Vol.2 Issue-3, NOV 2021 (e-ISSN: 2582-8223)

JUST AGRICULTURE
multidisciplinary e-Newsletter

3D Food Printing Advanced Technology in Food Processing

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ARTICLE ID: 012

The method of creating food products using additive manufacturing techniques is known as 3D food printing. Food-grade syringes are often used to store the printing material, which is subsequently deposited layer by layer through a food-grade nozzle. 3D printing technology is concern with an Additive Manufacturing (AM) technique applicable in the food industry which referred to as Food Layered Manufacturing (FLM) process. In recent years, with advancements in robotics era, 3D printing technology has gained importance in food processing sector by the application of advanced techniques to prepare the variation in the different processed products.

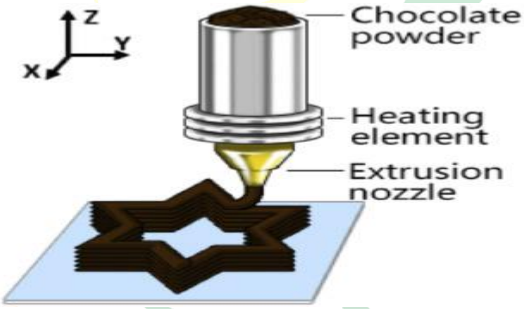
The Concept of 3D Food Printing:

Traditional food processing techniques involve a series of unit operations such as weighing and mixing of material supply, cutting and slicing of whole materials to desired sizes and shapes, and so on with the regular observation during the processing of the food product with the two dimensional forms. Food production in two-dimensional forms is not a novel concept with graphics printing to prepared meals like picture cakes and embedded letters and logos in cookies. These operations are time-consuming and more labour intensive process as it could be eliminated by using 3D printing techniques, which combine the majority of such a series of flow process unit operations into a single step with the advance technique. 3D-printed foods may not have the same high quality as goods made using traditional food processing methods, but some processes, like a gluten production and dough leavening, may need to be pre-conducted, while the remaining processing operations such as shaping the material its baking in oven may need to be replaced by Adductive Manufacturing Process. 3D food printing commonly said as a multi-material food printing is to integrate traditional food processing technologies and its correlated operational structure with AMP in a fascinating study orientation.

3D food printing technology (Source: Youtube.com &www.sciencemeetsfood.org)

Extrusion 3D food printing process:

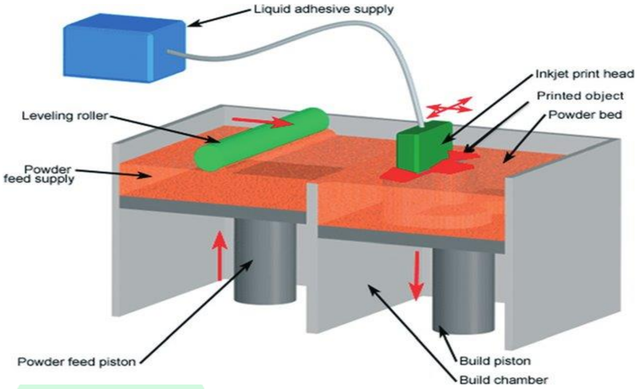
Layers are deposited by a moving syringe nozzle loaded with the material supply by extrusion in extrusion printing, which is adapted from the Fused Deposition Modelling (FDM) technique. After cooling, each layer is fused to the one before it. The method is simple to use and may be applied to printing liquid and semi-solid materials. After a hydraulic piston drives the material out of the nozzle with enough force for layer-by-layer deposition, motors attached to printer heads coordinate syringe movement. To bind separate layers, some formulations require post-deposition heating, cooling, or hydro gel formation.



Extrusion 3D Food Printing Process (Source: www.sciencedirect.com)

Ink-jet printing is a powder-based 3D Food Printing Process:

The essential principle of ink-jet 3D food printing is the controlled accumulation of material supply droplets. This method can be used indefinitely or only when needed. Ink-jet printing is a powder-based technology that uses a printed liquid solution to glue layers of solid particles together. A thermal or piezoelectric mechanism can be used in the printer head. In a thermal head, heating creates enough pressure to force droplets from the nozzle; in a piezoelectric head, an acoustic head splits the liquid into droplets, which are then ejected at regular intervals. Cookies, cakes, and pastries can all be printed using this method.



Ink-jet printing is a powder-based 3D Food Printing Process (Source: www.reserchgate.in)

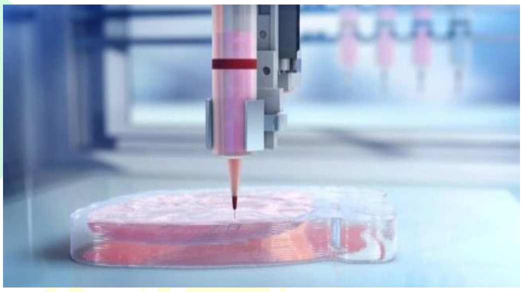
Powder Binding Deposition 3D Food Printing Process:

Powder binding deposition is a popular technique for 3D printing foods which includes the different processes according to the material used as follows:

- **Selective Laser Sintering (SLS):** A heat source is used to fuse layers together (hot air or laser). In SLS, the laser power source sinters particles together, and works best when producing multi-layered food. Nutrients and flavour are added to manufacture foods using this technology. Layer binding in SLS is accomplished through the melting of sugars or fats to create foods such as sugar cubes and curry cubes.
- **Selective Hot Air Sintering and Melting (SHASAM):** Sugar-based 3D objects were produced using SHASAM, which involved fusing powdered material supply with hot air.
- **Liquid or Powder Binding (LB or PBP):** In LB printing, powder layers are accumulated through direct fusion, which means the binder is put on top of the powder layer, sintering the powder particles together. Food fluids, such as hydrocolloids and protein-based substances, can be sprayed over powder beds to create edible 3D sculptures in a cost effective manner having suitability for printing powder-based materials.

Bio-Printing 3D Food Printing Process:

Bio-Printing process is to create tissues without using a biomaterial base in the 3D food printing process. It entails the deposition of biomaterials and living cell cultures layer by layer during the product formation. The bio-material is first deposited into an appropriate bio-compatible surface. After that, it moved to a bioreactor, where it develops the necessary biomechanical properties during the maturation process. The common practice includes with the micro-extrusion and laser-assisted printing techniques used to prepare edible porcine tissue as a sustainable alternative meat production method.



Bio-Printing (Source: all3dp.com)

Effect of various engineering properties on food constituents of 3D printed food:

A food material with dietary components such as protein, carbohydrate, and fat has a greater understanding of how each component affects the Extrusion-based 3D food printing process.

Carbohydrates content: Carbohydrates in extrusion enhance food structure retention after printing when employed at any concentration over the gelatinization point. As protein sources, the Skim Milk Powder (SMP) and Semi-Skim Milk Powder (SSMP), due to its high viscosity, extrusion with SMP proved difficult. The product's stickiness was reduced due to its higher fat (9%) and low carbohydrate content (23%) in SSMP. The printability of SSMP was good, and the structure was retained better after the printing process. Another significant metric in carbohydrate fractions is the material supply's glass transition temperature (Tg). Simple sugars like fructose (with a Tg of about 31°C) have a lower Tg than high molecular weight carbohydrates like maltodextrin. It is critical to maintain Tg control following the printing process in order to preserve the structure of the deposited material. Sugar affects Tg in food systems. Sugar is a key component of the particle system in printing processes like the powder bed binding process. They work as plasticizers by acting as a co-solvent. Process parameters such as melting point, powder density, compressibility, wettability, and size of sugar crystals have direct implications on the properties of the fabricated food. A variety of carbohydrates require pre-processing since they are not naturally printable. Food printability can be improved by adding water or appropriate gelling agents (such as hydrocolloids). The rheological characteristics of the material supply are altered as a result. They can also function as a binder, allowing liquid spray to migrate and flow more easily onto powder beds. Based on the total dry weight of the composition, researchers propose hydrocolloid values of 0.1–2% (by weight).

Starch content: Shear thinning is a rheological characteristic of starch that makes it ideal for hot extrusion. Based on this, researchers tested the link between rheological characteristics and printability using three different starches (potato, rice, and corn). All three starches showed shear thinning and strain response, indicating that they are acceptable for extrusion printing. Understanding such ideas can aid in the customization of starch-based printed meals.

Protein content: The micro structural and textural characteristics of printed food are influenced by protein. When proteins are the primary source of material, pH and isoelectric point become important criteria to consider. Protein aggregation can help in liquid-based printing techniques that are controlled by gelation and hydrogel formation mechanisms. Proteins and polysaccharide materials can be deposited along with polysaccharide materials during the printing process to change the texture of the product. Because of protein denaturation and aggregation effects, external stress (such as temperature) or chemicals (such as acids or bases) can change texture. In a study on meat, by addition of transglutaminase to beef puree is used to preserve the rheological characteristics of the flesh. Because of the self-supporting structure of protein conformation, this may be accomplished, and the addition of enzymes can change the process. Another component worth considering is gelatin, which has been shown to work well in 3D printer inks. The protein structure is changed and disturbed during printing, resulting in the "melt-in-mouth" feel. This approach has been utilized by researchers to improve the softness and meltability of cheese.

Fat content: The organoleptic and physical characteristics of printed meals are influenced by fat composition. Melting range, solid fat index, and crystal structure are all determined by the content and structure of triglycerides. The melting point of the material supply is used in the melt extrusion process. Based on the triglyceride content, the melting point of deposited layers, as well as their pre- and post-processing characteristics, may be changed. Fat crystallisation is related to structural stability in printed chocolates, changes in fat globule size might result in a deeper hue in printed cheese, increasing fat content to prevent printed meals from liquefying during baking.

Fiber content: The printability of various protein and fibre mixes in extrusion. The printability defined in terms of the extrusion process's simplicity and homogeneity, as well as the accuracy and stability of manufactured items in the semi solidified form. The amount of fiber in the material supply has an impact on printability. Fiber in the material supply might potentially induce nozzle blockage in 3D printer due to its larger particle sizes. They linked high yield stress to manufactured material stability and stated that when a material supply is sheared via the nozzle tip, flocculation effects might occur. The addition of fiber will have an impact on the product's customer acceptance. Fiber insertion causes a cascade of modifications, ranging from material characteristics to textural alterations during post-printing procedures. Nanocelluloses have also been employed due its excellent shear thinning action, even at low concentrations. In aqueous media, nanocellulose gel networks have the ability to self-assemble in food.

World Globalization of 3D Printed Foods

With advancement in 3D printing technology, culinary experts may exchange ideas for manufactured meals, making it simple for them to obtain original data files and print delicacies as it needed. 3D printing technology can assist in combining the culinary and creative abilities of many artists and chefs into a single printed file for the manufactured meals. As 3D printing advances, people may be able to create new things at their respective home within a short period by purchase ideas online in this smart era. Consumers can use mobile apps or websites to customize or purchase designs via an e-commerce platform. 3D printing can streamline the food service chain by lowering distribution, packaging and warehousing expenses. Each printing platform may be tailored to work with a specific set of file types. Even though different printer types can print the same file, there will be noticeable differences in the quality of the manufactured result. As more standards and standardized food printer configurations reach to the market, these concerns may be solved as recipe file sharing becomes a trade. Online trade of 3D food printing recipes is likely to join the market shortly, resulting in fierce rivalry in terms of cost, product variety, and manufactured product look. Another major consideration is that personalized goods would arrive at the table far faster than traditional food processing technologies could.

Application of 3D printing Food Packaging

Food packaging is an interesting area that 3D printing is moving into the commercialization of packaging system. 3D printing process utilized to build prototypes of food packaging using the fast prototyping durable approach. Consumer attraction and impression of food packaging system can be anticipated to make it commercialization in terms of flexibility, wording and designs aspects with modern packaging system. 3D printing may also make market testing simpler with some innovative and imaginative designs ideas that create the preference effect on the customer attraction. Customers may have their desired and engraved initials and photographs carved on their parcels with the 3D printed effect. A bio-degradable packaging incorporated to prepare cups packed with energy drink components, with a focus on food based sustainability. To make the ready to eat serve energy drink, consumers will only need to add sufficient amount of cleaned water for ready consumption purpose.

3D printing Food Packaging (Source: 3dprinting.com)

Market review and Consumer approach towards 3D Printing technology

The food 3D printing industry is rapidly expanding, driven by consumer demand for large-scale customization and increased convenience given by 3D printing technology in terms of aesthetic appeal and personalized nutritional profile of food matrices. 3D printing enabled stringent quality assurance and exact nutritional control. Environmental friendliness and long-term technology sustainability are two more factors that encourage industry expansion. A reduction in environmental footprint is linked to the use of less raw material and reduced energy usage. Many processes of traditional processing may be combined using printing technology, and meals can be produced on demand. This can decrease food waste generation. The market success of a novel dish is determined by customer preferences. Many technological constraints have been solved with little attention has been given to how consumers perceive 3D-printed foods. Many customers were dubious of 3D printed meals, wondering if they were safe to eat, if they were nutritionally deficient, and if they would have any adverse effects. Consumers like 3D-printed foods for a variety of reasons, including customized nutrient content, personalization, and the potential to help reduce food waste. These researchers performed a customer study using a questionnaire that included questions on previous awareness of printed meals, health advantages, convenience, customized nutrition, desire to consume, product attractiveness, creativity potential, and other socio demographic factors. People have little understanding and experience with printed meals as 3D printing is a new method that has yet to reach the market at the same level as traditional food reached. The survey assisted customers in learning about the advantages of 3D printed meals and in conquering food anxiety. In fact, the dread and apprehension that prevents consumers from embracing printed meals has become the bedrock for understanding consumer attitudes regarding printed foods. These important considerations must be made throughout the production and marketing of 3D-printed meals.

Challenges in 3D Food Printing

3D printing technologies provide numerous advantages over traditional production techniques with drawbacks. Printing process is dependent on the operation rather than the operator's competence in relation with mechanical force required, material standardization and process formulation with the selection parameters of acceptable food ingredients.

Challenges in 3D Food Printing (Source: cubemarketplace.com)

The new manufacturing process is influenced by the ambient temperature, nozzle size and diameter, material supply flow rate, deposition rate, and resolution of the 3D printer used for the preparation the food product. Some of the concerns related to the incorrect ingredient mixing in the material supply chain, material supply stability and strengthening during the pre and post-printing factors in its manufacturing process. AM has the same potential for trouble as the PC and the internet services. It is impossible to overlook the necessity for new regulations on intellectual property rights and piracy for such type of technology. The dangers associated in the cyber-physical environment of AM to arise as security issues at various stages of the AM supply chain. Defect detection in 3D-printed items requires a complementing technology, and quality assessment techniques must be established. Machine vision systems, for example, can be utilized in such applications. The printing speed is a major stumbling block to the commercialization of 3D printing in the food sector. Bulk manufacturing is difficult due to low capacity rate due to raw food flow process. Furthermore, printed meals have a short shelf life. Due to rheological behavior changes, the dough utilized in 3D printers, for example, is only stable for 1–2 hours after creation the final food product. In bulk production, safety will be a major concern. There is currently no industrial scale 3D food printer available in the market and developing such type of printers at low prices with great reliability and running capacity to produce large scale production.

The cost of five 3D-printed smart cups was goal of lowering down the price of the used package in the near future. This indicates that AM can encourage the recycling of plastic waste and the use of biopolymers in food packaging. Although cost is an issue, 3D printing can provide personalized food packaging. Leading food companies are currently experimenting with smart and intelligent package prototypes using the best of AM applications for food packaging.

Conclusion:

3D printing technology can offer processed meals a new dimension and assist in the production of individual-specific nutrient-dense foods that are accessible to the average person. It has the potential to open up the market for the development of new business models under start up community. In the developing digital culinary sector as a food restaurant, 3D food printing concepts will play a key role to establish a start up model. Printed foods, on the other hand, are still in the early stages of ongoing research and more development practices and will require no. of process optimization trials before it being released to the market with the accurate database and its set up in a commercial level. The capacity to print diverse food components with the local consumer acceptance in varying textures and structure as well as elements of printed food safety is the part of investigation and R &D Development process. For the structure of commercialized 3D printer, a no. of various process parameters with their optimization level, production innovation parameters, and scale-up for bulk level operations all remain challenges in this field for the next future. 3D food printers will comes up with the working component of household and retail customer-based systems where networked machines. The 3D printing principle also apply to various types of plastic, metal and glass containers packaging system for the betterment in food packaging scenario of such new 3D food printing technology.