Overcoming Challenges to Adoption Of 3D Printing: A Step Towards Sustainable Food Supply Chains

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Abstract. In the era of booming technological advancements and automations, integrating them into the industry becomes an aspect of paramount importance. The introduction of 3D printing in the industrial paradigm is a novel approach. Leveraging this approach in the food industry represents a transformative shift in food production, thereby offering customizations, innovations, and sustainability. A revolutionary change in food production, the implication of this technology in the sector relating to food offers improvements in sustainability, creativity, and personalization. This paper examines the evolution and growth rate of this technology, looking at issues facing the sector as well as how it affects customer happiness. Driven by technical developments like IoT, AI, and ML, 3D printing has grown from its initial use to generate sophisticated and customizable culinary items. This research utilizes secondary data from top-cited papers and industry reports to identify these challenges and propose solutions aimed at enhancing consumer acceptance.Adherence to strict food safety regulations, investment in R&D for improved texture and flavor, and enhanced transparency through educational initiatives.. In conclusion, the realises the full potential of this technology and incorporating it into regular food production would require further developments and industry cooperation.

Keywords: 3D food printing, challenges customer satisfaction.

1 Introduction

Since the complexity of understanding consumer buying decisions in food ordering is increasing, it becomes an issue of importance for the food industry to study it effectively. To amplify various aspects of consumer decision-making to consumer service a integration of advanced technologies including Machine Learning (ML), Artificial Intelligence (AI), Internet of things (IoT) has been observed. This includes AI-driven ordering kiosks, IoT-enabled kitchen appliances, and ML-based inventory management systems to streamline processes customer satisfaction.[25] In 1983, three-dimensional printing (3D), also termed as additive manufacturing (AM), was introduced, whose implementation to a higher extent has been done in the fabrication of physical prototypes, living biological structures, and healthcare products. [1,2]

The past years data shows the 3D printing technological ability to be precise, customised, and inventive to the formation and composition of the food. It can be said to be one of the most cutting-edge emerging technologies in food printing for creating extremely sophisticated and tangible prototypes, goods, or living biological structures. [3]. An initial use of 3D printing in the food industry involved the paste extrusion of a 'cake mix' that included sugar, corn syrup, starch, yeast and cake frosting.

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The total amount spent globally on this methodology (including hardware, supplies, software, and services) summed up to $11.4 billion in 2018, and it surpassed that amount by $14.0 billion in 2019 and $23 billion in 2022. It also recorded a five-year compounded growth rate annually to 18 percent, as reflected by research done by the International Data Corporation. [5]. The rise in the figures signifies an increasing scope of the market. Also, speed and efficiency factors are of importance, causing hindrance in 3D printing. Although there are discrepancies relating to technology, such as increasing printing speed, features like larger nozzles for faster disposition is to be considered and in making. [6] With technological interventions and advancements, the issue of printing speed in the 3D printing industry does not exist [7]. Additionally, there has been a paradigm shift in the use of this approach in the healthcare industry, as reflected in the configuration and fabrication of personal protective equipment for healthcare workers, including protective masks and ventilators and individual pieces. This approach facilitated in leveraging the private sector to meet the requirements of advanced technologies and to fulfil the medical supplies that earlier faced shortages, especially demand at COVID-19 pandemic times. [6] . Some disruption is being observed in traditional manufacturing by the inclusion of 3D printing machines, such as reduction in time, increased efficiency, and reduced costs. has been seen disrupting traditional manufacturing by inclusion of 3D printing machines that resulted in the reduction of time in product development of prototypes. Nowadays, this system is used in many different industries because they can create prototypes more quickly and at a lower cost. This allows businesses to test different configurations more quickly, which shortens the time it takes for new products to reach the market.[8].

We can also observe a paradigm shift in the cost structures of 3D printers. Initially, 3D printers were either having primitive capabilities at low cost or higher capabilities at higher costs. But in recent years, the difference between these two printer categories has narrowed as more affordable printers with higher-end features have been accessible. [7]. As the 3D printing market develops and grows, we anticipate that more powerful printers will remain available and affordable.[6] Increased accuracy is the result of evolved 3D printing technology. Even printers that have an auto-levelling feature, which completely automates the printer's platform levelling process, were sold to customers when configurations and Research and Development work came to fruition, guaranteeing precise signage. [6,28,29] This paper aims to investigate the primary challenges relating to 3D printing in the food industry that impact the level of satisfaction of the consumer. It will also explore technological advancements and propose some favourable solutions for the same. Three-dimensional printing is a cutting-edge and disruptive technology, as seen by the increase in reviews, book chapters, and research articles produced annually.[11]. The below Fig 1 and Fig 2 illustrates the growth of this strategy over the years and highlights its importance.

Fig.1. Source: Scopus.

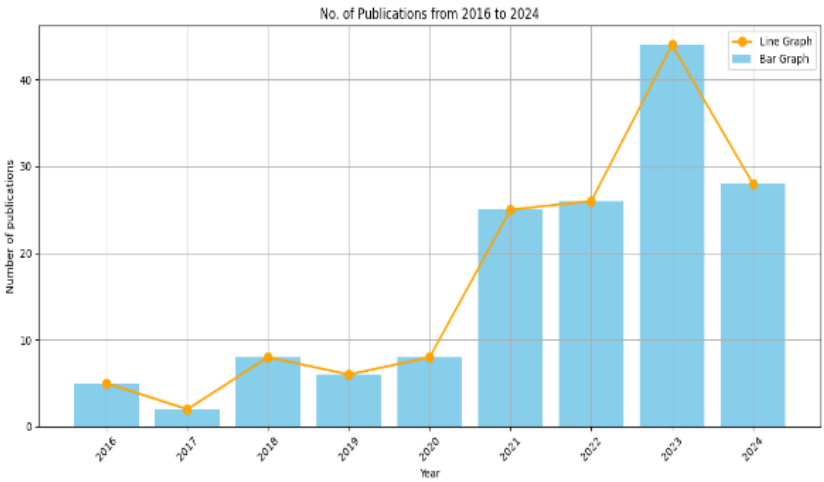

Fig.2. Source: Author.

2 Literature review

The previous research relating to the topic is done by systematic literature review. In a systematic literature review (SLR), a research topic is chosen, an analysis strategy is developed, articles are chosen, data is gathered, findings are synthesized, reports are written, and cross-evaluation is done. Choosing papers, creating inclusion and exclusion criteria, establishing the goal of the study, gathering data, and evaluating the results are all included. Database and keyword combination is shown in table 1.

Table 1. Research Studies on 3D Food Printing.

S.NO.	Author	Year	Objective	Method	Findings
1.	Liu et al [14]	2017	To research the methods for producing precise and accurate food printing while offering important perspectives on the developments and difficulties of 3D food printing.	Reviewed the utilization of 3d printing in various food areas	Highlighted the properties of material, processes and methods as major aspects to ensure accuracy in printing.
2.	Pitayach aval et al..[9]	2018	To discuss the printability, productivity and material properties mechanism of 3D printing.	Reviewed the available food printing technologies.	This paper considered the processing factors for each technique and provides advantages individually.
3.	Attaran &Attaran [6]	2020	Dwelled into the current available 3D printing technology.	Literature Review	Customization, better creativity and sustainability were part of food innovations that revolutionized the process from grocery shopping to cooking.
4.	Zhang et al..[10]	2021	Defining the food inks and determinants of food printing were focused in this study.	Literature review	This paper highlighted factors of 3D foods including moisture content, water activity, food attractiveness and microbiological safety.

5.	Tatiana et al..[11]	2021	This study examined the current state of this approach and conducted research and talked about some advancements in food texture and design.	Review paper	Focused on personalization and customization to create foods that are as per the customer requirements by three-dimensional printing.
6.	Sartal et al… [12]	2018	This paper focused to cater current global challenges in the food industry and how additive manufacturing could contribute.	Case study review	This paper included optimizing robotic claws through three-dimensional printing, that could decrease manufacturing costs while simultaneously improving line flexibility and shortening time to market.
7.	Hussain et al…[13]	2021	This paper explored extrusion-based 3D printing technology and advancements.	Review	Problems in printing non-native food items include high viscosity and strong gel strength are highlighted.
8.	Varvara et al..[15]	2021	The review paper's goal was to highlight the use of this approach in customized nutrition while taking into account the final product's texture,	Review	Consumer acceptability of novel food formulations was influenced by key elements such as food features, sensory qualities, and nutritional makeup.

			structure, and technology.		
9.	Rogers and Srivastava [16]	2021	This study examined the potential, hazards, and difficulties related to 3D food printing.	Case based data collection, interview analysis	There will be additional opportunities to incorporate novel food ingredients, designs, and 3D printing techniques as the market for 3D food printing is expected to develop and grow.
10.	Agunbiade et al… [23]	2021	Based on an advantageous synthesis of the literature, the authors evaluated the current state of 3D food printing in providing customised food engineering solutions.	Literature review	In comparison to other technologies the extrusion-based method would offer a more promising edge and increase the applicability of 3D food printing.

3 Research Methodology

This paper is based on secondary data, where we found the top citied papers from Scopus database by utilizing the literature review, identified the various underlying challenges in order to propose some solutions to enhance customer acceptability and satisfaction.

3.1 Challenges

Even after a lot of emphasis and researches done on the complex aspect of formulation process of 3D food constructs, still there exist technological challenges.[13] The mass customisation in food fabrication is another challenge for ensuring high production and reducing manufacturing costs. [13] Soft-textured materials were not able to extrude without additives such as agar or alginate. There are challenging ingredients, such as

fruits and vegetables, due to moisture content on the higher side and very limited structural stability. [20]. It is challenging even more for the elderly people with swallowing issues to consume texture modified food, which may be unappealing and may lead to malnutrition. [17,18] Presents high cost associated, time consumed to print, very low number of compatible materials, including food safety and printer sanitising concerns, along with limited printing accuracy and surface finishes.[11] There lies a number of technical issues that need to be considered including food material preparation, safety measures and compliance, speed of the process and the cost or reliability obstacles. [23]. Fig 3 shows the challenges identified.

Fig.3. Challeges Identified.

Source: Author

A lot of customers can be dubious about the safety and calibre of food that has been 3D printed. They can be worried about the food's safety and healthfulness, as well as the ingredients used. It might be difficult to get 3D-printed food to have the right texture and flavour that consumers are used to. Consumers who don't feel that a product meets their expectations in these areas may be reluctant to try it. Because of the technology and materials needed, 3D-printed food may be more expensive than conventionally cooked meals. Customers who are price-sensitive can be put off by this. Although 3D printing allows for customisation, the capability of the technology at hand might not allow for a large range of food kinds or intricate recipes, which could restrict the options available to customers. Customers may be worried about the nutritional content of food that has been 3D printed, especially if the components have undergone extensive processing or if chemicals are needed to enable the printing process. The environmental impact of 3D printing food may raise questions, particularly in light of the process's waste production and energy usage.3D-printed food is still not widely available. Comparing these products to more conventional options, customers may find them more difficult to get or acquire. It’s critical to make sure that food that has been 3D printed complies with all applicable laws and regulations. Any shortcomings in this regard may impact the acceptability and trust of customers.

3.2 Proposed Solutions

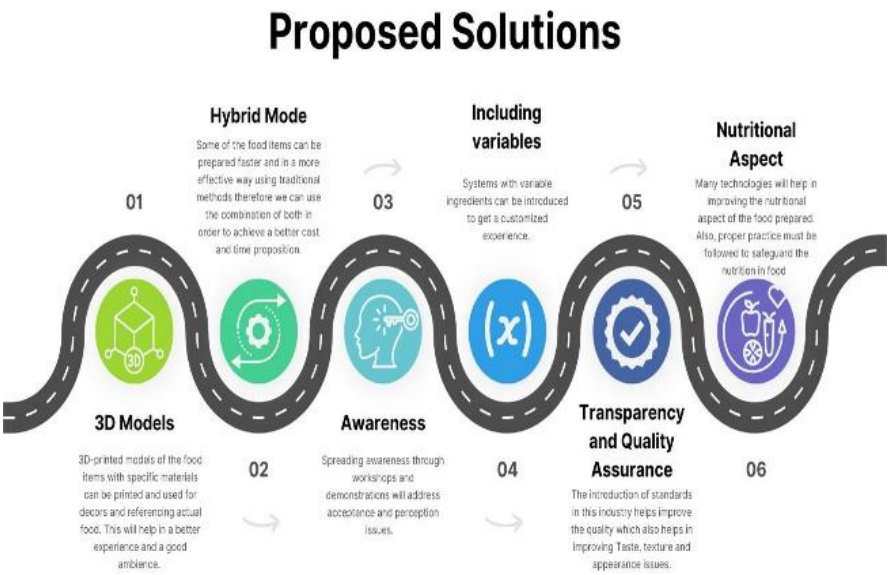

Fig.4. Proposed Solutions.

Source: Author

By means of advertising campaigns, seminars, and product displays, inform consumers about the advantages, safety, and manufacturing process of food that is 3D printed. To foster confidence and trust, give thorough details on the materials utilized, including their sourcing and nutritional makeup. To match consumer expectations, spend research and development money on 3D-printed food's texture and flavors. Work together to improve recipes with chefs and food scientists. Expand the customization choices to accommodate certain dietary requirements and tastes, which will appeal to a larger range of people. Make use of nutrient-dense ingredients and add necessary vitamins and minerals to food that has been 3D printed. Make sure that all food safety and legal requirements are strictly followed. Maintain excellent standards by routinely auditing and certifying 3D-printed food goods. Fig 4 shows the proposed solution.

4 Findings and Discussion

The food business has made significant progress with the potential to transform food production, sustainability, and customization through the use of 3D printing technology.[26][28]

This research extends its implication to hospitality industry in order to understand and optimize new systems and updated software striving towards increased customer satisfaction. The 3D printed food models maybe silicon or rubber based may able to increase the visibility and acceptance of new cuisines or socio-cultural exchange. These 3d models can be placed at the restaurant or outlet for the consumer to refer before making actual orders which will result in increasing the clarity of thoughts in consumer

and also to come upon the expectations of the consumer. By placing in outlet, the 3D food models can increase the consumer temptations regarding the food, also can provide a feel or touch and create an attractive ambience of the outlet that is different from the competitors. These 3d food models are a one-time investment for the restaurants especially that have different cuisines as the cost of preparation of the foods of fancy names will be diminished also will result in saving time, resources and reducing wastages. At the moment, businesses in the industry need more funding to advance technology and expand their product lines, especially with regard to the range of printing chemicals available [16]. These 3d models can also help online food ordering apps by showcasing it in the menu which will provide clarity of food and also slight idea of the quantity of the food. These 3d printed food models will help increasing consumers awareness and acceptance of the food. Small and batch manufacturing businesses can use 3DFP to support UN sustainable development goals because the model takes into account the SDG aims. [24,26,27]. Since this model also incorporates sustainability goals to be achieved the food industry can work on hybrid mode which means producing food in a way that the cuisines which can be prepared easily by the humans can be done by traditional methods whereas, food with complex design and recipes can be automated in a 3D printer. This will help the user to save the resources and improve the turnaround time for every possible recipe. 3D printing technology in food fosters high degree of innovation, customization enabling personalized food designs thereby enhancing aesthetic appeals. For example: In case of a cake the flavour essence can be made a variable entity in order to achieve a high level of customization in terms of taste in this industry. By creating systems that may use variable terms for the ingredient component so that variable components can be customized as customer requirements. Though this is limited to the number of ingredients and the method the recipe used. The food sector leverages this approach that revolutionized the potential of innovation, customization by automating digitization of nutrients broadening the source of food materials. Table 2 shows the application of 3D food printing in various industries and benefits are discussed below:

Table 2. Applications and Benefits of Food Technology Across Industries.

INDUSTRY	APPLICATION	BENEFITS
Hospitality and Catering	• Unique dining experiences for guests • Efficient production for complex dishes	• Differentiation in a competitive market. • Streamlining kitchen operations.
Food Manufacturing	• Production of alternative proteins	• Sustainability practices • Reduced food wastage

	• Optimization of ingredient usage	
Event Planning and Parties	• Thematic and customized food items • Eye catching food presentation	• Memorable events • Increased customer satisfaction
Retail and consumer goods	• On demand production of custom snacks and treats • Interactive retail experiences	• Enhanced customer engagement • Market differentiation
Education and Research	• Hands on learning about food technology • Innovation in food industry	• Practical learning experience • Advancement in food technology
Food Supply Chain	• Improved shelf-life management • Reduction in logistics and storage costs	• Extended product freshness • Cost effective distribution

5 Conclusion

The adoption of 3D printing in food industry lays numerous opportunities to enhance customer satisfaction through customization, innovation and sustainability. There are a number of underlying challenges for the adoption of 3D printing technology in the food industry including the infrastructure, investments required, training, compatible materials, nutritional value, cost, regulations, food texture and preparation time. Overcoming these challenges requires a multifaceted approach involving the advancements in printing technologies, the development of quality standards, and conduction of consumer awareness programs, workshops and seminars that may help the technology to gain the recognition in the industry to foster cooperation and trust. The 3D printed food models are a novel approach to increase the acceptance of the consumer towards 3D printed food and helping in creating a positive perception of this technology. In addition to other novel technologies, it is important to consider the consumers' attitude and awareness relating to 3d printed food and then taking the corrective measures such as educational initiatives and advertisements to explain the

underlying benefits of 3D printing [11]. Collaborative efforts among industry stakeholders including food manufacturers, technology developers, and researchers to drive progress in this field.Furthurmore,the relevance is been highlighted by the advancements in the 3D printing technology.3D printing technology in food is a innovative concept ,it opens up gate to many available opportunities that businesses may exploit and move towards path of improvement in food efficiency and design. This technology also streamlined the traditional methods and reflects a great potential of becoming the standard in the decade to come. [6] Ultimately by leveraging 3D printing technology in the food industry can create unique and personalized food experiences that cater to diverse consumer preferences and dietary needs. Today, this technology is no longer an idea but a reality. This technology not only enhances consumer satisfaction but also promotes sustainability and innovation in food production. It has been observed that there is no limit to increase in the scope pf 3D printing technology in food or 3D culinary printing industry. The technology will impact the economy massively, providing the customers the freedom of choice about the type of food they would prefer. [6] This review examined the past researches and identified the challenges thereby proposing the solutions for the same, trying to narrow the divide between traditional and 3D foods.

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