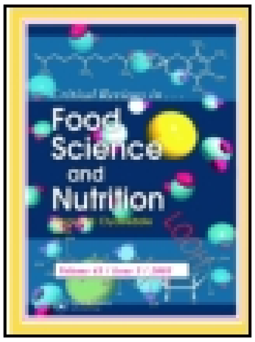

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Materials Properties of Printable Edible Inks and Printing Parameters Optimization during 3D Printing: A review

Chunyan Feng[a], Min Zhang[a,b*],Bhesh Bhandari[c]

[a]*State Key Laboratory of Food Science and Technology, Jiangnan University, 214122 Wuxi, Jiangsu, China*

[b]*Jiangsu Province Key Laboratory of Advanced Food Manufacturing Equipment and Technology, Jiangnan University, China*

[c]*School of Agriculture and Food Sciences, University of Queensland, Brisbane, QLD, Australia*

*Corresponding author: Dr. Min Zhang, Professor of School of Food Science and Technology, Jiangnan University, 214122 Wuxi, P. R. China

Tel.: +86-510-85877225; Fax: +86-510-85877225

E-mail: min@jiangnan.edu.cn

Abstract

Background: Interest in additive manufacture has grown significantly in recent years, driving a need for printable materials that can sustain high strains and still fulfill their function in applications such as tissue engineering, regenerative medicine field, food engineering and field of aerospace, etc. As an emerging and promising technology, 3Dprinting has attracted more and more attention with fast manipulation, reduce production cost, customize geometry, increase competitiveness and advantages in many hot research areas. Many researchers have done a lot of investigations on printable materials, ranging from a single material to composite material.

Main content: This review focuses on the contents of printable edible inks. It also gathers and analyzes information on the effects of printable edible ink material properties on 3D print accuracy. In addition, it discusses the impact of printing parameters on accurate printing, and puts forward current challenges and recommendations for future research and development.

Keywords: Printable edible inks, 3D food printing, Materials properties, Printing parameters, Printing precision.

Introduction

3D printing technology was firstly introduced in 1986 (Hull 1986). This is defined as “a process of adding materials to make objects from 3D model data (CAD models), usually layer upon layer, are contrary to subtractive manufacturing methodologies”, and also known as rapid prototyping and rapid manufacturing (Li 2016). 3D printing technology has evolved tremendously in recent years due to its potential advantages, such as customized geometry, reduces the production cost, shorten the manufacturing cycle and improve the competitiveness (Ning et al. 2015). Commonly referred to as 3D printing techniques include extrusion-based printing, selective sintering printing (SLS) (Kumar 2014), binder jetting, inkjet printing, stereolithography (SLA) and fused deposition modeling (FDM). There are a wide variety of printable materials, such as metal (Li 2016), plastic (Cui et al. 2017), composites, biomaterials (Murphy and Atala 2014), and food materials (Lipton et al. 2015). Therefore, additive manufacturing has been applied in wider fields, mainly in the fields of biomedicine (Seitz et al. 2005), aerospace (Zeng et al. 2012) and food engineering (Fan Yang, Zhang, and Bhandari 2017). Especially in the food industry, the main reason for the increased interest in 3D printing technology is that it can simplify the supply chain, expand the utilization of existing food materials, extend shelf life, customize food design, and personalize nutrition (Holland et al. 2018). In particular, personalized nutrition refers to specific print recipes based on the nutritional needs of athletes, pregnant women, and the elderly. For example, a European Union supported project aims to tailor a unique 3D printed smooth food product for elderly people who experience difficulties in swallowing or chewing (Grant agreement number: 312092). In the past few years, various raw food materials such as chocolate (Lanaro et al. 2017; Mantihal et al. 2017), mashed potato (Liu et al. 2018),dough (Fan Yang et al. 2018), insects (Severini, Azzollini, et al. 2018), surimi gel (Wang et al. 2018) and cheese (Le Tohic et al. 2018) have been used in 3D food printing. These materials must have shear thinning characteristics to be easily extruded from the nozzle and have sufficient strength to maintain the shape of the post-deposition pattern. The printable edible ink is generally a powder or paste-like material at room temperature or melting temperature (Wang et al. 2018). 3D printing technology enables the creation of interesting new shapes and offers innovative production ideas to create food products with greater freedom in composition, structure, texture, and taste.

In recent years, 3D food printing has received extensive attention. Although 3D food printing technology has made rapid progress, most research articles and reviews rarely focus on how to achieve accurate object (high resolution, shape fidelity) printing. To date, only one review has elaborated on how to achieve accurate and accurate food printing (Liu et al. 2017). They suggested that the quality of printed material depends mainly on the nature of the material, processing factors and post-processing processes (Godoi, Prakash, and Bhandari 2016). The choice of edible ink and the adjustment of the ink formulation is crucial for food printing, which is also the most important factor influencing the accuracy of 3D printing.

The print parameters and post-processing (baking) of the 3D printer are also factors that affect the accurate 3D printing. Compared with the print parameters and the post-processing process, the selection of edible inks and the adjustment of the inks formulation are the most important thing factors affecting the accuracy of 3D printing. From this, it can be seen that understanding and mastering the material properties of printable edible inks is critical for 3D accurate print patterns. Most research articles and reviews concentrate on food formulation adjustments, custom food manufacturing, food printing process control, and equipment modification (Lipton et al. 2015). There is not any article that analyzes and summarizes the effects of the material properties of food materials on accurate printing. This review focus on the contents of printable edible inks. It also mainly compiles and critically analyzes information on the effects of printable edible inks material properties on 3D print accuracy.

Printable Edible Inks

Printable edible ink refers to food materials used in 3D food printing. The printable edible ink is generally a paste-like or powder material at room temperature or melting temperature. The most common printable edible inks are chocolate, fat, gelatin, dough, pate, mashed potatoes, cream, sugar, cheese, and the like. These printable edible inks can be divided into the following two categories:

(1) Traditional food materials. Traditional food materials are divided into two categories that don’t require additives and require additives. Some food materials that can be easily extruded from a nozzle without the need of additives include chocolate (molten), cheese, and cream, while other food materials such as fruit, vegetables, chocolate powder, mashed potatoes, etc., require the addition of additives to improve the rheological properties of the material so that it can be extruded from the nozzle. Additives added to edible inks play a significant part in improving the flow behavior, sedimentation and lubricating properties of the supplied material. For example, Liu et al. (2018) added potato starch to mashed potatoes to improve the rheological properties of mashed potatoes. Wang et al. (2018) added additives such as NaCl into surimi that improve the materials properties to make surimi gels that can be used for extrusion-based printers. Severini et al.(2018) implemented the application of fruit and vegetables in 3D food printing technology. Hydrocolloids such as xanthan gum and gelatin added to natural food materials (vegetables, fruit, meat, etc.,) to manipulate the properties of food materials to achieve the desired print texture and maintain a satisfactory shape after deposition (Vesco et al. 2009). Lipton et al. (2010) successfully tested the possibility of printing a variety of material foods, among which the use of transglutaminase-treated and modified turkey, scallops and celery enables them to be

cooked or boiled after printing. Flow enhancers such as magnesium stearate (MgST) are added to the chocolate powder printed by the rotary screw extruder to control the viscosity of the mixture and improve the flow behavior and lubricant properties of the extruded material to achieve precise printing of the chocolate (Mantihal et al. 2017).

(2) Non-traditional food materials. Insects are so full of protein and seaweeds are rich in cellulose. Insects (Severini, Azzollini, et al. 2018), Seaweed, and plant- and animal-based by-products are also used in 3D food printing technology, which can solve the food crisis while expanding the existing food materials, and also injects new sources of ideas for food printing. Walters et al. (2011) proposed that pastes of insect powders, ice and soft cheese be used as printing materials for the production of delicious food. Severini et al. (2018) studied the printability and process characteristics of 3D printed snacks obtained using different levels of Yellow mealworm powder (Tenebrio molitor) instead of wheat flour. The results showed that addition of Yellow mealworm powder (Tenebrio molitor) changed the printability of the dough and significantly increased the protein content, as showed in Figure 1. Van Bommel et al. (2011) mixed the nutrients from algae and insects in different proportions to print things like steak and chicken meat. In addition, examples of 3D printing technology applied to edible insects are represented by Soares and Forkes (2014), who combined larvae of Yellow mealworm powder (Tenebrio molitor) with fondant to produce icing sugar decorated on top of the cake. Non-traditional food materials such as insects and algae are applied to 3D printing, which is conducive to eco-friendly and sustainable development, and it is also conducive to coping with the growing demand for food.

Ideal Material Properties of Printable Edible Inks

Material properties of printable edible inks are critical to obtaining high quality products, which should be kept in mind. Edible inks applied to the extrusion process should deposit material layer-by-layer and have "self-supporting" ability to retain the deposited structure. This "self-supporting" ability depends on material properties such as rheological properties (e.g. apparent viscosity) and thermodynamic properties (e.g.

glass transition and melting point). Thus, the material properties play an significant part in the post-curing of the deposited layer (Mantihal et al. 2017). Understanding and studying the ideal material properties of printable edible inks is a concern that cann't be ignored in the 3D food printing process.

In small studies on 3D food printing, adjustments to the material properties and formulation of printable edible inks have been the main focus. Godoi et al. (2016) proposed printability, applicability, and post-processing to influence the rational design of this 3D structure. Where printability refers to the nature of the structure that allows the material to be treated and deposited and maintain its deposition. It can be seen that printability is dependent on the properties of the material, but the applicability of additive manufacturing is also the same. For 3D food printing, the 3D structure (manufactured by 3D food printing) may need to be post-processed to be edible. The food materials that need to be baked and cooked should have properties that resist the post-treatment process. They emphasized that by manipulating the rheological properties of materials, structural and mechanical properties can achieve printability, applicability, and post-processing, and further realization of precision during 3D food printing. Therefore, it is essential to understand the nature of food materials and the basic ingredients of foods. Table 1 summarizes the material properties that must be considered when applying food materials to 3D printing. The next section will provide the details of the material properties of printable edible inks and discuss how the material properties of printable inks affect the accuracy of 3D printing (high resolution and high shape fidelity).

Starchy Foods

Starchy foods such as potato, wheat, and corn all contain large amounts of starch, as well as a small amount of sugar. The earliest application of 3D food printing was to print "cake mixes" by extruding a paste made of starch, sugar, yeast, corn starch and cake frosting (Yang, J et al., 2001). Starch has good shear stability applied to 3D food printing, and helps maintain the shape of the deposited structure when the starch concentration is higher due to the interaction between starch molecules. As the concentration of potato starch increases, the gel strength also gradually increases. This is mainly due to the fact that as the concentration of starch increases, the number of starch molecules per unit volume increases, the probability of hydrogen bonds between starch molecules increases, and the formed network structure becomes denser, which contributes to the preservation of the deposition structure (Goldstein, Nantanga, and Seetharaman 2010). Starch can be added as an additive to other food materials to make it printable, such as lemon juice gels; it can also be added to starchy foods to improve their rheological properties, making them useful in 3D printing for accurate printing of 3D products. Starch also exhibits shear thinning properties, that is, the viscosity decreases with increasing shear rate, which facilitates extrusion from the material but will recover to the highly viscous state in stationary condition after deposition. Starch also has the ability to bind water, and it is important to reduce shrinkage when dehydrating the 3D printed object. Liu et al. (2018) studied the effect of native potato starch on the rheological properties of gelatinized mashed potatoes. The results showed that increasing native ungelatinised potato starch content can increase the viscosity of mashed potatoes, however, when the amount of potato starch reached 4%, mashed potatoes had poor fluidity and showed solid-like behavior. When the amount of native potato starch added reached 2%, mashed potatoes can be easily extruded from the nozzle and had the proper mechanical strength to support the shape of the deposited product. The study by Yang et al. (2018) also suggested that the increase in potato starch content facilitates the retention of shape after extrusion. The increase in the content of potato starch causes the hardness, elasticity, and viscosity of the lemon juice gel to increase to different extents, which can effectively resist the external gel damage. In addition to potato starch, wheat starch can also be added as an additive to edible inks. Use of wheat starch as additive for 3D printing can see Azam et al. (2018). Potato starch consists of amylose chains and highly branched amylopectin chains (Vasanthan et al. 1999). Compared to cereal starch such as wheat starch, the starch size of potatoes is large and the starch granules are liable to swell during the gelatinization process. Moreover, the amylopectin of potato has a natural phosphoric acid group, thus exhibiting a strong hydration ability, and the properties of the cold paste agent are relatively stable (Alvani et al. 2011; Chen et al. 2010). A particularly valuable feature of 3D food printing is the ability of potato starch to gel when gelatinized. These unique properties indicate that potato starch is suitable for use in 3D food printing technology. However, there is no reported paper comparing the differences between these starch for 3D food printing. In summary, the application of starchy foods (such as potato) to 3D food printing proves that the starch has the material properties that can be used for 3D food printing. In addition, the addition of additives such as hydrocolloids can further enhance the properties of starch to make it more effective for use in 3D food printing. For instance, the addition of sodium alginate and carrageenan can maintain the granular structure of amylose-rich, expanded rigid particles and lead to increased product viscosity (Hongsprabhas, Israkarn, and Rattanawattanaprakit 2007). And the addition of xanthan gum and guar gum can prevent water infiltration to inhibit the expansion of the particles (Dankar et al. 2018). In order to make more different flavors of printable edible inks, Lipton et al. (2010) proposed that cocoa powder is added to the cookie recipes. In addition, we can add different plant powders such as purple sweet potato flour and sweet potato flour to 3D printing to create a colorful 3D structure to develop sophisticated, colorful and personalized nutritional 3D products. Studies have shown that adding 1% purple sweet potato flour and 2% potato starch to mashed potatoes can produce products with high resolution and smoothness (Liu et al. 2018).

Animal source foods

Animal source foods contain abundant protein and lipids. Some proteins dissolve in water and have colloidal properties, and can denature under conditions such as heat, acids, and alkalis (Landers et al. 2012; Marshall and Levy 2011; Sánchez-Muros, Barroso, and Manzano-Agugliaro 2014). Animal source foods such as pork, fish, and dairy products cannot be directly used for 3D food printing if the viscosity is very low (Sun et al. 2015). These foods must be added with additives to improve their material properties. In some cases enzymes can be used. It has been reported that the addition of this type of food additives can change the conformation of proteins and lead to changes in the properties of materials. For example, transglutaminase was examined as a food additive for the manufacture of printable meat sauce because transglutaminase can catalyze cross-linking between proteins to produce self-supporting structures (Davis et al. 2010). A very interesting article has reported that transglutaminase was added to thick slurry (Scallops and turkey meats are made of thick puree) can maintain the rheological properties of the material, but with the passage of time will produce a new protein matrix (Jeffrey Lipton, Dave Arnold, Franz Nigl, Nastassia Lopez, Dan Cohen, Nils Norén, 2010). Gluconate lactone (GDL) is an acidulant used widely in the food industry (Ringgenberg, Alexander, and Corredig 2013). When dissolved in water, it releases gluconic acid and slowly dissociates into hydrogen ions, which reduces the acidity of the protein system, thereby changing the microenvironment in which the myofibrillar protein is located. At the same time, it weakens the electrostatic repulsion between protein molecules, and the interaction increases, resulting in protein aggregation and precipitation in order to form a gel system (Weng and Zheng 2015). As for the gel system formed by GDL, its hardness and gel strength are weaker than the gel systems formed by other modes of action such as heating or adding polysaccharide colloid, and it shows better fluidity. The gel system with a certain gel strength and good fluidity is considered to be more suitable for 3D printing technology. In some cases, Animal source foods (e.g. gelatin derived from the animal's connective tissue and bones) can also be added as additive to edible inks (Rapisarda et al. 2018). The addition of gelatin can improve the elasticity of foods. At the same time, a characteristic of gelatin is that gelatin melts at a high temperature (>35°C) to give it better fluidity (Young et al. 2005). The charge on the molecule of gelatin affects the viscosity. When there is a positive charge and a negative charge, the molecule completely shrinks at the isoelectric point, and the minimum viscosity is observed. Mutual repulsion between charges causes molecules to extend and increase viscosity (Godoi, Prakash, and Bhandari 2016). This feature is very suitable for 3D food printing. Vesco et al.(2009) reported the use of hydrocolloids such as xanthan gum and gelatin in combination with food ingredients.

Properties of fat have various functions such as improving product hardness, juiciness, flavor and lubrication properties. However, for the 3D printing characteristics, the addition of fat mainly affects the fluidity of the slurry and the forming effect in the 3D printing process. A suitable fat content allows the food material to have proper fluidity and proper viscosity in 3D printing. But too high a fat content results in a significant decrease in the viscosity of the edible ink, and the link between the protein and the protein is excessively isolated from the fat, and is decomposed into a plurality of small aggregates. Lille M et al. (2018) applied skim milk powder (SMP) and semi-skimmed milk powder (SSMP) to 3D food printing in order to evaluate the application of fat to the performance of 3D printing materials. The results of the study showed that the fat in the semi-skimmed milk powder acts as a plasticizer or lubricant to make the material easier to flow.

Fruits and Vegetables

Vegetables and fruits contain a lot of vitamins and minerals that the body needs, not only high water content but also rich in fiber (Boeing et al. 2012; Larson et al. 2008) By applying vegetables and fruits to 3D printing, it can play a significant and profound implications on the design of personalized nutritional foods. However, only a few articles are published in the 3D printing of vegetables and fruits. Derossi et al. (2018) for the first time designed a fruit-based preparation for 3D printing of children snack foods containing 5-10 % of children's energy, calcium, iron and vitamin D. Yang et al. (2018) successfully printed a lemon juice gel. On this basis, Azam et al. (2018) achieve the printing of vitamin D enriched orange concentrate wheat starch blends. Severini et al. (2018) also successfully used 3D printing technology to print a mixture of fruits and vegetables to make edible foods. Main reasons that limit the application of vegetables and fruits in the field of 3D food printing are the material properties of vegetables and fruits. Vegetables and fruits contain a lot of moisture which reduces the viscosity of edible inks. Two methods can reduce the moisture content of food materials: one is to add a high concentration of viscosifier such as protein, starch or hydrocolloids; the other is to reduce the moisture content in food materials by moisture removal process

(Severini, Derossi, et al. 2018). By manipulating the amount of hydrocolloid addition one can produce the desired structural strength of the material. Agar was examined as a food additive for creating printable vegetables (Jeffrey Lipton, Dave Arnold, Franz Nigl, Nastassia Lopez, Dan Cohen, Nils Norén, 2010). Agar has shear thinning behavior and is therefore suitable for 3D food printing. Add agar to pureeing celery in order to reconstitute the celery fluid gel. The low methoxylated pectin gel can be used as a suitable edible ink for 3D printing custom water-based porous food simulants. An example of such a food is a candy based on pectin (Vancauwenberghe et al. 2018). Printable edible inks are configured by varying the concentration of pectin, syrup or bovine serum albumin (BSA) to obtain prints of different textures and structural characteristics. The viscosity of the edible ink is affected by the concentration of pectin and sugar. In addition, when fruits and vegetables are juiced or pulped, large particles that remain can cause nozzle clogging. (Vancauwenberghe et al. 2018). To avoid clogging the nozzles, Severini et al. (2018) used an Ultra Turrax T50 Basic （Ika，Werke） to process the paste and sieved to obtain a homogeneous printable edible inks.

3D Food Printing Process Platform Optimization

In addition to the above mentioned food material properties and edible ink formulation adjustments, the choice of print parameters and print model also affects accurate printing during 3D printing. Hao et al. (2010) reported that extrusion parameters such as extrusion speed, nozzle movement speed, nozzle diameter and nozzle height are crucial for the successful deposition of chocolate. The results of the study showed that the 1.25 mm nozzle diameter and the 2.9 mm nozzle height were the best parameters to provide good interlayer adhesion to maintain the proper geometry. Derossi et al. (2018) investigated the influence of printing speed and flow level on the accuracy of 3D printing. Wang et al. (2018) studied the effects of nozzle diameter, print height, nozzle movement speed and extrusion speed on 3D printed surimi gel. The results showed that a set of printing parameters such as a 5 mm print height, 2 mm nozzle diameter, 28 mm/s nozzle movement speed and 0.003cm^3/s extrusion speed can accurately print the surimi gel. The study found that the printing process parameters determine whether the discharging system can discharge the material normally with a shape fidelity of the printing structure. In the printing process, these parameters (e.g. nozzle diameter, nozzle movement speed, extruded speed and printing temperature) must be coordinated to achieve accurate printing, for example, extrusion rate and the nozzle movement speed affect the 3D printing simultaneously, as they change the amount of extrusion per unit length per unit time (Fanli Yang et al. 2018). And the extrusion speed and the printing speed, and the extrusion speed can be ensured to feed in time when the printing speed increases. Comprehensive research in the past such as Yang et al. (2018), Wang et al. (2018), Hao et al. (2010), we can see that the nozzle diameter, print temperature, nozzle movement speed and extrusion rate are the key factors affecting the print quality. The nozzle diameter mainly affects the printing accuracy and the exquisiteness of the sample surface. The lower the nozzle diameter, the higher the degree of refinement of the printed sample and the higher the sample quality. However, a decrease in the nozzle diameter not only increases the printing time, but also increases the feed pressure. Excessive feed pressure can cause the 3D printing device to be overloaded, resulting in machine wear. With a nozzle diameter of 0.8 mm and 1.5 mm, the discontinuous deposition phenomenon occurs when the surimi gel was extruded, however, using a nozzle diameter of 2 mm, the surimi gel can be printed accurately. The smaller the nozzle diameter used in the printing process, the greater the pressure required to print the printed edible ink, which may result in discontinuous deposition of the printable material (Wang et al. 2018). Therefore, when selecting the nozzle diameter, we need to consider the viscosity of the material and the maximum pressure that the equipment can load to avoid the situation where the material cannot be extruded and cause the machine to wear out. Nozzle height refers to the distance between the bottom of the nozzle and the worktable in the printing process. A large number of previous studies have used nozzle height as an important factor affecting the printing accuracy (Attalla, Ling, and Selvaganapathy 2016; J. Wang and Shaw 2005). However, Yang et al. (2018) have conducted extensive experiments to verify that the nozzle height and nozzle diameter have the same effect on the 3D printing process. And he suggested that the height of the nozzle can't be regarded as a key factor affecting the accuracy of 3D printing because when the nozzle diameter and the nozzle height are the same, the mismatch between the extrusion speed and the nozzle movement rate is the main reason that affects the printing effect. He explained that in the ideal printing process without shrinkage or expansion, that is, the extruded material diameter is equal to the nozzle diameter and the nozzle height is as small as possible to ensure that the material can adhere to the previous layer and avoid inaccuracies caused by delayed deposition. Therefore, the nozzle height is equal to the nozzle diameter and the height of the single layer. Nozzle movement speed and material extrusion speed are also the key factors affecting the accuracy of 3D printing. There is a certain link between these two influencing factors. If the extrusion speed is so fast that the nozzle movement speed is slower than the material extrusion speed, resulting in slurry accumulation to produce larger diameter wavy lines, as showed in Fig. 2(A). when the material extrusion speed is so slow that the nozzle movement speed is greater than the material extrusion speed, the low feed pressure and low flow rate will lead to wire breakage, as showed in Fig. 2 (C). If the nozzle movement speed and the material extrusion speed are within a suitable matching range, the extrusion linearity is a smooth straight line, as showed in Fig. 2 (B). Yang et al. (2018) summed up the relationship between the material extrusion speed, nozzle movement speed, and nozzle diameter. The formula is as follows.

$$\mathrm{Vd} = \frac{\pi}{4} VnDn^2 = \frac{\pi}{4} Vnhc^2$$

Where, Vd is the volume of the extruded rate(mm^3/s), Vn is the nozzle movement speed(mm/s), Dn is the nozzle diameter(mm), and hc is the nozzle height. By using a mathematical model, the material extrusion speed can be automatically calculated based on the user-defined nozzle movement speed, and vice versa. Printing temperature also has a significant effect on the thermal and rheological properties of edible inks, especially for chocolate as a printable edible ink. Heating the chocolate to reduce the viscosity facilitates the easy extrusion of the paste from the nozzle. A large number of studies have found that 32°C as the extrusion temperature is the optimum temperature for forming the most stable crystalline chocolate melt (Lanaro et al. 2017). As the temperature rises, the viscosity of the surimi gel decreases. The dynamic rheological properties of surimi gel showed a trend of decreasing first and then increasing with increasing temperature (Seighalani et al. 2017；Wang et al. 2018). When the temperature is low, the surimi gel is in the gel-cracking stage, and the myofibrillar protein is unfolded and extended in a large amount, resulting in increased mobility of the surimi and a significant decrease in the elastic modulus. When the temperature rises to 50°C, the viscosity of the surimi gel significantly decreases, the solid state is obvious, the fluidity decreases, and the elastic modulus increases significantly.

Printing the model designs also affects the quality of the print. The hexagonal model design is suitable for studying the stability and mechanical strength of the enhanced 3D structure. Vancauwenberghe et al. (2018) used a hexagonal honeycomb pattern as a universal print model for 3D food printing. Designing a suitable print model can enhance the stability and mechanical strength of 3D printed products. Fig.3 shows a chocolate product with cross-support/parallel support/no support structure formed using three different print paths (Mantihal et al. 2017). The cross-support structure formed by different print paths plays an important role in preventing the collapse of the 3D structure.

Challenges and future trends

3D printing technology is widely used in the food field because of its many advantages such as custom food, personalized nutrition, and broadening the types of food materials. Personalized nutrition means adjusting the formula of printable edible inks according to the preferences and needs of consumers to meet the needs, tastes and diet patterns of people of different occupations, ages and healthy lifestyles. Personalized nutrition is an important reason for the rapid development of 3D food printing technology. With the help of 3D food printing technology, a soft and nutritious food is produced for the elderly who have difficulty in chewing and swallowing. The Dutch Applied Scientific Research Organization (TNO) has launched a project called “Performance” that aims to print customized slimy foods. The design is flexible and helps older people cope with chewing and swallowing problems. With 3D food print printing technology, nutrients can be enriched to effectively solve some health problems such as vitamin D deficiency. Azam et al. (2018) achieved the printing of vitamin D edible inks. The successful printing of vitamin D-rich food and ink provides us with a source of ideas and promotes the development of 3D food printing technology. 3D food printing technology prints biodegradable bioactive elements suitable for food ingredients. In summary, all the data show that 3D food printing will move in a good direction.

Conclusions

In summary, edible inks material properties or formulation adjustments, printing parameters optimization and print model selection are the main factors affecting the accuracy of 3D printing. In the 3D printing process, we need to pay attention to the influence of food basic ingredients such as starch, protein, fat, cellulose, and moisture content on accurate printing. Researchers must keep in mind that the influence of food ingredients on 3D printing. Only in this way can we accurately adjust edible inks to achieve 3D printing. Not only does the ideal printable edible inks have the proper rheology to be easily extruded from the nozzle, but also have the proper mechanical strength to ensure the post-deposition shape retention. Compared with the material properties of food materials, the optimization of printing parameters can’t be ignored. To achieve accurate printing, the appropriate printing parameters must be selected based on the material properties of the edible ink. The direction of the printing path changes greatly, which may lead to a rough surface of the 3D printing product. The material properties of food materials, as well as printing parameters and print models, are mutually supportive and indispensable.

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Table 1 Material properties and food ingredients that must be considered when food materials are used in 3D printing

Materials properties			Food ingredients
Rheological properties	Structural and mechanical properties	Physical-chemical properties	protein starch Moisture content Vitamins
Viscocity Flowability	Self-supporting layers Fracturability	Gelation Tg and Tm wetability	

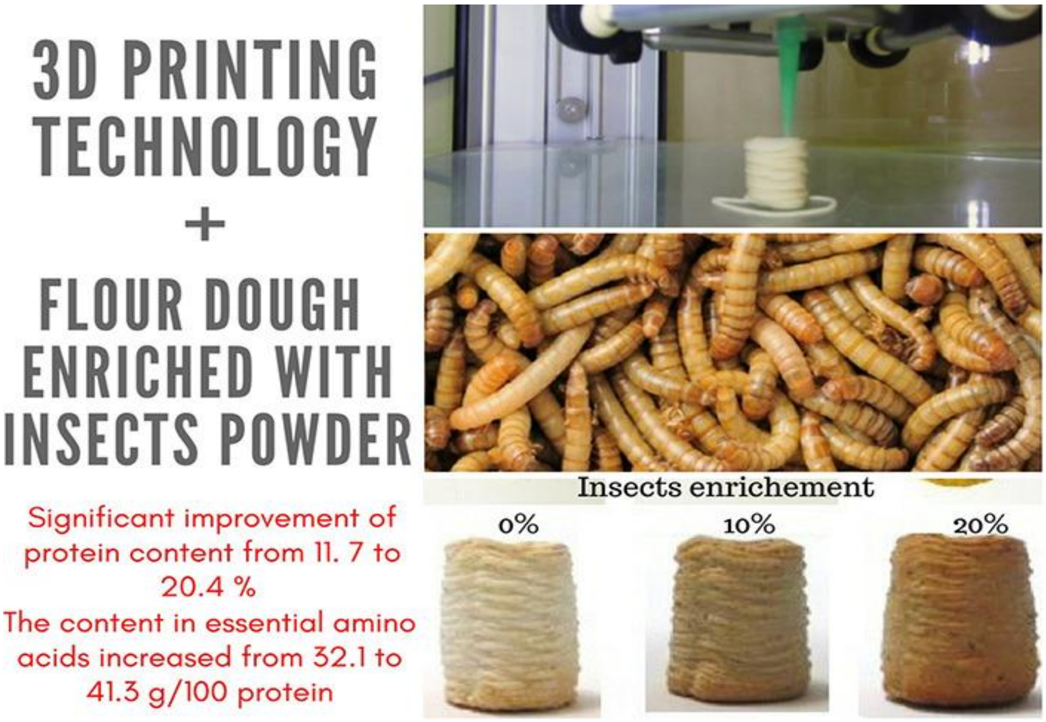

Fig 1. 3D printing insects. Reproduced with permissions from (Severini, Azzollini, et al. 2018) .

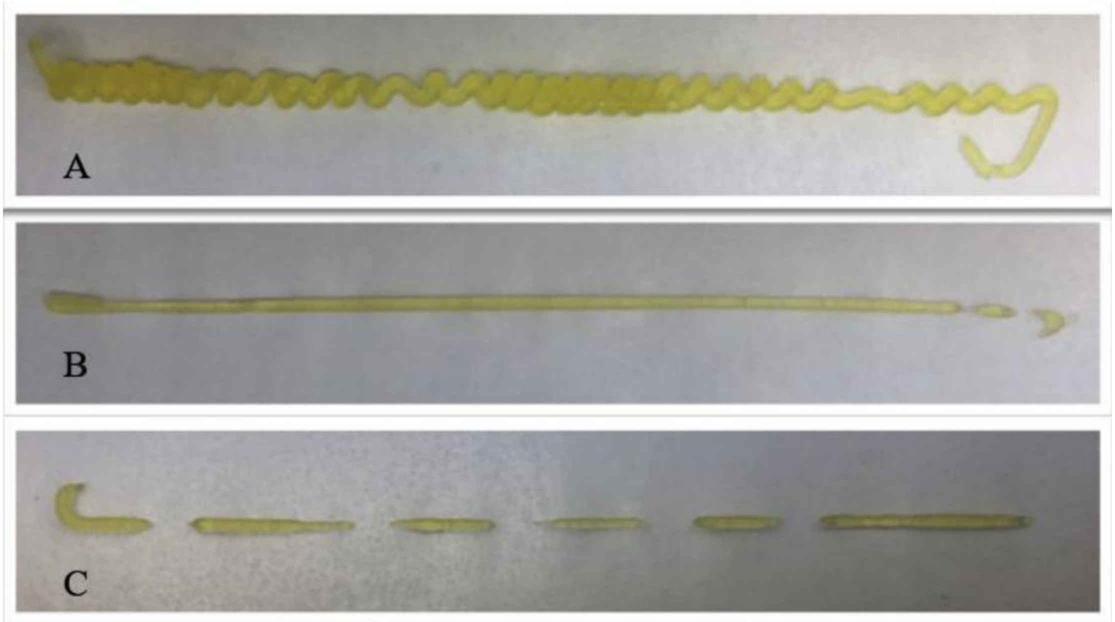

Fig.2 Effect of Material Extrusion Rate and Nozzle Movement Velocity on Line Type. Reproduced with permissions from (Fanli Yang et al. 2018).

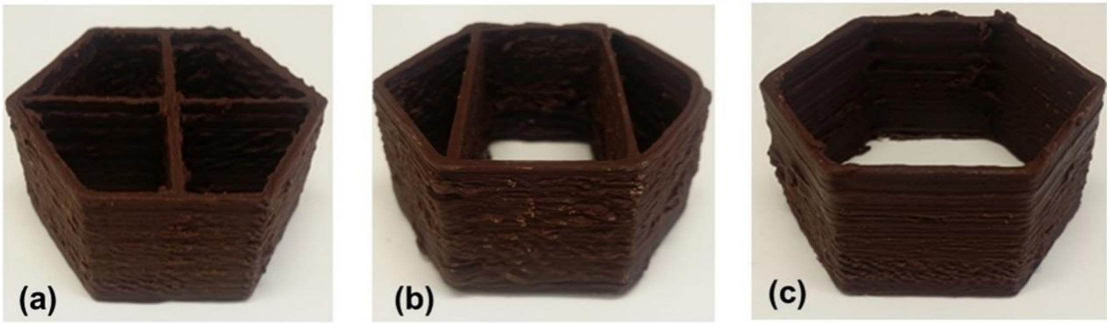

Fig. 3 (a) 3D printed chocolate product with cross-support structure and (b) 3D printed chocolate product with parallel support structure and (c) 3D printed chocolate product without support structure. Reproduced with permissions from (Mantihal et al. 2017).