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Applications Of 3d food Printing in Food Industries

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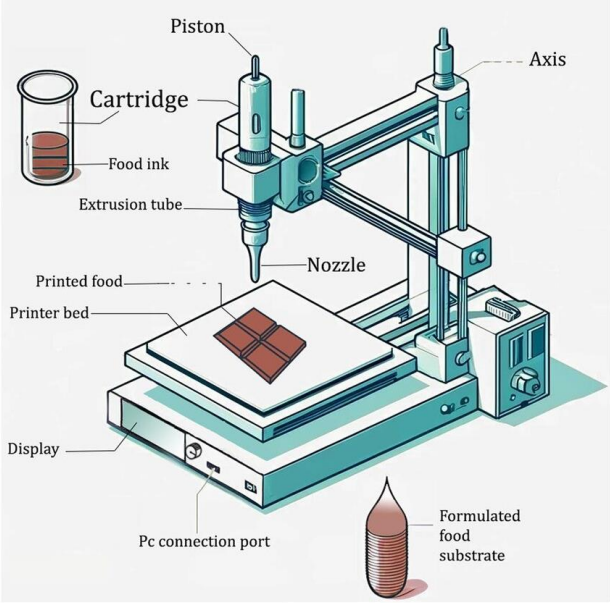
INTRODUCTION

3D food printing, a novel additive manufacturing method, revolutionizes food production by enabling precise layer-by-layer creation of edible products. This technique integrates culinary arts, engineering and materials science, employing specialized printers to stack food-based ingredients into customizable shapes and textures. Central to 3D food printing is its ability to tailor nutrition by customizing meals with specific dietary supplements, optimizing nutrient content, and individualizing portions to suit diverse dietary needs. Additionally, 3D food printing promotes sustainability by reducing food waste and improving resource efficiency (Waseem *et al*., 2024).

A standard food printer comprises three main components: A computer for user interaction, software that communicates with a motor control box and motors that control material extrusion and other parts (as shown in Fig.1.). The success of 3D food printing relies heavily on understanding the physical characteristics of food ingredients, such as viscosity, rheology, surface tension and thermal properties. Viscosity influences material flow and extrusion, while rheological properties, including shear-thinning behaviour and visco-elasticity, ensure proper layer adhesion. Surface tension contributes to the smooth shaping of printed food and thermal effects impact texture, taste and material state during processing. By combining physics and food science, researchers aim to address challenges in achieving precise designs, enhancing structural integrity and optimizing taste profiles. This emerging discipline holds the potential to transform food production and consumption, from personalized nutrition to environmentally conscious manufacturing. By advancing the interplay of physics and technology, 3D food printing can redefine how we create, experience and interact with food, driving innovation, sustainability and culinary possibilities (Waseem *et al*., 2024).



Fundamentals of 3D food printing

3D food printing combines engineering, materials science, and the culinary arts. By layering edible components, it creates complex food structures. Personalized nutrition, unique culinary experiences, and efficient food manufacturing can change the food business with this technology. 3D food printers need parts as mentioned earlier *i.e.*, a computer, control box, and printer. Food is printed from a computer model (CAD). Controlled extrusion or other deposition processes in the printer enable accurate material placement. The printer also heats or cools materials while printing (Mantihal *et al*., 2020).

Steps in 3D food printing include:

- Digital Creation: CAD software or 3D scanning is used to create the printed food item.
- Material Preparation: Edible pastes, gels and powders are carefully chosen or made to fulfill printing requirements.
- Material Loading: The printer loads prepared food into cartridges or syringes.
- Printing Execution: The printer builds the food structure layer by layer using the digital design file.
- Post-Processing: After printing, food may be cooled, heated, or dried to improve texture, form retention, or flavour.

Applications of 3D printing in food processing

1. **Personalized nutrition:** Advancements in 3D printing technology have revolutionized the food processing industry by enabling the production of customized food products tailored to individual dietary needs, offering significant benefits for medical nutrition, sports nutrition and consumer health (Leontiou *et al*., 2023).
2. **Personalized supplements and nutritional products:** 3D printing technology enables the precise formulation of supplements and nutritional products customized to individual needs, including athletes, the elderly and those with specific health objectives, by delivering exact doses of vitamins, minerals and other components optimized for their unique metabolic profiles and performance requirements, thereby enhancing efficacy and convenience (Leontiou *et al*., 2023).
3. **Enhanced food textures and structures**: 3D printing technology has transformed the development of intricate food textures and

structures, enabling innovations unattainable through traditional methods. This advancement enhances sensory experiences, improving food appeal and enjoyment. For instance, plant-based meats can replicate the fibrous and juicy texture of animal products by precisely layering plant proteins, catering to consumers reducing meat consumption. These capabilities enable personalized textures and novel culinary designs, enhancing dietary satisfaction and health outcomes (Pavan Kalyan *et al*., 2022).

4. **Reduction of food waste:** Food waste is a significant challenge for the food manufacturing industry, but 3D printing offers an innovative solution by repurposing surplus or imperfect ingredients into edible products. This technology minimizes waste by transforming leftover materials into valuable goods instead of discarding them. For example, a bakery uses 3D printing to convert bread and pastry scraps into creative snack items with unique shapes and textures. By turning these leftovers into paste and reshaping them, the bakery reduces waste while generating additional revenue streams. This approach promotes sustainability and profitability by optimizing resource utilization and reducing environmental impact (Padhiary *et al*., 2024).
5. **Environmentally sustainable packaging:** 3D printing significantly enhances sustainability in food packaging by enabling the production of eco-friendly alternatives. Biodegradable and compostable materials used in 3D-printed packaging reduce the environmental impact of conventional plastic. For instance, a company may develop plant-based, 3D-printed packaging that decomposes naturally, minimizing pollution and plastic waste. This innovation not only supports environmental conservation but also aligns with global efforts to reduce single-use plastics. By adopting 3D-printed biodegradable packaging, businesses contribute to a circular economy while addressing consumer demand for sustainable and responsible practices in food manufacturing and distribution (Versino *et al*., 2023).

CONCLUSION

3D printing technology is transforming food processing, offering innovative solutions for sustainability, efficiency and customization. At the food processing stage, 3D printing facilitates personalized nutrition, improves food textures and structures, and incorporates alternative protein sources, significantly reducing food waste. From a physics perspective, variables such as viscosity, rheology, surface tension and temperature play a crucial role in material selection, food design and structural integrity in 3D food printing. Physics also influences sensory attributes like appearance, texture and flavour through material porosity and heat transfer. Despite challenges like high initial costs, production speed limitations and regulatory concerns, advancements in bioprinting, blockchain and multifunctional materials present promising opportunities. Collaboration among physicists, food scientists, engineers and industry stakeholders are essential for driving innovation. By leveraging physics principles and technological advancements, 3D printing can redefine food production, delivering tailored, sustainable and high-quality culinary experiences.

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