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Review Article

3D Food Printing Technology

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Abstract

Three-dimensional food printing (3DFP) is a promising technology where food science principles and manufacturing technologies come together. 3DFP, also known as additive manufacturing, is a technology that creates three-dimensional food products by depositing edible materials layer by layer based on a digital design. 3DFP demonstrates significant potential in personalized nutrition, novel food design, and sustainable food production. The aim of this review is to provide information about fundamental mechanisms and applications of 3DFP technology. This review will be presented in an unconventional manuscript structure and the readers will encounter a frequently asked questions section following the introduction.

Keywords: 3D Food Printing; Additive Manufacturing; Food Technology; Food Design; Food Processing

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Introduction

3D printing, or additive manufacturing (AM), is a technique for constructing three-dimensional objects by adding material layer by layer, guided by a digital design. Unlike traditional manufacturing processes like machining or casting, which involve cutting away or pouring material into molds to shape an object, 3D printing (3DP) builds objects incrementally, reducing waste and offering greater flexibility in design (1).

3DP encompasses several technologies, each suited for specific applications, materials, and desired outcomes. According to ASTM Standard F2792 (2), 3DP technologies were catalogued into seven groups, as the binding jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photopolymerization. The most common methods of 3DP can be listed as follows:

- Fused Deposition Modeling: a filament (plastic or composite) is heated and extruded through a nozzle.
- Stereolithography: uses a UV laser to cure liquid resin into solid layers.
- Selective Laser Sintering: A laser fuses powdered material layer by layer.
- Digital Light Processing: Similar to Selective Laser Sintering, but uses a digital light projector to cure resin layers.
- Material Jetting (PolyJet/MultiJet): Tiny droplets of liquid photopolymer are deposited and cured layer by layer using UV light.
- Binder Jetting: A liquid binder is selectively deposited onto powdered material.
- Direct Metal Laser Sintering / Selective Laser Melting: A high-powered laser fuses powdered metals into solid layers.
- Electron Beam Melting: Uses an electron beam to melt powdered metals layer by layer in a vacuum.
- Laminated Object Manufacturing: Layers of material (paper, plastic, or metal) are cut and bonded together.

At the very beginning, 3DP were used for rapid prototyping and over time rapid prototyping evolved into AM which is a more advanced form that can construct intricate 3D objects (3). This revolutionary technique has found it place in the food sector as in many other fields such as military, aerospace, medical and etc. 3DP was firstly introduced in food by using an extrusion based printer named Fab@home and probably, Noy Schaal was the first person who printed a chocolate bar (4).

3DFP is an emerging technology with the potential to revolutionize the food industry and has several important applications (5-8). It combines 3D printing technology with food manufacturing (9). Some of the key areas of this game-changing and flexible technology can be listed as below:

Customized Food Designs: 3DFP allows for the creation of food products with complex and customized geometries (9-13). This enables the production of visually appealing dishes and unique food shapes that are not easily achievable through traditional methods (12,13). Personalized nutrition: 3DFP enables the production of food tailored to meet individual nutritional needs (10,11). This can be especially beneficial for people with specific dietary requirements, such as athletes, the elderly, or those with health conditions (8). 3DFP can also help to address nutritional deficiencies by enriching foods with vitamins and other nutrients (8).

Simplified Supply Chain: 3DFP has the potential to streamline supply chains by enabling on-demand production of food (8,14). The technology can reduce the need for extensive storage, and transportation costs associated with traditional food production 16. 3DFP can be particularly useful in remote locations or in situations where access to fresh food is limited 18.

Broadening Food Material Sources: 3DFP can expand the range of edible materials that can be used in food production (8,14). This includes using plant-based materials, insects, and other alternative protein sources to create novel food products (8).

Reduced Food Waste: By using only the necessary amount of material for each printed product, 3DFP can significantly reduce food waste (6,8,10). Additionally, 3DFP enables the utilization of underappreciated food ingredients, further reducing waste (8).

Texture Modification: 3DFP allows for the creation of foods with modified textures (11). This capability is especially useful for individuals with swallowing difficulties (dysphagia), as it enables the production of food with a texture that is safe and easy to consume (6, 8, 15).
Automated Food Preparation: 3DFP offers automated food preparation, reducing the need for manual labor (6, 16). This can be beneficial in commercial settings, such as restaurants and hospitals, as well as in domestic situations.
Potential for functional foods: 3DFP facilitates the incorporation of functional ingredients into foods (8-9, 13). This includes the addition of probiotics, vitamins, and other beneficial compounds to create foods with enhanced health benefits (17).
New Textures and Flavors: 3DFP can produce novel textures and flavors, expanding culinary options and improving the overall dining experience (7-8). By precisely controlling the composition and structure of food, 3DFP can unlock new sensory experiences.
Drug Delivery: 3DFP has the potential to be used as a drug delivery system in food (8). This allows for the combination of food and medicine, to deliver medication in a more palatable way.
Applications In Military and Space: 3DFP is being explored for use in military and space missions to provide tailored rations and nutritional support (8). The technology can address the unique nutritional requirements of soldiers and astronauts and provide ready-to-eat food on demand.
Sustainability: By reducing food waste, transportation costs, and the need for extensive packaging, 3DFP can contribute to a more sustainable food system (7-8).

Frequently Asked Questions

What are the primary 3d printing technologies used in food production?

Several additive manufacturing techniques are adapted for food, including:

Extrusion: This is the most common method, where food materials are pushed through a nozzle. It includes soft material extrusion for pastes and doughs, melt extrusion for chocolate and similar substances, and hydrogel-forming extrusion for gels and semi-liquids. The material's viscoelasticity is critical for successful printing.
Inkjet Printing: This technique uses print heads to deposit tiny droplets of edible ink onto surfaces for decoration and surface filling. It's often used for 2D images due to its handling of low-viscosity materials. There are two methods: Continuous jet printing, where ink is ejected continuously, and drop-on-demand, where ink is ejected under pressure.
Powder Binding Deposition: This includes methods such as selective laser sintering (SLS), liquid binding (LB), and selective hot air sintering and melting (SHASAM). SLS uses a laser to fuse powder particles together, while LB uses a liquid binder. SHASAM uses hot air for sintering.
Bio-printing: This technology is used for printing living cells and biological materials, especially in meat production.

What role do material properties play in 3D food printing?

The success of 3D food printing heavily relies on the rheological properties of the materials.

Key factors include:
Viscosity: How easily the material flows.
Yield Stress: The amount of force needed for the material to start flowing.
Elastic Modulus: How much the material can deform before breaking.
Consistency Index and Flow Behavior Index: These parameters are critical for extrusion-based printing, where low values allow material to be extruded easily.
Hydrocolloids: These substances, such as Xanthan gum, gelatin, and methylcellulose, enhance texture, stability, and extrudability.
The material's behavior is also influenced by its composition, temperature, and moisture content. Proteins such as gelatin behave differently at varying pH levels and shear rates due to the molecule's charge.

What are some examples of food materials used in 3D printing and what preparation is needed?

Many ingredients can be used, but they often require processing for optimal printing:

Mashed potatoes: Addition of potato starch improves its extrudability and shape retention. 2% potato starch showed excellent results.
Surimi (fish paste): Salt is used to adjust its viscoelasticity, improving print quality. 1.5 g of salt per 100g of surimi showed the best results.
Dough: The ratios of flour, sugar, butter, egg, and water must be optimized for proper gel and physical properties, with studies showing that gelatinized dough has improved precision. Additional ingredients and hydrocolloids such as xanthan gum and methyl cellulose are often added to improve consistency and printability.
Chocolate: It can be used in melt extrusion but requires precise temperature control to maintain structure. Tempering of chocolate using a seeding method can increase its viscosity for printing.
Egg and Rice: Eggs can be dried into powder form using methods like Refractance Window Drying for printing.
Wheat Flour: Can be mixed with other materials like freeze-dried mango powder and olive oil for printing with best results at a 57.5:30:3:2.5 ratio, respectively.
Lemon Juice Gel: When combined with potato starch, this can form stable 3D food constructs.

What is the current state of the 3D food printing market?

The 3DFP market is rapidly developing, with a focus on:

Confectionery: Many leading companies and research centers are focusing on sweets, especially chocolate, and several commercial chocolate 3D printers are available.
Customization: The ability to create customized shapes, textures, and nutritional content is a major driving force.
Personalized Nutrition: 3DP can produce food tailored to individual health needs and preferences, including modifying the shape, size, color and texture of a wide array of food products.
Industrial Applications: 3DP is emerging in bakery, restaurant, and food production facilities.
Automation: The potential to automate production of pureed foods and thickened liquids for people with dysphagia is currently being developed.
Open Source Projects: The open-source nature of some printers makes it possible for anyone to experiment with different materials, allowing for greater innovation.

What are the future directions for 3D food printing?

Future research and development in 3DFP includes:

Expanding Materials: Increasing the range of food materials suitable for 3DP.
Advanced Textures: Exploring novel textures and structures via heat treatments.
Nutritional Control: Enhancing control over nutrient content and delivery.
Multi-Material Printing: Developing printers with multiple print heads for complex food structures with varying materials.
Functional Foods: Creating foods with controlled release of flavorings, nutrients, or other functional ingredients.
Sustainability: Reducing food waste by using alternative ingredients such as insects and other unconventional components.
Improved Printing Technologies:
Developing faster and more precise printing techniques for mass production.
Microencapsulation: Integrating microencapsulation technologies for better delivery of bioactive compounds.

What is "Food Ink," and Why are its properties critical for 3D printing?

"Food ink" refers to the material used in 3DFP. Its rheological properties, such as viscosity, shear thinning behavior, and viscoelasticity, are crucial for printability. The ink needs to flow smoothly during extrusion, maintain its shape after deposition, and support subsequent layers. Characteristics like yield stress, thixotropy, and consistency behavior index are also important. Shear-thinning is particularly desirable as it allows the material to flow easily under pressure and then solidify after being deposited, holding the designed shape.

How do the properties of food components (carbohydrates, proteins, and fats) influence their suitability for 3D printing?

Each of the main food components present unique challenges and opportunities for 3DP. Carbohydrates can be used in various forms, such as flours and starches, but their printability often depends on their interaction with water and other ingredients. Proteins can be challenging due to their sensitivity to heat and shear stress which can impact functionality and structure, though they are often critical for the structural integrity of the printed product. Fats, while crucial for flavor and mouthfeel, can lead to issues like cooking loss and shrinkage during printing, making control of their content important. The specific interactions of these components greatly influence the rheology and printability of food inks.

What role do hydrocolloids play in 3D food printing?

Hydrocolloids (such as methylcellulose, guar gum, xanthan gum, and carrageenan) are essential in 3DFP. They enhance the printability of food materials by modifying their rheological properties, improving the stability and structure of printed objects, and aiding in shape retention. They can increase viscosity, prevent separation of ingredients, and reduce issues related to drying or melting during the printing process. The type and amount of hydrocolloid used must be carefully optimized for each food material to achieve the desired textural and structural properties of the final product.

What is the relevance of "yield stress" in food printing?

Yield stress is a crucial property, especially for extrusion-based 3DFP. It refers to the minimum force that must be applied to initiate the flow of a material. A food ink must have sufficient yield stress to remain in place once printed and to prevent slumping or deformation, while still being able to flow out of the nozzle under applied pressure. This balance is essential for maintaining the shape and structure of the designed product.

What are some key printing parameters that affect the quality of a 3D printed food product?

Several key parameters significantly impact print quality. These include extrusion speed, nozzle size and diameter, layer height, print speed, travel speed, and in-fill density. Material parameters such as the compressive pressure applied for extrusion, and the type of printer used (syringe vs. screw-driven extrusion) also play a big role. The ideal parameters can vary significantly depending on the type of food ink being used, often requiring extensive experimentation for each material. The balance of these parameters is critical to the success of the 3DP operation.

How do post-processing methods influence the final structure and properties of 3D printed foods?

Post-processing techniques are often used to finalize the product and to achieve the desired sensorial characteristics. Baking, steaming, air drying, microwave drying, and frying are used to modify the structure, texture, and appearance of 3D-printed foods. These processes can significantly affect moisture retention, hardness, chewiness, and shrinkage. The choice of post-processing method and its parameters depend on the materials used and the target properties of the product. Some food inks require cooking post-processing to become safe to eat.

What specific food products have been successfully 3D printed, and what materials were used?

A wide range of food products have been 3D-printed, including baked goods (like cookies, doughs, and snacks), chocolates, pasta, cheeses, meat alternatives, seafood, purees, fruits, vegetables and protein gels. Successful printing relies on carefully formulated food inks, and a variety of ingredients have been used to create those inks: wheat, rice and potato flour/starches, soy protein isolate, purees, fruit and vegetable powders, eggs, gelatins and a wide variety of hydrocolloids including alginate, xanthan gum, and carrageenan, among others. The recipes also include common ingredients like water, oils, salt, sugar and other seasonings. The diversity of these projects demonstrates the potential for a range of food applications.

Conclusion

3DFP technology presents significant potential for revolutionizing food production and consumption patterns. While challenges remain in terms of process optimization and material development, ongoing research and technological advances continue to expand its capabilities and applications. Future developments in this field are expected to address current limitations and unlock new possibilities in food manufacturing.

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References

1. Shahrubudin N, Lee TC, Ramlan RJ. An overview on 3D printing technology: Technological, materials, and applications. Procedia manufacturing. 2019 Jan 1;35:1286-96.
2. ASTM F2792-12a, Standard terminology for additive manufacturing technologies. ASTM International. West Conshohocken, PA, 2012.
3. Mantihal S, Kobun R, Lee BB. 3D food printing of as the new way of preparing food: A review. International Journal of Gastronomy and Food Science. 2020 Dec 1;22:100260.
4. Malone E, Lipson H. Fab@ Home: the personal desktop fabricator kit. Rapid Prototyping Journal. 2007 Aug 7;13(4):245-55.
5. Godoi FC, Prakash S, Bhandari BR. 3d printing technologies applied for food design: Status and prospects. Journal of Food Engineering. 2016 Jun 1;179:44-54.
6. Pant A, Lee AY, Karyappa R, Lee CP, An J, Hashimoto M, Tan UX, Wong G, Chua CK, Zhang Y. 3D food printing of fresh vegetables using food hydrocolloids for dysphagic patients. Food Hydrocolloids. 2021 May 1;114:106546.
7. Waseem M, Tahir AU, Majeed Y. Printing the future of food: The physics perspective on 3D food printing. Food Physics. 2024 Sep 1;1:100003.
8. Escalante-Aburto A, Trujillo-de Santiago G, Álvarez MM, Chuck-Hernández C. Advances and prospective applications of 3D food printing for health improvement and personalized nutrition. Comprehensive reviews in food science and food safety. 2021 Nov;20(6):5722-41.
9. Zhao L, Zhang M, Chitrakar B, Adhikari B. Recent advances in functional 3D printing of foods: A review of functions of ingredients and internal structures. Critical reviews in food science and nutrition. 2021 Nov 25;61(21):3489-503.
10. Bedoya MG, Montoya DR, Tabilo-Munizaga G, Pérez-Won M, Lemus-Mondaca R. Promising perspectives on novel protein food sources combining artificial intelligence and 3D food printing for food industry. Trends in Food Science & Technology. 2022 Oct 1;128:38-52.
11. Mantihal S, Kobun R, Lee BB. 3D food printing of as the new way of preparing food: A review. International Journal of Gastronomy and Food Science. 2020 Dec 1;22:100260.

12. Sun J, Peng Z, Zhou W, Fuh JY, Hong GS, Chiu A. A review on 3D printing for customized food fabrication. Procedia Manufacturing. 2015 Jan 1;1:308-19.
13. Kewuyemi YO, Kesa H, Adebo OA. Trends in functional food development with three-dimensional (3D) food printing technology: Prospects for value-added traditionally processed food products. Critical Reviews in Food Science and Nutrition. 2022 Oct 3;62(28):7866-904.
14. Liu Z, Zhang M, Bhandari B, Wang Y. 3D printing: Printing precision and application in food sector. Trends in Food Science & Technology. 2017 Nov 1;69:83-94.
15. Lorenz T, Iskandar MM, Baeghbali V, Ngadi MO, Kubow S. 3D food printing applications related to dysphagia: A narrative review. Foods. 2022 Jun 17;11(12):1789.
16. Lee J. A 3D food printing process for the new normal era: a review. Processes. 2021 Sep;9(9):1495.
17. Baiano A. 3D printed foods: A comprehensive review on technologies, nutritional value, safety, consumer attitude, regulatory framework, and economic and sustainability issues. Food Reviews International. 2022 Jul 4;38(5):986-1016.

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