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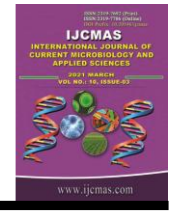

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3D Printing of Meat: A New Frontier of Food from Download to Delicious: A Review

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Novel digital food technologies utilizing the laboratory culture meat are emerging these days to support the ethical and environmental friendly production of meat as well as ensuring food security, food safety and environmental sustainability. Three-dimensional (3D) printing of a meat is a novel technology of food fabrication having huge market potential and potential application in developing a unique food with desired nutritional profile. The 3D printed meat products should possess multiple flavours, colours and intricate texture to make these products popular among consumers and overall success of 3D printing technology in meat sector. This review summarise the various aspects of 3D printing technology, its application and future challenges.

Introduction

3 D printing (3DP)technology, also termed as additive manufacturing (AM), rapid manufacturing, rapid prototyping, freedom fabrication solid freeform fabrication (SFE)is one of the disruptive technologies that create instrumental change in food and agricultural sector which has attracted attention from the food industry and digital technology entrepreneurs in recent years. The principle idea of additive manufacturing is to develop the product from digital Computer-Aided Design (CAD) software. The technology had been used for preparation of extrusion-based 3D printing of chocolate (Mantihal *et al.*, 2019), pasta (Sol *et al.*, 2015), meat puree (Lipton *et al.*, 2017), dairy products (Ross *et al.*, 2019), etc.

History

The technology of three-dimensional printing (3DP) appeared at the end of the 1980s and has emerged in the field of material engineering. The 3DP technologies gained considerable interest across various fields over the couple of years and have been utilised in different disciplines including, medical applications, dentistry, tissue designing, textile industry, electronics, avionics, automobiles and draw the attention of both industry and scholarly world and more recently in the food industry. Charles W. Hull was considered as founder of the 3D System who invented 3D printing and coined the term "Stereo Lithography". He proposed a method for the layer-by-layer synthesis by ultraviolet irradiation. In 1990's first 3D printer was built by 3D Systems by using ceramics, metal and some polymers and 3D products Z corp. For a long time, it was considered a leader in the sphere of common printing of 3D objects.

Widespread acceptance of digital technologies in the field of design (CAD) computer aided design (Attaran.,2017) engineering (CAE) and manufacturing (CAM) stimulated the explosive character of the development of the 3D-printing technologies. At present, it is extremely difficult to indicate a field of material production, where 3D printers are not used to one degree or another. In the year 2006 Fab@Homeand the RepRap are credited with sparking the consumer 3D Printing revolution. Paste extrusion by f.ex. Frostings, Nutella, chocolate (CornellUniv) 2006-2009 CandyFab, Sugar printing (Evil Mad Scientist Lab). In the year 2012-2015 FP 7-PERFORMANCE formulated food which is easy to chew and swallow for senior who was followed by the printing of advanced shapes by sugar or sugar sculpture by 3D Systems (Biozoon). In 2013, Modern Meadow Pvt. Ltd. USA designed unique bio-printing technology by utilizing multicellular aggregates (the bio-ink particles) forming biocompatible support structure as per design template having compatibility with desired biological construct with the help of bio-printer.

Market potential

The 3D food printing is having tremendous potential and at present mostly applied in in formation of complex textural designs and food products with desirable nutritive composition. According to UN by the year 2050, global human population will cross 9.6 billion marks and it will not be possible to meet the food demands of whole population by using the available resource unless newer more promising and sustainable technologies are applied in for this. The global market value is expected to exceed $ 520 million in 2023, with an estimate of only 38.5% growth in 3D food printers **(**Mordor Intelligence, 2019**).**

Development of different technologies could potentially solve the most eminent crisis of the not so distant future which has led scientist to develop a 3D printed meat despite impediments like the palatability factor. Global 3D food printing market accounted for USD 224.5 million in 2016 growing at a CAGR of 57.6% during the forecast period of 2017 to 2024. The 3D printed meat would not necessarily be considered as the substitute for conventional meat but it could rather be considered as the mean of providing people with healthy protein source in an ethical way.

Procedure

The major steps which can be effectively used in implementing additive manufacturing were described by (Haleem *et al.,* 2016) which follows a well-defined sequential process. First and foremost thing is to create a computer added design (CAD) model of configuration followed by the conversion of CAD model into standard triangulate language (STL) format followed by cutting into thin section and build the part of the model layer by layer followed by post processing\finishing and the joining processes.

Food technologists have upgraded the application of additive manufacturing (AM) in food sector due to its inherent multiple advantages such as with personalized food shapes and designs according to tastes and preferences, accuracy and very high degree of precision, desirable nutritive quality, etc. This is a very sophisticated technology which makes it possible to produces three dimensional designs of very complex shapes or geometries that could otherwise not possible to form manually by combining material together in various layers. By using this technology, it is possible to form product with hollow parts, complex geometries, hollow truss structures and internal structures with reduced weight, etc. Despite the fact that researcher face various challenges for competing, managing and incorporating the 3DP technology in the food industry due to immense variation in the physio-chemical properties of the food (Godoi *et al.,* 2016; Sun *et al.,* 2018). Presently, its applications are applied in wide areas of research such as elderly food, military and space food, sweet food. (Liu *et al.,* 2017) postulated three main aspects which profoundly affect the printing precision and accuracy are material properties, process parameters, and post-processing treatments.

The design of the 3D design is an important factor that can determine or influence the stability and precision of final printed objects. A good design should meet the needs of consumers and should be suitable for the parameters used in printing processes, such as printers, food inks, and post-printing processing treatments (Guo *et al.,* 2019).

Technologies used for 3DP

In 2012, the American Society for testing and materials (ASTM), developed standard ASTM/ F2792–12a, which provides definition of additive technologies. ASTM in cooperation with the International Organization for Standardization (ISO) developed international standard ISO/ASTM 52900:2015.There are seven categories of additive manufacturing (Table 1) recognized as per the ASTM standard terminology for Additive Manufacturing Technologies (ASTM,2020).Some technologies are classified on the following traits and their corresponding emerging technologies.

The processes of additive manufacturing are classified based on the material used and printable material which usually involves liquid processes like stereo lithography, fused deposition modelling and inkjet printing. (Vithani *et al.,* 2019)described following three main factors which have been primarily utilized in 3D printing of food viz.

To design the layout of food with special textures

To develop new nutrient rich food materials

To enhance the appearance by planning the design the food in complex structures via controlling the development of structures at micro- and macro levels

Different 3DP technologies have been applied to process the vitamins, additives, and flavours to propel food properties with tailor-made chemical, structural characteristics and to extend the shelf-life of food with increase demand to satisfy the exceptional need of individuals are explained in general.

Inkjet printing

Inkjet printing food ingredient is a technique to form 3D-printed food. In inkjetprinting, material dispenses stream/droplet from syringe type print head in a drop on demand way. The ejected stream/droplets comprised gravity, impact on the substrate, and dry through solvent evaporation. The drops can form a two and half dimensional digital image as decoration or surface fill (Godoi *et al.,* 2016). Fujifilm Dimatix is one of among the few companies to supply edible inkjet inks for drop-on-demand inkjet **(**Fujifilm Corporation, 2015**).** This technology mostly employed in low viscosity materials where surface energy of the inks rheological properties and temperature plays a very important role. Such type of printing technology uses commercial printing systems and inks which have been broadly used in food decoration design by the US Food and Drug Administration (FDA) (Lupton *et al.,* 2018).PolyJet processes use ink jetting to directly deposit material which is then solidified. This process allows for very different materials to be placed next to each other in complex patterns in traditional applications. Procter &Gamble Ltd granted patent for an inkjet ink that adds favour(Wen *et al.,* 2008). Biozoon with FoodJet have used this technique to make gelatine based foodstuffs. The jetting and setting process can be a difficult process to properly develop for foods**.** Hakola *et al.,* (2013, 2015) described the decoration of meat and bakery products by inkjet printing and laser marking. Both methods have been evaluated to be suitable for making temporary or durable markings on food. However, due to some constraints of inkjet printing for the construction of complex structures (Pallottino *et al.,* 2016**)** extrusion is still recommended as the most suitable methodology for 3D printingfibrous materials(Liu *et al.,* 2018).

Extrusion technology

Extrusion 3D printing or Hot Melted Extrusion (HME) or Robocasting is an emerging technology widely applied in food industry. Extrusion-based food printing is a digitally-controlled extrusion process to build up complex 3D food products layer by layer and is differentiated from food extrusion cooking. It is the most adopted method in food printing, whose real objective is to accomplish the output of the conventional food extrusion processing physically with a digitalized design and a personalized nutrition control. (Goyanes *et al.,* 2015) reported that fused deposition modelling (FDM) is an example of extrusion technology which expel or extrudes the hot melted material through nozzle**.** Primarily it was utilized for prototyping plastic and at present the technology has been applied to 3D food printing. The De Grood Innovations' FoodJet Printer (Foodjet., 2014) used pneumatic membrane nozzle-jets to deposit selected ink drops onto cupcakes pizza bases and biscuits. Among the available extrusion mechanisms (syringe-based, air pressure-driven and screwbased extrusion)air pressure driven extrusion for viscous paste materials are not recommended owing to their ease of attaching to the walls of the cartridge besides its use in food industry(Sun *et al.,* 2018). However Hot-melt extrusion has the similar potential since it has also been used for printing pharmaceuticals (Goyanes *et al.,* 2015).A few examples of food materials that have been successfully printed using this technique are fruit and vegetable (Severini *et al.,* 2018), dough (Yang *et al.,* 2018), pectin-based food formula (Vancauwenberghe *et al.,* 2018), meat (Dick *et al.,* 2019) and gel based material (Wang *et al.,* 2018; Yang *et al.,* 2018a)**.** The food printer designed for hot-melt extrusion likely to have compact size, and low maintenance cost but may have a seam line between layers, long fabrication time, and delamination caused by temperature variation, that need to be further investigated.

Binder jetting PBP(powder binder printing)

Binder jetting powder binder printing(PBP) also termed drop on powder printing, works on an intrinsic mechanism which permits to construct model by employing a binder less than 100 μm to selectively bond layers of powders which is successively deposited on to the powder bed surface in a drop-on-demand print head based on ratter scanning pattern. Once one layer is printed, a roller or blade deposits a fresh layer of powder for the next cross sectional design to be jetted on to and follows an inkjet print head moves across a layer of powder and selectively deposit liquid binding material.(Sun *et al.,* 2015) added that in order to prevent spreading from nozzles binder should have low viscosity during which physical phenomenon and ink density plays a crucial role.(Holland et al.2018)developed food grade inks for Fujifilm Dimatix printer which possessed the required properties that can be successfully printed. The relevance of binder jetting to food has typically utilized starch and sugar powder mixtures with water or alcohol based binders to produce macro scale, decorative 3D structures (Walters *et al.,* 2011**)**.The wide use of applying binder jetting to food materials, or a diet with high consumption of sugary foods has been linked to numerous health affects like obesity and type 2 diabetes and its reduction or substitution within the diet is being lobbied for by activist groups and governments globally (Edwards *et al.,* 2016)**.**Sun *et al.,* (2017) noted that 3D Printing technology options for food materials are beginning to be discussed to suit specific processing requirements**.** Powder printing has some potential in food printing for powder type of foods similar to pharmaceutical applications (Ventola., 2014)

Selective Laser Sintering (SLS)

This type of 3D printing uses a computer to control the location of laser irradiation to successfully sinter the powder layer by layer. Complex shapes can be successfully formed by sintering powders selectively. **(**Noort *et al.,* 2016**)** successfully used power laser on fresh powder, which move along X and Y axes to fuse powder particles so that they can bind together and forms a solid layer. This process is continued until the desired structure is made. Finally, the unfused powder is removed and reclaimed for next printing TNO's Food Jetting Print.(Gray *et al.,* 2010)applied the laser to sinter sugars and Nesquik powders. The Candy Fab selectively used low-velocity stream of hot air to sinter and melt a bed of sugar. In the, the SLS procedure was performed by (Diaz *et al.,* 2014)by creating colourful and detailed edible object using a carbon dioxide laser with laser spot diameter 0.6 mm, and specific process parameters (layer distance of 0.1 mm, writing speed 1250 mm/sec, laser power 50% and layer thickness 0.3 mm). Although there are several hurdles for using SLS in the food sector.

Hydrogel-Forming Extrusion(HFE*)*

Rheology of the gel and polymer plays an important role while extrusion. Hydrogel-forming extrusion (HFE) is an another extrusion technology which generally print the hydrocolloid solutions or dispersion having viscoelastic property into a polymer/hardening/gel setting bath using syringe pipette, vibrating nozzle, jet cutter, and alike apparatus and convert into self-supporting structure before the consecutive deposited layers (Sun *et al.,* 2018). Moreover solution temperature is required to form a stable shape in HFE. (Serizawa *et al.,* 2014) designed 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. Most of the complex 3D shape structures, which usually mimic skeleton and cardiac muscle, were achieved by this method. It is possible that, with the help of detailed model designing and with the help of 3D printing technology, muscle tissue entity with protein rich food inks can be printed and processed for consumption of astronauts in outer space. Interestingly, a hi-tech system, which combined tissue engineering with 3D printing technology, is able to generate foods with high protein content and a fibrous appearance to produce vegetarian steak (Vialva., 2018). Some vegetarian consumers think 3D printed vegetarian meat products are alternative to animal foods and are willing to try them **(**Chung., 2013)

Merits of 3DP

The texture and organoleptic attributes of a product is very important for determining its acceptability in the market. Novel meat products having unique flavour combinations, intricate and attractive designs, eating experience, on-demand modified nutritive value and texture, three dimensional designs etc. are having great potential in meat sector and can open unlimited opportunities in near future. The development of such products is possible by using 3D printing technology. Due to the potential advantages of 3D printing technology in food industry in near future, it has gained interest by researchers and academicians of food industry. It is possible to formulate novel food products with higher nutritional value, complex shapes and unique textures by using different food ingredients and various printing technologies.

The 3D printing is a sustainable and energy efficient technology. It has inherent advantages such as efficient utilization of food ingredients with minimum or no waste, on demand inclusion of functional ingredients, improving eating experience, automation, saving on labour, lower energy and transportation cost, easier supply chain, increase scope of ingredients used for food, shifting of food manufacturing in proximity to consumers, etc (Dick *et al.,* 2019; Lie *et al.,* 2017).

In food science, 3D printings finding its application in improving efficiency of operations, composite and designer foods, developing novel and convenient functional products, on-demand nutritional food, waste utilization and alleviating global hunger and ensuring food security, developing of specific or personalized food products for particular sections such as for elderly person having problem in swallowing or mastication, etc. For wide popularization and application in industry at large scale, the issue of high capital investment at the beginning, time consumption, issue of limited printable materials, safety issues, accuracy and surface finish of the food material should be sorted out at earliest.

Printability of food

On the basis of printability, (Sun *et al.,* 2015) categorized food ingredients into three categories viz. native printable, non-native traditional printable and alternative ingredients. A material with native printability possesses sufficient flow ability and can easily extrude through nozzle and does not require addition of any flow enhancer substances. However in this some materials have sufficient structural strength to withstand the 3 D structures such as cheddar cheese whereas some have low rigidity and difficulties in maintain 3D structure or design such as Greek yoghurt. The materials not having sufficient structural strength are not suitable for 3D printing even having sufficient flow ability. In case of non-native printable traditional food ingredients, there is a need to add flow enhancer substances to facilitate extrusion and subsequent cooking operations such as staple foods. The flow enhancers are added to improve the rheological and mechanical behavior during layer deposition during 3D printing process such as 1% fish collagen in fruit and vegetable blend to form edible pyramids (Severini *et al.,* 2018), agar in celery to form extruded gel (Lipton *et al.,* 2010), addition of gelatin, starch, gum, pectin, alginate (Vancauwenberghe *et al.,* 2017). Alternative ingredients refer to emerging novel source of functional compounds having potential to be used in 3D printing of food in development of food with balanced nutrition, customized foods and traditional foods.

Application in meat science

The global world population is on the rise. With the foresee scenario, it is predicted that this population will not be able to meet the protein needs. According to World Health Organization (WHO) need for protein sources and nutrition, the daily protein intake is determined as 0.66 g protein / kg body weight. In other words, the amount of quality protein needed by a 50 kg person per day is calculated as 33 g (WHO / FAO) Expert. According to the Environmental Protection Agency (EPA), the traditional meat industry (combined with the agriculture industry) produces 18% of greenhouse gases on the planet changing from typical meat to 3D printed meat accompanies a horde of advantages so shifting from conventional slaughterhouses will enormously diminish the creation of ozone harming substances. So as to increase margin of profitability and to respond the challenge of feeding the ever increasing population very few researchers worked to reshape meat and meat products &produce high value added meat products (Dick *et al.,* 2019a).Thereby printing meat is a positive development to decrease human impacts on a worldwide temperature alteration.

Potential of 3DP in meat industry

Meat industry can possibly assume a significant part on the consolidation of this innovated technology dependent on the rich protein content in the muscles combined with the variety of fatty oils and mineral substance. Meat industry can possibly assume a significant part on the consolidation of this innovated technology dependent on the rich protein content in the muscles combined with the variety of fatty oils and mineral substance. Printing of fibrous material is a pre-processing technology whereby complex, specific and uniform structure can be made easily by extrusion with added binders or texturizers, emulsifiers such as hot binders hydrocolloids (Voon *et al.,* 2019**)**, viz xanthan gum, guar gum and gum tragacanth, Blood plasma proteins (KPP), Blood plasma proteins (BPPs), from meat source (Theagarajan *et al.*, 2020) have potential use on 3DP processes due toits emulsifying and heat coagulating properties. They can enhance the binding mechanisms between proteins-proteins or proteins-polysaccharides giving rise to stable self-supporting layers. Starch, cellulose, gellable protein additives, transglutaminase, sodium alginate can be added to provide fibrous material used should be in viscoelastic form and have rheological and flow able properties so that it can be printed into the specific free structure after deposition without slumping, spreading, or bridging(Lipton *et al.*, 2010). A few investigations expected to create emulsion based product which can be utilized as fat replacer in meat items (Souza *et al.*, 2018).Some natively extrudable material like dairy by-products whey protein, casein, and egg by-products should have the same property. Moreover, (Dick et al.2019) suggested that low-value meat or carcass parts can possibly be converted into the personalized meat product by adding value to it by 3d printing technology.

Limited research have worked in the area of 3D printing of meat products which consists of building the desired CAD model from finely meat paste with controlled particle size to ensure extrusion through the printer nozzle and controlled temperature below 4°C, especially for fluid -based methodologies, like extrusion based printing and inkjet printing.

As a rule, a particle size of paste ingredients should be significantly lower than the intended diameter of the 3D printer nozzle to prevent clogging. Lipton *et al.*, 2010investigated varieties of multi-material food among which turkey, scallop and celery that were processed and modified using transglutaminase was successfully cooked and fried by Fab@Home extruder type 3Dprinter which exhibit that 3D printed food could be prepared like customary food. (Lipton *et al.*, 2015) observed change either by combining materials with different textures in patterns or by changing porosity of the product printed mesotructure, while the nutritional composition is regulated by changes in its recipe. (Godoi *et al.*, 2016) used transglutaminase enzyme to form a protein matrix between lysine and glutamine residues in a calcium-dependent reaction which enabled meat printing.

In the 3D Food Printing Conference Asia-Pacific, Meat and Livestock Australia 2017proposed the creation of meat scrolls made from emulsified secondary carcass cuts, which all around kept up their shape after frying. In the same year, the printability of seafood materials has likewise been tested to some extent whilst blended canned tuna with spring water was 3D printed as part of a meal designed for dysphasic patient. (Liu and Wang 2018) were able to 3D print chicken, pork and fish in a slurry form with the addition of gelatine solution. (Dong *et al.*, 2019) used sweet potato starch (8% w/w) as a structural modifier for achieving stable 3D-printed constructs from fish surimi gel. More recently, another study was reported on the effect of hydrocolloids on the printability of pork, providing ideas for the development of dysphagia foods (Dick *et al.*, 2020). Dick *et al.*, (2019a) applied 3D printing technology in meat and studied the factors impacting the printability and post-processing stability of printed products. They found that the infill density (50%, 75%, and 100%) affected the internal voids and post-processing stability and ultimately affected the texture of cooked products.

Table.1 Various technologies for the 3D printing of food

S.No.	Technology	Traits	Corresponding technology
1	Binder Jetting	Binding agent deposition	Powder bed and Inkjet heat (PHIH) Plaster-based 3D printing (PP)
2	Material Extrusion	Material pushing.	Fluid deposition modelling(FDM)
3	Material Jetting	Material dispensing, Jet technologies	Multijetmodelling (MJM)
4	Sheet Lamination	Sheet material binding	Laminate object manufacturing (LOM) Ultrasonic consolidation (UC)
5	Vat Photo polymerization	Photo polymerization in a vat of liquid photopolymer resin	Stereo lithography (SLA) (Digital light processing (DLP)
6	Powder Bed Fusion	blending of material in a preformed layer	Electron beam melting (EBM) Selective laser sintering (SLS) Selective heat sintering (SHS)
7	Directed energy deposition	Direct energy supply quickly in the spot of building and Thermal energy is applied to intertwine materials by softening upon expulsion	Laser metal deposition (LMD)

Table.2 Applications of 3d printing in food sector

3D product	Work	Reference
Processed cheese	Structure and textural properties	Tohic et al.(2017)
3D edible objects	Printing a blend of fruit and vegetables, critical variables and shelf life	Severini et al.(2017)
Fruit based snack for children	Application of 3D printing for customized food	Derossi et al.(2018)
Chocolate objects	platform design, optimization and evaluation	Lanaro et al. (2017)
Vegemite and marmite	Redefine, Breadboards	Hamilton and Alici(2018)
Fish surimi gel	As promising food material for 3D printing.	Wang et al. (2018)
Extrusion-based 3D printing	Applicability of protein and fiber-rich food materials	Lille et al.(2017)
Food grade powders and inks	Design and characterization, microstructure control using 3D printing.	Holland et al.(2018)
Canned tuna	3D printing of blended with spring water	Kouzani et al.(2017)
Healthy and stable foods	Application of extrusion-based 3D printing technology to mixtures of egg yolk or egg white and rice flour	Anukiruthika et al.(2020)
Egg yolk	Impact of thermal treatment on the rheological, microstructural, protein structures and extrusion 3D printing characteristics	Xu et al. (2020)
Egg white protein objects	Optimization of the formulation and properties of 3D-printed complexes	Liu et al.(2020)

Table.3 Ingredient systems used in 3d printed foods and the purpose of their incorporation

Ingredients	Sub ingredient	Purpose	References
Carbohydrates	Maltitol and Xylitol	Sucrose replacement, Reduce the risk of obesity caused by highcalorie chocolate	Xiao et al. (2019)
	Isomaltose	Prevent the contact between the Cordyceps flower powder molecules, Decrease formation of rigid network structure	Teng et al.(2019)
Protein	Pectin	Produce pectin-based food simulants	Vancauwenberghe et al.(2019)
	Pea protein	Used for printability of potato starch-based 3D printing ink.	Feng et al.(2018)
Dairy additive	Whey protein isolate	Used for whey protein isolatescontent on the printing performance of milk protein concentrate	Liu et al.(2018)
	Whey protein isolate	Studied Gel-like emulsions prepared from WPI and soy oil through micro fluidization processing technique.	Liu et al. (2019c)
Miscellaneous	Egg white protein	Added to improve rheological, texture properties of the mixture system	Liu et al.(2019)
	Insects powders	Used as source of alternative to animal protein	Severini et al.(2018)
	Pea protein & Xylose	Used forMaillard reaction product of xylose–pea protein enzymatic hydrolysate in 3D printing	Zhou et al.(2020)

Table.4 Some 3D printed meat products

Food material	3D Printer/model	Approach for enhancing the printability	Materials added	Reference
Meat puree	Fab@Home, Cornell University	Enzyme addition	Transglutaminase (no information for the amount	Lipton et al. (2010)
Surimi slurry	Not given, but auger mixer with screw-based system	Gel weakening by salt addition	NaCl (0, 0.5, 1.0, 1.5, 2.0% w/w	Wang et al. (2018)
Beef-lard composite	Shinnove, Shihin Technology Co. Ltd.	Hydrocolloid addition and gel weakening	Guar gum (0.5 wt %) and NaCl (1.5 wt %)	Dick et al. (2019)
Ground chicken meat	3D food printer CARK (Controlled Additive manufacturing Robotic Kit)	Enhance printability	Refined wheat flour (1:1), (2:1) and 3:1w/w)	Wilson et al.(2020)
Surimi products	microwave 3D printer (XOM-3D, Nanjing Xianou Instruments Manufacture Co., Ltd., Nanjing, China	To promote self-gelation process	Synergistic effect of a microwave 3D print (MW3DP) and transglutaminase (TGase)	Zhao et al.(2020)
Sesame paste, chicken paste, and shrimp paste	Custom designed syringe based extrusion Modified X-Carve	Print multi-material food	3D-printed with in situ IR heating	Hertafeld et al.(2019)

Fig.1 Mechanism of 3D printing

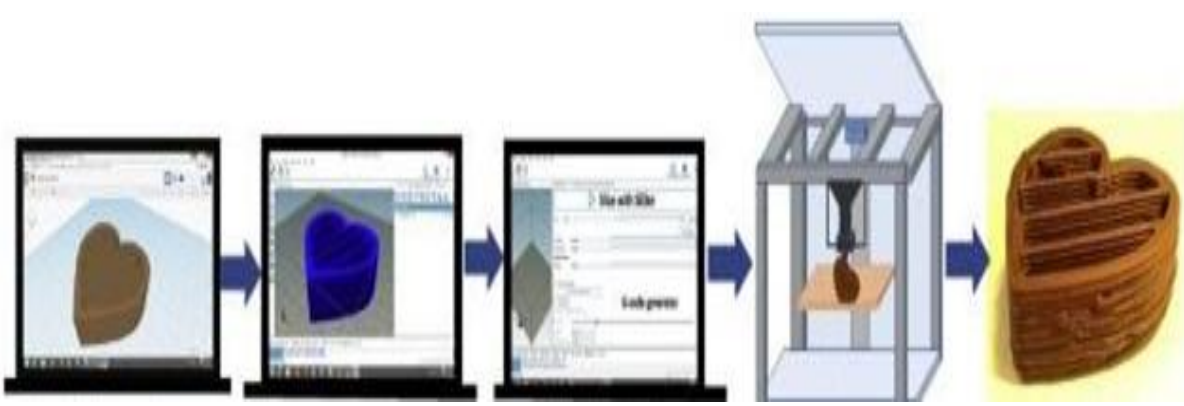


Fig.2 Benefits of using 3D Food Printing Technology

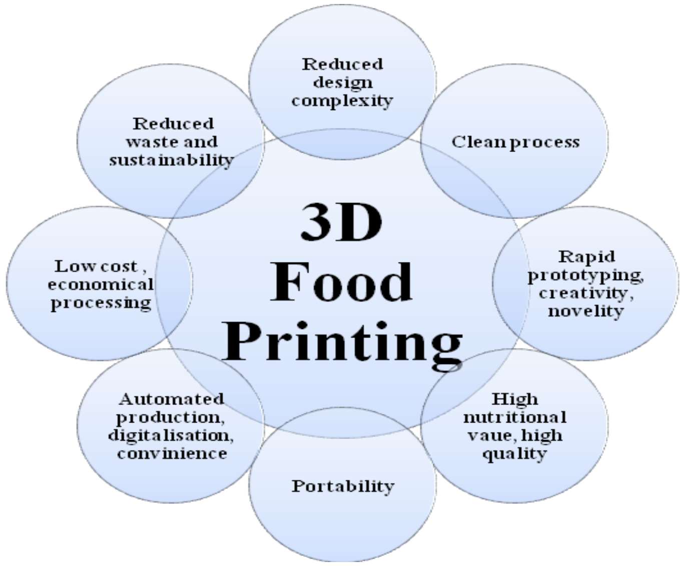
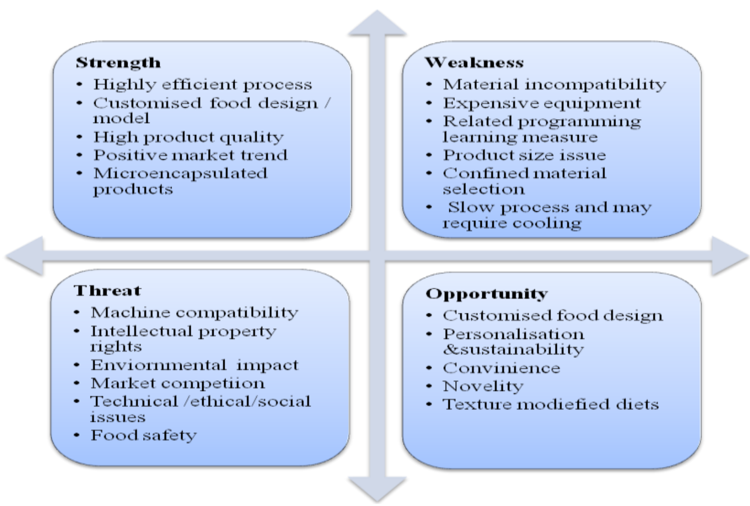


Fig.3 Swot analysis of 3d food printing



Different infill structures also affected the stability of 3D printed meat products. They also studied the effects of fat content and infill density on texture and physical characteristics of 3D printed meat products, cooked with lean lard composite layer (0, 1, 2, and 3 of minced lard). With the increase in infill density (50%, 75%, and 100%) chewiness, hardness, and moisture retention increases whereas the cohesiveness and shrinkage decreases significantly but had no effect on fat retention. These 3D printed products were conveniently cooked and preserved external and internal structures effectively.

(Liu *et al.*, 2019) examined the properties of milk protein gel framed utilizing sodium caseinate as a normal reference for 3D printing gel-like structures in different level viz. lower protein substance (350 g/L), medium protein substance (400-450 g/L), higher protein substance (500 g/L). As protein substance of the gel influenced the printability. A medium protein substance gave the best outcomes for printability and shape retention properties whereas lower protein content yielded unprintable gel structures and higher protein contents yielded lower printing quality. All things considered, proteins can actually be utilized as an added substance in 3D food printing innovation to improve textural properties of complex food structure.

Opportunities and Challenges

(Liu *et al.,* 2017) noted the issues of printing precision and accuracy, process productivity and production and production of multi-flavour, multi-colour, multi-structures products as major challenges in application of 3D printing technology in food industry. Printing precision is very important for success of 3D printing technology in food industry. For designing 3D printed food with high precision, the knowledge of various printing parameters and processing conditions such as rheological properties, particle size, nozzle diameter, utilization of multi-nozzle printers, proper printing speed, printing distance and post-processing methods as baking, frying, cooking should be given due considerations and properly optimized for better product development and increase the process efficiency along with improving cost effectiveness by reducing production cost.

Further as we increase the complexity of structures and ingredients, it also increases the complexity of the whole process of printing and put a control system and technical challenge (Liu *et al.,* 2017). (Liu *et al.,* 2017) noted that to meet desired nutritional value and structural design, in addition to printing machine, there is requirement of printing methodologies, food ingredients, prototype design, compatible software, optimization of various processing parameters, consideration of post-processing process such as cooking, etc. (Lin *et al.,* 2020) developed an android app where the consumer can choose their satiety level and play with the infill properties and size of the printed food. Last but not least, even though labelled to be among the "future food", the prospect of finding a 3D printer in every kitchen rely on one thing: "They need to become cheaper, faster, and easier to use

The need of the hour is focus on development of 3D printed meat products with multiple flavours, colours and intricate texture to make these products popular among consumers and overall success of 3D printing technology in meat sector.

In conclusion three-dimensional (3D) food printing is a progressive innovation that has stimulated the interest of various areas in the scholarly world and industry. This promising innovation permits manufacture of complicated and customized food configuration including surface, appearance texture, taste, nutrition. Nonetheless, 3D printing is insignificantly applied in large scale manufacturing by the business of food regardless of its important points as far as adaptability, exactness, low wastage and capacity and its opportunity in design. The current 3D printing innovation is in reality limited by cost, time, and measure of creation for an enormous scope. However post processing of 3D printed food is required to render it edible, making possible to create a wide range of printed food.

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