Comprehensive Review on Extrusion-Based 3D Food Printing

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Abstract:

Extrusion-based food printing, is a digitally-controlled extrusion process unlike from food extrusion cooking. It is to build up complex 3D food products layer by layer. Currently, it is one of the innovative method in the area of Food printing. The food printing can provide key solutions for digitalized food design as well as targeted nutrition control as per different needs and application. Different methods are employed for 3D Food printing such as selective laser sintering/hot air sintering, hot-melt extrusion/ room temperature extrusion, binder jetting, and ink jet printing. Among the available methods, extrusion-based 3D food printing is the one of the most widely adopted and applied method. The ideal end result of extrusion-based 3D food printing is to achieve a comparable or superior the present time. Geometric output to that attainable with conventional food extrusion processing but with this output obtained through digitalized design while also incorporating personalized nutrition control. Single or multi nozzles can be used to hierarchically print products to meet consumer demands generating unique tastes, extrinsic features and tailored nutritional profiles. This paper gives in detail about extrusion 3d printing, different mechanics involved, pretreatment and post treatments required. Food safety and design considerations, consumer acceptance and role of food ingredients, applications and developments .

Keywords: 3 D printing, food extrusion, syringe based, screw based extrusion, food design.

Introduction

3D printing which is also known as additive manufacturing (AM), rapid prototyping (RP), is an emerging digitalized technology, which is controlled using computer-aided design (CAD) software & instructs a digital fabricating machine to shape 3D objects by successive addition of material layers. It is Processes in which material(s) is/are joined or solidified under computer control to create a 3D object. An main advantage is to construct a complexity model without mold and die, fixtures, cutting tools and coolants. Total history of 3D food printing is less than 15 years, although the desire of rapidly fabricating custom-made food was expressed early in the 1960s through the movie, STAR TREK. The idea of creating 3D decoration on the cake surface using hand cream extruder can be considered as precursor. The latter is an automated version with computerized design pattern for fabrication compared to the previous manual process**.** 3d printing is multi disciplinary science which involves food processing in formulating the recipe and study of characteristic property of raw materials, food chemistry in study of nutritional profile and food engineering in designing food printing , developing CAD softwares. Hideo Kodama (1981) of Nagoya Municipal Industrial Research

Institute invented two additive methods for fabricating 3D plastic models. The first working 3D printer was developed in the 1980's and used polymer and plastic as printing material (Horvath, 2014). The first 3D food printer was developed around 10 years ago employing a syringe-based extruder to deposit food pastes on a platform. It is gaining large interest from researchers, industry and public with its varied fields of applications in the areas such as medicine, gastronomy, engineering, manufacturing, art and education. However, a sustainable nutrition and food security are the global agenda and key themes, which are considered during, apply 3D food printing. This technology was firstly presented for food industry by researchers from Cornell University by use of an extrusion based printer, which was named Fab@home in 2001.

With reference to the food sector, it will define innovative borders for food processing by being able to deliver a product that suits special consumer's criteria of taste, cost, convenience and nutrition. Therefore, although foods are complex systems with wide variations in physio-chemical properties, researchers have worked on widening the application of 3D printing to various types of food products. In the recent time food market is growing for personalized healthy food to targeted consumer with specific medical conditions and personal gift market such as frosted patterns on biscuits and chocolates, letters carved into cookies, and logos painted on food. It helps to bridge the gap between culinary arts and nonprofessional food artisans by decreasing the cost of production. Novel Food Structuring Using a Broad Range of Alternative Food Ingredients. Its Environmentally Friendly and Sustainable Technology and helps in promoting. After fabrication success, they considered that 3D printing of food offers many possibilities for customized nutrition, including exceptional flexibility in geometries, textures and flavors.

Compared with foods manufactured in mass production, they are more nutrition controllable, but significantly more expensive and only available from very limited suppliers. Traditional mass food preparation processes, even those with advanced processing technologies, cannot meet such personalized demands. Some food companies are exploring alternative food preparation methods to capture and maintain market share, in turn providing opportunities for food preparation methods such as three-dimensional (3D) printing.

Different methods are employed for 3D Food printing such as selective laser sintering/hot air sintering, hot-melt extrusion/ room temperature extrusion, binder jetting, and ink jet printing. Among the available methods, extrusion-based 3D food printing is the one of the most widely adopted and applied method. The ideal end result of extrusion-based 3D food printing is to achieve a comparable or superior the present time. Geometric output to that attainable with conventional food extrusion processing but with this output obtained through digitalized design while also incorporating personalized nutrition control. Single or multi nozzles can be used to hierarchically print products to meet consumer demands generating unique tastes, extrinsic features and tailored nutritional profiles.

Extrusion in 3D food printing

Extrusion process normally uses force to pass materials through a die opening thereby creating different products/objects as per intended requirement and application. 3D Printing using extrusion is a digitally-controlled, robotic construction process which aims to build up complex 3D food products layer by layer. It initiates with material loading and thereafter pushing the material out of the nozzle in a controlled manner, moving the material stream according to predefined path, and eventually bonding the deposited layer to form a coherent solid structure. The extrusion-based food printer consists of a multi-axis stage and one or more extrusion units. With the assistance of computer and algorithms, such advanced printers can manipulate food fabrication in real.

The current extrusion-based food printing starts with

1. Designing a virtual 3D model.
2. Slicing software than translates this model into individual layer pattern.
3. This than generates machine codes for printing.
4. Once the codes are uploaded into a printer, preferred food recipe is introduced and after this food printing process is initiated.
5. As per the layer patterns generated from the 3D model, the extruded material is dispensed either by moving the nozzle above a motorized stage or by moving the stage underneath the nozzle to form a layer.
6. Each layer welds to the previous layer on the stage, and forms a layer based 3D structure.
7. The printed foods may go through a post-deposition cooking process such as baking as per requirement and target application.

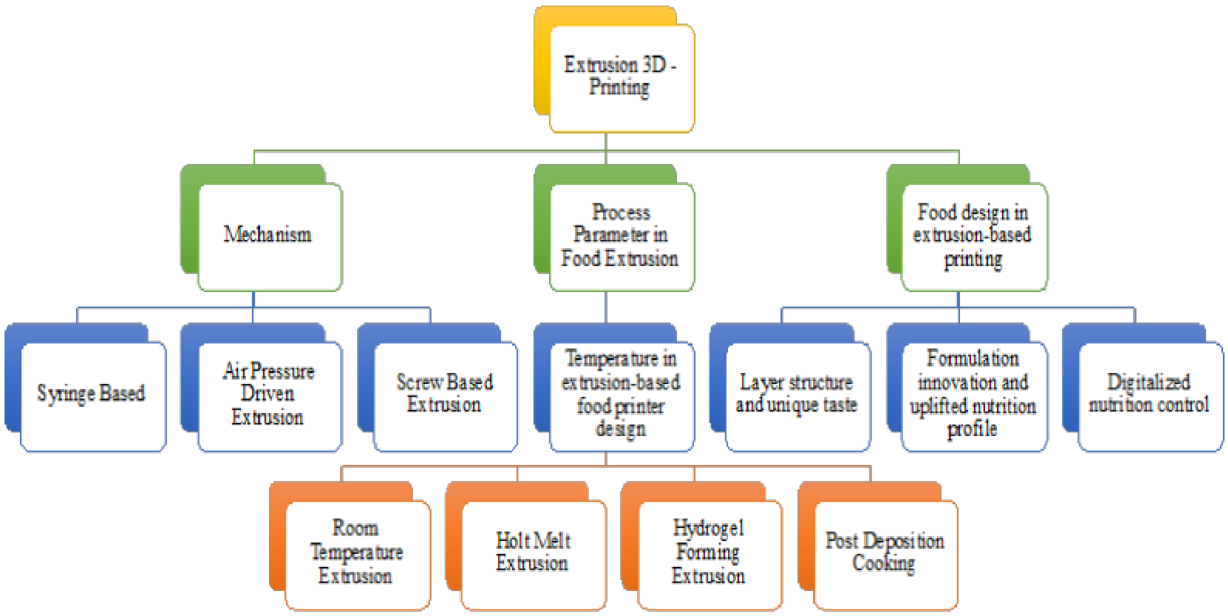
In terms of similarity, Both the food extrusion cooking and extrusion-based 3D food printing can automate a food preparation process, improve the process efficiency and the resultant food quality. However, these two methods create two considerably different user experiences automate a Food preparation with improved efficiency in the process resulting in the enhancement of the food quality. Extrusion-based 3D food printing aims to achieve the output of the conventional food extrusion processing physically with a digitalized design and a personalized nutrition control. Extrusion-based printing systems basically withstand dispensing of macromolecules such as hydrogel strands or polymers through a micro nozzle and actual position of them with computer-aided motion either heads of printing or collecting of phases. Difference between food extrusion cooking and extrusion-based food are food extrusion aims to reduce human involvement and workload by automating various manual processes, and the extrusion based 3d printing places users' creativity and control at the center of the process by allowing the users to manipulate food forms and materials directly.

Table .1. Difference between conventional extrusion cooking and extrusion based food printing

EXTRUSION COOKING	EXTRUSION BASED FOOD PRINTING
• The key component in the extrusion cooking is an extruder, which can mix, heat/cool, and shape highly viscous raw ingredients. • This extruder consists of single/twin rotating screw tightly fitting within a stationary barrel. • Pre-ground and conditioned ingredients powders are fed into the extruder, and pressurized into viscoelastic fluid using mechanical and thermal energy. • They are then texturized and shaped in a die located at the end of the extruder, and transited from high pressure to low (atmospheric) pressure. • Both solid and liquid ingredients can be fed to the extruder for manufacturing products such as pasta, snacks and precooked pellets that vary in structure, shape, texture, and density.	• The extrusion process in food printing is a digitally-controlled, robotic construction process which can build up complex 3D food products layer by layer • It starts with loading of material, pushing the material out of the nozzle in a controlled manner, moving the material stream according to predefined path, and eventually bonding the deposited layer to form a coherent solid structure. • The extrusion-based food printer consists of a multi-axis stage and one or more extrusion units. • It has compact size and low maintenance cost but is criticized due to limited material choices and long fabrication time.With the aid of computer

• The end products are well cooked, shelf stable and ready for packaging.	control, such printers can manipulate food fabrication in real time

Figure 1. below provides overview of the mechanism, Process parameters and design used in the Extrusion 3D Printing.



Extrusion Mechanism and Process Parameters in Food Printing

Three extrusion mechanisms have been used to extrude liquid/semisolid materials: syringe based extrusion, air pressure driven extrusion and screw-based extrusion.

Syringe-Based Extrusion

The syringe-based extrusion unit includes a syringe to store food materials and a step motor to drive the extrusion process. The step motor is programmed to generate liner motion, control the position of the syringe plunger, and push the food material out of the nozzle. It has been applied in commercial machine designs such as Choc Creator, and CocoJet 3D Printer. The extrusion rate (i.e. how quickly the material can be extruded out of the printhead can be easily and rapidly adjusted by varying the motor speed, and more power is required to extrude high viscosity materials. This design requires one motor for each print head, thus the printing payload for multi-material increases greatly. This type of extrusion unit is suitable to print semi-solid or solid food materials. The syringe unit should be selected carefully, otherwise it may require additional power due to increasing friction force caused by overloading.

Air pressure driven extrusion

An air pressure driven extrusion unit includes a pneumatic pump and an encapsulated food cartridge, and has been applied to design Barilla's pasta-making 3D printer (Barilla, 2016) and BeeHex 3D printer (BeeHex, 2016). Air pressure produced by the pneumatic pump pushes the material in the encapsulated food cartridge out of the nozzle. The pump can drive multiple extrusion heads with varied extrusion rates at the same time through regulating valves.

The response time is relatively long when changing the extrusion rate. While, to fill/refill high viscous material homogeneously into the syringe\cartridge without air bubbles may need additional devices if scaled up for industrial production. The air pressure driven extrusion is more suitable to print liquid materials, while the solid and semi-solid material can easily attach on the inner wall of the food cartridge. To sterilize the air from the pneumatic pump, a filtration system is necessary to be installed on the airway to minimize contamination of the printing material.

Screw-Based Extrusion

Food materials are fed into the cartridge and transported to the nozzle by an auger screw for continuous printing. In this screw-based extrusion, the food cartridge is designed to have a wide opening on top for material loading, followed by the narrower tube structure and the extrusion nozzle. During the printing process, the screw driven by the motor continuously brings the materials downwards and passes through the extrusion nozzle with a minimum disturbance from air bubbles. Due to the direct contact to food materials, the screw and cartridge should use food-grade stainless steel for autoclave. In the context of printing, extrusion through the printing nozzle is the action of forcing moldable materials through a die opening to create objects with desired cross sections based on their deposition and post extrusion fusion with their geometry determined by appropriate modeling methods. Syringe screw and air pressure are the most common parameters to force the raw materials through the extruder die

Extrusion 3D printing is suitable for producing carbohydrate based food, such as bread, pizza and cookies. Customized cookies made by additive manufacturing technologies and illustrated the probability in 3D printed baking, slow cooking, frying, etc. A company called Natural MachinesVR created an air pressure driven 3D printer for baking materials such as customized pizza and cookies. BeeHexVR used a commercial 3D printer (air pressure with multi nozzles) to process customized pizza. To improve the quality of 3D printed food, exogenous substances are often added to the carbohydrate, fat, protein and fiber raw materials to enhance their process ability, aroma, nutritive value or storability (pre and/or post printing).

Syringe and food cartridge

To accommodate the extrusion mechanisms mentioned above, diverse syringes and food cartridges are developed accordingly. In general, the inner wall should use non-sticking material with a smooth finish to minimize the energy consumption during the food extrusion process and to allow easy sterilization after extrusion. Besides, a streamlined connection between syringes/food cartridges and nozzles is expected to mediate the extrusion force. Both disposable and refillable food-safe syringes/food cartridges are applied in commercial designs. While the disposable syringes/food cartridges are convenient but not environmental friendly, the alternative method is to refill them. To print foods that are both edible and safe, food-safe materials have to be used for any parts of the machinery that touch the foods during the printing process. They include the syringe that stores the material to be printed, the printing stage where the printed food piece stands, and certain machine parts. Currently in use are food-grade syringes made of food-safe plastic or food grade stainless steel and food grade paper placed on the printing stage.

Process parameters in extrusion-based food printing

In traditional food extrusion cooking, the process parameters include temperature, shear force, pressure, screw speed, extrusion rate and extruder design parameter (such as nozzle diameter) and extruder type. The process parameters in the extrusion-based food printing include extrusion-related parameters similar to the traditional extrusion cooking, and also printing related parameters (such as stage moving speed and printing layer thickness).

1. In food printing, the fabricated layers require sufficient rigidity and strength to support their own weight and the weight of subsequent layers without a significant deformation or shape change.
2. The layer thickness is determined by the stage speed, extrusion rate and diameter of the nozzle. Smaller nozzles may lead to thinner layer thickness, better food surface, and vice versa.
3. For the same extrusion rate, a faster stage moving speed may break the deposited stream or cause deformation, and a slow stage moving speed may result in the accumulation of the extruded stream, in turn increasing the layer thickness and sacrificing the surface quality. Thus, the selection of stage moving speed is a tradeoff between the extrusion rate and the material solidification rate after extrusion. It is suggested to implement an intelligent control algorithm to adjust the extrusion rate along the printing path. Most of the food printing software designs just modifies open-source software, which are developed for plastics material printing.
4. Other factors influencing the extrusion come from food material volume, gradual magnification of internal disturbances from the print head actuation process, and inhomogeneous printing materials. Here, it is a complicated task to plan and implement real time control of the food printing process.

Temperature in extrusion-based food printer design

Due to varied temperature control, the current printers can be classified into: room temperature extrusion (RTE), hot-melt extrusion (HME) and hydrogel-forming extrusion (HFE).

Room temperature extrusion (RTE)

RTE refers to smoothly extruding natively printable materials like dough, cheese, frosting, creamy peanut butter, jelly, Nutella and hummus at room temperature. RTE has been applied to fabricate complex confections with high repeatability, which are difficult to make by hand. Essential carbohydrates, proteins, meat purees and other nutrients extracted from alternative sources (algae and insects) have been used as printing materials in RTE. The RTE can also be applied for pasta printing using classical recipes (durum wheat semolina and water), and surface filling on pizza, cookie and graphical decoration. Cold extrusion or room temperature extrusion relies solely on the inks' rheology for printing. In contrast to hot-melt extrusion, there is no manipulation of temperature. The ink should be both extrudable and capable of forming self-supporting layers (Godoi et al., 2016). Ink rheology may be modified through the addition of thickeners or changing the composition.

Hot-melt extrusion (HME)

HME was firstly described by Crump in 1991, and has been widely applied to create customized 3D chocolate products. Melted semisolid food polymer is extruded from a movable HME head, solidifies almost immediately after extrusion, and welds to the previous layers. MIT researchers used hot-melt chocolate as a dispensing liquid and developed a functional prototype "Digital Chocolatier". Over the years, Choc Edge, Natural Machines and TNO have utilized HME to build 3D chocolate objects. A '3D Food-Inks Printer' with embedded 3D colour images on extruded base material may also fall into this category, while a post-deposition cooking step was required to fuse layers together. Hot-melt extrusion involves an initial heating step to allow the ink to flow out of the nozzle followed by a cooling step to solidify the ink. In general the ink in hot melt extrusion is not heated to the same degree as FDM. The melting temperature for ABS filaments is around 200 °C In comparison, gelation point for gelatin and agar is around 30-40 °C. The ink is kept a few degrees above the material's gelation point such that the ink can gel rapidly once extruded. For inks with gelation point around or below room temperature the printing platform or chamber may be cooled with an ice bath

Hydrogel-forming extrusion (HFE)

HFE is the extrusion of hydrocolloid solutions or dispersion into a polymer/hardening/gel setting bath using syringe pipette, jet cutter, vibrating nozzle and similar apparatus. In general, gel droplets' diameter is about 0.2e5 mm, and solution temperature control is the key to forming stable shapes in HFE. This extrusion is critically dependent on the rheological properties of polymer and the mechanism of gel formation. In other words, the polymer solution should present viscoelastic characteristic first, and then turn into self-supporting gels prior to the consecutive deposited layers. HFE has been used in commercial machine designs to print intricate food pieces.

Post-deposition cooking

The printed food pieces usually go through a post-deposition cooking process (e.g. baking and boiling) which involves different levels of heat penetration and result in non-homogenous textures. Many chemical reactions and physical transformations occur during the cooking process, such as protein denaturation, reduction of water content, and changes in colour, volume, texture and nutrition value. After baking, the pizza fabricated by the BeeHex 3D printer had an ultra-thin crust, which tasted exactly like a normal pizza at the beginning and closer to crackers after After using frozen ingredients to print gel-like a few minutes, i.e. a totally new chewing and swallowing experience. materials and cooking the printed product in a desktop format. a new texture could be created in the final product which people have not experienced before. Temperature changes within the extrusion process can alter the taste/texture of printed food pieces. For example, the mouthfeel of 3D printed products such as chocolate, relies on the melting and crystallization behaviours of fats present in the chocolate, which are determined by the tempering process history in the HME . As an electrical consumer device in kitchens, an ideal food printer should fully integrate the process of food making (i.e. all-inone), particularly food printing and post-deposition cooking. They are separated in the current designs, and there is no consensus at this moment due to cost consideration and technical challenges. Natural Machines is already working on introducing cooking capabilities to their Foodini printer with increased complexity and cost of machine design. In the near future, the post-deposition cooking may be achieved by alternative methods, for example, baking may be delivered by using an instant infrared radiation device or electrically heated coils to cook each ultra-thin printed layer.

Food safety consideration

Both specialized food printers and 3D printers with food printing function are available in the market. The specialized food printers usually can give better fabrication performance, but are very expensive. The components of the machines should fabricated using food safe materials, and are considered safe when being in contact with food. A component cleaning process is also designed and implemented to avoid food contamination. For example, Foodini uses a re-usable extruder made of stainless steel, and the nozzle is easy to clean either in a dishwasher or by hand. Bacteria can buildup in the extruder when food gets stuck in small cracks and spaces. Most of desktop printers are made of plastics, which may emit ultra-fine particles. Such toxic particles can release during the printing process and lead to adverse health effects. Hence there are concerns about the general food safety for this type of printers, and it is difficult to certify them as safe.

Food design in extrusion-based printing

The overall perception of food design covers visual appearance, sense of touch (stickiness, roughness, hardness), first bite, chewing, swallowing (flow properties, roughness or smoothness), and residual effects on mouth. Traditional food processing technologies mainly use formulation and process parameters to alter food design. Food printing provides greater freedom to experiment with designs in a manner that was previously impossible. To change mouthfeel, people can print one material with different patterns or modify two materials during a printing process to create new patterns. This enables users to do things such as building back the texture of an existing food product after changing some key ingredients to upgrade nutritional profile, improving the texture of an existing product to become more desirable, and developing new food products with desired texture as part of the overall eating experience. Food designers can also purposely feed macronutrients such as starch, protein and fat into the printers, and add appropriate flavours to form appealing textures. The section below focuses on how the extrusion-based food printing can alter food design due to layer structure, appearance, nutrition and formulation.

Layer structure and unique taste

The extrusion-based food printing builds 3D food pieces layer by-layer, thus producing a staircase effect on oblique and curved surfaces. This staircase effect can be used to create decorative features on printed cookie and chocolate objects. Layer structure on pasta models (cubes, moons, and rose shapes) can create decorations of original designs to form unique styles Along a very gradual slope, the layers with staircase effect create more artistic visual appearance. Layered structure from complicated hexagons and intricately laced patterns fabricated by CocoJet 2015, which was developed by 3D Systems and Hershey Company, gives consumers endless possibilities for personalizing their chocolates. This layered structure also creates a new form of chewing experience. One example is that, in addition to customized shape, colour and flavour, people chewing 3D printed chewing gum can feel its layered texture in their mouths . In taste design, Nufood Robot can print jelly-like liquid capsules that pack intense flavour into unexpected shapes and textures. For example, a jelly looks like a strawberry, but tastes like a raspberry. The capsules contain only natural ingredients, which can imitate existing fruits and foods, or combine them to create completely new tastes.

Consumer attitude on 3D food printing

Consumers usually view novel food technologies and their resultant products with suspicion. Factors for the acceptance of new food technologies can be classed as flavor, potential health risk, nutrition, price and personal preference. Any suspicion of the presence of harmful byproducts and more generally, any potential health risk associated with the consumption of novel food would undoubtedly preempt consumers' acceptance of interest. Chemical transformation (e.g. modification of the food composition) is an additional factor that similarly jeopardizes people's acceptance of new foods and new technologies. In developing/less developed countries (e.g. China), price of food also plays the determinant role in food selection of consumer (Yu 2018). consumers have feared food produced with an inedible, unsafe or at least nutritionally depleted material. Hopefully, the attitudes of consumers towards 3D printed food could be improved significantly after extensive advertisements and introductions on theories and benefits of 3D food printing are delivered. Fun, convenience, health and personalized nutrition should be the major factors to promote the applications of 3D printing technology in food production.

Knowledge of the rheological properties

Study of food materials is important to estimate and necessary to improve their printing performance and self-supporting ability for use in extrusion-based printing. Food materials for extrusion printing should be pseudo-plastic fluids with suitable shear-thinning behavior and be easily extruded from the printer nozzle under an appropriate shear force and be capable of rapid structural recovery solidification following extrusion. To predict the effect of extrusion through the nozzle, rheological properties, including yield stress (s0), storage modulus (G'), loss modulus (G'') flaw behaviour index (K) and flow characteristic index (n), are commonly used, while s0 and G' are a critical indicator of the ability of the matrix to self-support while K and n play an important role in extrudability and printability. A good balance must be made to ensure that the printed object is as strong as possible and will maintain its printed shape while still printable and capable of adhering to previously deposited layers (Liu, Zhang, Bhandari, et al. 2018). The food materials should be flowable (liquid or powder) during extrusion and also support its structure during or after the extrusion. Flowability can be achieved by plasticization and melting. Additives including starches, polysaccharides or proteins have a definite effect on melting behavior, glassy state and plasticization of the food-materials during liquid powder-based 3D printing processes.

Composition of triglyceride in the raw material can help to regulate the melting point of the deposited layers and ultimately determine their self-supporting properties pre and post processing. This is of particular importance in the melting of extrusion-based 3D printing materials, which are melted upon application of heating and solidified by cooling. Chocolate is a good material for extrusion-based 3D printing as the cocoa butter (the main structuring material in chocolate) can be easily melted and form the self-supporting layers upon cooling. Shear rate is another important factor affecting the flow of proteins like gelatin in extrusion processes.

The rheological properties of mashed potatoes with the addition of potato starch and its impact on their 3D printing behavior were investigated by Liu, Zhang, Bhandari, et al. (2018). They found that mashed potato with 2% added potato starch displayed excellent extrudability and printability. 3D printing also can be used in cheese printing. Tohic et al. (2018) studied an extrusion-based food 3D printing in conferring structural changes pre- and post-processing to a cheese product. Lille et al. (2018) used protein (milk powder, oat protein, concentrate, and faba bean protein concentrate), starch and cellulose nanofibre as the materials for extrusion-based 3D printing. They found that the best printing precision and shape stability was obtained with a semi-skimmed milk powder which was mixed with starch and cellulose nanofibre. The applicability investigation of protein and fiber-rich food materials for baking in extrusion-based 3D printed structure was carried out by Lille et al. (2018). Post-processing by oven drying was most successful at high initial solid contents (<50%) in the printed samples

One of the characteristics of 3D food printing is the personalized nutrition design. For this reason, the functional components were also applied on the 3D food printing, including fruits juice, insect powder, vitamin and algae.

Table.2. Applications of extrusion based 3d food printing

S.no	Feed material	Type of printing	Characteristics	References
1	Insect powder in combination with other foods including cream cheese, icing butter, chocolate and spices	Extrusion	Accepting personalized food is motivated by two factors: health and fondness. In light of edible insects' high nutritional value, researchers created 3D food printed attractive food to increase “preference” for the diet which have positive effect on health human	Erik Bohemia et al. 2014
2	hydrocolloid systems (mixture of gelatin Xanthan gum) and flavorings	Cold Extrusion	By combining two hydrocolloids and flavor additives, a wide range of textures and tastes can be achieved. Regulated food, on the other hand, is usually kept in reserve for medical and space applications.	Vesko A et al. 2009

3	Milk chocholate	Hot Extrusion	The most important parameter for 3D printing chocolate like nozzle aperture diameter, best possible nozzle height from the bed, and the axis movement speed had established.	Hao. L et al 2010
4	Blend of Mashed potato, cream cheese and chocolate	Extrusion (both cold and hot)	Using a variety of foods and edible materials, tested and compared three methods like extrusion, binder jetting, molding.	Southerland D et al. 2011
5	Wheat made of dough	Cold Extrusion	Before and post cooking, Effect of height of layer and infill on the printing quality of snacks made of cereal with a cylinder shape has been calculated. As a consequence, when the new ink is replaced with another substance with different rheological properties, they are unable to maintain a fine equilibrium between diverse printing parameter.	Severini. C. et al. 2016
6	chocolate garnish with Pavlova (mainly egg white)	Cold Extrusion	The influence of the bed surface printing on the 3D printing quality was briefly investigated by the authors. In the field of food printing, topic has been least discussed or studied in depth.	Kouzani. A.Z et al. 2017
7	Dark chocolate with magnesium stearate	Hot melt Extrusion	Magnesium stearate acts as a flow enhancer by reducing extruder slippage during deposition, resulting in improved printability.	Manhtihal. S et al. 2017
8	Hot Dark chocolate	Hot melt Extrusion	Chocolate is a popular material for food printing since it can be printed in a number of ways and is appealing to the high-end food industry. Particle size, level of crystallinity, melting behaviour, and food composition are all main factors in hot melt extrusion printing of chocolate.	Lanaro. M et al. 2017
9	Processed cheese	Hot melt Extrusion	The several variables that effect the textural and melting property of 3D printed cheese was investigated in this study. Owing to the size distribution of diverse fat particle size, 3D printing greatly modified the behaviour of cheese, making it least hard and easier to melt.	LeTohic. C. et al. 2018

			They haven't start with good fresh milk as a raw material, so a complete step alter from sol (milk) to gel is being contemplated (cheese). The influence of 3D food printing on the ultimate color of samples is doubtful, and it needs to be explore in point of various customer preferences.	
10	Enrichment of orange concentrate with vitamin D, starch of wheat, and hydrocolloid/s like gum Arabic, k-carrageenan gum, guar gum, and xanthan gum	Cold Extrusion	Starch is a powerful binder that is commonly used in the food industry as a thickening agent. The presence of carrageen an resulted in the best printability and mechanical power. It may be due to carrageenan's affinity for the double helix network form of amylose in starch molecule.	Azam et al.2018
11	Pectin added to a food blend (dried non-fat milk, banana, white canned beans, dried mushrooms (B. Edulis), lemon juice, ascorbic acid.	Cold Extrusion	The ability of 3D food printing technology to design creative 3D shaped snacks made of fruits targetting children aged 3 to 10 years old, using a customised food recipe. Just showed how 3D food printing can be used to avoid malnutrition. Studied about preventing enzymatic browning of a printable food formulation containing mainly bananas, lemon juice and ascorbic acid when used.	Derossi a et al.2018
12	formulation of three dissimilar starches (potato, rice, and corn starch)	Hot melt Extrusion	The starch molecule's crystalline structure is broken during the extrusion process. During the gelatinization process, the intermolecular hydrogen bonds are broken by the distraction of the crystalline structure. This is one of the parameter that can prepare a continuous starch paste matrix of intertwined amylose units with sufficient shear-thinning and visco-elastic properties.	Chen. H et al. 2019
13	The mixtures of sodium alginate, soy protein isolate and gelatin	Hot melt Extrusion	Soy protein isolate gel has a high viscocity. Rheological properties make 3D food printing unfeasible. Hydrocolloids were used to fine-tune the visco-elastic properties even further.	Chen J et al.2019

14	Hershey's cocoa powder , Cake icing, Hershey's chocolate syrup, and chocolate spread of Nutella hazelnut	Cold Extrusion	This method avoided a crucial necessity for temperature regulation in HME 3D food printing of chocolates. Using several dispensers, the presented technology makes it simple to create 3D structures with ink made of chocolate and with liquid fillings.	Karyappa. R et al.2019
15	Dark chocolate	Hot Extrusion	For textural and sensorial evaluations, 3D printed chocolates with different infill structures (infill patterns and percentages) were made. chocolate sample with a 100 percent infill printed chocolate sample is compared and revealed that both samples were equally preferred, which is affected in part by perceived texture.	Mantihal.S et al. 2019
16	Dark chocholate of two kinds, magnesium stearate and plant sterol	Hot melt Extrusion	Ingredients were used to create honeycomb and star infill shapes had a stable and firm shape at 60 % infill.	Mantihal.S et al. 2019
17	Egg yolk and egg white with blends of rice flour	Cold Extrusion	Rice flour acts as a filler agent and improves the strength and stability of printed materials with egg white and egg yolk.	Anukinuthika. T et al. 2020
18	Pastes of Sesame, chicken, shrimp	Extrusion	Extrusion and cooking with more precision are possible to the printer's integration of an infrared lamp heating system.	Hertafeld. E et. Al.2019
19	Lemon juice-potato starch gel, Anthocyanin-potato starch gel	Cold Extrusion	Moving from 3D to 4D food printing is demonstrated in this example. The consequence of a 3D printed foods to environmental stimulus, which cause both physical and chemical changes in state over time, is referred to as 4D printing. The colour of the 3D printed items changes with time in this scenario. It can be used to make food items that are more visually pleasing.	Ghazl. A F et al. 2019
20	egg yolk paste which was Heat-induced	Cold Extrusion	Since, When egg yolk is heated, it forms a network of 3 D protein that is firm, cohesive, and chewy in texture. Another way to create protein resources can be with 3D printing	Xu.L et al.2019

Favourable material properties for printing

Yang et al. (2001) has been reported to be the first time using the extrusion-based technology to produce a complex 3 D cake. Since then, 3 D printing technology has gradually developed in food sector. To achieve successful printing, appropriate visco-elasticity of the material is the key property, which allows the material to be extruded through a fine nozzle and support the product structure after deposition. For melt extrusion molding, the molten paste is extruded from a nozzle and almost immediately solidifies and is welded to the previous layer, and this technique has been widely used to create customized 3 D chocolate products (Liu et al. 2017; Mantihal et al. 2017).

Different from the former two types of extrusion molding, the application of gel extrusion molding is much broader, such as the printing of hydrogel, meat, mashed potatoes, cheese, and fruits and vegetables. Among various food printing techniques, extrusion-based 3D printing involves the pressure-driven extrusion of a semi-solid material supply through a nozzle for layer-by-layer fabrication of 3D structures. Extrusion printing includes both hot and cold extrusion methods. Hot melt extrusion printing can convert raw food ingredients such as chocolates to ready-to serve end product white rice starch was printed as such, without any additives; the effect of varying printing conditions on its extrusion printability was studied. The extrusion behavior of a material depends significantly on the type of material and the amount of force required for extrusion

The 3D printing process was carried out using an extrusion-based 3D printer, which was originally designed for plastic material and modified with the motor-driven system for food matrix extrusion The prepared printing materials were carefully put into the syringe and then the syringe plunger was pushed inside the syringe by a moving screw, finally the printing materials were transported to the nozzle tip and extruded out continuously to fuse the preceding layers and deposit the designed shapes layer by layer. All the syringes loaded with mixtures were kept in the water bath to reach the printing temperature before inserting into the chamber with the same temperature

To function properly as 3D printing ink, the sample must combine liquid-like characteristics to flow under the shear in the extruder and solid-like characteristics to form a self-supporting structure once the applied shear is removed. Pasty materials (gels) are capable of flowing only when a sufficiently large stress has been applied to it, a characteristic feature associated with their ‘‘jammed’’ structure. Cold extrusion 3D food printing is an emerging technology which enables the manufacture of food in different shapes and structures and offers huge potential for personalised food products.

Applications of extrusion-based 3D printing

Applications of extrusion-based 3D printing with food is recent; however, 3D printing with hydrogels (Hydrogels such as alginate, gelatin, and agarose are often used since they can be extruded as liquid and gel once printed in order to minimize shear-induced damage to cells Inorganic inks such as metal, glass, or ceramic are generally suspended in a polymer solution to create an ink that can be used for 3D printing. Thickeners such as methyl-cellulose are sometimes added to make the ink more shear thinning and to prevent the inorganic particles from settling.

3D printing food allows for product design, personalized nutrition, and rapid experimentation with various flavour and texture combinations. 3D printing also produces less waste since only what is needed is printed. In addition, the deconstruction and reconstruction of food allows for incorporation of functional ingredients such as vitamins and minerals. After the food paste, purée, or gel is printed, it may be subjected to post-processing steps such as steaming, baking, deep frying or freezing. In the case of food, speed is favored over accuracy since the shapes are mostly for aesthetic purposes. Food-pathogens might be of concern if printing takes too long. Starch, gelatin, or Xanthan gum can be used to modify the ink to make it suitable for 3D printing.

In addition to private investment, governmental organizations have shown interest in food printing. NASA, NSRDEC, research centers in Singapore, Australia, as well as the Netherlands are all looking to develop their own 3D food printing system. 3D printing food is appealing for NASA and NSRDEC for its ability to eliminate waste and replace meals ready-to-eat (MRE). NASA is looking into long term manned space mission so they need a way to provide food to the astronauts. The current MRE is not feasible due to limited shelf life (3-6 months) and excessive waste generated from packaging. 3D printing food could help eliminate waste since it only prints what is needed. It can also extend shelf life when the raw ingredients are stored as powder. Nutritional content can be customized to suit personal needs since the food will be constructed from individual macronutrient components. The food preparation process can be automated to save time. In addition, the cooking step can be integrated in the 3D printer since traditional cooking techniques may not be suitable for given environment.

The army faces a similar issue since the amount of equipment carried out to the field is limited. Troops deployed to remote areas rely mostly on MRE. 3D printing food could provide a variety of food using only a few basic ingredients. It could allow for personalized nutrition based on activity levels and can work in conjunction with wearable technology that monitors the user's physiology and nutritional requirements

Conclusion

Food printing may exert a significant influence on various types of food processing which allow food designers/ users to manipulate forms and materials. Against to many advantages, the use of 3D printers in the food industry is still limited. More and more companies and research institutes are working on improving the extrusion-based food printing technology, To commercialize new digital cooking devices in kitchens, and promote innovative design and healthy life style. However, the available applications are still primitive and need further investigation. These versatilities applied to domestic cooking or catering services will allow more efficient delivery of high-quality, freshly prepared food items to consumers, personalized nutrition and enable users to develp new flavours, textures and shapes to create entirely new eating experiences.

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