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Review Article

Plant Based Ingredients in 3D Food Printing: A Sustainable Approach to Personalized Nutrition

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Abstract

Plant Based Ingredients to make edible inks for 3D food printing might help solve issues about food quality, food nutrition, and sustainability of food. We examine the molecular, functional, & nutritional characteristics of different plant proteins, plant Fibers & Hydrocolloids to determine their potential & their use as food industry. Additionally, we look at the possibilities of plant protein-based edible inks for 3D printing applications, where a material's form or other characteristics might alter over time to allow for precise issue profiles & texture modulations. Because of their superior structure-forming capabilities, and also their functional & nutritious qualities, Wheat gluten, pea protein, Lentil protein & soy proteins are frequently utilized as an ink for the 3D food printing applications. The use of 3D printing technology to create texture & improve probiotic & nutrient encapsulation in plant-based compositions was emphasized. Recent developments in 3D printing have been documented using edible smart materials that have been subjected to air-drying and microwaving processes. It was determined that the market sector for plant-based foods will be disrupted in three ways by 3D printing, Plant based meat, Personalized nutrition & Sustainability. This review addresses the latest developments in plant-based functional ingredients, or non-traditional food sources, that can be used as basis materials for 3D ink formulations & attention to the novel ingredients, their physiological role, and how their inclusion affects the product's rheological, structural, and printing qualities. 3D food printing has shown remarkable results in providing individualized nutrition and customized foods

Keywords: 3D food printing; Edible inks; Plant Protein; Personalized nutrition; Sustainability; probiotic.

1. INTRODUCTION

3D food printing is a technique that uses additive manufacturing to create three-dimensional food. Generally, the goal of this technique is to improve food's sensory qualities, nutritional content, or texture. In order to enhance nutritional value, novel protein sources for 3D food printing have been investigated, including edible insects [1] and milk protein concentrates.[2, 3, 4] 3D printing using dual extrusion and a multi-material extruder or adjusting the internal form [5] might change the textural characteristics of the 3D-printed object. However, in comparison to conventional food production processes, the goods that can produced using Technology for 3D printing is still limited. Furthermore, 3D printing is a significant barrier to acceptance as a food manufacturing technique because it is currently impossible to replicate the texture of real food. [6] In order to get over these restrictions, have explored a unique method to generate food that resembles plant tissue utilizing plant-cell-based food-inks (Valerian Ella locusta). They demonstrated the 3D printing capabilities of the plant cell-based ink by effectively encasing lettuce cells & air bubbles in a pectin-based matrix. However, the concentration of pectin employed as a matrix and the changes in porosity brought on by albumin were the only factors that significantly influenced the mechanical characteristics of the printed items in their investigation. Furthermore, the study did not look at how plant cell expansion affects the expression of cellular tissue. Thus, more research would be required to build microstructures resembling plant tissue and to increase the cell density.

Plant cell culture is the process of growing plant cells, organs, or tissues ,that have been separated from the mother plant in a suitable artificial setting [7] Since 1902, when Haberlandt [8] introduced the idea of cellular totipotency, this technique has been used and improved incrementally in a number of industries, including food production. According to [9], the majority of methods for working with plant cell cultures have included extracting the biomass metabolite from the cells by cell rupture. The potential of employing Technology for plant cell culture for the manufacture of plant-based food was confirmed more recently[10].

They cultivated cell lines after lingonberries (Vaccinium vitis-idaea), cloudberries (Rubus chamaemorus), and stone berries (Rubus saxatilis) to produce cell suspensions made up of sizable cellular clusters. In particular, the visual and sensory features of each cluster demonstrated fresh and berry-like qualities. The nutritional examination of the Berries grown in plant cells also revealed that protein levels were rather high, ranging from 13.7 to 18.9%, & that the protein digestibility in vitro demonstrated breakdown by digestive enzymes. According to these findings, the advancements in 3D food printing may benefit from the creation of plant-based foods. The culture process of 3D printed items containing plant cells may result in the formation of cellular tissue-like structure, which would allow for the replication of the natural texture and nutritional makeup seen in real meals. Creating food-inks using plant cell lines remains one of the most difficult parts of cellular tissue replication using plant cells. To facilitate cell multiplication, the matrix utilized in cell-based 3D printing should be biocompatible. The final product should also have sufficient printability and appropriate stiffness .[11] Alginates are a naturally occurring polymer made up of the residues of β-d-mannuronic acid and α-l-guluronic acid are linked by a linear co-polymer.[12] The egg box model is formed by alginates, wherein divalent cations, including calcium ions, crosslink the carboxyl groups in guluronic acid. The integrated plant cells may be fastened to the egg box model's gel scaffold, allowing the gel's structural porosity to constantly provide fixed plant cells with nutrients and oxygen during the culturing process.[11] Additionally, it was shown by Aguado et al. that alginate has a protective impact on cells and reduces stress on internal cells during the printing process.[13] Alginates are therefore seen as interesting options for plant cell 3D printing. Investigating the Possibilities of plant cell lines obtained from calli as a material to create a hydrogel model including plant cells and cellular structure was the aim of this investigation (Fig. 1). To create the ink formula, the plant cell lines—that is, samples of carrot callus were materially divided & embedded in an alginate matrix. The printability and proliferation efficiency of the callus-based food-inks (CBF) at different initial cell densities, & textural characteristics of the finished product were examined. The methods examined in this paper provide a foundation for assessing whether plant cell lines are suitable for the 3D food printing in order to replicate edible artificial cellular tissues that resemble natural food textures. Research into 3D food printing using plants is based on this.

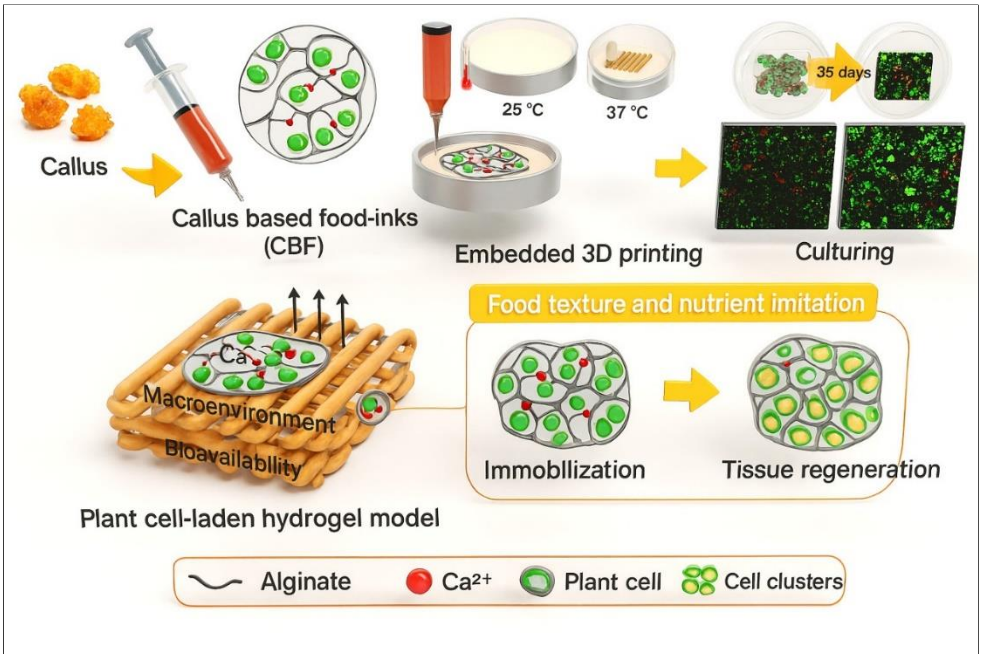

Figure 1. Hydrogel model loaded with plant cells that has a predetermined geometric precision thanks to the combination of 3D printing & plant cell culture technology

2.0 Primary Materials Utilized in 3D Food Printing

2.1 Intrinsic Printability of Natural Food Materials

These materials, which include hydrogels, cheese, hummus, cake frostings & chocolates, typically exhibit shear-thinning behavior to enable smooth extrusion from the syringe.[14] To illustrate the method, Cereals, starches, sugars, and mashed potatoes have been combined and tested as powdered materials using a 3-D printer that uses extrusion.[15] Combining baking with an extrusion-based 3-D printer, protein and dietary fiber-rich snack items were created using a blend of the milk powder and whole-grain rye flour. As sugar alternatives, maltitol, isomaltose & xylitol with sweetness levels of approximately 40–50% of sucrose has been employed to create a 3-D printed chocolate with composite polysaccharides.[16]

A variety of proteins, including pea protein, have been used to create culinary inks because of their gelling qualities.[17] adding 1% pea protein significantly enhanced the textural, thermal, and structural characteristics of starch-based ink. Therefore, adding a suitable quantity of pea protein to the ink mixture increased the printed food product's texture, stabilized its structure, and balanced its nutritional content.[2] Developed and manufactured printing paste made with a 2:5 ratio of whey protein separate (WPI) to whey protein concentration (WPC). According to reports, it had the highest printability since the addition of WPC and WPI softened the final paste and reduced its apparent viscosity, both of which improved printing. A research by Liu *et al.,* [18] created a milk protein composite material by combining WPC with a sodium caseinate solution, resulting in a 3-D print that contained around 400–450 g L−1 of total protein.

According to the results, this combination coordinated the model design the best & printed the best. These naturally printed materials enable a great deal of food material alteration depending on flavor, texture, and nutritional value. Some of these materials can be employed in space and medicine because they are stable enough to maintain their form after deposition, negating the need for additional post-processing. Post-deposition cooking procedures may be necessary for other complicated formulations, including protein pastes and uncooked batters, which makes it more challenging to maintain the food items' shape.[19]

2.2 3D Printing Constraints in Traditional Food Materials

Meat, fruits, grains, and vegetables are examples of food items that are not natively printed. Hydrocolloids like gelatin and xanthan gum (XG) have been permitted for use with these solid materials to increase their extrusion capability in a variety of gastro-culinary areas. For example, the Fab@Home3-Dextruder was used to combine XG and guar gum with brown rice. Various hydrocolloids were used to modify the microstructure, rheological characteristics, & texture of brown rice in order to create brown rice gels that printed well.

The mix of carrots, broccoli, and spinach leaves with XG printed well. The rheological value of gel system did not significantly change before and after the addition of the vegetable powder because of its high hydration capacity, which inhibited the extension of powder particles.[20] & demonstrated that by incorporating In the raw material, add 0.5 g XG 100 g−1. XG was able to resolve the deformation issue of 3D printed cookie products using After treatment procedures including baking. [21] Investigated pectin-based 3-D printing, including applications that print pectin-based food simulants utilizing low methoxylated Using pectin gels in the 3-D-ink. Through the formation of calcium cross-links between carboxyl groups that are free, Ca^{2+} was utilized in these investigations to create the pectin gels. Additionally, old recipes were redesigned into composite geometries and novel compositions using basic ingredients. Agar and the transglutaminase enzyme remained added to the printed turkey meat, minimizing structural flaws during the post-printing heating phase[22].

2.3 Analogous Food Constituents

Extracts from seaweeds, lupine, fungus, insects, algae, and coffee 3-D filaments are included in this group of substances. [23]A firm in the United States called AlgaVia uses microalgae to create a protein powder through remarkable functional qualities, including being gluten-free, non-allergic, & a strong basis of dietary fiber. These qualities are helpful for creating fortified vegetarian protein. The edible insects are dried and ground into powder. To get the proper consistency for the 3-D printer's nozzle, Mixing flour with icing butter, cream cheese, water, flavoring, and gelling agent.

The use of insect protein as an ingredient in 3-D printing is a creative way to overcome people's aversion to eating insects and promote this sustainable food source. Insects are a high-value protein that ranges between about 40 and 70 percent (w/w) & minerals, such as calcium, based on the life cycles and species[1]. A snack with varying amounts of wheat flour & yellow mealworm powder was created and cooked at 200 °C. Their total amino acid essential content was 41.3 g per 100 g−1 of protein. In order to produce a protein powder with remarkable efficient qualities, such as being gluten-free, non-allergic, & a high source of dietary fiber, the American business AlgaVia employed microalgae. This helps when creating fortified vegan protein, for example. As a naturally occurring gelling material with favorable rheological characteristics, biomass from Nostoc sphaeroides has also been utilized in 3-D printing. Biologically dynamic metabolites, enzymes, & food flavoring chemicals may be produced from the residues of the present food processing & agricultural industries, providing ecologically safe and maintainable raw materials for the printing [24].

Table 1: Nutritional Components in 3D Food Printing

Nutrients	Types	Utilization	Reference
Carbohydrates	Agar	Effortlessly melted to create gel at high temperatures	[25]
	Gelatin	melted with water to create gel.	[26]
	Flour	More viscous than starch from rice	[27]
	Potato starch	Apply as a structural modifier to fish surimi gel to create sturdy 3D printed structures.	[27]
	Rich starch	cooks to a crispy texture.	[28]
	Maltitol/Xylitol	Sucrose substitution lowers the chance of obesity brought on by chocolate's high calorie content.	[29]
	Isomaltose	inhibits the development of a stiff network structure by preventing interaction between the molecules of Cordyceps flower powder.	[30]
Proteins	Patty	can increase adherence by combining mashed meat with appetizing materials that resemble starch.	[31]
	Surimi	Make use of crushed fish for fish cakes & feed.	[32]
	Edible insects	used as a substitute for animal protein.	[33]
	Bean Protein	used as alternative for animal protein.	[34]
	Pectin	Acknowledged for its nutritious worth as a protein for newly popular vegetarian diet	[35]
	Pea protein	Create food simulants with pectin.	[36]
	Whey protein	used to make potato starch-based 3D printing ink printable.	[37]
	Egg protein	used to determine the impact of the whey protein isolates on milk protein concentrate printing performance.	[38]
		used to enhance the mixed system's rheological and textural characteristics.	
Fat	Butter	As an animal fat made from milk, it contains several health-promoting vitamins, with vitamin K2, along with vitamins A, B, E, and D.	[22]
	Margarine	It is a product that is similar to butter and is manufactured from vegetable and animal fats, but it may also contain trans-fat, which is carcinogenic and prohibited in certain countries.	[39]
	Cooking oil	Makes the dough smoother and makes the lamination layer easier to apply.	[40]

3. Materials and Food recipes

3.1 Printing-Compatible Materials

Three types of materials can be used for food printing: materials that are natively printable food ingredients, non-printable traditional food ingredients, & substitute ingredients.

3.2 Natively Printable food ingredients

The smooth extrusion of natively printed materials from a syringe is possible for hydrogel, cake icing, cheese, hummus, and chocolate.[41] Completed goods are manufactured with a variety of textures, flavors, and nutritional values. But in meals, none of them are offered as the main course. A few of these naturally printed materials are sufficiently steady to retain their form after deposition. For instance, Z Corporation's powder/binder 3D printers [42] employed a blend of sugars, flour, and mashed potatoes as ingredients for powder

to create sugar teeth. Without any additional post-processing, the artificial teeth were sufficiently robust. Other composite inventions, including batters & protein pastes, could need to be post-cooked [43], which would make it hard for the printed forms to stay in the manufactured structures.

3.3 non-printable traditional food ingredients

Viscosity, consistency, and solidifying qualities were used to evaluate the printability of conventional food ingredients. Pasta dough proved to be the most effective material to print. Foods that humans eat on a daily basis, such as meat, fruit, grains, & vegetables, are not printed by nature. Adding hydrocolloids to These substantial materials have been utilized.in several culinary domains to permit their extrusion capabilities. Gastronomic methods have previously been used to make several solid and semisolid meals printed, but testing and changing the entire list is challenging. Making an element set out of a limited number of ingredients that may produce a great deal of variation in texture and flavor is one possible remedy. In study,[41] examined the hydrocolloids' fine-tuning concentration(gelatin and xanthan gum) & produced a very broad variety of textures (i.e. mouthfeels). Most traditional delicacies need post-deposition heating, such as, steaming, frying, or baking following the printing process. These procedures produce a non-homogenous texture and entail varying degrees of heat penetration. [43]experimented with altering cookie recipes for post-cooking and printing. He discovered a method that, when deep-fried, preserves the form of 3D objects with intricate interior geometries.

3.4 Substitute ingredients

Different components made from insects, lupine, seaweed, fungus, and algae are innovative sources of fiber and protein. To create edible pieces and form culinary structures, the "Insects Au Gratin" project employed bug powders combined with soft cheese and extrudable icing as printing materials[42]. Current agricultural & food processing residues may converted into enzymes, physiologically active metabolites, & food taste compounds[44], making them environmentally benign and sustainable sources of printing materials. With the use of current food processing technologies, alternative food material molecules may be further reduced in size, more particles can be produced for a larger surface area overall, and food stability and nutrient absorption can be enhanced. In a nutshell, using different components in food printing will help create healthier food items (such low-fat ones).

4. Improving Nutritional Value of 3D-Printed Foods Using Additives

Humans have achieved remarkable progress in food production over the last 50 years, solving the food supply for over 6 billion people. However, over 2 billion people remain undernourished, and More than 2 billion people are obese or overweight.[45]. These are the consequences of malnutrition; it must be acknowledged that the term "malnutrition" encompasses poor nutrition as well as undernutrition, & the phenomena of weight gain, obesity, and development retardation brought on by malnutrition is becoming increasingly apparent due to their imbalanced dietary intake. It is crucial to give customers food & nutrition that satisfy their requirements for quantity, quality, and safety because the UN has also developed six definite nutritional goals to address different malnutrition issues[45, 46, 47, 48]. According to the requirements of various consumers (consisting of those with varying, health conditions ages & genders), 3D food printing can alter the categories & contents of nutrients. This includes introducing healthy ingredients like cellulose, plant chemicals, and premium proteins, as well as reducing harmful substances like allergens and anti-nutritional factors[48, 49] In order to increase their acceptance of this type of food, consumers who are obese or overweight can cut back on their excessive consumption of nutritious foods. This can be done by distributing the nutritional configuration & printing ink or substitute product in a way that makes sense to them before it is printed. Fruits & vegetables, as the ink matrix can introduce micronutrients & cellulose and some other nutrients [50], & 3D printed snacks for children aged 5 to 10 that provide daily energy, calcium, iron, and vitamin D can all help compensate for the population's nutritional deficiencies. [51]While fruit & vegetable matrix ink can provide customers many nutritious components, the natural fruit and vegetable system is not printing-compatible and frequently uses common additives (hydrocolloid, starch) to enhance performance of printing. Additionally, they can substituted with bioactive peptides, fibers, algae, & plant functional component extracts, which can further increase the nutritional content of fruit & vegetable ink & improve its printing performance [52]. In insertion to fruit and vegetable matrix ink, nutritional improvement may also be achieved by incorporating fruit & vegetable components into further ink systems. When concentrated orange juice is added to printing ink, it not only makes the ink easier to print on but also increases its vitamin C & vitamin D content & improves its nourishing makeup [53]. Lemon juice and strawberry juice[54] also had the same impact when added to the ink system. Adding fruits, vegetables, and processed foods (such jams and juices) to 3D printed foods can improve their nutritional value, but It's critical to remember that the ink's printability must be considered. Probiotic-infused 3D printed foods, including mash potato ink infused with Bifidobacterium, also improve gastrointestinal health, lessen diarrhea, & immune system is controlled[55,56]printing probiotic-containing dough to create baked items with adjustable color, texture, and form may lessen the negative side effects (allergies or lactose intolerance) that customers encounter when probiotics eating from dairy products. Further nutritionally useful components including protein, fatty acids, sterols, and vitamins are also provided by the 3D printed cereal snack with microalgae [57].

However, adding probiotics and enzymes will make certain natural food systems less stable. It was demonstrated that gelatin-alginate mixed hydrogels may summarize probiotics & enzymes, increasing the kinds and amounts of functional substances and active components in food[56]. Thus, probiotics encapsulated in gelatin & alginate may be added to the unbalanced 3D printing system to guarantee the constancy of the nutritional enhancement based on product stability. In addition to altering the nutritional value of food, 3D printing may also alter the texture and appearance of it. The distinct characteristics of waterborne colloids have the ability to alter the rheological characteristics or condition of conventional meals and address the nutritional intake issues faced by aged or dysphagic individuals [58].The use of 3D food printing in food manufacturing can accomplish goals that are not possible with conventional technologies and result in more complicated, individualized, and refined food. In addition to producing more visually appealing and intriguing food, it also satisfies the nourishing requirements of specific peoples and sensory requirements, which is crucial for the use & advancement of natural food gels. It must be mentioned, nonetheless, that the majority of Natural food systems are not suitable for printing & need to be strengthened with the right treatments or additions.

4.1 Personalized Nutrition

In order to avoid illnesses and malnutrition, precision food formulas are made with precise amounts of nutrients and beneficial substances [59]. In order to aid older adults who, have trouble chewing and swallowing, TNO has developed ideas for printing pureed meals. Age-specific nutritional compositions may also be used to generate fabricated meal [23]. Biozoon Food Innovation made cookies using flour produced from insects for those with mastication issues as part of project "Execution about Progress of Rapid manufacturing of customized food for senior Consumers' nutrition." The capacity to alter food's nutritional value to suit consumer tastes is provided by food printing. Incorporating components that promote health, such cellulose, modified proteins, & plant compounds while reducing the amount of toxic substances, like allergens and anti-nutritional compounds, can help achieve this. Alternative printing methods or the thoughtful positioning of nutrients in inks can also be used to regulate the nourishing makeup of the printed foods. Vegetables and fruits can provide food ink with vitamins, polysaccharides, and other components. Tissue engineering has the potential to enhance food's nutritional qualities through 3D printing. Tissue growth can be promoted by exposing the material to ideal circumstances. Cells from plants or animals that can produce nutrition and build tissue-like structures when triggered can be used to create printed things. Adding microorganisms to printed food improves the finished product's nutritional value. Practical and nutritional elements such as protein, sterols, vitamins, and fatty acids are added when microalgae are included. Ultra violet irradiation dramatically increased the amount of vitamin D2 in ergosterol-supplemented 3D-printed purple sweet potato pastes, which in turn led to higher vitamin D2 levels in the exposed region. Similarly, a reduced-fat printed product based on beeswax was created using purple potato oleo gel powder ink that was microwave-stimulated. When 3D food printing, the nutritive value of the meal can be affected by selection of food ingredients, printing method, and post-processing procedures. Choosing food ingredients, printing, and post-processing are all included in this. The food ingredients used to make the printing ink assess the nutritional content of the printed meals. Unlike processed ingredients, whole grains, fruits, and veggies provide printed foods with fiber, vitamins, and minerals. The nutrition of food can also be impacted by the printing process. Nutritional retention may be impacted by variables including printing speed, temperature, and light exposure. High printing temperatures can destroy heat-sensitive vitamins, and prolonged exposure to light can lower the amount of vitamin C in some meals. Additional post-processing steps that might affect the nutritious value of printed food include drying, heating, & freezing. Drying may help essence nutrients, but it can also destroy vitamins that are sensitive to heat & oxidation.

Cooking can improve the way nutrients are absorbed, but it can also destroy heat-sensitive vitamins. Dining experiences are improved and customization is manufacture possible by 3D food printing. For printed foods to maintain their nutritional content and promote a balanced diet, it is essential to thoroughly evaluate any possible nutritional changes during printing. Nutritional integrity of 3D-printed food may be maintained by selecting nutrient-rich materials, maximizing post-processing, utilizing protective packaging, and optimizing printing circumstances.

5: Innovations in 3D Food Printing

Food printing eliminates liquid elements from food composition entirely without the need for a high-energy source by creating food parts layer by layer. Rather of being fully formed, fabricated films must be strong & stiff sufficient to bear both their own weight and the weight of films that come after it without distorting or changing of shape significantly. The design & procedure, not the talent of the workers, determine the quality of manufactured food products. The relevant 3D food printing technologies are outlined below.

6: Advancements and Emerging Trends in 3D Food Printing

In order to print 2D pictures, an inkjet printer transfers the nozzle for ink injection to the x and y axesafter receiving digital data.[39] To produce a three-dimensional model, 3D printers furthermore incorporate a z-axis orientation. Binder jetting, material extrusion, material jetting, powder bed fusion, sheet lamination, vat photopolymerization & directed energy deposition are some of several 3D printing processes. Prior to Three-dimensional raw material stacking, 3D food printing technology applies the ratio of food composition and nutritional data using a 3D scanner or a 3D design (CAD). Ink materials may often be separated into two categories using three-dimensional printing technology: additive (stacking) and cutting (subtractive). Raw materials are carved using sharp blades in the cutting type, whereas materials are stacked in the additive kind. In a 3D printer, the cutting type is often positioned in a range that is comparable to computer numerical control (CNC). Its way of cutting materials results in a significant loss of materials, whereas the additive kind has a comparatively lower loss of materials. The majority of 3D printers nowadays come equipped with design program and an additive manufacturing system. A significant agonistic advantage is offered by additive manufacturing technology as it makes it possible to modify the geometrical complexity needed for the bespoke design.[60] Figure 1 illustrates the primary 3D printing technologies: color jet printing (CJP)[61],Particular laser sintering (SLS) [62], & fused deposition modeling (FDM) [63]. Extrusion approaches like FDM (Figure 1A) drive materials into holes at high pressures & temperatures, piling them one layer at a time. Because it is the least expensive 3D printer technology, it is also the most popular among homes and small enterprises. Originally created for plastics modeling, extrusion-based printing has now been modified for use in the food industry.[64] It uses a nozzle to extrude a liquid or semisolid substance.

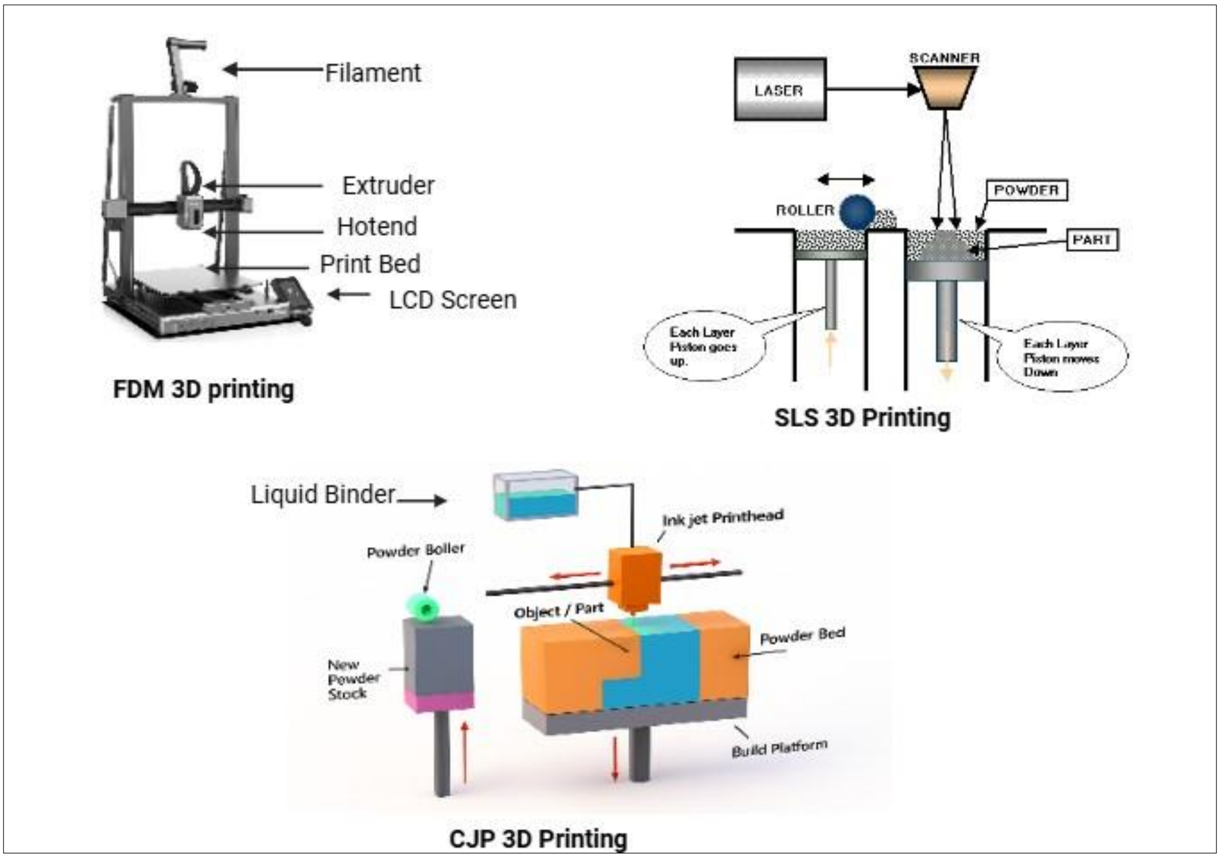

Figure 2: The illustration presents isometric 3D models of FDM, SLS, and CJP printers with modified geometries, color-coded parts, and clear labels

To produce a whole meal, a diversity of food constituents are extruded at once in extrusion-based printing [65]. The material must, however, be able to readily extrude out of tip of the nozzle & sustain the mass of the further printed layers without deforming[4]. Using the SLS process, powder-like materials are put to the bed, and just the required portion is solidified by shining a laser on it. A shape is formed as just the laser-exposed area hardens. Metal powders, ceramic powders, and thermoplastic powders are common powder materials. This technique involves applying a thin layer of powdered raw materials and applying resin or a laser to them prior to the hardening process. Extrusion-based printing method uses ceramics, metals, thermoplastics, and other common powdered raw materials. When it comes to food, the SLS process uses powdered substances like sugar and starch, and with the addition of food additives like artificial pigments and scents, different colors and tastes may be generated. The SLS technique printer's working concept is depicted in Figure 2B [39].

Nutrients	Food Ingredients	References
Carbohydrates	Baking cookies	**[43]**
	Hydrocolloids	**[66]**
	Smoothie	**[33]**
	Fruit snack	**[51]**
	Squashed potato	**[4, 17, 67]**
	Dough varying	**[27]**
	Pectin	**[68]**
	Lemon juice gel	**[69]**
Proteins	Turkey meat and scallop	**[70]**
	Fish surimi gel	**[71]**
	A cereal dough snack with powdered yellow mealworms	**[1]**
Lipids	Cheese	**[72]**
	Bacon fat	**[73]**
	Chocolate	**[64]**

In the color jet printing (CJP) process, the binder is selectively dispersed into a powder layer using a print head. This method uses rollers to disperse thin particles on the tray, similar to the SLS system, and is less expensive than other 3D printers Figure 2C. While contacting the powder particles, the print head continuously dispenses the powder solution after scanning the powder tray. The surrounding powders sustain disconnected sections during prototyping, therefore supporting structures are not needed. After inhaling the residual ambient powder, the cyanoacrylate-based substance penetrates the prototype surface and solidifies [74]. Without the need of artificial support structures, complicated geometries, including partitioning inside cavities, may be manufactured using CJP printing technology [61,75].

Figure 3 illustrates two other techniques: Stereolithography (SLA) & digital light processing (DLP), as well as extra manufacturing using photopolymers[76]. Liquid photocurable resins are used in photopolymerization techniques, which create solids by conducting chemical reactions under light [77]. For high resolution & superior surface quality components, SLA may scan the photopolymer mixture's surface using laser beams, whereas DLP employs a projector to selectively reveal & cure the resin's cross-sectional slice for photopolymerization at a certain moment.[78, 79, 80]. All subsequent layers are polymerized by light once more while platform constantly soaks into resin tank, allowing the uncured photo-reactive mixture to pass over previously cured layer and produce a finished product[81]. Comparing these photocurable resins to other 3D printing techniques, the former cannot produce large-scale products and need special hardening resins. Therefore, it is a technique that is typically employed to produce miniature models that need to be extremely precise, such those seen in the jewelry industry.

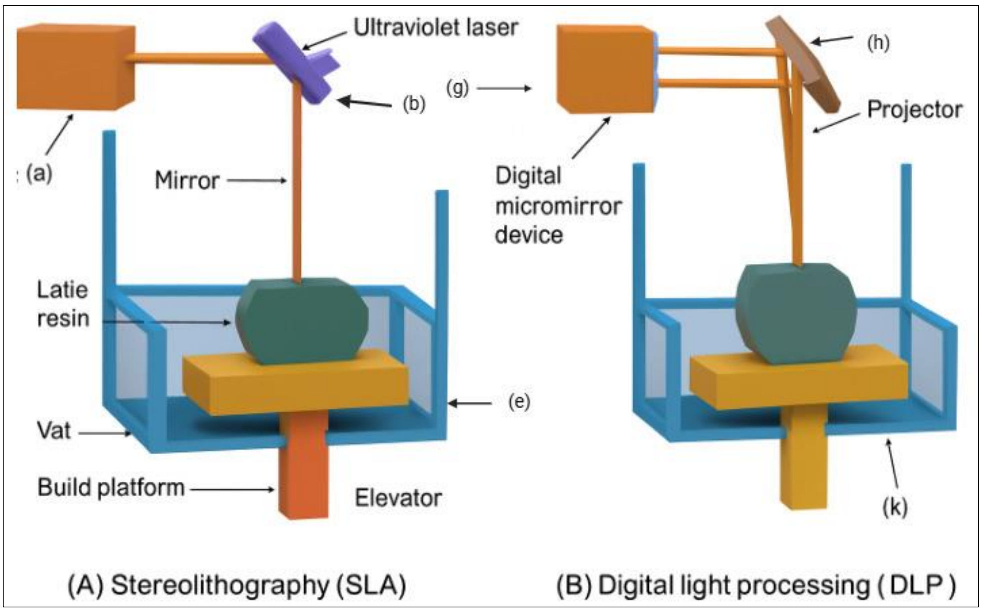

Figure 3: The left half illustrates the SLA process with a laser (a) curing resin in the tank (e) layer by layer. The right half depicts the DLP system projecting light (g) through a digital micromirror device (h) onto resin (i) to form each layer on the build platform (k)

7: Future Directions and Limitations

3D printing is a cutting-edge & original processing technique that can create intricate & customized meals. This allows them to personalize their own "art food" for customers and stimulate their appetite. Additionally, the market share of the 3D printed food will increase, which is something food companies should be aware of [22] the food industry's future production can evolve and transition from consumer-produced food to small-scale to large-scale food manufacturing, depending on the current application of food 3D printing. More organic food gels that can also be used with 3D printing will need to be created in the meantime to satisfy market and customer demands. Nevertheless, individual food gels with acceptable printing qualities may be 3D printed effectively; the majority of organic food gels have low printing qualities and are not suitable for direct printing[82]. To increase the usage of Organic food gels in 3D printing, some food ingredients or flavors must be pretreated to enhance the printing capabilities of the natural food substance system and give it the right physical & chemical qualities for printing [83].

It is crucial and significant to use food materials (hydrolysable, carbohydrates, lipids, colloids, etc.) sensibly in order to enhance the printing thermal, nutritional, rheological, and electrostatic qualities of food printing ingredients as well as the sensory quality of printed goods. In addition to offering new opportunities for the advancement of 3D food printing technology, it may serve as a foundation for its growth. The use of organic food gel in 3D printing is constrained by the extremely restricted development of additives suitable for this process. Therefore, more study and development of chemicals that might enhance natural food gel's printing properties is required. Another important usage of 3D printing is the manufacturing of food with exact nutritious qualities to address hunger. Without the capability to 3D print foods high in protein and fat, more research on the nutritional and sensory qualities of 3D printed foods employing additives and multi-component food matrices is required [84]. However, the low level of consumer awareness of 3D food printing at the moment is disappointing, but this unfavorable perception is not permanent [85].Consumer attitudes are easily resolved, and some people who participate in research or comprehend 3D food continue to have favorable views [85]. Thus, in addition to ongoing research and technological advancements, we need also keep an eye on the growing popularity of 3D food printing and shifting consumer perceptions. In general, in order to guarantee that 3D printing technology is applied more extensively in the food industry, researchers must not only create additives that may enhance the natural food system but also eradicate consumer prejudices. In order for customers to identify the value of 3D printed food, producers and businesses must integrate their marketing and communication skills via ongoing energies to make items more user-friendly.

CONCLUSIONS

Plant-based 3D food printing offers a viable route to functional, customized, and sustainable nutrition. Edible inks have solid structural and nutritional underpinnings from plant proteins (such as wheat gluten, pea, lentil, & soy), plant fibers, and hydrocolloids. The development of meals that more closely resemble natural sensory qualities is made possible by the combination of plant cell cultures, hydrocolloids, and innovative biopolymers, which improve texture, printability, and nutrient delivery. Moreover, the technique enables the integration of bioactive molecules, probiotics, and functional chemicals to enhance health advantages and tackle nutritional issues. Technical obstacles like the limited printability of natural gels and problems with consumer acceptance notwithstanding, ongoing advancements in formulation, processing, and materials hold great promise for changing the food industry through customized diets, plant-based meat substitutes, and ecologically friendly methods.

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