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3D FOOD PRINTING: A REVOLUTION IN FOOD MANUFACTURING TECHNOLOGY- A REVIEW

J. Sofia[1], N. Ethiraj[2]
[1]Department of Mechanical Engineering, Panimalar Engineering College, Varadarajapuram, Poonamallee, Chennai, 600123, India
[2]Department of Mechanical Engineering, Dr. M.G.R Educational and Research Institute, Chennai, India
**Corresponding author: jsofiav@gmail.com*

Abstract
In recent past, the technology of production with additives has emerged as one of the most promising. Unlike traditional manufacturing methods, material is piled one layer on top of the other to build the geometrically complicated structures. As a result, additive manufacturing is widely employed in a variety of industries such as aerospace, automobile, construction engineering and healthcare. The food industry is not immune to this technology. 3D printing is a term for additive manufacturing, which is used to create food with a broad range of forms, textures, and nutrients. As a result, 3D food printing is a technology for using 3D printing in the food industry (3DFP). The modern worldwide population is quite fussy about many elements of food such as appearance, flavour, health advantages, and so on. 3DFP has the potential to be a game changer. Hence, this paper presents an overview of the various processes of 3DFP along with the inks used, nutrition of such foods and consumer attitude.
Keywords: Additive manufacturing, 3D Food Printing, Inks, Nutrition, Attitude.

1. Introduction

The food industry is undergoing a significant transformation. Person's greater understanding about what they eat, as well as their desire for unique, fresh sensory input, are driving the technological innovation to meet these needs. 3D printing, widely referred by the name additive manufacturing, opens up a novel host of prospects in the food industry. The method of generating three-dimensional material substances from a computer database is known as additive manufacturing. An object is built in an additive technique by depositing successive layers of required material until it is complete. All layers depicts a meticulously carved cross-section of the object. The polar opposite of additive manufacturing is subtractive manufacturing, which includes cutting or hollowing out materials pieces using any type of machining processes. The additive technology is used in various industries such as automobile, aerospace, construction engineering, textile and healthcare. It is widely used in healthcare industry for fabricating patient specific implants, scaffolds used in the surgical processes, even for the delivery of drugs. [1,2] 3D printing, proposes plethora of new opportunities in the foodstuff industry. 3D printers offer various benefits to the food and catering businesses, from the fabrication of sophisticated foodstuff designs to the manufacturing of customized meals. A literature review was conducted to extract all papers connected to 3D Food printing to learn more about it. Because 3D food printing is new and only low-level evidence is available, there were no time or evidence constraints specified. All similar and irrelevant papers were eliminated after titles and abstracts were evaluated. This review included papers on 3D food

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printing that were hand-selected. Nanotek Instruments Inc. received a patent in 2001 for "rapid prototyping and manufacturing technology for 3D food products". Unfortunately, Electrolux and Philips, two appliance specialists, failed miserably in their future attempts from a number of technological flaws, and they were unable to find any industrial or residential uses for food printing in 3D.[3] Motivated by the MIT's FabLab project, two of the Cornell University students introduced the Fab@Home Model1, the operational, compatible with food & reproducible 3D printing system, in 2007.[4] Since then, many projects are being carried out to improve and adapt this technique to various food constructs[5]. Godoi et al. [5] have discussed additive techniques on the food ingredients. Unlike him, this article has reviewed not only the processes, but also the attitude of consumers towards food printing in 3D along the nutritive benefits it imparts to various classification of consumers.

2. Technologies for 3D Food Printing

Additive manufacturing offers a big significant competitive advantage as it allows the geometric complexity to tailor to individual design requirements [6].

2.1 Extrusion technology

Fused Deposition Modelling (FDM) or Fused Filament Fabrication methods (FFF) are employed in the extrusion process. These methods use a fixed or movable nozzle to extrude material in a hot or cold condition different layers onto a base plate to create a 3D object. The advantage of the extrusion technique over other options is the broader variety of food items that may be extruded at the same time to form a complete meal. Extrusion-based printing creates a whole meal by extruding a range of food-grade materials at the same time.[7] However, the material must be able to extrude readily from the nozzle tip and support the weight of subsequent print layers without warping.[8] Input factors such as nozzle size, printing speed, and extrusion rate must all be optimised.[9] The Button mushroom snack printed using extrusion technology is shown in Figure 1.

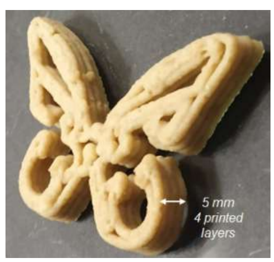

Fig. 1 Printed Button Mushroom Snack [9]

2.2 Inkjet printing

It is the most typical approach for surface stuffing or food decorations. To create an image out of a digital file, food ink droplets are produced and deposited on the exterior of the food, which might be a cookie, cake or candy. Because the print head is not exposed to the food during the printing process under non-contact method. This protects food from contamination while image fills. Materials having a low viscosity, such as water-based inks, pizza sauce etc., are ideal for this approach.[10] The benefits of this approach includes excellent resolution, precision, and the ability to print on numerous materials, however, post-processing can obliterate fine details, which is a disadvantage of inkjet printing.[11] Fig. 2 shows mashed potatoes printed in different forms using this approach.

Fig. 2 Mashed Potato [8]

2.3 Pneumatic Jetting

Pneumatic jetting is a type of inkjet printing that uses an extremely viscous ink. This is pushed by air pressure in a continuous and controlled manner through a discharge valve whose movement is inhibited by piezoelectric effect triggered by electric signals. In comparison to traditional inkjet printing, based on nozzle diameter, pneumatic pressure supports for the employment of higher viscosity inks. The employment of four distinct inks, honey, cream, starch, and fruit gel combined with a pneumatic jet to make a candy in colour has been reported and presented in the Fig.3 by YanPu et al. [12]. The alginate droplets were jetted into CaCl2 solution to form calcium alginate droplets, which is extensively used in drug delivery and tissue engineering applications. [13]

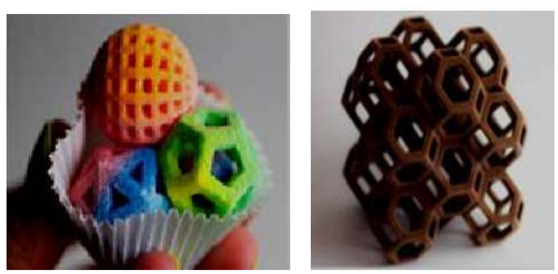

Fig. 3. Candy Structures [12]

2.4 Electrostatic Jetting

Jetting is assisted by the electrostatic attraction between both the ink and the substrate, which enables for the printing of inks with a higher viscosity. This method is used to print chocolate based toner with a density of 0.6 Pa.s. Electrostatic printing enables high-precision printing, culinary inventiveness, and improves the internal structure of the food, resulting in quality.[14] Suzuki et al. [15] created Chocolate Printers at Waseda University with electrostatic jetting technology, and the printing precision was obtained with Acrylonitrile Butadiene Styrene microfiber.

2.5 Binder jetting PBP (Powder Binder Printing)

Binder jet gets its name from the adhesive substance which holds the material particles in powdered form together during process. The process consists of two major steps that are repeated until the object is produced, using a plot created from a digital plan file. The re-coater applies the food flour layer upon layer in the initial step. The re-coater applies the powder layer to the structure area with exceptional precision, completely aligning the grains overhead each other. In the next phase, the liquid binder is sprayed by the print head, which then dispenses the binder material, letting it to come into touch with each grain of the moulding. Radiation heats the exterior often to improve mechanical properties and enable for the deposition of the following layer.[16] These methods are continued till the anticipated item is made, and then the moulding material is detached, allowing the desired object to be extracted.

Fig. 4 Chocolate Structures [18]

As a result, compared to traditional approaches, this modern concept makes it simple to create unique and complex items in less time as illustrated in Fig. 4 [17-18]. This method gives the rough look of the products obtained along with the requirement to dry the finished component at times of post processing for attaining better strength [11].

2.6 Selective Laser Sintering (SLS)

The SLS method is an expertise that involves applying materials in powdered form to a bed and then using a laser to harden only the desired object. Only the part of the surface that is uncovered to the laser solidifies and gives on a shape. Thermoplastic, metal, and ceramic powders are commonly used materials. In food, the SLS process uses powder ingredients like starch and sugar, and food additives like artificial hues and aromas can be added to give a range of flavours and colours.[19] Fig. 5 shows Nesquik printed using this process. However, the fabrication process is challenging owing to the complexity of the process variables.

Fig. 5 Nesquik [5]

3. Inks

Food substance, often known as "food ink," is the most significant component in the 3D food printer. These items must flow through a nozzle, but their properties are established once they are deposited on the surface. As an outcome, food components used in inks can have their thickness and flavour controlled.[20] Despite the fact that 3DFP is presently primarily used to prepare people's food containing special nutritional needs (dysphagia), in addition to snack and novelty products [21,9], By recycling food leftovers that might otherwise wind up in landfills, it has the ability to reduce food waste.[22] There is an expanding trend in the use of substitute protein sources such as algae, insects, spirulina, duckweed, lupin seeds, grass and beet leaves make foodstuffs that can meet buyer taste and nutritious needs.[23,24,25] Chocolates and other delicacies, as well as pasta shapes and protein patties may now, be made in previously impossible-to-manufacture forms and figures. Fruits and vegetables are printed as purees, with hydrocolloids (such as xanthan gum and gelatine) supplementary to retain the shape. They have good printability since they can simply be extruded from a syringe [26]. The summary of most commonly used food ink is shown in the Table 1.

Inks Used	Author
Processed Cheese	LeTohic et al. [27]
Vegetable and Fruit Blend	Severini et al. [28]
Snacks- Fruit based	Derossi et al. [29]
Chocolate	Lanaro et al. [7]
Vegemite and marmite	Hamilton et al. [30]
Canned Tuna	Kouzani et al. [21]
Healthy food made of Egg and Rice	Anukiruthika et al. [31]
Egg Yolk	Xu et al. [32]
Egg white protein food	Liu et al. [33]
Meat Puree	Lipton et al. [34]
Surimi Slurry	Wang et al. [35]
Beef Lard	Dick et al. [36]
Ground chicken meat	Wilson et al. [37]
Surimi products	Zhao et al. [38]
Sesame, Chicken and Shrimp Paste	Hertafeld et al. [39]
Snacks with Button Mushroom	Keerthana et al. [9]
Wheat Flour dough	Masbernat et al. [40]
High Protein Snacks ink	Zhu et al. [41]
Functional foods ink	Donn et al. [42]
Apple and edible rose	Qiu et al. [43]
Soft Cheese	Bareen et al. [44]
Jack Fruit	Chiu et al. [45]
KiwiFruit	Peng et al. [46]
Banana Paste	Ki et al. [47]
Rice Flour and Jaggery	Thangalakshmi et al. [48-
Starch	Chen et al. [50]
Lemon Mousse	Chow et al. [51]

Table-1 Commonly used Food inks

4. Nutritional Value

Innovations in 3D printing can be used for a variety of purposes making a huge assortment of prepared-to-eat food sources that fulfil the necessities of the people with explicit food-related afflictions (for instance, diabetes, hypertension, celiac infection and obesity) and individuals with personal nutritional inclinations (vegan, vegetarian etc.). Further, patients with Dysphagia, or difficulty in chewing and swallowing, can be helped by 3D nourishment printing. Generally smashed food, which are aesthetically unpleasant and nutritionally inadequate is being offered to dysphagia patients. In reality, food that are ground to a smooth paste can be used as printing ink in 3D printing, after filtering to recreate their primitive look or develop novel appealing textures while not diminishing their nutritive value [52-54].Thus 3DFP comes to the aid of such people to have appealing and appetizing food.

Also 3D printing is capable of producing custom food for people with special needs such as senior people, pregnant women, athletes and children by differing concentration of nutrients, lowering or removing unwelcome substances like anti-nutritional substances, introducing healthy constituents like fibres, phytochemicals and vitamins conventionally and hence offering foods of pleasant form [55]. Severini et al. [28] created smoothies with vegetables especially broccoli leaves and a mix of fruits comprising of avocado, carrots, pears and kiwi that retained their antioxidant activity after packing period of 8 days at 5°C. Lille et al. [46] employed 3D printing to create healthful foods which were high in protein and fibre but less in fat or sugar. Azam et al. [57] created Vitamin D enhanced blend of wheat stiffener and orange concentrate and using arabic guar along with k-carrageenan gums. Liu et al. [58] produced an air-fried food that, when compared to currently available potato snacks, could be deemed alternative with lower oil content. Feng et al. [59] observed that fracturability and hardness of potato snack when air fried were affected by infill pattern and diminishes with infill level.

Extra intriguing 3D printing use is creating functional foods by including probiotics to food inks. Zhang et al. [60] used fused deposition process to create probiotic-rich cereal-based meal architectures. They discovered that boosting the structure's surface-to-volume ratio allowed them to dip the time (6 minutes at a temp of 145°C), resulting in a product fulfilling requirements of probiotic food with feasible count of bacteria > 106 CFU/g after baking. When printing nutrient - rich foods, the impact of process parameters on cell survival is a challenge. Liu et al. [61] for example, optimised the nozzle diameter and printing temperature to incorporate Bifido bacterium animalis subsp. Lactisinto mashed potatoes. The nozzle span (0.6 mm) and temperature preserved at 55°C for 45 minutes reduced probiotic viability of mashed potatoes, according to the researchers. The probiotic viability was unaffected by storing the printed functional food at a temperature of 5°C for 12 days.

5. Consumer Attitude

Food choice of consumers are significantly influenced by many factors. But, one of the driving factor is pleasantness. As a result, numerous studies on consumer perceptions toward 3DFP are done during recent times. The research of Brunner et al. [62] is limited to the emergence and evolution of client attitudes toward 3D food printing and the resulting food conceptions. The survey comprised 260 German-speaking Swiss residents who had no prior experience with 3D-printed meals. The researchers discovered that providing specific information to individuals did not help them overcome their aversion to 3D printed foods.

Lupton [63] examined web news on 3D printed food technology on the basis of sociocultural view in another study, and discovered that 3D food printing is widely seen as innovative, healthful, creative, efficient, and eco-friendly technology. These topics, as stated by the author, were strongly tied to contemporary issues related to food such as safety and nutritional elements, healthiness, novelty, comfort and time-saving, and ecological implications.

Lupton and Turner [64] conducted a research qualitatively to study customer perceptions of 3D food printing. In March 2016, they conducted a four-day online focus group discussion with 30 Australians. Their study brought out the fact that there is hesitation towards 3D printed foods on its safety and edibility owing to unaccustomed factors like: food processing using a computerised technology that only few individuals have seen first hand; unusual looks of the food printed; the ingredients used to make such foods, which comprise of substances treated as inedible or inappropriate in western society such as algae, insects etc. Participants also voiced concerns about healthiness because of fat, salt, sugar and preservative levels in 3D printed foods; the safety of the manufacturing settings; the presence of allergens, and the technique's capability to conserve nutrients. The authors opined that 3D printed foods will gain more welcome form people if the visuals are more appealing and features like nutritional value, quality and freshness were apparent and assured to consumers.

Manstan and McSweeney [65] evaluated consumer outlook about 3D printed foods compared to traditional food products. First, two focus groups was held to know customers opinion on foods being 3D printed. outcomes of the focus groups were then utilised to lead an internet based survey with 329 inhabitants of Atlantic Canada. From the survey, three consumer clusters were distinguished: most interested cluster (140 respondents), which consisted of individuals who were willing to learn 3D food printing deeply and were convinced that this process could diminish food costs while elevating pros; the moderately intrigued cluster (98 members), which comprised of individuals who were eager to attempt 3D printed foodstuffs; and the not interested group (91 members), which consisted of individuals who were of the opinion that printed foods were inappropriate and risky.

Forgacs et al. [66] stated that implementation of bioprinting to manufacture meat substitutes by the fusion of multi cellular bodies partially. Lupton and Turner [67] recently conducted a research using an online discussion forum with Australian members on their thoughts about 3D food printing. They discovered that just a small number of participants were interested in food products prepared out of cultivated meat. Most of them thought this new meat substitute was "unnatural," and consequently not new, maybe hazardous, and ailing in taste and sustenance. Mantihal et al. [68] recently conducted a research to evaluate preference of 3D printed chocolate with the modified texture. Based on appearance and hardness, thirty semi-trained participants were polled on their overall preference for three chocolate samples printed with infill percentages of 25%, 50%, and 100%, respectively. The same group was insisted repeatedly to pick either a cast chocolate or a 3D printed chocolate. In terms of hardness, the Friedman test revealed no significant differences; however, panelists favoured look of samples with 25% and 50% infill percentages. The cast and 100 percent infill samples showed no significant differences.

6. Challenges and Future Potential

There is a significant mismatch between present printing technology and 3DFP in terms of software methods. As a result, there is a lot of space to improve and adapt current food ink technologies. According to some studies, Existing slicing software, such as Cura, has print specifications and path planning optimised for thermoplastic materials like PLA, which behave differently than food grade inks, resulting in poor print quality meals [69].This difference may be bridged by optimising process parameters like print speed and extrusion rate. This, together with other factors that may be corrected in the printer software, results in disparities between intended models and produced items, as well as printing times (both projected and actual). As a result, getting decent results now necessitates a lot of trial-and-error with the printing process. From hardware perspective, lack of appropriate technologies is seen in the copier types utilised in 3DFP testing. Although some research employed profitable food printers like Shiyin Tech's FoodBot-S2 or PORIMY's FSE 2, numerous others used open-source platforms like the RepRap or even bespoke printers constructed or modified from non-printers (typically CNC machines) outfitted with syringe extruders. It is unknown in most situations if these printers meet food safety regulations, which would be required for foods if printed. One plausible solution for this challenge is to develop both software and printer hardware planned explicitly for printing food. But, this is an arduous task due to wide range of food material properties used as inks and reduced compatibility with the existing system.

Improvements must be done in three factors in order that 3D food printing can be commercialised namely food safety, printing time and repeatability between batches. Because a high resolution may not be a necessity in most culinary applications, adaptive algorithms that adjust process parameters to balance print quality with time involved may improve speed. But Zhao et al. [70] conducted an in-depth study on various types of food inks in order to evaluate print height and stability of dimensions and eventually has proposed a model for the same. Food ink safety must be assessed by procedures such as monitoring the microbiological composition of food during preparation, printing and post processing despite the fact that a majority of people seemed hesitant to eat 3D printed food due to safety concerns [65]. The use of 3DFP, particularly for commercial uses, shall be aided by the development of guidelines and quality control methods. Although poorly displayed foods with altered textures could help persons with dysphagia as proposed by Xuebing Xing et al. [71], there are a number of obstacles to the viability of 3D food printing, along with the effort and time it takes to print personalised food and clean the printer[72].

7. Conclusion

Three-dimensional (3D) foodstuff printing is a rapidly evolving technology that has captivated the interest of academics and industry alike. This possible breakthrough allows for the creation of sophisticated and adjustable food configurations that include surface, texture, taste, appearance, and nutrition. Despite its significant advantages in terms of flexibility, exactness, minimal waste, and capacity, as well as its design potential, 3D printing is insignificantly, used in large-scale manufacturing by the food industry, as existing 3D printing innovation is constrained by cost, time, and capacity for a wide range of applications. In order to make 3D printed food edible, post-processing is also required, allowing for the fabrication of a varied range of printed foodstuffs. There are numerous ongoing research on 3D Food Printing which suggests that there is plethora of opportunities for customised food production with this boon technology.

Conflict of Interest

There are no conflicts of interest declared by the authors. Furthermore, no funding source in the governmental, private, or non-profit sectors provided a specific grant for this study.

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