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A Systematic Review on 3D Food Printing: Progressing from Concept to Reality

Tinjauan Sistematis tentang Pencetakan Makanan 3D: Perkembangan dari Konsep Menjadi Realita

Koushikha Namakkal Manivelkumar[1]*, Chinnappan A Kalpana[1]

[1]Department of Food Science and Nutrition, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nādu, India

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****Correspondent:***
Koushikha Namakkal Manivelkumar
22phfnf003@avinuty.ac.in

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ABSTRACT

Background: Using 3D printing technology, novel items can be created from various materials, including edible ones, addressing the growing importance of sustainable food chains and personalized nutrition. As the latest advancement in additive manufacturing, 3D printing meets diverse customer demands by producing customized food items tailored to individual nutritional needs.
Objectives: This literature evaluation focuses on the applications, technical advancements, and future possibilities of 3D food printing. By assessing recent developments, the study explores its adaptability and transformative potential in addressing global issues such as sustainability and personalized nutrition.
Methods: To include up-to-date and relevant data, PubMed, Google Scholar, and Scopus were searched for research on "3D Food Printing," "Food Technology," "Food Formulation," and "Customized Diet" from 2018 to 2024. Data extraction and synthesis were conducted on 31 reports selected from 687 search results after removing duplicates and applying filters.
Discussions: The study highlights the use of 3D food printers for creating dairy products, fish and meat, pasta, biscuits, chocolates, and cereal-based foods. Applications span industries such as space food, elderly and school children's nutrition, military food, hospitals, and restaurants. Future research directions include food characterization through color analysis, moisture content, water activity, physiochemical properties, and microbiological studies.
Conclusions: This study highlights the potential advantages of 3D food printing technology, including healthier food options, novel dining experiences, and diet customization. It underscores its transformative capacity to impact the global economy while addressing sustainability and personalized nutrition challenges.

INTRODUCTION

One kind of additive manufacturing that uses computer-aided layer creation is the 3D printing of food ingredients. Food production involves using CAD software, which allows for the creation of 3D models or the use of other electronic data sources. This enables the food to be made in virtually any desired shape. The edible ink is often held in food-grade plastic syringes and then gradually injected through a nozzle constructed of the same material. State-of-the-art 3D food printers enable consumers to remotely print their meals using a computer, smartphone, or other Internet of Things (IoT) device. Additionally, these printers offer recipe options. The meal is very beneficial in several fields, including space exploration and healthcare, due to its versatility in shape, texture, color, taste, and nutrition[1]. Innovative approaches are being investigated for a zero-waste economy, including converting food waste into increased-value products. Food is squandered at every level of production, ranging from cultivation to fabrication to processing to retail and household consumption. Homes are frequently the primary generators of waste. One cutting-edge technology that might successfully address food waste from various sources is 3D food printing (3DFP). The innovation offers prospective remedies to food debris and resource scarcity, contributing to environmental sustainability.

Numerous obstacles still exist that deter individuals from regarding food waste as available source of sustenance. 3D printing can be utilized to produce distinctive and personalized designs, enhancing their attractiveness and acceptance, for specific types of garbage[2]. 3D food printing is a manufacturing technique that integrates 3D printing and digital gastronomy techniques to enable customization of food items regarding their form, texture, hue, flavor, and nutritional

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content[3].This enhances the range of customization choices available for the industrial cooking sector and introduces artistic expertise to the realm of fine dining. The impacts of Food printing in personalized nutrition, immediately food manufacturing, food preparation technologies, and process planning are fully elucidated. Utilizing these services in the catering industry or for domestic cooking can offer more than just a technical resolution for personalized nutrition management and meal planning. It frequently presents an opportunity to reorganize an individualized food distribution system[4]. In the coming years, 3D food printing industry is expected to develop significantly worldwide.

There is a high demand for customized food items on the market, most of which are produced by individuals with specific skills. 3DFP is utilized in several ways within the food industry, including preparing food and creating personalized dietary plans in food processing facilities, restaurants, and healthcare institutions[5].3D food printing technology is quite as the Indian market.3D food printing is an innovative method that makes it possible to make food items as needed encourages the development of new products and allows for customization. Using technology, individuals can customize their food preferences, generate innovative dining encounters, and indulge in fresh and nutritious meals[6]. Food Layered manufacturing, also known as 3D food printing, products that eliminate the need for moulds and tools that can create new industries, jobs, and economic growth. 3D food printing can address pressing global challenges such as food insecurity, food waste, and customized diets. The 3D food printing industry is expanding quickly, necessitating timely research and development. Increasing awareness and acceptability of 3D-printed cuisine among consumers are fueling market expansion. Because technology have the capacity to resolve pressing global issues, 3D food printing is thus quite popular; its serious implications for health, the environment, and the economy, and its promising growth prospects to enhance production efficiency and reduce manufacturing expenses when producing personalized food products. This Systematic Literature Review (SLR) aims to evaluate the current status of 3D food printing, emphasizing its uses, technological developments, and prospects.

Research Question

How can 3D food printing technology be applied across various industries, what are its current technological advancements, and how might these shape its future perspectives in sustainable and personalized food production?

METHODS

The present study seeks to delineate the obstacles, remedies, and advantages of incorporating 3D food printing technology into actuality. We used the Preferred Reporting Items regarding Systematic Reviews and Meta-Analyses (PRISMA) standards for doing a thorough literature review to look at these questions. Criteria are explained in detail in this section. We list the crucial phases, which encompass determining research goals, formulating a search strategy, establishing criteria for study selection, conducting data extraction, and evaluating the quality of the studies included. The study implemented specific search criteria, phrases, and parameters for inclusion and exclusion to discover pertinent research papers.

Search Criteria

Several online databases, including PubMed, Google Scholar, and Scopus, were thoroughly searched using keywords such as ("3D food printing", "Food Formulation", "Food Sustainability" "freshly prepared meals" OR "Customized Diet") AND ("current applications" OR "real-world uses" OR "commercial use") AND ("technology advancements" OR "recent developments") AND ("benefits" OR "advantages" OR "challenges") AND ("case studies" OR "success stories" OR "innovations") AND ("market trends" OR "future potential" OR "predictions"). The PRISMA checklist (item 6) mandates that authors "detail the study's features (e.g., 3D food printing) and report criteria (e.g., years considered, language, publication status) employed as requirements for eligibility, providing justification." Additionally, these time-bound methods are used in this research to monitor workload and steer clear of out-of-date information while guaranteeing the inclusion of the most recent and pertinent details.

Inclusion Criteria

1. Scholarly writings subjected to peer review, conference papers, theses, and dissertations.
2. Studies published in the last 7 years (from 2018 to 2024) to ensure up-to-date information with the most current and relevant facts while monitoring the workload and avoiding outdated information.
3. Techniques and technologies of 3D food printing.
4. Usage of 3D food printing in nutrition, culinary arts, personalized diets, or the food industry.
5. Material science related to food inks and ingredients used in 3D printing.
6. Reviews that provide comprehensive overviews of the cutting-edge advancements in 3D food printing.

Exclusion Criteria

1. Editorials, opinion pieces, news articles, or other non-peer-reviewed publications.
2. Grey literature, such as blogs, websites, and social media posts.
3. Research disseminated in languages apart from English.
4. Research that do not specifically focus on 3D food printing.
5. Studies that are too outdated and do not provide relevant insights into current trends and technologies.

Screening Process

The screening approach entailed retrieving and examining complete papers pertinent to the research issue and their role in comprehending data extraction in 3D food printing. The authors performed screening and critical appraisal of the papers. The articles underwent review to determine the data's relevance, methodology, reliability, and validity. Additionally, a quality assessment was conducted using factors such as methodology, reliability, and validity, which involves multiple stages such as identification of relevant papers, screening for eligibility, data extraction, and quality assessment. This process helped minimize bias and ensure the results were comprehensive and representative.

Data Extraction

A data extraction form was designed in compliance with the PRISMA statement. One author, Ex: (S.G.), extracted pertinent data from studies; two authors (S.G., MP) evaluated coding by the areas covered in the 3D food printing standards. Disagreements among the authors were resolved via discussion. The data received included guideline components, author/year, research design, sample size, setting/country, study quality, and consistent outcomes.

DISCUSSIONS

The major literature searches above produced 687 articles in total, gathered from several databases. A thorough review of all reports after 375 reports' duplicate items were removed and clinically important information was found using a screening procedure. Five articles were removed from the research because their content was irrelevant and written in languages other than English. This was done after 179 materials were screened to find clinically irrelevant information, and 97 reports could not be recovered. A thorough analysis was carried out, including 31 papers. The results of the main literature search are demonstrated in the PRISMA Flow Diagram (Fig. 1).

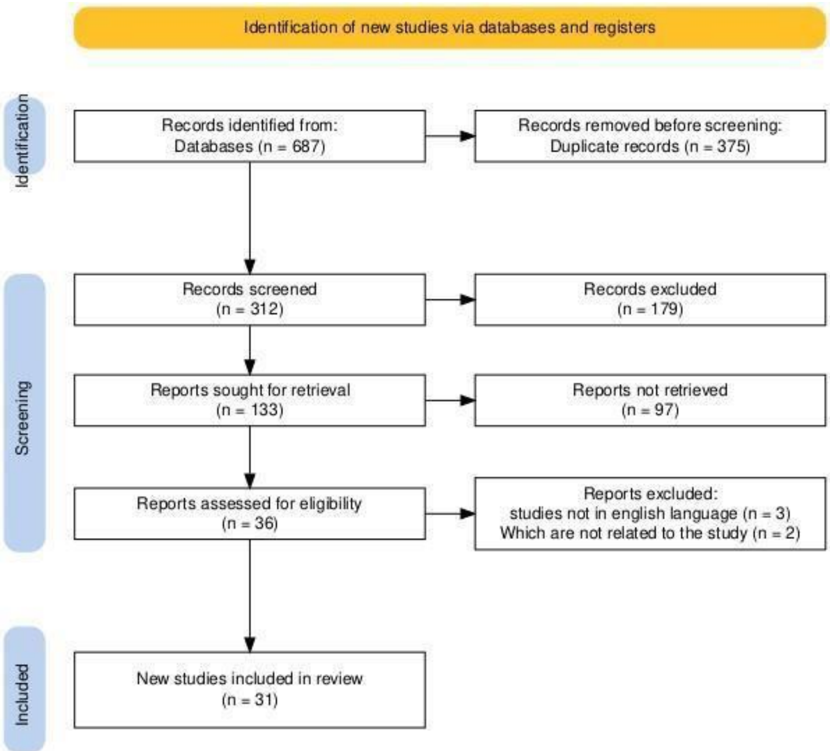

Figure 1. PRISMA Flow Diagram

3D Food Printing

3D printing is a sophisticated manufacturing process that is rapidly advancing to meet the standards of Industry 4.0. The materials provide a vital function in achieving the transformation. Much research has been conducted on 3D printing materials, including metals, nonmetals, and polymers. Figure 2 illustrates how the development of 3D food printing technology can completely revolutionize the food industry by making it possible to produce sustainable, individualized, and customizable food items. New avenues for food design, nutrition, and production are made possible by the capacity to precisely manipulate the form, texture, and content of food via printing. Additionally, a few materials with special applications have also been developed.

In the study, Tomislava (2021)[7] utilized lemon juice gel and potato starch as substances exhibiting moisture levels of 59.82g/100g. Characteristics including viscosity, dynamic viscoelastic properties, and shear stress were examined in an experiment. The effective printing of lemon juice gel achieved a successful conclusion. The products printed using Gelled lemon juice are seen in Figure 2(a). Anukiruthika et al. (2019)[8] utilized Hen's egg and rice used as print substrates. They used rice as a carbohydrate source. The test included breaking eggs and using the Refractance Window Drying (RWD) technique to extract powder. Research was carried out to look at the elements' qualities and find the best way to run the process. The thing was made with 3D printer technology the eggs, as seen in Figure 2(b). Liu et al. (2019)[9] utilized wheat flour, freeze-dried mango powder, water, and olive oil as materials. The experiment involved the performance of many tests on dough, both individually and in combination with other materials. The most optimal outcomes were observed when adhering to the flour- to-ratio ratio. The proportion of water to olive

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oil to frozen mango powder in the final product was 57.5:30:3:2.5, as depicted in Figure 2(c). Khemiga Khemacheevakul (2021)[10] utilized Cadbury chocolate as milk chocolate buttons. The seeded tempering method was used to temper the chocolate. The viscosity of chocolate has increased as a result of this process. Numerous aspects were examined, including the chocolate's rheological behaviour, nozzle height, and nozzle aperture size. Chocolate has been printed in a variety of forms as a finished product. Additionally, it has been shown that chocolate's viscosity stays constant between 3.5 and 7 Pa and between 32 and 40 degrees Celsius. The goods manufactured by 3D printing Cadbury chocolate are depicted in Figure 2(e). Wangetal. (2018) used sodium chloride and Surimi gel derived from fish as a surface for printing. This test investigated several properties: water distribution, gel strength, surimi gel microstructure, and water retaining capacity. It has been shown in this experiment that the addition of HCl facilitates the prompt extrusion of printing materials from the nozzle and, following deposition, increases their viscosity, enabling them to hold their form. The result was printed from surimi gel in Figure 2(d) using a nozzle speed of 32 mm/s and a 1.5 g/100 g NaCl concentration[11].

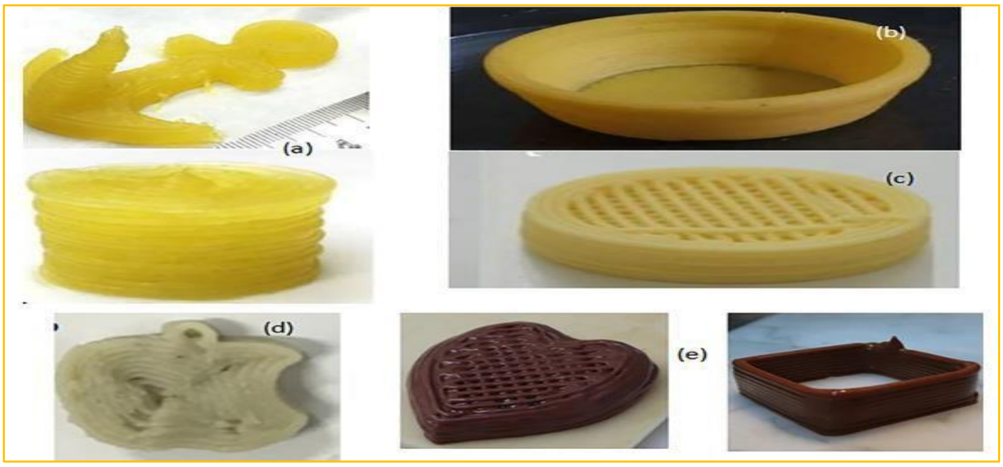

Figure 2. (a) Products made by lemon juice gel and potato[7], (b) Products made by egg and rice[8], (c) Products manufactured by dough, dry, frozen mango and olive oil[9], (d) Food material printed by keeping nozzle speed 32 mm/sec and NaCl content 1.5/100 g[10]

Fig. 3 (a) and (b) demonstrate strong hand water-holding capacity for NaCl content. This demonstrates how the gel strength and water retention capacity are influenced by the concentration of NaCl. Understanding the gel's characteristics and possible uses requires knowledge of this information. Researchers and developers may improve the composition of gels for certain applications by comprehending the link between NaCl content gel strength and water-retaining capacity. For example, they can increase the NaCl concentration to improve gel strength if the gel needs to be more rigid or decrease the NaCl concentration to improve water holding capacity if the gel needs to be more moist Zhenbin et al. (2018)[12] printed- carrageenan (KG) and xanthan gum (XG)gumataweightof0.06g/100g. First, the potato flakes in this experiment was cooked in water at 4:1 kg to XG.

Additionally, both were used to produce a 3:1 ratio. After that, the blend was combined with the mashed potatoes and some boiling water (98±0.4). This mixing operation took two minutes to complete. The outcome of this experiment was a successfully 3D-printed mashed potato toe. Certain characteristics, such as the rheological qualities, amounts of filling and conditions were examined. These metrics significantly impact Young's modulus, gumminess, hardness, and firmness.

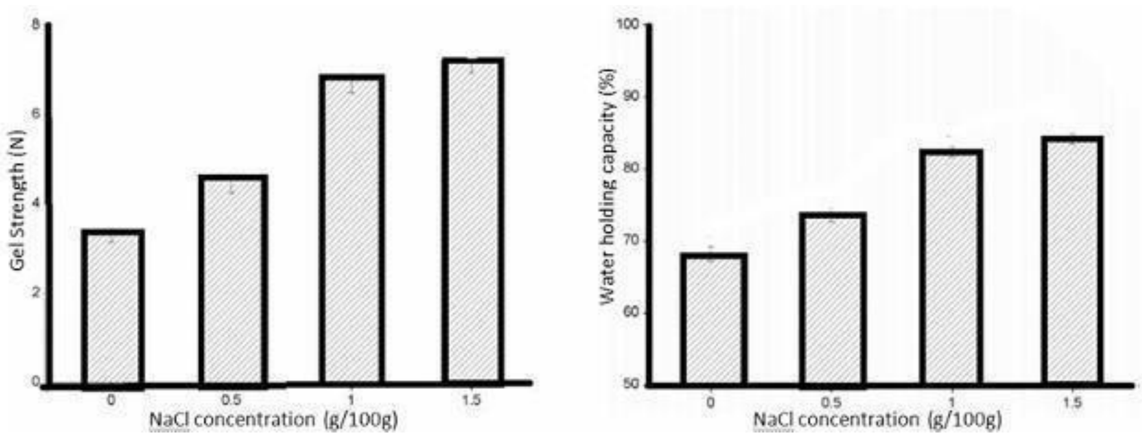

Figure 3. (a) Effects of NaCl concentration on gel strength and (b) on water holding capacity[17]

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Bananas, dried mushrooms, canned white beans, dry non-fat milk, lemon juice, and as corbic acid were employed by Derossietal. (2018)[13]. Conducted, rheological behaviour, and other printing factors. Consequently, the product. The finished printed product has 5–10% of the energy, vitamins, iron, and calcium that children ages 3–6 need. Sever initial. (2018)[14] has used avocado carrots, pears, kiwis, broccoli, and rice. After that, these fruits were combined at mass fractions of 1.5%, 45%, 7%, and 36.5%. Both the morphological and micro structural characteristics were observed. For eight days at 5C, antioxidants, microbiological, and sensory characteristics were also observed. The finished product with a pyramid shape was 3D printed using these fruit materials. According to Zhu et al. (2019)[15], tomato puree, Nutella spread, original Speculoos paste, mayonnaise, Argeta chicken meat spread, and Zonnatura vegetarian spread all have natural flavors. The pureed tomato was whirled around for 20 minutes at 20 degrees Celsius with a force of 1000–10,000 grams. They concluded that flow stress might be used to forecast how something will function when 3D printed with aqueous-based food ingredients after examining Density, dry material content, relative volume fraction, stress amplitude, creep, and rheological characteristics. Park et al. (2020)[16] utilized carrots, sodium alginate, dehydrated calcium chloride, sucrose, agar powder, and gelatin. They furthermore used coconut water and Murashige & Skoog (MS) media supplemented with Gamborg vitamins. The dispersion of carrot cells was combined with an agarose solution in 1:2, 1:1, and 2:1 (w/w%) ratios to facilitate 3D printing. The investigation focused on dynamic viscoelasticity, curing capacities, optical density, and rheological parameters. The data indicate that 2:1 samples had worse outcomes compared to 1:1 samples, whereas 1:2 samples demonstrated excellent printability and structural conformity.

Printing Materials

Numerous materials are examined and discovered to be printable in traditional foods and materials that can be printed locally. Cake frosting, chocolate, hummus, and cheese are among the naturally printed foods that are simple to extrude from a syringe[18]. Traditional food items, such as rice, meat, fruits, and vegetables that cannot be printed, fall into these categories. Much research is also being done to boost the printability of traditional food goods by adding gums like xanthan gum or certain hydrocolloids[19]. However, efforts are underway to use the recipes to make this traditional cuisine category downloadable. These are now available or made with a small adjustment that eliminates the need for chemicals[20]. Hao Jiang et al. [21] investigated the Rheological properties of compounds utilized for food printing in 3D and the specifications needed to predict and enhance their printing capabilities and capacity for autonomous in extrusion-based printing. 3D food printing, as an innovative approach, has significant promise to completely transform a few areas of food production. Escalante-Aburto et al.[22] looked at how this technology might enhance the appearance of food, which has lately been the most popular use for 3D printing. Finally, they offered a forward-looking and perspective-oriented vision of this technology. To fulfil the promises of 3DFP in improving human health, it also mentioned its multidisciplinary character and recommended areas where social and regulatory challenges need to be addressed. This final category will be crucial since consumers are becoming more health-conscious.

Table 1 lists the qualities that many academics have looked into, along with research on the various materials utilized in 3D printing. Table 2 provides printable constructions produced under fruit, vegetable, staple food (rice), fish, egg, and by- products. Whenever material is discussed for printing, it must meet the rheological requirements for flow ability via the printer's nozzle. In addition, it possesses sufficient mechanical qualities to support the preservation of printed structures and prevent them from collapsing the weight of several printed layers. When materials are addressed, a thorough understanding of their characteristics is necessary to compare and evaluate if a material is suitable for printing. Thus, various tests, including the rheological test, texture profile analysis, Scanning Electron Microscopy (SEM), Nuclear Magnetic Resonance (NMR), and other techniques, are often used to describe a printing medium.

Table 1. Materials used for 3D Food Printing and their Properties Investigated

Category	Material Used for Printing	Material Properties Studied	Reference
Fruits	Snacks composed of 73.5% pureed bananas, 15% white canned beans, 6% dry non-fat milk, 3% lemon juice, 2% dried mushrooms, and 0.5% ascorbic acid, totaling 70%, along with a pectin solution comprising 30%.	Rheological measurements (viscosity and apparent viscosity), X-ray computed microtomography, and anthropometric data (height and weight)	23
Vegetables	Potato printing materials include Mashed Potatoes (MP), Potato Starch (PS-0%, 1%, 2%, 4%), and 15% trehalose.	Water distribution using Nuclear Magnetic Resonance (NMR) and the features of the G0, G00, and loss tangent	24
Staple food	Brown rice gel containing agar (AG), sodium carboxymethyl cellulose (NCMC), guar gum (GG), brown rice flour and xanthan gum (XG)	Low Field Nuclear Magnetic Resonance (LF-NMR)—moisture distribution, texture analysis (hardness, gumminess, springiness, cohesiveness), rheological parameters (G0, G00, loss tangent, apparent viscosity, flow behavior index, and consistency index), and microstructural features by Scanning Electron Microscopy (SEM)	25

Category	Material Used for Printing	Material Properties Studied	Reference
By-product utilization	Processing of potatoes and yams by-product in varied ratios of (0: 10, 1:9, 2:8, and 3:7)	rheological properties, textural properties, and physicochemical parameters (WAI—Water Absorption Index, WSI—Water Solubility Index and colour).	26
Fish	Fish surimi gel is made with fresh silver carp meat and NaCl ranging from 0.5 to 2%.	Rheological characterization (G0, G00, loss tangent), gel strength (TPA), centrifuge Water Holding capacity (WHC), Micro Structure Characteristics (SEM), and water distribution (NMR)	11
Egg	Egg yolk, egg white, rice flour	Shear stress, shear rate, apparent viscosity, textural analyzer (full TPA), colour measurement, and water activity are examples of rheology.	8
Functional food (protein rich)	Butter, water, pea protein isolate, and refined flour.	The rheology, texture profile, moisture content, protein content, ability to absorb oil and water, and mixing behavior were all looked at.	27

Characterization of 3D Foods Physicochemical Properties

Comprehending the physicochemical characteristics of 3D-printed meals is essential to assessing their security and caliber. Further study is required to evaluate the quality, safety, and commercial viability of edible prototypes for 3D food printing to become more widely used. To better understand food quality (and safety), we will review more conventional food science-based methodologies that better define food in 3D food systems.

Moisture Content

Optimal moisture content is crucial for achieving preferred appearance and sensations. Moisture levels is essential in preventing microbial growth. Controlling moisture levels can significantly reduce the risk of foodborne illnesses. The information for food ink ingredients and printed items has been reported in a small number of 3D FP experiments. The dry oven the approach is often used to ascertain the amount of water of three-dimensional food. Water affects several important food characteristics, including texture, weight, viscosity, shelf life, and microbiological safety[26]. Liu and Severini both employed dry oven techniques to determine the moisture content; Severini used gravimetric weighing and Liu utilized the Chinese national standard GB/T8858-88. However, the vacuum drying approach was used in a study with lemon juice[27]. According to those researchers, the percentage of potatoes that made up the constituents of food ink included 78 to 81%, including carrots, pears, kiwis, broccoli, and avocado that made up the mixture, and the percentage of lemon juice that made- up 73.5–88.9%[28]. Furthermore, following the 3D printing procedure, the moisture content was assessed. The moisture level of the mushroom-based food ink was 7.45% before printing, and it grew to 9.29% after processing as a result of adding water during the ink creation process[29]. To enhance rheological characteristics, printability, and Moisture levels may be used to alter food viscosity lacking the need for chemicals[14].

Water Activity

Water activity (A_W) is the volume of water available for use in chemical processes and microbiological activity[30]. Water activity influences the texture, mouthfeel, and overall sensory experience of 3D-printed foods. A higher water activity can make the product feel more moist and palatable, while a lower water activity may result in a more crunchy or dry texture. Water activity constitutes a pivotal element in deciding the potential for microbial growth. Maintaining a low water activity can minimize the risk of foodborne pathogens. Before printing and after printing, water activity levels for a food ink based on mushrooms were reported as 0.60 and 0.66, respectively[31]. The small An elevation in water activity results in the entrapment of moisture inside the fiber network while processing. According to Keerthana[29], bound water retention improved the food ink's printability and flow ability.

Nevertheless, there is room for more research as no additional papers describe hydric movement in 3D food. A lower water activity can inhibit microbial growth, extending shelf life. A low A_W (0.5) makes food is more susceptible to oxidizing and rancidity, causing lower quality and shortens shelf life, even if it can also inhibit microbial growth[32]. Additional heat treatment is a potential solution but can negatively affect appearance and quality. Therefore, to generate excellent results, aesthetically pleasing, and secure item, careful consideration of water activity in 3D food must be considered[33].

Colour

Color is a major factor in customers' first assessments of food quality and attractiveness; hence 3D printed food color measurement is crucial. Few studies have been done on how color is affected by 3D printing technology. In Dankar's work, for instance, the hue angle, brightness, and chroma color characteristics were measured before and after printing in a three-dimensional printed potato purée application. The results indicated that the 3D printing process did not influence color. However, additives like agar and alginate decreased brightness levels[33]. Le Tohic (2018)[34] and Keerthana et al. (2020)[29] gave colour values of L, a, and b to demonstrate color and clarity ranges in addition to research using 3D cheese and mushroom ink. The printing procedure in Le Tohic's study resulted in a drop in the printed cheeses' surface brightness. Furthermore, Keerthana's research investigated the impacts of printing and microwaving. and discovered that heat-induced enzymatic browning caused a noticeable reduction in lightness. These results indicate that the 3D printing process may affect overall. As such, it has an extensive appeal to food and is a first indicator for comparing it to conventional food items.

Microbiological Analysis of 3D Food

The development of a rapid sanitation method for bacterial elimination is a critical challenge that must be addressed in light of the Latest scientific advancements in 3D FP invention and the potential of further commercialization. Microbiological safety is one of the most important topics researched and implemented in traditional food manufacturing. Foodborne infections brought on by bacteria, yeast, and mould might result from poor sanitation and storage techniques.

According to Severini, Derossi, et al. (2018)[14], The plates underwent testing in both aerobic and Modified Atmospheric Packing (MAP) conditions. The detected log CFU of 3-5 for the final 3D printed object remained consistent across both environments, despite the raw materials being meticulously sanitized to reduce microbial contamination. This suggests that the planning and 3D printing processes may have substantially contributed to microbial contamination. The microbiological investigation in this experiment and other research concentrated on the final result; no printer components were swabbed or assessed for microbial load to identify danger areas or determine hygiene and sanitation efficacy.

Through the denaturation of proteins and the reduction of surface tension, alkali products and surfactants can be employed as cleaning agents on surfaces that come into contact with food to remove food debris[35,36]. investigated the creation and Characteristics for food solutions for 3D printing, emphasizing material features and printing parameters. Comprehending and regulating these variables is essential for producing superior, effective 3D-printed meals. The essay emphasizes the significance of food ink printability, contingent upon its composition, structure, and physicochemical qualities. It proposes standardized ink for mutations and performance metrics, along with recommendations for optimizing 3D-printed meals. Prior research is deficient in specifics on printer design and functionality. Furthermore, materials, hydrogen peroxide, oxidized water electrolyzing, and UV light therapy are among the sanitation treatments that may be employed in 3D printing. Though not all of these methods may be appropriate for 3D equipment, the efficacy of These procedures for 3D FP usage require modification. assessed and verified. The 3D printers' food contact surfaces, such as the pump, piston, extruder, tube, printing platform, and more can be specifically targeted for planting and swabbing before treatment[37].

Strengths and Weakness of the Study

This paper considers relevant literature from between 2018 and 2024. Pertinent research on making food in 3D technology use and potential future developments in space food, elderly people, military provisions, hospitals, and schools are presented. The review points out the role of technological and physiochemical food analysis based on variable factors things like color, microbial safety, and the amount of water present. It also gives new visions of the future for 3D food printing- from novel materials and flavoring enhancement to consistency improvements. The literature review is restricted to published literature, excluding any grey literature or ongoing studies, wherein the value of emerging trends or unpublished research can be missed. Practical context also limits the findings based on a lack of primary data. It does not consider regulatory and legal challenges, focusing only on technological advancement without socio-economic, cultural, and ethical implications for their success. The findings might be too general to apply across various industries, possibly missing out on some of the needs specific industries have to overcome their respective challenges.

CONCLUSIONS

The research highlights 3D FP's potential as a game-changing technology in the food industry, offering creative ways to customize food items and reduce food waste. The characteristics of the materials, including particle size and rheological characteristics, directly impact the creation of food items using additive manufacturing. The study highlights the increasing significance of 3D FP in future of the food to exploit its capabilities with high nutritional values and desirable taste profiles. Integrating AI and machine learning into 3D FP is also predicted to add more precision with automatization and predict the behaviour of foods during production and consumption, leading to more efficient and personalized ways of producing foods.

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AUTHOR CONTRIBUTIONS

KNM: conceptualization, literature search, methodology, writing–original draft, supervision; CAK: investigation, discussion contributions, writing–review and editing.

REFERENCES

1. Peshave, J. milind & Hodlur, A. S. 3D printing-the future In culinary arts! *Multi-Disciplinary Journal* **1**, 1–7 (2022). Available at https://www.researchgate.net/publication/3625

68506_Multi-DisciplinaryJournal_3D_Printing-The_Future_In_Culinary_Arts_Introduction.
2. Zhang, Y. *et al.* Systematic engineering approach for optimization of multi-component alternative protein-fortified 3D printing food Ink. *Food Hydrocolloids* **131**, 107803 (2022). Available at https://linkinghub.elsevier.com/retrieve/pii/S0268005X2200323X.
3. Dankar, I., Haddarah, A., Omar, F. E. L., Sepulcre, F. & Pujolà, M. 3D printing technology: The new era for food customization and elaboration. *Trends in Food Science & Technology* **75**, 231–242 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0924224417304818.
4. Mantihal, S., Kobun, R. & Lee, B.-B. 3D food printing of as the new way of preparing food: A review. *International Journal of Gastronomy and Food Science* **22**, 100260 (2020). Available at https://linkinghub.elsevier.com/retrieve/pii/S1878450X20301372.
5. Zhang, J. Y., Pandya, J. K., McClements, D. J., Lu, J. & Kinchla, A. J. Advancements in 3D food printing: A comprehensive overview of properties and opportunities. *Critical Reviews in Food Science and Nutrition* **62**, 4752–4768 (2022). Available at https://www.tandfonline.com/doi/full/10.1080/10408398.2021.1878103.
6. Piyush, Kumar, R. & Kumar, R. 3D printing of food materials: A state of art review and future applications. *Materials Today: Proceedings* **33**, 1463–1467 (2020). Available at https://linkinghub.elsevier.com/retrieve/pii/S2214785320307318.
7. Vukušić Pavičić, T., Grgić, T., Ivanov, M., Novotni, D. & Herceg, Z. Influence of flour and fat type on dough rheology and technological characteristics of 3D-printed cookies. *Foods* **10**, 193 (2021). Available at https://www.mdpi.com/2304-8158/10/1/193.
8. Anukiruthika, T., Moses, J. A. & Anandharamakrishnan, C. 3D printing of egg yolk and white with rice flour blends. *Journal of Food Engineering* **265**, 109691 (2020). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877419303231.
9. Liu, Y., Liang, X., Saeed, A., Lan, W. & Qin, W. Properties of 3D printed dough and optimization of printing parameters. *Innovative Food Science & Emerging Technologies* **54**, 9–18 (2019). Available at https://linkinghub.elsevier.com/retrieve/pii/S146685641831289X.
10. Khemacheevakul, K. Manufacture and characterization of 3D-printed sugar-reduced layered chocolates and their sensory perception. (Department of Agricultural, Food and Nutritional Science, University of Alberta, Canada, 2021). Available at https://era.library.ualberta.ca/items/6a653417-dfba-4264-bc0f-037c062cbe31.
11. Wang, L., Zhang, M., Bhandari, B. & Yang, C. Investigation on fish surimi gel as promising food material for 3D printing. *Journal of Food Engineering* **220**, 101–108 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877417300742.
12. Liu, Z., Dick, A., Prakash, S., Bhandari, B. & Zhang, M. Texture modification of 3D printed air-fried potato snack by varying its internal structure with the potential to reduce oil content. *Food Bioprocess Technol* **13**, 564–576 (2020). Available at http://link.springer.com/10.1007/s11947-020-02408-x.
13. Santini, C., Johnson, C. & Cavicchi, A. Design and food robots: Changing processes in the restaurant industry. in *Transdisciplinary Case Studies on Design for Food and Sustainability* 97–114 (Elsevier, 2021). doi:10.1016/B978-0-12-817821-8.00005-9. Available at https://linkinghub.elsevier.com/retrieve/pii/B9780128178218000059.
14. Derossi, A., Caporizzi, R., Azzollini, D. & Severini, C. Application of 3D printing for customized food. A case on the development of a fruit-based snack for children. *Journal of Food Engineering* **220**, 65–75 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877417302133.
15. Severini, C., Derossi, A., Ricci, I., Caporizzi, R. & Fiore, A. Printing a blend of fruit and vegetables. New advances on critical variables and shelf life of 3D edible objects. *Journal of Food Engineering* **220**, 89–100 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877417303643.
16. Zhu, S., Stieger, M. A., Van Der Goot, A. J. & Schutyser, M. A. I. Extrusion-based 3D printing of food pastes: Correlating rheological properties with printing behaviour. *Innovative Food Science & Emerging Technologies* **58**, 102214 (2019). Available at https://linkinghub.elsevier.com/retrieve/pii/S1466856419308811.
17. Liu, Z., Bhandari, B., Prakash, S., Mantihal, S. & Zhang, M. Linking rheology and printability of a multicomponent gel system of carrageenan-xanthan-starch in extrusion based additive manufacturing. *Food Hydrocolloids* **87**, 413–424 (2019). Available at

https://linkinghub.elsevier.com/retrieve/pii/S0268005X18311688.

18. Thangalakshmi, S., Arora, V. K., Kaur, B. P. & Malakar, S. Investigation on rice flour and jaggery paste as food material for extrusion-based 3D printing. *J. Food Process. Preserv.* **45**, (2021). Available at https://onlinelibrary.wiley.com/doi/10.1111/jfpp.15375.
19. Derossi, A., Caporizzi, R., Paolillo, M. & Severini, C. Programmable texture properties of cereal-based snack mediated by 3D printing technology. *Journal of Food Engineering* **289**, 110160 (2021). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877420302570.
20. Jiang, H. *et al.* 3D food printing: Main components selection by considering rheological properties. *Critical Reviews in Food Science and Nutrition* **59**, 2335–2347 (2019). Available at https://www.tandfonline.com/doi/full/10.1080/10408398.2018.1514363.
21. Escalante-Aburto, A., Trujillo-de Santiago, G., Álvarez, M. M. & Chuck-Hernández, C. Advances and prospective applications of 3D food printing for health improvement and personalized nutrition. *Comprehensive Review Food Science Food Safe* **20**, 5722–5741 (2021). Available at https://ift.onlinelibrary.wiley.com/doi/10.1111/1541-4337.12849.
22. Liu, Z., Bhandari, B., Prakash, S. & Zhang, M. Creation of internal structure of mashed potato construct by 3D printing and its textural properties. *Food Research International* **111**, 534–543 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0963996918304435.
23. Huang, M., Zhang, M. & Guo, C. 3D printability of brown rice gel modified by some food hydrocolloids. *Journal of Food Process Preservation* **44**, (2020). Available at https://onlinelibrary.wiley.com/doi/10.1111/jfpp.14502.
24. Feng, C., Zhang, M., Bhandari, B. & Ye, Y. Use of potato processing by-product: Effects on the 3D printing characteristics of the yam and the texture of air-fried yam snacks. *LWT* 125, 109265 (2020). Available at https://linkinghub.elsevier.com/retrieve/pii/S002364382030253X.
25. Hussain, S., Arora, V. K. & Malakar, S. Formulation of protein-enriched 3D printable food matrix and evaluation of textural, rheological characteristics, and printing stability. *J. Food Process. Preserv.* **45**, (2021). Available at https://onlinelibrary.wiley.com/doi/10.1111/jfpp.15182.
26. Liu, Y. *et al.* Applicability of rice doughs as promising food materials in extrusion-based 3D printing. *Food Bioprocess Technol* **13**, 548–563 (2020). Available at http://link.springer.com/10.1007/s11947-020-02415-y.
27. Yang, F., Zhang, M., Bhandari, B. & Liu, Y. Investigation on lemon juice gel as food material for 3D printing and optimization of printing parameters. *LWT* **87**, 67–76 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0023643817306242.
28. Liu, Z., Zhang, M., Bhandari, B. & Yang, C. Impact of rheological properties of mashed potatoes on 3D printing. *Journal of Food Engineering* **220**, 76–82 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877417301644.
29. Keerthana, K., Anukiruthika, T., Moses, J. A. & Anandharamakrishnan, C. Development of fiber-enriched 3D printed snacks from alternative foods: A study on button mushroom. *Journal of Food Engineering* **287**, 110116 (2020). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877420302144.
30. Kowalska, H. *et al.* Shaping the properties of osmo-dehydrated strawberries in fruit juice concentrates. *Applied Sciences* **13**, 2728 (2023). Available at https://www.mdpi.com/2076-3417/13/4/2728.
31. Dhaliwal, H. K., Gänzle, M. & Roopesh, M. S. Influence of drying conditions, food composition, and water activity on the thermal resistance of Salmonella enterica. *Food Research International* **147**, 110548 (2021). Available at https://linkinghub.elsevier.com/retrieve/pii/S0963996921004476.
32. Jackson, V. & Penumetcha, M. Dietary oxidised lipids, health consequences and novel food technologies that thwart food lipid oxidation: An update. *Int J of Food Sci Tech* **54**, 1981–1988 (2019). Available at https://academic.oup.com/ijfst/article/54/6/1981/7805458.
33. Sánchez-Maldonado, A. F., Lee, A. & Farber, J. M. Methods for the control of foodborne pathogens in low-moisture foods. *Annu. Rev. Food Sci. Technol.* **9**, 177–208 (2018). Available at https://www.annualreviews.org/doi/10.1146/annurev-food-030117-012304.
34. Dankar, I., Haddarah, A., Sepulcre, F. & Pujolà, M. Assessing mechanical and rheological properties

of potato puree: Effect of different ingredient combinations and cooking methods on the feasibility of 3D printing. *Foods* **9**, 21 (2019). Available at https://www.mdpi.com/2304-8158/9/1/21.

35. Zhang, J. Y., Pandya, J. K., McClements, D. J., Lu, J. & Kinchla, A. J. Advancements in 3D food printing: A comprehensive overview of properties and opportunities. *Critical Reviews in Food Science and Nutrition* **62**, 4752–4768 (2022). Available at https://www.tandfonline.com/doi/full/10.1080/10408398.2021.1878103.

36. Le Tohic, C. *et al.* Effect of 3D printing on the structure and textural properties of processed cheese. *Journal of Food Engineering* **220**, 56–64 (2018). Available at https://linkinghub.elsevier.com/retrieve/pii/S0260877417300420.