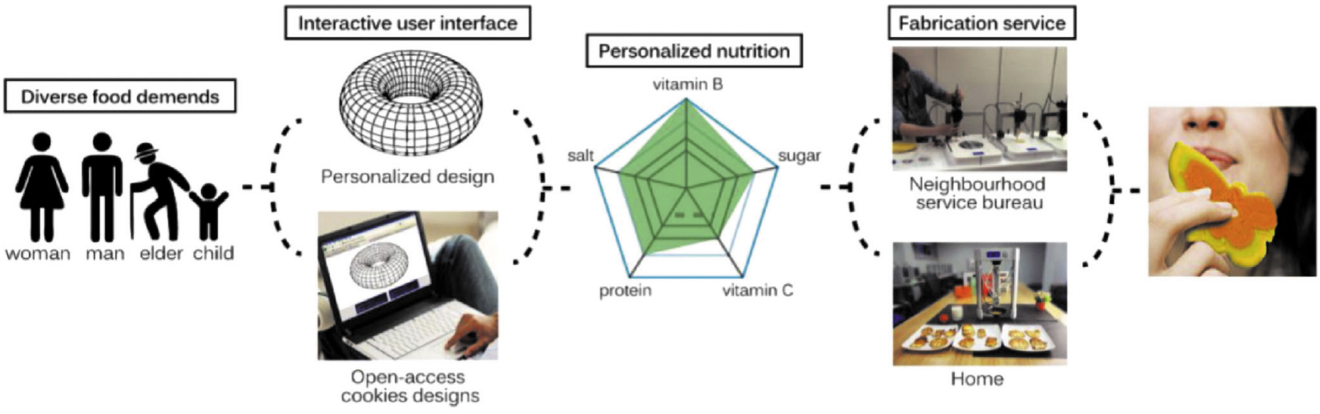


Fig. 8. Schematic diagram of food design and fabrication service.

Fig.2 Schematic diagram of food design and fabrication process

process and this is due to ingredients and their interactions, structure, texture, and taste, but also 3DP machines. The crucial factor here is to adapt the recipe design and printing process to achieve the planned contents on the sensorial and nutrition profiles (Fig. 2). 3DP pre-processing includes the adaptation of ingredients (e. g. gluten formation and leavening), but also post-processing (e. g. forming and baking, cooking, drying).

Future of 3DP

Food printing has demonstrated its ability structure personalized chocolates and produce simple homogenous snacks, but these applications are still primitive with limited internal structures or monotonous textures. Food is the most complex material to shape, and it is necessary to study printing materials, platform designs and printing technologies thoroughly. There are several EU-funded projects that support the development of food printing to produce tailor-made soft foods with tailored nutrient contents for older people with swallowing or chewing difficulties, which provides a great insight into the future importance of 3DP foods. However, in order to obtain better and more accurate data on people's nutritional needs and energy intake, data modelling through algorithms will allow us to obtain accurate food intake based on the height, weight, gender and health needs of each patient. To obtain similar foods as conventionally produced, detailed studies on ingredient effects on the texture and its interaction, as well as the accurate effect of cooking-related chemical reactions should also be modelled. The future for 3DP will bring a tailor-made food supply chain where consumers will be able to produce physical products that are not needed at home but in nearby local restaurants, resulting in lower distribution costs, simplified food supply through a mobile and web application and satisfied customers3DP offers a zero waste cycle of food waste in any household or restaurant kitchen, but also ensures the development of novel and functional foods with different textures and flavours. Fine dining restaurants could reduce prices of chefs' high end meals by using 3DP final decoration steps which could replace manual decoration as well to precisely calculate almost each drop of ingredients on the serving plate. These are just a few possible examples of the use of 3DP in the food sector, and there are certainly many more that we may not yet be aware of.

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