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3D Food Printing

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ABSTRACT:
Additive manufacturing was developed in the 1980s and for a long time, it had limited applications. In recent years additive manufacturing has found increasing uses in a variety of industries such as the medical field and the construction industry. One industry in particular that has received increasing attention is that of 3D printing food. One of the parties that is interested in this is NASA as 3D printing improves the ability for space exploration. In this study, we examine the current technological developments in the 3D food printing industry. The focus is on describing the applications, challenges, market scenario, main technologies that are applied in this industry, the materials that are being printed, and the main companies and business strategy. It is concluded that the industry is very young and that most of the commercialization is based on the application of only one of the seven additive manufacturing technologies.

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I. INTRODUCTION:

Additive manufacturing, also known as 3D printing, is often compared to the concept of the Star Trek replicator. It is a production process where physical parts or structures are built by laying down successive layers of materials, i.e. adding materials. This is in contrast to the traditional subtractive process where for example a production process starts with a block of metal and then material is removed until the final product remains. 3D printing has grown rapidly in recent years because of its great potential in several application forms such as rapid prototyping, on-demand production, facilitating complex design and product innovation, reducing waste, shortening design cycles as well as supply chain, and reconciling the conflicts between customization and economies of scale.

1.1 DEFINITION OF FOOD PRINTING:

3D printing is a technique used for the manufacture of three-dimensional objects with high accuracy and quality finishing in their dimensions. The technique finds applications in industries, including aviation, automotive, packaging, construction, pharmaceuticals, and food. In the food sector, 3D printing is widely investigated across areas, such as customized food designs, personalized and digitalized nutrition, simplified supply chain, and broadened source of available food material. A 3D food printer comprises a food-grade syringe or cartridge that holds material, a real food item, and deposits exact fractional layers through a food-grade nozzle directly onto a plate or other surface in a layer-by-layer additive manner. Another method is a mold-based method wherein 3D printing food machines are used to give shapes to a dough with the help of a hollow container or molding box. 3D printing requires hardware and software to work in collaboration. Advanced 3D food printers are equipped with user-friendly interfaces and pre-loaded recipes with designs that can be easily accessed by the computer or even with a mobile or IoT device.

Currently, 3D food printers make use of nozzles, fine materials, lasers, and robotic arms. The raw material flows smoothly from the print cartridge to the printing platform and protects the solid build on the platform. In a similar fashion, substances such as starch and proteins, which can form hydrogel structures, can easily be obtained from cheese, chocolate, and humus that can easily flow from the printer cartridge to the platform. The 3D printed food consuming community favours a variety of culinary options, such as crystallized sugar cake, detailed chocolate designs, readyto-bake pizzas and ravioli, and cracker-like yeast structures having seeds and spores, which can sprout over time. With the above in mind, the purpose of this study is to explore the 3D printing of food. Various parameters to be discussed further like:

- Benefits
- Challenging Aspects
- Printing Techniques

Few research questions were posed:

- What materials are being used to 3D print food?
- What companies are active in the process of 3D printing food and how do they compete? The paper is organized as follows. After this the methodology is described followed by the findings of the study. Last, conclusions are drawn.

2.1 BENEFITS TO LOOK FORWARD TO:

3D printing usage comes with its own set of advantages:

- Allows food customization according to the choice, as the 3D printer can help determine the exact quantity of vitamins, carbohydrates, and fatty acids as per the input and assess the correct percentage of nutrients for a particular age.
- 3D printing saves both time and energy when it comes to experimenting with different types of food dishes. It also helps in achieving perfection with less effort and less time.
- The use of the food printing technique enforces innovation and creativity. Users can create dishes in entirely new ways by customizing ingredients. In addition, users of 3D printing can modify composition or amalgamate two products to produce an innovative dish.
- Food reproducibility is possible using 3D printing. Using the same set of ingredients to produce a similar dish again eventually drives the minimization of food waste. Additionally, it allows the sustainable usage of materials, such as duckweed, grass, insects, or algae, which can be used to form the basis of familiar dishes.

2.2 CHALLENGING ASPECTS:

A few challenges associated with the use of 3D printing are mentioned below. Firstly, food safety is a significant concern. 3D printing process develops food in minimal time, which eventually restricts cooking food at certain temperatures or may result in fluctuating temperatures due to which microbes can grow and contaminate the food. Hence, to avoid contamination-related issues, manufacturers are required to follow certain standard practices and guidelines while processing the food. Food manufacturers cannot use all ingredients that are used at the time of conventional cooking. Every ingredient has its storage and cooking requirements, such as an optimum temperature, which needs to be met. All 4 ingredients cannot be placed together in one container, along with the main component or dough, when manufacturing food via 3D printing The use of a 3D printing machine requires skillfull personnel. Appropriate training is offered to individuals on how to use a 3D printer for food manufacturing, which results in high-cost investment. The knowledge base and skills needed to operate the machine adds to the cost for training purposes. Additionally, 3D printers are expensive, with prices ranging between USD 1,000 to USD 5,000. The use of skilled labour and machine cost exerts a huge burden on the manufacturer.

3.1 METHODOLOGY:

This exploratory study centers on an exploration of the development of 3D food printing. Of the five main research strategies, i.e. survey, experiment, case study, grounded theory approach and desk research, the desk research strategy was selected because this fit with the exploratory nature of this study. Desk research is characterized by: 1) the use of existing material, 2) the absence of direct contact with the research object, and 3) looking at the material being used from a different perspective than at the time of its production. The most important characteristic is that the material used has been produced entirely by others. Three categories of existing material can be used for carrying out a desk research project: literature, secondary data, and official statistical material. Literature is understood to mean books, articles, conference proceedings etc. Secondary data is empirical data compiled by other researchers. Official statistical material is data gathered periodically or continuously for a broader public. Due to the newness of the industry and therefore the limited amount of secondary data and official statistical material, the focus in this study was on literature. In particular, articles and news from industry sources and some academic sources. The search was kept broad so that literature from a variety of sources representing a variety of perspectives which helps with forming a picture of what is happening in this industry. Literature sources included company websites, news reports, journal articles and academic reviews. Examples of academic journals that were included in the search for information were: Journal of Food Engineering, Trends in Food Science & Technology, and Innovative Food Science & Emerging Technologies. Articles in these types of journals provided insight into details of 3D food printing technologies and materials. Additional information was retrieved by searching online for information on the history and development of the companies that were identified as being active in 3D printing of food. For instance looking for information on their founding and product development. More stories were found in news reports and 3D printing industry newsletters such as: 3dprint, 3dprintingindustry, All3DP.

4.1 FINDINGS:

4.1.1 TECHNOLOGIES EMPLOYED IN 3D FOOD PRINTING

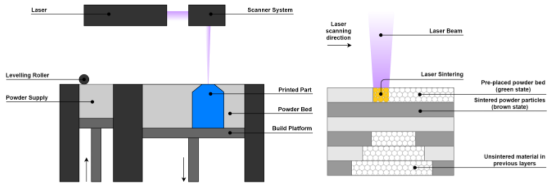
• EXTRUSION-BASED PRINTING:

Although there are different approaches to extrusion based printing, these approaches follow the same basic procedures. The platform on which food is printed consists of a standard 3-axis stage with a computer controlled extrusion head. This extrusion head pushes food materials through a nozzle typically by way of compressed air or squeezing. The nozzles can vary with respect to what type of food is being extruded or the desired printing speed (typically the smaller the nozzle the longer the food printing will take). As the food is printed, the extrusion head moves along the 3-axis stage printing the desired food. Some printed food requires additional processing such as baking or frying before consumption. Extrusion based food printers can be purchased for household use, are typically compact in size, and have a low maintenance cost. Comparatively, extrusion based printing provides the user with more material choices. However, these food materials are usually soft, and as a result, makes printing complex food structures difficult. In addition, long fabrication times and deformations due to temperature fluctuations with additional baking or frying require further research and development to overcome.

• HOT-MELT AND ROOM TEMPERATURE:

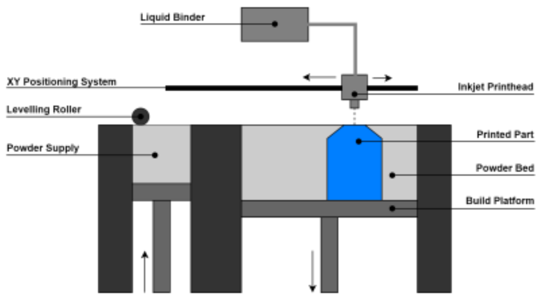
In Hot-melt extrusion, the extrusion head heats the food material slightly above the material's melting point. The melted material is then extruded from the head and then solidifies soon thereafter. This allows the material to be easily manipulated into the desired form or model. Foods such as chocolate are used in this technique because of its ability to melt and solidify quickly. Other food materials do not inherently require a heating element in order to be printed. Food materials such as jelly, frosting, puree, and similar food materials with appropriate viscosity can be printed at room temperature without prior melting.

• SELECTIVE LASER SINTERING:



In selective laser sintering, powdered food materials are heated by and bonded together forming a solid structure. This process is completed by bonding the powdered material layer by layer with a laser as the heat source. After a layer is completed with the desired areas bonded, it is then covered by a new unbonded layer of powder. Certain parts of this new unbonded layer are heated by the laser in order to bond it with the structure. This process continues in a vertical upwards manner until the desired food model is constructed. After construction, unbonded material can then be recycled and used to print another food model. Selective laser sintering enables the construction of complex shapes and models and the ability to create different food textures. It is limited by the range of suitable food materials, namely powdered ingredients. Due to this limitation, selective laser sintering has been used primarily for creating sweets/candies.

• BINDER JETTING:



Similarly to selective laser sintering, binder jetting uses powdered food materials to create a model layer by layer. Instead of using heat to bond the materials together, a liquid binder is used. After bonding the desired areas of a layer, a new layer of powder is then spread over the bonded layer covering it. Certain parts of this new layer are then bonded to the previous layer. The process is repeated until the desired food model is constructed. As with selective laser sintering, binder jetting enables the construction of complex shapes and models and the ability to create different food textures. Likewise, it is also limited by the range of suitable food materials, namely powdered ingredients.

4.1.2 MATERIALS USED IN 3D FOOD PRINTING:

The exploration of edible materials, which have the properties of printability, can help to meet the demand for customized food items for special groups who need special blends of nutrition or textures, such as elderly, children, patients, soldiers and astronauts. The term printability is defined as the properties that allows the material to be handled with dimensional stability and that is capable of supporting its own weight. In the development of printing materials for food, the capability of building complex structures and textures while incorporating nutrition values, as well as the pursuit of a cooking-resistant structures are essential. Furthermore, high printability enables the fabrication of constructs with geometric complexity. This opens the possibility for the applicability of 3D printed food for artistic design with customized shapes and controlled texture. Currently, raw food materials that are used in 3D food printing include: sugar, chocolate, cheese, cereals, fruits, cookie dough, and ground meat. The 3D printing technologies adopted in food printing combined with the (edible) materials are summarized in the Table given below.

TABLE I 3D FOOD PRINTING TECHNOLOGY AND MATERIAL

Technology	Sub-category	Materials
Material extrusion	Hot	Chocolate, confection
	Room temperature	Frosting, processed cheese, dough, meat/scallop puree
	Cold	Ice-cream
Powder bed fusion	Hot Air (SHASAM)	Sugar
	Laser (SLS)	Sugar
Material jetting	Ink Jet	Chocolate, liquid dough, sugar icing, meat paste, cheese, jams, gels, fruit juice
Binder jetting	Liquid binding	Chocolate, sugar

4.1.3 MARKET SCENARIO AND MAJOR 3D FOOD PRINTING COMPANIES:

The different technologies were identified that are being used for 3D food printing in section mentioned above. However, many of the new advances in 3D food printing technology are made at universities or scientific labs and the commercial application through companies is limited For example Fab@home (Cornell University) was the first to adopt extrusion in food printing. They are dedicated to design teaching tools and explore new materials. Chocolate was among the first materials that they experimented with and it became one of the main application of 3D food printing. Dr. Hao (University of Exeter) led a new fabrication method applied specifically to chocolate and founded the firm ChocEdge. This led to the creation of the first commercialized 3D chocolate printer around 2010-2012. ChocEdge, is currently still specialized in Chocolate printers.

For situations where a company has been formed that sells a 3D food printer, fourteen companies were identified. Included were only those companies that are beyond the concept stage and which offer the printers. For instance, 3D Systems acquired Sugar Lab in 2013 and within a year came out with the ChefJet and ChefJet Pro printers. However, since then not much has happened. In August 2017 there was another announcement indicating a partnership of 3D Systems with CSM to bring the food printer to the market but as of January 2018, the company website contains limited information on its involvement in the 3D printing of food. Therefore, 3D Systems and its ChefJet food printer were not included. Another example is Message in a Cake. This project was started by Daniel Wilkens when he was a student at Folkwang University of the Arts. Although there is a working printer, this does not seem to be for sale commercially and therefore is not included.

The growth of 3D printing technology in the market depends on factors, such as the growing demand for 3D printed food products in the market and health perspective. Consumers, with the help of the internet, can check online databases for recipes to design their healthy diet by using the right ingredients in the meal. Before 2014, the food printing method was very complicated. However, at present, food manufacturing players are showing interest in 3D printing technology for food items manufacturing. These players are moving from conventional food preparation methods to advanced technologies, such as 3D printing.

The below bar chart illustrates a comparison between the top priorities related to 3D printing in 2015 and 2020, as reported in Forbes Study.

TABLE II: 3D FOOD PRINTING TECHNOLOGY AND MATERIAL

Technology	Company	Year	Materials
Material extrusion	PancakeBot	2010	Pancake
	Zmorph	2013	Chocolate and cake batter
	Natural Machines	2015	Multi-material Foodini
	Beehex	2016	Pizza, cake decorations
Material extrusion (Melting capable)	ChocEdge	2010	Chocolate
	byFlow	2010	Chocolate
	Essential Dynamics	2012	Chocolate and others
	Structur3d	2013	Chocolate, frosting
	ORD solutions	2015	Chocolate, pasta
	Procusini	2015	Chocolate, icing, cream cheese, jams, mixes, batters
	Becoda	2015	Chocolate
	Shiyin Tech	2016	Chocolate, cheese, jam, candy, biscuit, multi-material
Binder jetting	Dovetailed	2014	Fruit
	FoodJet printing systems	2015	Chocolate, liquid dough, sugar icing etc.

Table II shows the 14 companies, the different technologies they have adopted, the year their printer became available, and the food items their printers are capable of printing. Table II illustrates that in cases where 3D printing food has been commercialized, i.e. a company exists, and that most of these companies are based on material extrusion. Furthermore, many firms are specialized in chocolates/sweets food printers.

For instance, by Flow, Essential Dynamics, and Structur3D. Since their technology is based on the melting extrusion technology, and therefore they are capable of printing cakes and macaroons, however, these firms haven't extended their business into other soft-material extrusion printers, such as pasta or pizza printers. Table II also illustrates that for the companies that are using other technologies/materials are also specialized in a very specific type of food items/materials, such as Dovetailed and Food Jet printing systems which use material jetting printers. Therefore, it can be concluded that different 14 properties of materials require different processing technologies which drive the specialization of food printers and also the technology choices and decisions of food printer companies.

The companies in table II follow different business models. Some of them focus on consumer printers. Most of these are start-ups or companies inspired by individual researchers out of curiosity. For example, PancakeBot, whose inventor Miguel Valenzuela came up with the idea of the pancake machine from his 3-year-old daughter who wanted a pancake maker that can create all kinds of designs. This company is now a partner of Storebound and still specialized in pancake consumer printers. Other companies that focus on consumer food printers include, by Flow Procusini, and Shiyin Tech. Other companies focus on industrial printers, i.e. printers for industrial users or professional kitchens. For instance, Natural Machines, Beehex, and Choc Edge. Some companies have a business model where prepacked ingredients that are sold by the company are required in order to operate the printer, e.g. Natural Machines and Choc Edge. These companies relate these bundled products to quality issues.

5.1 3D PRINTING ADOPTION SCENARIO

While there are companies still exploring the idea of technology potential, there are powerhouse brands, such as PepsiCo and Hershey, continuously using 3D printing. While PepsiCo uses 3D printing to create a plastic prototype of different shaped and colored potato chips, Hershey's scientists use 3D printing for uniquely designed candy. Oreo has used 3D printing to create cookies with customized creme patterns and flavors. Barilla, an Italy-based pasta manufacturer, collaborated with TNO, a Dutch scientific research firm, to develop a 3D printer capable of printing a variety of differently shaped pasta, allowing customers to 3D print their CAD files with different pasta designs quickly and easily.

Image credits: Callebaut

Recently, a Zurich-based leading manufacturer of high-quality chocolate and cocoa products, Barry Callebaut Group, announced the launch of the world's first 3D printing studio to make personalized 3D printed chocolate at a large scale. It launched its chocolate creations through its global decoration brand, Mona Lisa. Mona Lisa teamed up with one of the most creative pastry chefs, Jordi Roca, to help him create 'Flor de Cacao,' a unique 3D piece made out of chocolate. It represents a cocoa bean that opens up like a cacao flower through contact with hot chocolate sauce.

6.1 3D FOOD PRINTING COSTING IN INDIA

Equipment and manufacturing costs are some of the other barriers to the adoption of 3D printing. Cost ranges from as low as □80,000 to □1.5 crore, depending on technology and build size for polymer printing. Material cost varies from □2 per gram to □15 per gram depending on the choice of material. One-time deployment cost with all the infrastructure will range from □150,000 to □750,000, depending on the printer technology and size.

CONCLUSION

3D printing technology in food industries offers new possibilities, such as personalized nutrition, automated cooking, reduction in food wastage, etc. This 3D printing technology in the food industry can fulfill the unmet needs in terms of personalized nutrition, food wastage, demand, and availability of food. It is an evolving technology that has a large number of benefits, such as saving time, highly efficient, sustainability, and many more. Nowadays, food manufacturing companies are moving towards the techniques or methods that can help them use food ingredients in the right manner for making healthy and tasty food to reduce food wastages. The population of the world is increasing rapidly, so there will be an increase in the food demand as well as wastage of it will lead to food source scarcity. This situation needs to be handled with novel technologies, such as 3D printing, which can efficiently use food resources with no or very less amount of wastage.

Globally, there are a variety of prototype printers available for food production. 3D printing will continue to evolve as an exceptional technology in the food industry; however, high adoption will likely come from companies focused on product innovations and/or direct-to-consumer strategies.

Although, the cost of 3D food printing is high but the noticeable merits of it surely outshines the demerits, so the technology should be considered for the future and it is not too far to believe that 3D food printers could eventually become ubiquitous as the microwave in your kitchen.

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