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3D food printing: paving way towards novel foods

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Abstract: 3D food printing, a part of additive manufacturing technique is used to modify the process of the food manufacturing in terms of color, shape, flavor, texture and nutrition. It liberates the user to identify and modify their meal according to one's desire, matching to the very minute details. Currently, it is used in decorating and fabricating, food products such as chocolate, cookies and cakes. The process of printing foods depends on several factors such as the physical state of food (whether powder, liquid or semi-solid), size and shape of the syringes to be used and the composition of the ingredients such as carbohydrates, proteins and fats. Apart from the use of 3D food printing for fabrication, it can also play an important role in solving malnutrition by enhancing the nutritional profile of the meal. The objective of this review is to highlight the different methods used in 3D food printing, 3D food printers, benefits of 3D food printing and challenges faced while food printing. Moreover, the paper discusses the applications of 3D food printing and its scope in the near future.

Key words: 3D food printing, food printers, nutrition, additive manufacturing, fabrication.

INTRODUCTION

Cost, taste, experience, nutrition and convenience are the main factors to attract the consumer towards any food product. As the lifestyle of people is changing day by day, thus, convenient food plays an important role as it is attractive and have health benefits. Due to the low price and high glycemic index, convenient foods are highly consumed by the people all around the world. An incremental awareness about the health concepts and functional value of the foods among people also favors the consumption of nutritionally rich foods. According to the 2015 American Pantry Study, 35% of consumers are "ingredient sensitive" while 47% of the people are "health conscious" (Deloitte 2015). The ingredients present in the food exhibit different effect on people due to their different metabolism. This enhances the market as they aim to plan the diet based on the consumer's health status (Sun et al. 2017). Now-a-days, there is an increase in the production and consumption of the customized food products such as frosted patterns on biscuits, logos painted with food, carving of letters into cookies and many others. As compared to the mass produced foods, customized food is expensive because of their high nutritional value and most prominently high rate of acceptance . Traditional mass food manufacturing processes along with the advanced processing technologies are not up to the mark in meeting such personalized demands (Zoran & Coelho 2011).

3D printing is a method in which a three-dimensional object is made by depositing the material layer by layer. It is done with the help of 3D printers which can print anything such as lithium-ion micro-battery (Sun et al. 2014). It can also print materials such as food, ceramics, wood, extruded or powdered plastic and even human cells. 3D printers can print almost all kinds of food that we usually consumed including fruits (Waldbau et al. 2011), pasta (Pan et al. 2012), cookies (Cooke et al. 2003), chocolate (Lu et al. 2006), chewing gum (Huang et al. 2004), personalized nutritional food (Ikuti & Hirowatari 1993) and food like edible growth which is not usually found in nature (Takagi & Nakajima 1993).

Few companies are using alternative food manufacturing methods such as three dimensional (3D) printing to gain profit. Various foods produced by the 3D printing are already available in the market. People in Netherlands have already started to use 3D printing in microwave pancake fabrication and eventually, there could be the rise in the use of 3D food printing machines much like microwave ovens (Hadhazy 2013). Various institutions are involved in 3D food printing such as Cornell University (New York), CandyFab Project, Philips, Electrolux, University of Exeter (England), Massachusetts Institute of Technology (Cambridge, Massachusetts), sugar lab Toegepast Natuurwetenschappelijk Onderzoek (TNO) innovation for life, Modern Meadow, London South Bank University, Riddet Institute, Choc Edge, ‘piq’ chocolates, Bosystems, Nestle, Mondelez International, Hershey’s, Natural machines, SMRC NASA, RIG, 3D Ventures, FabLab Maastricht, US Army Natick Soldier Systems Center and various others.

METHODS OF 3D FOOD PRINTING

There are various techniques employed in food printing such as extrusion based printing, inkjet printing, binder jetting and bio-printing. These methods are discussed below:

Extrusion in 3d food printing

Extrusion in 3D food printing is slightly similar to the food extrusion cooking. They both help in accelerating the efficiency of the process and increase the food quality. Basically, the physical output of the extrusion based 3D food printing is same as that of food extrusion cooking, but the process underlying in both of them differs. Extrusion based 3D food printing involves the digital design of the end product and the personalized nutrition control. The purpose of both the methods is different, where food extrusion cooking was introduced to reduce the manpower and process load on manual processes, extrusion in 3D food printing is introduced to exhibit the creativity and control in the process by allowing them to directly manipulate the food components and forms. The summary of the differences between extrusion in 3D food printing and extrusion cooking is outlined in Table I.

In the extrusion process of food printing, there is digitally controlled robotic construction process operation which produces complex 3D food products by depositing layers on to another layer (Huang et al. 2013). Firstly, material is loaded in the syringe and then pushed out from the nozzle in a controlled manner. The stream, in which the material is loaded, then moves to a predefined path and finally the deposited layers of the food material forms a coherent solid structure.

In extrusion-based food printer, there is a multi-axis stage with single or multiple extrusion units. Overall, it is compact in terms of size and has low maintenance cost. However, it is not used widely, as only limited materials can be used to print the food and it also takes more time in fabrication.

Table I. **Comparison between extrusion in 3D food printing and food extrusion cooking.**

	Food Extrusion cooking	Extrusion based 3D food printing
Purpose	Reduce the manpower and dependency on the manual processes.	Have freedom to design and control the processes by manipulating the food components and forms.
Key components	Extruder	Computer aided design (CAD)
Products	Cereals and starches (Altan et al. 2009) Snacks (Ding et al. 2006) Pasta (Zardetto & Dalla Rosa 2009) Restructured products (Knoch 2015) Legumes, pulses and oilseeds (Pilli et al. 2005) Confectionary (Mulji et al. 2003)	Chocolate (Lipton et al. 2010) Pizza (Linden 2015) Cookies (Lipton et al. 2010) Gel food (Serizawa et al. 2014) Pasta (Linden 2015)
End status	Ready to eat Ready to cook (frying/toasting/ baking) Ready for further processing	FDM: ready to eat RTE: ready to cook
Application	Low cost mass production	Customized fabrication in small batch
Shelf life of product	9-12 months	A few hours

Mechanism of extrusion

There are three extrusion mechanisms which are employed to extrude a semi-solid/liquid materials: syringe based extrusion, screw based extrusion and air pressure driven extrusion.

It consists of a syringe to deposit food materials along with the step motor to enable the extrusion process (Figure 1a). Step motor is used in various commercial machine designs like a Cocojet 3D printer (3D systems 2013) and the Choc Creator (Choc Edge 2014). Step motor is designed in such a way that controls the movement (linear motion) and location of the syringe plunger, and forces the food material out from the nozzle. The speed of extrusion can easily be monitored by just adjusting the motor speed. For the products that are high in viscosity, more power is required to get extruded. For this design, one motor is required for print head and hence, the payload of printing material goes on increasing with the material (Zhuo 2015). Semisolid or solid food materials can be printed easily with this extrusion. The only concern while selecting this method among other food printing methods is the additional power consumption that would be increased due to the frictional force during overloading (Sun et al. 2017)

Air pressure driven extrusion

Air pressure driven extrusion includes majorly two components viz. pneumatic pump and encapsulated food cartridge (Figure 1b). Pneumatic pump is used to generate the air pressure that helps to extrude the food material from the nozzle, allows it to use more than one

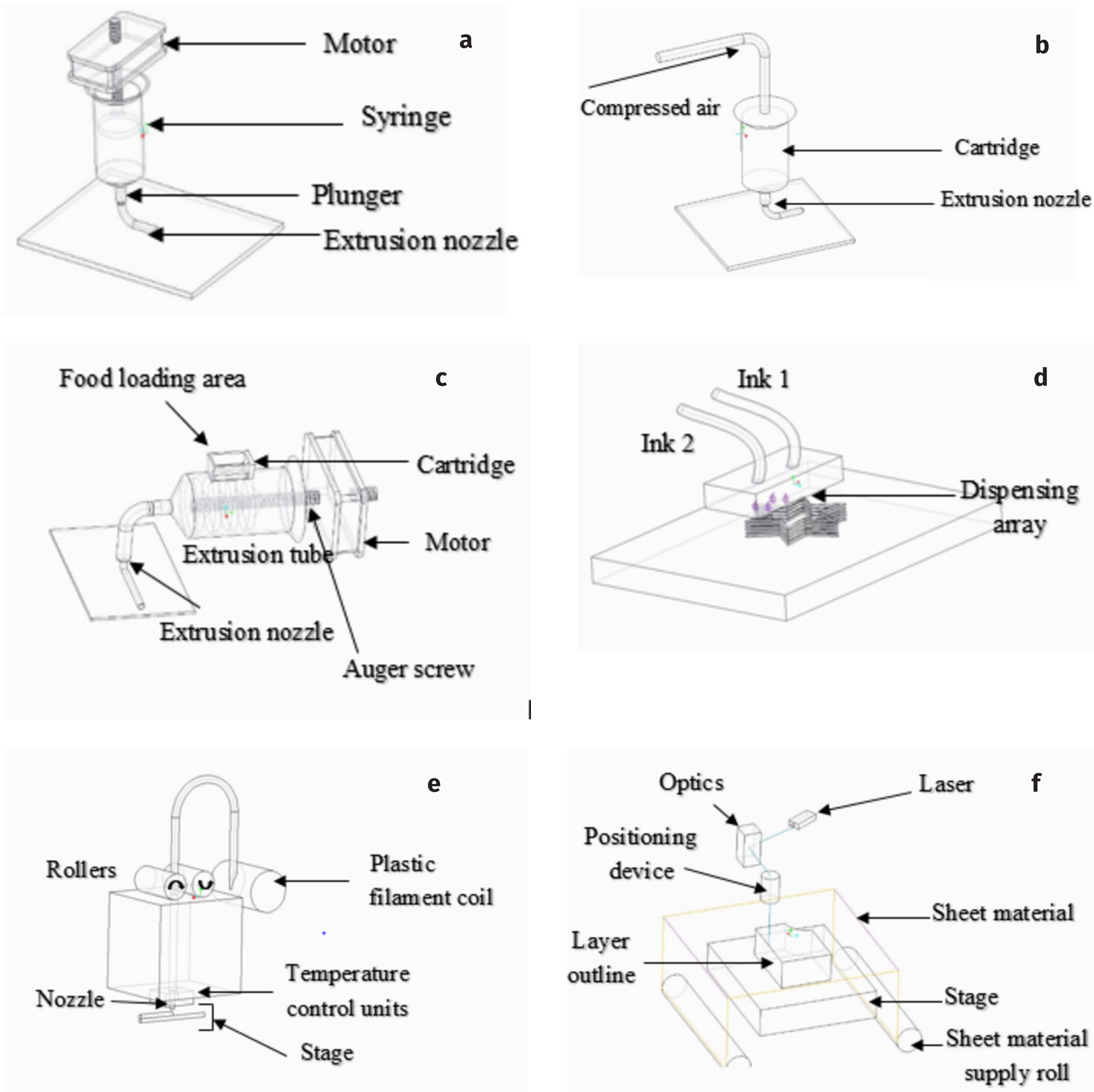

Figure 1. Methods of 3D food printing.

extrusion heads with different extrusion rates at the same time by the regulating valves. However, while changing the extrusion rate, response time also gets changed. Through this kind of extrusion, liquid materials are easy to print, whereas, the solid and semisolid food can deposit on the inner side of the cartridge which ultimately lead to blockage of the cartridge. There is a filtration system that is used to sterilize the air present in the pneumatic pump (Sun et al. 2017).

In both syringe based and air pressure driven extrusion systems, the food materials which are to be printed are not in the direct contact with the mechanical systems present in the unit. This indirect contact of the food material and mechanical system prevents the contamination of food material to a large extent.

However, to avoid the air bubbles while refilling the syringe or cartridge, additional devices need to be installed when used in large sale.

Screw-based extrusion

In this unit, food material is fed into a cartridge which is broad from the top (for easy material loading) and narrows from the bottom. With the screw driven motor, food materials are continuously pushed downwards through an extrusion nozzle. This pushing of the material through screw driven motor leads to the formation of minimum bubbles. However, there is a direct contact between food material, the screw and the cartridge, thus food grade stainless steel is used for autoclaving (Figure 1c) (Sun et al. 2017).

Syringes and food cartridge for different extrusion mechanisms

For different extrusion mechanisms, different syringes and cartridges are used. Overall, inner layer of both syringes and cartridges should be non-sticky and smooth to lower down the energy utilization and allow an easy sterilization after extrusion. Syringes and food cartridges used could be both disposable and refillable. The one which can be disposed off is better to avoid contamination in food, however, it is not much eco-friendly. Thus, syringes and food cartridges which can be refilled are used dominantly. Presently, food grade syringes composed of safe plastic materials are used. For printing, food grade paper and for equipment, food grade stainless steel are being used (Sun et al. 2017).

Process parameters of extrusion based mechanisms

Process parameters of extrusion based 3D food printing are similar to traditional cooking. Both of them gets affected by the factor like temperature, pressure, extrusion rate, shear force, screw speed and extruder design parameter and extruder type. In extrusion based 3D food printing, an additional factor which is to be considered is printing related measures such as printing layer thickness and stage moving speed. Stage speed, diameter of the nozzle and extrusion rate determines the shape, strength and rigidity required by the food product. When the food material is deposited layer by layer onto each other, there are many chances that there might be some deformation in terms of shape due to the individual strength of the food materials. Another thing to be taken care of is when smaller nozzles are used, the layers of food materials might lead to thin layer leading to better smooth surface. Thus, it should be used according to the end product (Sun et al. 2017).

To get the refined product, extrusion rate should be set optimally. As if the stage is moving fast, then there is possibility of breaking of the deposited steam further leading to shape deformation, while if the stage is moving slow, then there would be an accumulation of the food material in one place that would again lead to shape deformation (Sun et al. 2017).

Some other factors that influence extrusion is the volume of the food material to be used, inhomogeneous printing materials and gradual magnification of internal disturbances from the print head actuation process. In addition to these, nozzle diameter, stage moving speed and deposition height (Hao et al. 2010) also plays an important role in determining the quality of food and extrusion rate.

Food design in extrusion based printing

Food design includes the visual appearance of the food, first bite, swallowing (roughness/smoothness, flow properties), sense of touch (roughness/hardness, stickiness), chewing and anonymous effects in the mouth. Owing to food printing, it is possible to formulate a huge range of food design (Sun et al. 2017).

Layer structure and unique taste

As 3D food printing is done by depositing the raw material layer by layer, a staircase effect can be observed that can be used to refabricate or to decorate the foods such as cookie or chocolate. This deposition of layering plays a key role in giving new chewing experience such as 3D printed chewing gum gives the consumer, a new effect of chewing the layers in their mouth (Alec 2015).

In formulating the tasteful design, jelly like liquid capsules can be printed using Nufood Robot. This Nufood Robot, compact the intense flavor into unexpected textures and shapes such as a jelly which tastes like raspberry and has an appearance of strawberry (Molitch-Hou 2014). These capsule possess all the ingredients that can be extracted naturally, but merge them in such a way that a new taste can be aroused from it.

Formulation innovation and uplifted nutrition profile

Different foods provide different textures and taste to the food such as presence of fat causes lubricity or mouth coating while the presence of starch increases the viscosity. Now, it is seen that cookies are consumed all over the world and liked by everyone; however, they also contribute to health problems for people suffering from obesity and chronic diseases. Thus, the recipe of the cookies could be modified with the help of digital food printing. The undesirable components present in cookies like fat, sugar can be replaced by the ingredients that are more suitable to the condition. In cookie, fats can be replaced by the omega-3 rich vegetable oils, some portion of flour can be replaced by oats or barley (rich in the soluble fiber) and plant proteins and sugars could be replaced by the natural sweeteners (Sun et al. 2017).

Although it seems simple, but it comes out to be a great challenge as the change of ingredients in the recipe would alter the rheological properties such as texture of the product. Thus, to attain the optimum texture and rheological properties as of the same products, certain combination of ingredients would be added. Hence, the nutritional profile of the 3D printed food can be increased by lowering down the glycemic index from the food and increase the portion of soluble fiber, omega-3 fatty acids and protein in the food. Further, minor components such as vitamins and pigments can be easily added by this technique (Sun et al. 2017).

Digitalized nutrition control

It is being used in various projects all around the globe to provide the nutrition for the elderly by alternating the physical attribute such as hardness or softness of the food or by supplementing the food with multiple vitamins and essential compounds required by the body. Figure 2 explains how the nutrition of the food can be personalized.

One such project is EU personalized food for the Nutrition of Elderly Consumers (PERFORMANCE), this project is oriented towards the food consumed by the elderly people. In this project, with digitalized 3D food printing, they are increasing the softness of the food so that older people can easily chew. The outcome of this project was a great success as the preliminary results obtained were positive in EU care homes (Kira 2015).

Binder jetting

In binder jetting, firstly, uniform distribution of the powder layer is done on the fabrication platform. Then, to minimize the disruption caused by the binder dispenser and to stabilize

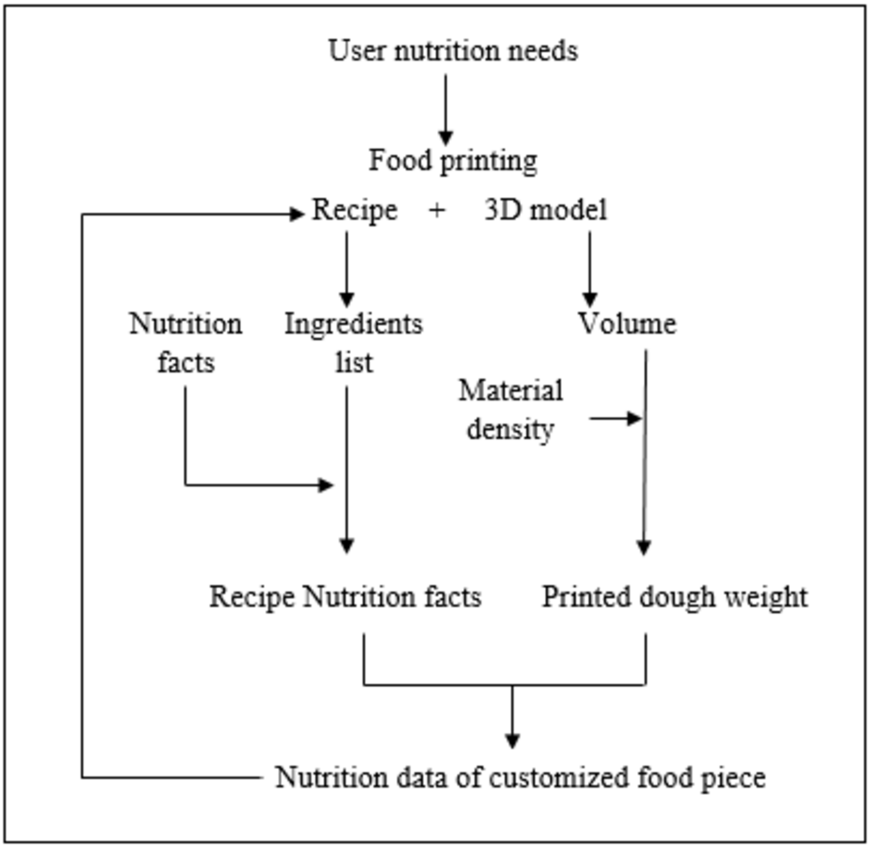

Figure 2. Digitized nutrition control in food piece design.

the layer of powder, a stream of water mist is sprayed onto the layer of powder. Now, with the help of liquid binder, two or more layers are attached to each other (Sachs et al. 1992). It has various advantages over other techniques as it requires less time for fabrication and have low material cost. However, its machine cost is high and has a rough surface finishing (Sun et al. 2015). Various projects have utilized this kind of technique. One such example is the edible 3D printing project. In this project, mixtures of starch and sugars were used as a powder and a Z-corporation powder/ binder 3D printer was used as the platform to re-modulate to form customized shapes (Southerland et al. 2011). Another such example is the use of different flavor binders along with the sugar to fabricate complex designed cakes for occasions like wedding by the Sugar Lab (Boston, Massachusetts, United States) in 2013. This kind of fabrication used 3D Systems' Color Jet Printing Technology. Although the ingredients used in this project for fabrication are up to the standard of food safety requirements, however, market potential of this technique is limited. As these products are high in sugar, they invite various diseases such as hypergylcemia, dental caries, heart diseases which have harmful health effects (Godoi et al. 2016).

Inkjet printing

This technique is mainly used for the cake, pastry and fabrication purposes. In this, syringe-type print head exhibits a stream of droplets on the food such as pizza or cake by a drop-on-demand way (Sun et al. 2015). The size of the droplets can be set manually according to the end use of the product. This technique was employed in the De Grood innovations' Food Jet Printer. This printer through pneumatic membrane nozzle jets set the drops onto biscuits, pizza bases and cupcakes (Foodjet 2012). The droplets settled by the action of gravity formed a two and half dimensional digital image, as surface filler or as decoration on the different substrates (Figure 1d) (Godoi et al. 2016).

Power binding deposition

This technique is used widely after the extrusion process. It can be categorized into three types: selective hot air sintering and melting (SHASAM), selective laser sintering (SLS) and Liquid binding (LB). In all the three techniques, deposition of powder in bed is common; however, the phenomenon of deposition of the powder is different. Liquid binding is used widely in 3D printing, thus patented as 3DP (Godoi et al. 2016).

Selective laser sintering (SLS)

To use this technique, a power source and a laser are required to sinter the powder particles. In this, firstly the laser emitted from the power source is directed to the points which formed a layer of pre-determined solid structure. As soon as that layer is formed, that layer is shifted downwards and again with the use of laser, another layer is formed. This continuous deposition of layer on other layers ultimately leads to the formation of the product. In this, different food material components can be used in different layers, enabling to design the end product (Diaz et al. 2014).

The communication of laser and food particles is very essential in the SLS as it determines the quality and feasibility of the SLS process (Kruth et al. 2007). Thus, the layer should be selected well as the absorptivity of the layer by the materials depends on the wavelength of the laser. In addition, the input of laser energy density also plays role in determining the powder densification (Figure 3a) (Gu et al. 2012).

Liquid binding (LB)

This technique was initially patented as 3D printing (Bredt & Anderson 1999). While doing the fabrication by liquid binding, there is a need of liquid binder which gets ejected through drop-on-demand print head. This liquid binder when settles on a layer of powder gives 3D model predetermined by the computer. This binder plays a key role as it attaches the nearby particles to each other to get solid structure. This interaction and attachment of the nearby particles occur due to the cross linking or dissolution-fusion to the surface of the particles (Peltola et al. 2008).

This technique was utilized by the 3D System's Chef Jet printer. The printer utilized the Z-Corp inkjet process to manufacture a wide range of confectionery based recipes such as sugar, sweet and sour candy in a number of flavors-sculptural appearances (Figure 3b) (Von Hasseln et al. 2014). In the past few years, TNO researchers proposed an idea of the liquid binding based method known as Power Bed Printing (PBP). In PBP, by the help of spatial jet, a binder was ejected on a powder bed composed of hydrocolloid and water soluble protein. This was done in a form of an edible 3D object (Diaz et al. 2017).

Selective hot air sintering and melting (SHASAM)

This technique also fuses the powder together to create a solid edible object. In this, the use of direct, narrow and low-velocity beam hot air is responsible for fusing together the particles. To make a 3D object, several layers of 2D objects are merged together. The 2D layer is formed by joining the particles on the power bed through hot air. This technology was used by the Evil Mad

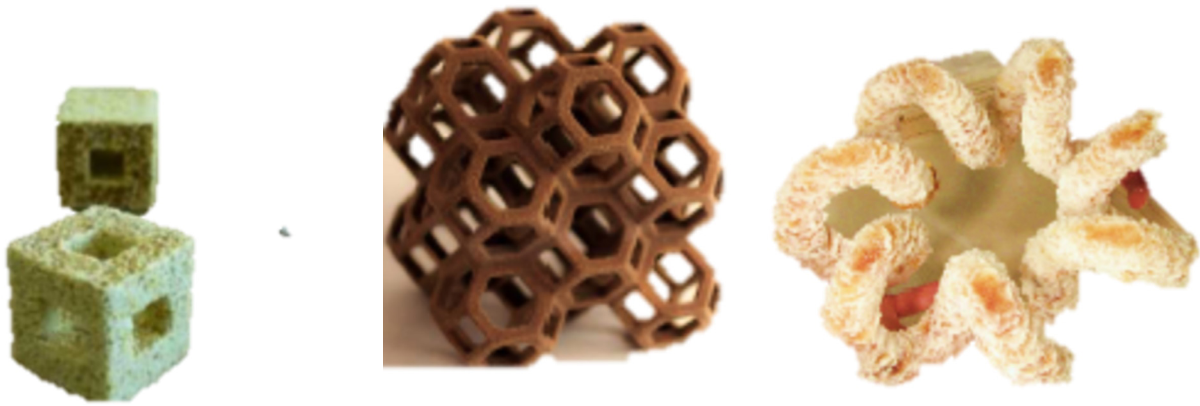

Figure 3. Power Binding Deposition Techniques.

Scientist Laboratories (California, USA) in one of their projects to print sugar based 3D objects (Figure 3c) (CandyFab 2006).

Stereolithography (SLA)

It was initially known as rapid prototyping method. There are various approaches of SLA like mask based writing and direct/laser writing (Pan et al. 2012, Lu et al. 2006). Indirect/laser writing technique consist of various components such as a tank of liquid resin, computer interface, a movable base and a UV light beam, whereas, mask based writing, comprises a computerized, movable platform, UV beam, resin vat and a digital mirror device (mask) for treating the single layer at once (Gross et al. 2014).

There is a UV beam present in the bath configuration that is responsible for scanning the 2D cross section. This 2D cross section is present on the base of the bath configuration dipped in the tank of liquid photoactive resin which polymerizes upon illumination. There are various factors affecting the thickness of the cured resin such as the intensity of the power source, exposure duration and scan speed. All these factors depend directly or indirectly on the energy of the UV light. After complete scanning by the 2D cross section, the base carrying the cured resin lower down. The next cycle to lay the next layer is then initiated, that is polymerized on the top of the previous layer. There is a blade loaded with resin levels present in between the layers to maintain the uniform layer of liquid before another level of UV light experience. This repetition of the process continues till the complete 3D object is formed.

In SLA, the oldest technique is the bath configuration. It has various shortcomings such as resin waste, extreme procedures for cleaning and size of the vat limiting the height of the desired product. Thus, layer configuration proves to be better than bath configuration (Cooke et al. 2003, Lee et al. 2007). Both layer configuration and bath configuration have similar components. However, in layer configuration, movable platform is present above the resin reservoir, contrary to the bath configuration. In addition, light source is present below the optically clear bottom vat. This advancement in the setup overcomes the need to require more resin and also the height of the printed part was unrestricted. The space between movable platform and reservoir is fulfilled with a thin layer of resin. As soon as the former layer is cured, there is an increase in the level of the platform leading to the filling of the gap by the uncured resin. The higher the viscosity of the resin, the more difficulty will be encountered while filling the gaps. These steps are repeated again and again till the process is completed (Ikuta & Hirowatari 1993, Takagi & Nakajima 1993, Huang et al. 2004).

In a post fabrication step of both configurations, a UV light is used to polymerize all the reactive groups present in the resin. In addition, this step is required to strengthen the bond more in the final 3D object (Harris et al. 2004, Wang et al. 2011). However, the time consumed to print the 3D object from the direct laser writing method is more. The common sources of UV light include the HeCd laser (325 nm) (Takagi & Nakajima 1993, Bertsch & Renaud 2011) and the xenon lamp (Ikuta & Hirowatari 1993) however, the type of source of UV light depends entirely on the resins. In order to reach high resolutions, two photon polymerization is used in SLA fabrication (Maruo & Ikuta 2002). The major limitation of SLA is the resin due to their high cost and since one resin can be utilized at a time of printing, and this limits the overall device design. In addition, resins are also less favored due to their acrylic or epoxy bases, but maximum of these materials is brittle and can shrink when polymerized (Harris et al. 2004).

Fused deposition modelling (FDM)

It is among the most prominent technologies used widely now-a-days for rapid prototyping. It was introduced by the Scott Crump of Stratasys in 1989. While fabricating the 3D model, FDM extrudes the thermoplastic materials and simultaneously deposits the semi-molten material layer onto the layer on the stage (Figure 1e) (Waldbaur et al. 2011).

The thermoplastic filaments used here are pushed by the two rollers towards the nozzle tip of the extruder. Then these filaments are heated till it acquires the semi-molten state. According to the design mentioned in the input, the semi-molten thermoplastic is extruded and solidified. Similarly, the rest of the layers are deposited on to one another till the final structure is achieved. In this, primarily the outline part of the structure is printed and then the adjacent parts are printed layer by layer. The possibility of arising defects is from surface defects and internal defects. Surface defects arise from the STL (*.STL) file format and the nature of the slicing software. It includes the chordal and staircase effects. However, internal defects are those defects that affect the process of extrusion of the material from the nozzle. It results from the heterogeneities in the filament feed diameter and density (Van Weeren et al. 1995).

FDM is beneficial in creating the objects fabricated from the several types of material by printing and changing the type of material used for printing. This gives more liberty to the users to control the process for experimental means. In addition to the Polycarbonate (PC), Acrylonitrile Butadiene Styrene (ABS) and Polystyrene (PS), other materials used for printing could be glass reinforced polymers (Zhong et al. 2001), ceramics (Agarwala et al. 1996, Jafari et al. 2000), bio-resorbable materials (Zein et al. 2002) and metals (Agarwala et al. 1996, Wu et al. 2002). Usually, binder, ceramic or metal powders are mixed together to enable the material to be used in filament form (Agarwala et al. 1996).

Laminated object manufacturing (LOM)

This technique was introduced by the California based Helisys Inc. (Cubic Technologies). Helisys with the help of defined layers made from materials like paper, plastic and metal developed a 3D model (Figure 1f) (Yan & Gu 1996). Initially, a layer consisting of any material is loaded on a stage. Then, with the laser usually carbon dioxide lasers (Klosterman et al. 1998) or razor traces, the pattern is identified and the excess material present on the layer is removed. After the removal of the extra layer, another layer is printed onto the previous layer. Now again the extra material is removed from the knife or laser based on the input given in the STL file. The rest of the layers are attached to one another by the welding or adhesives (Frank et al. 2010). This repetition of the printing of the layers is done until the complete 3D model is prepared.

In order to use the adhesives to attach the sheets with one another, heat is applied either with the roller or on the support stage. The defects arise in this technique are fairly less compared to the defects encountered in other techniques like FDM (Mueller & Kochan 1999). However, the temperature set should be optimum, otherwise, it can lead to structural deformities, or could lead to the damage of adhesive (if the temperature is too high) or the part could be de-laminated because of insufficient heating of the adhesive. The additional consideration is that the materials which are to be used in printing should be able to form sheet and can be attached by adhesive. Table II describes the principle, materials, solvent compatibility, resolution and cost of the 3D printing techniques.

Table II. **Comparison of 3D printing technologies.**

Methods	SLA	Inkjet	SLS	FDM	LOM
Principle	Curing of defined photoresin layers by UV.	Powder–liquid binding, polyjet technology enables inkjet printing of photoresins.	Heating of powder particles using laser.	Molten thermoplastics are extruded.	Cutting of heated, adhesive coated sheet material using laser/razor.
Materials used	Epoxy or acrylate based resins with proprietary photo initiators, support material (mixture of propylene/ polyethylene glycols, acrylate and glycerin).	Photoresins, plaster powder particles (50-100 µm in diameter).	Powdered PVC, ABS, resin, metals, PC, nylon, polyester, ceramic powders.	Wax blends, PS, nylon, PC, ABS, metals/ ceramics (with binder).	Adhesive coated polymer, cellulose, paper and metal sheets.
Solvent compatibility	Most polymer materials are able to absorb small organic molecules, organic or aqueous solvents which results in welling of the bulk material.				For some chemical applications, paper or cellulose may not be amenable.
Resolution (XY/Z) (µm)	70-250/1-10, <1 with two photon polymerization.	20-50/50	50/1-2	250/50	10/100
Cost (USD)	Formlabs Forml 3 299; 3D systems ProX 950:> 500000	3D systems Zcorp Zprinter 150: 16 580, 650: 59 000, 850: 93 000; Stratasys (polyjet) Objet 30: 55 660, Objet 24: 19 900	3D systems: 250-450 000	Stratasys Mojo: 9900, Dimension: 24 900, Uprint: 20 900; Makerbolt Replicator 2 000	Cubic Technologies 14 995.

Source: Gross et al. (2014).

Bio-printing

This method follows the principle of precise layer-by-layer deposition of cultures and biological materials of living cells. The technique was initially used to print tissues without the use of any biomaterial-based scaffold. Mostly, inkjet, laser-assisted and micro-extrusion printing is used for these kind of biological materials (Murphy & Atala 2014). This was applied by the researchers of the University of Missouri to print strip of edible porcine tissue by using 3D printing technology. They used multicellular cylinders (building blocks), therefore, making them depend on the self-adhering cell types. Through an inkjet nozzle, fresh droplets of multicellular aggregates (bio-ink particles) were settled on a biocompatible support structure (agarose rods). This settling process of the droplets is achieved by the drop-on demand technique. Furthermore, by the special purpose bio-reactor, the final end product was made suitable to use. During the maturation of the product, a pulsatile flow and the maturation graft were generated by the bio-reactor to develop the biochemical properties of the product (Figure 4) (Norotte et al. 2009, Marga 2012, Forgacs et al. 2014).

Marga (2012) reported that there was an increase in the acceptance level of the bioprinted meat of the vegetarian community. Thus, in future, there is a great possibility that vegetarian community of the world would get the health benefit as that of non-vegetarian diet. However, there are various drawbacks of the product such as spatial resolution of the end product which need to be overcome.

CLASSIFICATION OF 3D PRINTERS

Based on the different temperature control, 3D printers can be categorized into the room temperature extrusion (RTE), hydrogel forming extrusion (HFE) and hot-melt extrusion (HME).

Room temperature extrusion (RTE)

RTE is generally used to fabricate the food products which are difficult to make by hand (Periard et al. 2007). The merit of RTE is its high repeatability. In this, components of the food printing materials (such as meat purees, proteins, essential carbohydrates and other nutrients) used are generally extracted from the alternative sources (insects and algae). Food like cheese, jelly, hummus, dough, frosting, creamy

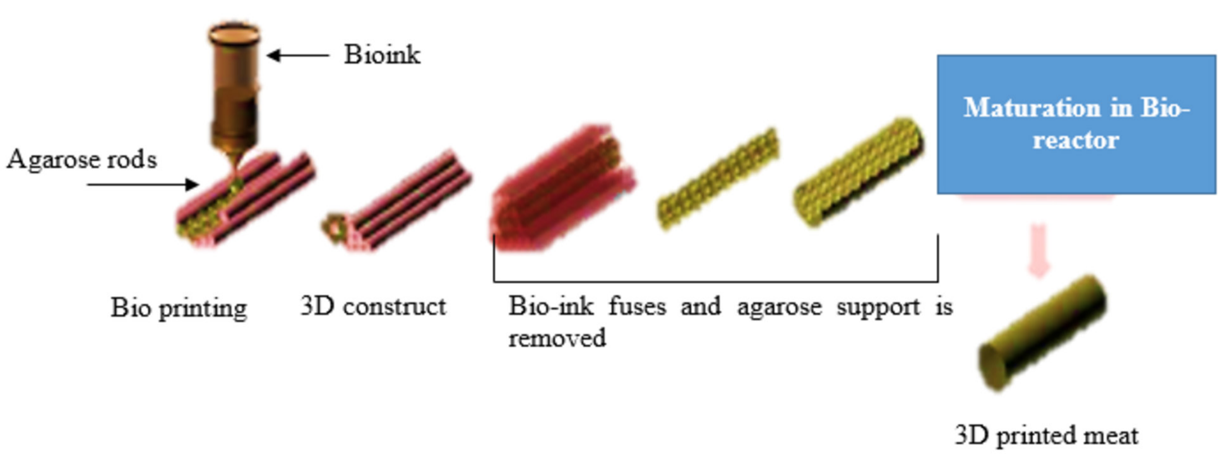

Figure 4. Process of bio-printing.

peanut butter and Nutella are printed. It can also be used to print 'pasta' by a traditional recipe involving durum wheat, water and semolina. Also, it is used as surface filler for cookie, pizza and graphical decoration (Linden 2015).

Hot melt extrusion (HME)

It was first discussed by the Crump (1991) and is used majorly to produce customized 3D chocolate products (Hao et al. 2010). In these kind of printers, melted food polymer semisolid in nature is extruded through a movable HME head (Figure 5a). When the polymer comes out from the nozzle, it immediately gets solidified as soon as extrusion is complete and gets attached to the previous layers.

Researchers from Massachusetts Institute of Technology developed a functional prototype "Digital Chocolatier" and utilized hot-melt chocolate as a dispensing liquid (Zoran & Coelho 2011). Since then, Choc Edge (Choc Edge 2014), TNO (Linden 2015) and Natural machines (Natural Machines 2014) have used the HME to produce 3D chocolate objects. In the HME process, 3D Food-Inks, Printer can also be included. This printer can print the 3D color images using extruded base material (Golding et al. 2011). However, additional cooking step is needed after using this printer.

Hydrogel-forming extrusion (HFE)

HFE is a kind of extrusion of hydrocolloid solutions or dispersions into a hardening/ polymer gel sets, bath using jet cutter, syringe pipette, vibrating nozzle and similar equipment. Usually, diameter of gel droplets is 0.2-5 mm. The basic key to form stable shape in HFE is the control of solution temperature.

Rheological properties of gel formation and polymer play an important role in this extrusion. For example, polymer solution should be viscoelastic first, and then should be converted into the self- supporting gels prior to the adjacent deposited layers. HFE is used to print intricate food pieces in commercial machine designs. Serizawa et al. (2014) invented a 3D edible gel printer consisting of the syringe pump and dispenser that helps in producing soft foods for older people suffering from swallowing problems. A UK Dovetailed invented a 3D fruit printer. In this printer, they merged the strawberry flavoring and sodium rich gel into layers in a cold calcium chloride solution

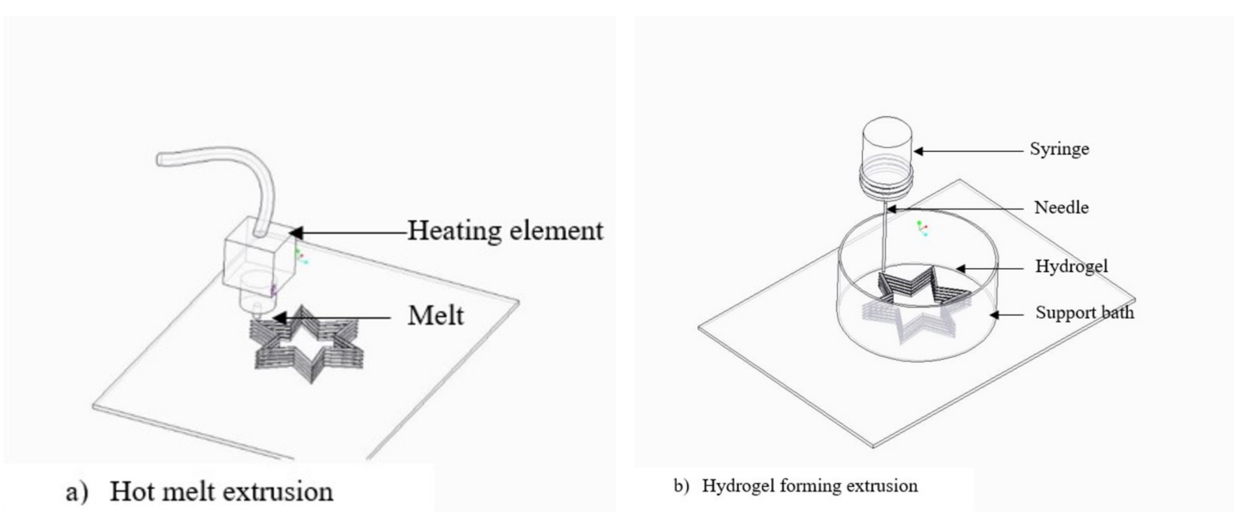

Figure 5. Different types of 3D food printers.

in order to create fruit like raspberry (Figure 5b) (Molitch-Hou 2014).

Various commercial machines are made on the basis of temperature control viz. RTE for pasta printing and pizza (Molitch-Hou 2015, Barilla 2016), HME for chocolate printing (Choc Edge 2014) and HFE for fruit printing (Molitch-Hou 2014). Some of the printers are even superior to these food printers such as Bocusini plans which widens the range of printer's head temperature from 20-70°C and print easily or more than thirty variable pre-filled cartridges included in 6 different categories- bakery products, fruit and vegetable products, snack products, meat products and dairy products (Millsaps 2015). This kind of planning enables the print of several food materials by using only a single machine setup which helps the professional chefs and home users to make attractive food.

POST DEPOSITION COOKING OF 3D PRINTED FOODS

The 3D printed food after getting printed pass through several post deposition cooking processes such as boiling and baking before consumption. These post deposition cooking processes, exhibits different non-homogenous textures and levels of heat penetration. During these cooking procedures, various physical and chemical alteration takes place in the food such as denaturation of protein, reduction in water activity, changes in texture, color, volume and nutritional value. For example, 3D printed pizza fabricated by a BeeHex 3D printer when baked, results in a same kind of crust as normal pizza in the starting but after a few minutes, it starts to resemble crackers by exhibiting different chewing and swallowing experience (Garfield 2016). Similarly, when frozen materials are used to print gel-like materials, a complete alteration in the taste and texture can be observed (Hall 2016).

ESSENTIAL CONSTITUENTS OF FOOD AND THEIR FEASIBILITY FOR 3D PRINTING

For easy printing, the materials used must have good flowability. This flowability is attained by melting and plasticization. The self-supporting structure of the materials can be done by reversing the process or just through gelation by making a difference in temperature or by an additive. Melting property, plasticization and glassy state of the food is affected by the composition of carbohydrate, fat and protein during powder based and liquid based 3D printing process. It has been reported that the introduction of the water in the plasticization phenomenon of the food polymers reduces the glass transition temperature. The food polymers referred here are gluten, starch, gelatin and similar polymers (Bhandari & Howes 1999, Bhandari & Roos 2003, Slade & Levine 1994). The major constituents are discussed below:

Carbohydrates

The gelatinization temperature of food product depends greatly on the type and amount of carbohydrates. Carbohydrates usually polysaccharides (such as starch and maltodextrins) with higher molecular weight cannot be printed until it is modified or diluted with water or gelling agent (Adhikari et al. 2000, Bhandari et al. 1997). In the presence of water and heat, intermolecular bonds present in starches get scattered, making the hydrogen bonding sites free to bond with water (gelatinization), thus enabling the sugar to act as a plasticizer in low-moisture systems. When the sugar is mixed with starch, it reduces the gelatinizing temperature. The determination of the glass transition temperature is important to make the deposited material support its own structure.

In case of chocolates, crystallization of sugars is very important and this is achieved by melting extrusion. While preparing milk chocolate, complete crystallization of sucrose and lactose is required. The merit of using highly crystalline crumb is that it reduces the amorphous glassy sugar left to trap fat. Substantially, less amount of fat is needed to adjust the final viscosity of the final chocolate. Below the gelatinization temperature for sucrose in water, viscosity is increased which enables the growth of various crystal nuclei. By releasing fat from the sugar, the chocolate manufacturer is facilitated because the overall fat required to reach the ideal viscosity is reduced (Gonçalves & Lannes 2010).

In the powder bed, binding mechanisms, sugar constitute as the dominant component of particulate systems. The interaction among the layers induced by the heat source such as hot air or laser is based on the melting point of the material. Factors such as compressibility and powder density play a significant role in the powder flowability inside the container that in turns helps in forming the designs when the heat source is directed to the powder bed (Berretta et al. 2013, Schmid et al. 2013). For the liquid based 3D processing, powder flowability along with the wettability of the powders plays a crucial role. Powder flowability is important while spreading the powder and also helps in setting up the thin layers. If the flowability is high, then it would lead to powder bed instability, however, if the flowability is low, then there would be insufficient recoating. Wettability of the particles is important as it affects the volume and amount of the binder that ultimately affects the mechanical/ structural and the resolution of the design. If the wettability of the particles is low, then it would lead to the rearrangement of the powder bed, whereas if the wettability of the particles is high, then it would slow down the powder reaction and reduce the feature size. Another important factor is the particle size distribution that may differ the bulk density of powder and distribution of the pore size. Moreover, it also affects the drop penetration behavior of the water-based binder. The powder and binder interact with each other through the adhesive forces and chemical reactions (Shirazi et al. 2015). In order to print the food design, the water based binder is favored as polymeric binders may lead to the formation of undesirable unsafe food products.

Hydrocolloids are the hydrophilic polymers that form the colloidal dispersions in water. In the liquid based additive manufacturing technique, hydrocolloids forms gel with the food ingredients and alter the rheological properties of the mixture. A wide variety of food textures have been created by using the gelatin and xanthan gum along with the flavoring agents (Cohen et al. 2009). Moreover, hydrocolloids are also used in the powder based additive manufacturing techniques by acting as a binder of the edible powders. In addition, it also helps in controlling the migration and flow of the spray (liquid) into the powder bed while printing (Diaz et al. 2015). Hydrocolloids for powder based mechanism should be approximately 0.1-2.0 weight % based on the total dry weight of the composition (Diaz et al. 2015, 2017).

Proteins

Proteins constitute amino acids that have both negative and positive charged functional groups. On the basis of the pH of the solution and the isoelectric point (pI) of the protein, proteinaceous polymers can be categorized as positive or negative charge. At the 'pI' of the protein, protein will show aggregation.

This feature of aggregating of the proteins at 'pI' proves to play a major role in liquid-based AM processes. Through this, a variety of new textures can be created. The combination of food proteins and polysaccharide materials (like gelatin and alginate) can also help in creating a wide range of new textures in AM processes. Moreover, compounds such as strong acid or base and application of the external stress (mechanical strength or temperature) can also be used in AM technologies as denaturation and aggregation of the proteins can also create new textures.

The conformation of the food proteins can also change with the addition of enzymes. In a study, a food additive transglutaminase was added in the meat to build complex structures. It was seen that when the transglutaminase was added in the meat puree just before the printing, the material retained its rheological properties, but developed a new protein matrix (Lipton et al. 2010). The reason for such kind of behavior was due to the fact that transglutaminase (enzyme) catalyzes the reaction involving the formation of covalent bonds between glutamine and lysine in a calcium dependent reaction. Therefore, the proteins of the meat puree were enzymatically cross linked and lead to the formation of self-supporting hydrogels (Davis et al. 2010). Another crucial ingredient that can be used as a 3D printer inks is the gelatin. Gelatin is a derived protein obtained from the irreversible breakdown of the fibrous structure of the collagen (acid or alkali treatment). It has a feature to melt-in-mouth that enables the consumer to taste a different flavor and texture. The air-dried gelatin has an ability to dissolve instantly in water at 40°C as hydrated molecules of the gelatin forming flexible single coils randomly. When cooled, these junction zones are linked with short polypeptide chains that again transform it to triple-helix type structure, giving rise to the formation of gel (Burey et al. 2008, Ward & Courts 1977). In the dilute solution, gelatin shows the Newtonian flow. Therefore, gelatin like flexible molecules should be considered in 3D extrusion process as charges present on the molecule can exhibit different effects on the viscosity profile of the product. Least viscosity is produced when there are both positive and negative charges on the molecule leading to the complete contraction of the molecule at the isoelectric point. Although the pH change can vary the ionization capacity of the functional groups that increases the value of charges. However, repulsion between the same charges can extend the molecule and give rise to a more viscous solution. The values of pH where the molecules show maximum extension, that point of molecule exhibits non-Newtonian behavior. In addition to pH, shear rate also plays a significant role in the flowability property of the proteins. The extremely high value of shear rates can give rise to non-Newtonian behavior (Kragh 1961).

Fat

Fat is formed when three molecules of fatty acid react with the glycerol to give one molecule of triglyceride (TAG). The structure and composition of the TAG can determine the material formulation for AM technology and also the end use of the functional properties of the material like the crystal structure, melting point range and solid fat index.

Fatty acids having higher number of carbon atoms exhibits high melting point. Therefore, the composition of TAG can help in determining the melting point of the layers deposited on the stage. Moreover, it can also help to know the self - supporting properties both before and after processing, especially in melting extrusion based AM processes. Lipton et al. (2010) altered the amount of butter in the traditional recipe of dough making. This alteration was done to ignore the liquefaction of the printed structures while baking. Moreover, bacon fat was used as a flavor enhancer along with the transglutaminase (additive) for printing the turkey meat puree.

For printing the 3D chocolate, it is very important to know the action of fat crystallization and their role in supporting the self- supporting layers. The essential component of the chocolate, cocoa butter, can exhibit up to six polymorphic forms (from I to VI, where, I have the lowest melting point and VI has the highest melting point) (Marangoni & McGauley 2003).

ADVANTAGES OF 3D FOOD PRINTING

There are several advantages of the 3D food printing. It gives the freedom to personalize ones own food. Composition of the meals can be decided according to the individual' health status. New components are used which are not used commercially. Preparation of meals is easy and simple. Both functional and aesthetic customization can be done at the same time. Moreover, novel food textures can be obtained. 3D printed food has a longer shelf life than the traditional processed food if the parts of the machines that are in contact with the food are properly sanitized. There is ease of transportation, even in the space (NASA). 3D printing opens the gateway of new techniques and opportunities to show creativity while designing the food (Izdebska & Zolek-Tryznowska 2016)

CHALLENGES IN 3D FOOD PRINTING

3D food printing is a bit more complex than traditional food cooking. Optimization of numerous conditions is required such, as the intended use of mechanical force, designing of the digital recipe and appropriate feeding ingredients. Every fabrication requires different pressure and technique to do it. In addition, the nozzle through which streams of food emit out, plays an important role in printing the food. According to the end product, size and diameter of the nozzle should be taken care of. Another important factor is the temperature at which the processing is being done as it affects the food mixture flow rate by the nozzle (Lipson & Kurman 2013).

Optimization of 3D food printing is a great challenge that needs to be solved at individual level according to their needs. When designing file of food design, certain things are needed by the computer, such as writing speed, number of layers, nozzle diameter, line distance, laser power, shape and layer thickness, temperature at which printing would be carried out and rapid cooling that should be set carefully. Moreover, when finalizing the ingredients and the recipe, the behavior and nature of that ingredient should be given special emphasis on (Yang et al. 2017).

APPLICATIONS OF 3D PRINTING IN FOOD SECTOR

The application of 3D food printing of various foods such as processed cheese, fruit and vegetables, chocolates, snacks, breakfast spreads, mashed potatoes, and many more are discussed under various headings as reported in different researches.

Effect of 3D printing on the structure and textural properties of processed cheese

In the study, Tohic et al. (2017) investigated four types of cheese viz. Untreated cheese (UC), melted cheese (MC), high speed printed cheese (HSPC) (extruded at 12 mL/min) and low speed printed cheese (LSPC) (extruded at 4 mL/min) for structure and textural properties. The cheese used in this study was standardized to 3% carbohydrate (2% lactose), 18% protein, 25% fat and 3% salt. The HSPC and LSPC samples were printed using syringe based extrusion printing technique. These samples were then analyzed to observe their textural and melting properties, microstructure and color. Confocal laser scanning microscopy (CLSM) was employed to study the microstructure of the varied cheese samples. When UC was seen through CLSM, it showed round fat droplets enclosed in a continuous protein phase, whereas, in MC sample, the size of fat droplets observed was more as compared to UC. However, the printed cheese samples viz. LSPC and HSPC when observed, showed a great variation in the microstructure. In LSPC, non-spherical fat globules were seen with discontinuous protein phase, whereas, in HSPC, non-spherical fat droplets were found to be smaller and uniform when compared to LSPC. This association of protein and fat molecules exhibits a certain effect on microstructure. This effect justifies the variations occurring in rheological and textural properties of cheese samples. Thus, the printed cheese samples showed the softer textures and can be easily melted due to the disruption of the protein phase, variation in the size and morphology of the fat globules.

It was observed from the study that cheese samples which were printed had lower hardness values and more consistent structure as compared to UC and MC. However, the hardness values of both HSPC and LSPC samples were similar to each other which concluded that the extrusion speed has no effect on the hardness. The decrease in the hardness values among the cheese samples shows that the stresses exerted by melting and combination of melting and shearing exhibits a significant effect on the texture of the cheese. In contrast, adhesiveness was increased in the MC, HSPC and LSPC when compared to UC. This increase value of adhesiveness might be due to the increase in the quantity of surface fat released during shearing of the sample. Although, the values of springiness of MC, HSPC and LSPC were similar to those of UC. A limited increase in the resilience and cohesiveness values were observed in MC, LSPC and HSPC when compared with UC (Tohic et al. 2017).

MC, LSPC and HSPC showed a vast difference in color as compared to UC. The samples having greater fat globule size were found to be darker than those having smaller fat globule size. Thus, MC, LSPC and HSPC were darker than UC (Tohic et al. 2017).

The high precision drawing method of chocolate utilizing electrostatic ink-jet printer

In this study, an electrostatic inkjet 3D printer was used for chocolate printing. Presently, the electrostatic inkjet 3D printer is utilized to print pastries. However, for printing chocolate, it is first printed on edible films and then is transferred to the complex free surface. In the present study, three types of discharge viz. Multi cone, drop and droplet state were invented. This change in the type of discharge is done by changing the gap between print surface and nozzle. It was also observed that when the voltage applied was higher than the drop state, then multiple corn was formed on the tip of the nozzle in multiple directions. In vice-versa condition, when voltage applied was lesser than the drop state, then there was no discharge. Thus, enabling this kind of printer to print complex patterns of chocolate on a free surface by using oblate film (edible) (Takagishi et al. 2018).

Printing a blend of fruit and vegetables. new advances on critical variables and shelf life of 3D edible objects.

A smoothie in the form of the pyramid was printed from fruit and vegetable blend. From the study, it was observed that the nutritional composition of the printed smoothie had relatively lower values than that of non- printed smoothie. However, microbial load was found to be more in a printed smoothie (4.28 log CFU/g) than that of unprinted one. This brings into focus that each part of the printer which is in contact with the food should be properly sanitized before actually utilizing it for printing the food. In addition, it was also observed that the acceptable level of printed smoothie was more than that of unprinted one amongst the consumers, although the sensory characteristics were same in both the cases (Severini et al. 2017).

Investigation on lemon juice gel as food material for 3D printing and optimization of printing parameters

In a study, Yang et al. (2018) proposed an idea of producing 3D printing, food based on the lemon juice gel system. The attempt to print lemon gel was due to its translucent, chewy and flexible properties. Potato starch was used as a gelling agent due to its transparency, water retention properties and aging resistant properties. It was observed that rheological behavior and mechanical properties of the gel was found out to be the best with the 15% incorporation of the potato starch in the lemon juice gel. In addition, it was also noticed that the 24 mm^3/s extrusion rate, 1 mm nozzle diameter and 30 mm/s nozzle movement speed were found to be the optimum conditions for printing the lemon juice gel.

Application of 3D printing for customized food. a case in the development of a fruit based snack for children

A study was conducted to print the snacks of varied shapes and designs in order to provide nutrition to the children. In this study, a food formula suitable for 3-10 years old was designed and printed to obtain an edible product of desired shape and dimension. The microstructure of the desired product was majorly affected by the flow of material. When the product was printed at lower flow, there was an irregular internal structure with interrupted filaments and had over porosity fraction too. However, when the product was printed at higher flows, the filaments of the product got merged and resulted in an increased thickness and total volume of the product. In addition, porosity also gets reduced. The study shows that there is a linear relationship between the weight of the product and printing time. Moreover, it was also concluded that both printing speed and flow level affects the growth rate in weight. At the printing speed of 70 mm/s, maximum rate obtained was 0.00362 g/s with a flow of 130%. Hence, a wide range of innovative food with different dimension and shape can be printed using 3D food printer (Derossi et al. 2018).

3D printing complex chocolate objects: platform design, optimization and evaluation

A low-cost 3D chocolate printer (melt extrusion based) was designed that is readily available and has open source components. In addition, different parameters were studied, including the extrusion rate, movement speed and cooling rate while printing the chocolate. Through this design, a complex structure of 3D chocolate bunny was printed. While printing the design, two major areas for optimization were identified viz. The extruder assembly should be designed as rigid as possible, as more the rigidity of the extruder assembly, lesser will be the flexion and hence, more accurate will be the deposition of chocolate. Another area for optimization is the design of an active cooling system which enables the quenching of chocolate at low temperatures. It is observed that when the chocolate is quenched with cool air, there is an increase in its ability to form the self-supporting layers. At 3.8°C temperature difference, the bridging span was increased by up to 2 mm. In addition, it was also shown that there is negligible effect of movement speed on the self- supporting layers. The extruded chocolate volume to translation speed ratio resulted in superior performance at 0.8 to 0.9 (Lanaro et al. 2017).

3D printing vegemite and marmite: redefining "breadboards"

Hamilton & Alici (2018) demonstrated the compatibility of the two breakfast spreads commercially available viz. Marmite and Vegemite with Food Layered Manufacturing (FLM) while producing 3D designs on the bread substrate. In order to print food material with FLM, the food material should have certain rheological characteristics to allow for its extrusion. Moreover, the study includes the creation of "breadboard", through which the breakfast spreads were edible circuitry fabricated by the use of inherent electrical conductivity. This creation and fabrication of food not only demonstrated the capacity of FLM but also demonstrated the learning tool for students. In addition, food products in edible electronics can be made commercially available. 3D printer based on a CNC milling machine controlled by LinuxCNC software was used to print edible circuits. After printing, different color LEDs were added and then, the "breadboard" was connected to the power supply (12V).

Impact of rheological properties of mashed potatoes in 3D printing

In the study, the impact of rheological properties of the combination of mashed potatoes (MP) and potato starch (PS) on 3D printing was studied. The relationship between formulation and process ability while printing the food was observed. It was found that the MP had low yield stress (195.90 Pa) and when printed, the product deformed and slip sideways eventually. However, when the MP was incorporated with 2% PS, the product showed impressive extrudability and printability. In other words, the product expressed good shear-thinning behavior, yield stress of 312.16 Pa, consistency index of 118.44 $Pa.s^n$ and fine elastic modulus. The conditions used while printing this product gives the product an adequate smoothness, resolution and makes it withstand shape over time. However, when the MP was incorporated with 4% PS, although it had an appropriate yield stress (370.33 Pa) and elastic modulus which enabled the product to retain good shape, but the high value of consistency index (214.27 $Pa.s^n$) and viscosity resulted in poor extrudability hence difficulty in printing (Liu et al. 2018).

Investigation on fish surimi gel as promising food material for 3D printing

Some researchers have studied the utilization of surimi gel as a material for 3D printing. Surimi was used as it is highly viscous in nature and can create new textures through a surimi gelation mechanism with alginate, gelatin and other polysaccharides that exhibit both hydrogel-forming and particle based gelation mechanisms. However, too high viscosity leads to the difficulty in printing, thus to decrease this problem, a concentration of 1.5% NaCl was used. The salt helped the slurry to flow from the nozzle and also, aided in the post-deposition for supporting its shape. In addition, with an increase in the concentration of salt, there was an improvement in the water holding capacity (WHC), gel strength and network structure. It is observed that there exists a linear relationship between the diameter of surimi slurry and extrusion rate. Higher the extrusion rate, more requirement of volume of surimi slurry will be and hence, the extruded product would be of larger diameter. Optimal parameters while printing the surimi gel was 2.0 mm nozzle diameter and 5.0 mm nozzle height (Wang et al. 2018).

Fused deposition modelling of sodium caseinate dispersions

An attempt to utilize the sodium caseinate for printing 3D objects was made due to its ability to reverse the gelation behavior. Sodium caseinate also provides an alternative to print the low protein food by forming the cross linkages with the solution, thus, increasing the gelation temperature of the solution. The sodium caseinate structures with the help of sucrose, pectin and starch were printed using Fused Deposition Modelling (FDM) approach (Schutyser et al. 2018).

Design and characterization of food grade powders and inks for microstructure control using 3D printing

In the study, cellulose powder (amorphous form) and xanthan-based binder were used in a 2D jetting process for making creative designs of food. The cohesive 2D designs were produced by setting the temperature of both substrate and ink cartridge and by altering the number of ink layers that are deposited on the powder. For 3D application, moisture present in ink along with heat recrystallizes the cellulose powder to form a network. This crystalline network acts as the dominant binding mechanism in the vertical and horizontal planes. Here, xanthan gum was used in small proportions for favoring ink jetting properties. Although, it also acts symbiotically with cellulose to reinforce the binding mechanism (Holland et al. 2018).

Applicability of protein and fiber-rich food materials in extrusion-based 3D printing

In the present study, foods rich in fiber and protein, however, possess sugar or fat in low amount are designed using 3D printing. For the effective 3D printing, there must be a proper interaction between the food chemistry, processing and the engineering. In the current study, foods such as milk powder, rye bran, starch, cellulose nanofiber, oat protein and faba bean protein concentrate and their mixtures were taken as a sample. These foods and their mixtures were printed using syringe based extrusion 3D printer. The formulation with 60% semi skimmed milk powder, 10% cold swelling starch, 15% skim milk powder, 45% faba bean protein concentrates or 35% oat protein concentrates was found to give the best 3D printing results. It was also observed that in order to obtain stable shape after printing, high yield stress was required (Lille et al. 2017).

Other 3D food printing applications

A 3D printed device was created that measures the strength, compression and fracture properties of the gelatins at the same time. The device consisting of concentric piston and cylindrical shaped tool was printed three dimensionally. Concentric piston was used to compress the sample of a cylinder shaped gelatin portion. While, the cylindrical shaped tool was used to sample the gelatin from the cup, a bloom-like test is required for the upcoming compression-extrusion test. For gelatins, a conversion factor of 4.2 ± 0.2 between bloom -like and bloom test was evaluated. The major benefit of this device is its ability to analyze several textural parameters (Rapisarda et al. 2017).

CONCLUSION

3D printing is widely used in various places for printing miscellaneous objects in various areas such as automobiles, pottery, robotic designs and food. 3D food printing has several advantages over the traditional food, cooking methods, however, a little bit complex to understand and apply while printing the food. There are various techniques through which food is printed such as extrusion based printing, inkjet printing, binder jetting and bio-printing. Presently, 3D food printing is mostly used in decorating and fabricating the food products such as chocolate, cookies and cakes, however, the actual printing of the food is done in a few areas only and by few companies. The process of printing depends on several factors such as the physical state of the food (whether powder, liquid or semi solid), size and shape of the syringes getting used, the composition of the ingredients such as carbohydrates, proteins and fats. However, to understand the effect of 3D printing on the microstructure of the food, detailed study is required. In spite of using 3D food printing as a source of fabrication, it can also be used as a treatment for the people suffering from nutrition related problems such as malnutrition by enhancing the nutritional profile in their meal. Thus, 3D food printing is a revolutionary technology used now and will have a much larger scope in future.

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