Advantages and disadvantages of 3D food printing

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Abstract

3D printing is a production that can transfer a 3D virtual model to material structure. It is one of the fastest growing production processes in many industries. The advantage of 3D printing lies in the creation of original and unusual objects nutritionally adapted to the needs of the individual. On the contrary, the disadvantage is the impossibility of printing some foods and the problematic durability and stability of matrices. 3D food printing can be done by extrusion, selective sintering, or blasting. Each of these techniques uses matrices with different physicochemical properties. The aim of the review was to overview some advantages and disadvantages of 3D food printing. Furthermore, individual printing techniques and the possibilities of using food substances as printing matrices are described too.

3D printing, extrusion-based printing, selective sintering, jetting based techniques

Introduction

3D printing is an automatic production process (AM, SFF), which works by applying individual layers on top of each other in a pre-modeled shape. This technique was discovered in the 1980s and today is one of the fastest growing manufacturing techniques (Piyush et al., 2020; Yang et al., 2018). At the present time, 3D printing produces a number of complex shapes and models in many sectors (Piyush et al., 2020). It is used in biomedical engineering, mechanical engineering, the pharmaceutical industry, jewelery and also in the food industry (Piyush et al., 2020; Derossi et al., 2020; Portanguen et al., 2019). In the food industry, 3D printing was represented for the first time at Cornell University as an extrusion-based printer (Liu et al., 2017). There are currently a number of successfully printed 3D objects from various matrices, such as chocolate (Lanaro et al., 2017), meat pastes (Dick et al., 2020), fruit pastes (Yang et al., 2018) and vegetable pastes, sugar powder (Lanaro et al., 2019), and biscuit dough (Pulatsu et al., 2020).

3D printing technology is mediated by a robotic process, where the printed model is created in a CAD software program, or by downloading 3D data from online services, such as Shapeways, Ponoko, Sculpteo and Thingiverse (Dankar et al., 2018). 3D food printing could be a breakthrough in the popularization of this technique and could be the future of food production (Yang et al., 2018).

The aim of the review is to briefly introduce to the benefits and possibilities of using 3D food printing, including the description of issues concerning 3D food printing, same as various techniques and materials used in the production of these kinds of products.

Advantages of 3D food printing

The use of a 3D printer has many advantages in this sector of food production. With this technology, food can be adapted to various forms that would not be possible to produce manually or conventionally. 3D printing allows the creation of new and unusual structures (Portanguen et al., 2019). In this technology, not only artistic skills are applied, but also nutritional aspects that can be adapted to the needs of the individual (Liu et al., 2017). The study by Liu et al., (2020a) states that 3D printing could be a promising method for food fortification with probiotic microorganisms. Another advantage may be the simplification

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of products' delivery. 3D print food technology allows production activities to be moved closer to the final consumer that can affect the reduction of transportation volume (reducing the cost of food packaging and distribution) (Liu et al., 2017). In addition, traffic reduction has a positive impact on the environment (Lupton et Turner, 2018). Non-traditional food materials, (insects, plant materials with high fiber content, same as by-products of plant and animal origin), can be also affectively used in 3D food production. Authors Severini et al., (2018a) stated that the use of ground insects mixed with wheat flour may be a suitable ingredient for the production of 3D food (Liu et al., 2017). The good example of 3D food printing is the study done by Singh et al., (2017), where poultry feather biomaterials were used for the 3D printing. 3D printing has also aroused interest in the military sector. This technology allows the creation of different foods in demanding military environments. NASA is also interested in 3D food printing. 3D printing technology enables the production of nutritionally stable, safe and food-friendly space missions (Le-Bail et al., 2020). 3D printing can also be very important in the process of preparing food for the elderly and for people with chewing and digestive problems (Kouzani et al., 2017). Currently, these socio groups are getting meals in the form of porridge, which can have nutritional deficiencies and cause loss of appetite. 3D food printing could allow food preparation for individuals dealing with food allergies and intolerances (Le-Bail et al., 2020). This food technology brings a number of ideas and insights since matrices often consist of components with different physicochemical properties (Pérez et al., 2019).

Disadvantages of 3D food printing

The man disadvantages of foods created by 3D printing are their durability and stability. Mixtures prepared for 3D printing change rheological properties over time. 3D mixtures are often heated for printing to form a nozzle-passable mass and then cooled. This technological step increases the susceptibility of food to microbial growth (fungi and bacteria) that reduces the shelf life of food (Dankar et al., 2018). Microbial contamination can be caused by the printer itself (Severini et al., 2018b) or can occur during food packaging. If printing is aseptic, the package itself may be part of the print. Microbial contamination could be rapidly reduced by edible coating with a bacteriocidal or bacteriostatic effect (Portanguen et al., 2019). The big drawback of 3D printing is the material itself. The matrix consists of a number of components that have different chemical properties and storage requirements, such as temperature and humidity. Another disadvantage is the inability to print certain types of food (fruit, meat, etc.). For example, 3D printing of meat products is performed from a mixture of protein powder and water (Dankar et al., 2018). Some food matrices require further treatment, before and after application, such as ultrasound and radio frequency treatment, cooking, frying, baking, or lyophilization (Portanguen et al., 2019). These adjustments can have a major effect on textural properties changes that can be either desirable or undesirable. During heat treatment, food is exposed to high temperatures, which is the cause of many chemical reactions (protein denaturation, water loss, discoloration, volume and nutritional value changes) (Dankar et al., 2018). However, two post-processing techniques have been compared: hot drying and freeze-drying. These techniques are intended to maintain the shape of the structure, increasing the stiffness of the material containing the mixture of proteins and fiber. It has been found that freeze-drying better protects the 3D structure and increases the hardness and dry matter content than heat-drying that caused a decrease in the stability of objects due to a decrease in viscosity after heating (Lille et al., 2018).

At the present time, 3D food printing can be performed by extrusion based printing and selective sintering printing (Liu et al., 2017) (binder jetting, electrostatic jetting, pneumatic jetting and inject priting) (Vadodaria et Mills, 2020).

Extrusion based printing

In terms of development, fused deposition modeling (FDM) is considered to be the fastest growing method of 3D printing. This method was first introduced in plastic printing (Le-Bail et al., 2020). The principle of the method is the continuous extrusion of the mass by the moving nozzle on the previous layer into the selected shape. The disadvantage of this technique is complex shapes formation limit since they are prone to deformation. Therefore, it is necessary to print support structures that are removed from the end product at the end of the process. To successfully master this method, it is necessary to understand the properties of used materials. Several factors are responsible for the accuracy and appearance of the printout: the extrusion mechanism; material properties (rheological properties, gel formation, melting point and glass transition temperature); nozzle size, velocity and displacement, fill level, layer height, and structure finish (Le-Bail et al., 2020). The printing itself is mediated by the move of nozzle in x, y and z directions (Pérez et al., 2019). An important parameter is the viscosity, especially apparent viscosity. The viscosity should be low enough to pass through the nozzle and high enough to form a structure (Gholamipour-Shirazi et al., 2019). Material that meets these criteria is easy to apply and provides sufficient stability to the printed object (Zhu et al., 2019). The so-called shear modulus parameter (G*) is important for the matrix assessment, which is considered as an indicator of the ability of the material to flow and be extruded. The shear modulus parameter can be expressed: $G^* = G' + iG''$, where G' is the shear storage modulus and G'' is the shear loss modulus. G* is a complex number. If G'' is greater than G', the matrix can flow and be extruded at the same time (Lipton, 2017). The materials used for extrusion printing are liquids and semi-solids (materials with high viscosity) (Pérez et al., 2019; Yang et al., 2019). Modifiers that meet food safety are used to achieve the desired properties (Godoi et al., 2016). Extrusion 3D printing is usually used to extrude hot-melt chocolate or soft matrices, such as minced potatoes or meat (Liu et al., 2017). Determining the structure of a printed object depends on the used material. Gel matrix printing from lemon juice with added potato starch (15 g / 100 g) is the most suitable for 3D printing of cylindrical structures (Plate VIII, Fig. 1 A) (Yang et al., 2018). The study conducted by Wang et al., (2018) dealt with the printing of surimi structures and it was observed that surimi gels made from a mixture of 1.5 g NaCl per 100 g surimi are the most suitable for 3D printing in terms of geometric accuracy and object size (Plate VIII, Fig. 1 B).

The print cartridges can be divided into three groups depending on the extrusion techniques: hot-melt extrusion (HME), room temperature extrusion (RTE) and hydrogel-forming extrusion (HFE). Hot extrusion and gel extrusion must follow gel formation mechanisms (Gholamipour-Shirazi et al., 2019).

Hot-melt extrusion

In hot extrusion (HME), the semi-solid ink is extruded from the nozzle at a high temperature and should solidify immediately after extrusion and adhesion to the previous layer (Sun et al., 2018). HME is mainly used in the extrusion of chocolate structures (Plate VIII, Fig. 1.C) (Gholamipour-Shirazi et al., 2019). This printing was demanding due to the crystallization behavior of cocoa butter (the main ingredient in chocolate and confectionery). Extrusion melting of chocolate masses ranges from 28° C to 40° C (Godoi et al., 2016). Starch materials are also very suitable for HME. According to the study conducted by Chen et al., (2019) potato starch pastes with a concentration of 15 – 25 % at temperature of 70 – 85° C are suitable for 3D printing (Liu et al., 2020b).

Room temperature extrusion

In order for a cartridge to be used for room temperature (RTE) extrusion, it is desirable for it to exhibit a shear behavior (determining whether it may be extruded from a nozzle).

A suitable shape should also be considered so that the structure does not slumping, spreading, or bridging (Gholamipour-Shirazi et al., 2019). This method of printing was used to produce structures that were difficult to produce by hand. Mixtures with starch, fruit, vegetables, cheese, peanuts, jellies represent materials suitable for 3D printing (Le-Bail et al., 2020). Pasta, pizza and meat products have been printed using this technique (Godoi et al., 2016).

Hydrogel-forming extrusion

Gels with fast and reversible responses to shear stress and temperature have been found to be suitable for 3D hydrogel printing (HFE). These gels were easily extruded while maintaining a sufficient mechanical integrity to form another layer without deformation (García-Segovia et al., 2020). Furthermore, the hydrocolloid solution should have a viscoelastic characteristic before application (Le-Bail et al., 2020) and should turn into a gel before application of further layers (Godoi et al., 2016). Time control of gelation mechanisms is required to prevent premature gelation. Gelation mechanisms can generally be summarized into three types: 1) chemical cross-linking, 2) ionotropic cross-linking, 3) complex coacervate formation. In the food industry, only ionotropic cross-linking (eg alginate) and the complex coacervate formation are used (Godoi et al., 2016). The effect of temperature must also be taken into account during printing. Sometimes the ambient temperature can affect the passage through the nozzle (García-Segovia et al., 2020). During extrusion, hydrocolloid solutions or dispersions are applied to a polymer/hardening/gel setting bath using an syringe pipette, jet cutter, vibrating nozzle and others. This technique has been used to print food based on fruit mixtures (Le-Bail et al., 2020), including xanthan, gelatin, pectin, etc. (Godoi et al., 2016).

There are currently several extrusion printers on the market. Foodini, byFlow, and Procusini 3.0 printers are able to print spicy and sweet foods. Choc Creator V2.0. Plus and BeeHex Robot are able to print foods such as pizza and chocolate structures (Pérez et al., 2019).

Selective sintering

3D food printing using selective sintering is used to print complex structures from sugar or powder mixtures (Liu et al., 2017). This method can be divided into selective laser sintering (SLS) and selective hot air sintering and melting (SHASAM). Both methods of selective sintering work on the same principle (Sun et al., 2015). During the process, the powder mixture is melted by a laser or hot air according to the desired pattern. After sealing, another layer of powder mixture is applied to the previous layer and the whole cycle is repeated until the specified object is created. Unlike extrusion printing, SLS does not require the complex production of an extrusion matrix and structures have a higher resolution (Fina et al., 2017). Though, due to the content of more variables, it requires more complex operations (Le-Bail et al., 2020). In SLS it is necessary to take into account: 1) the dependence of the material absorption on the laser wavelength; 2) the influence of the laser energy density on the material compaction mechanism. An infrared laser is used for 3D food printing. SHASAM uses a narrow beam with a low speed of hot air. Therefore, the powder mixture is selectively melted (Godoi et al., 2016). The first attempt of 3D printing from a powdered sugar mixture was performed using a CandyFab 4000 printer based on SASAM technology that enables the printing of caramelized sculptures (Le-Bail et al., 2020). Objects created by SHASAM and SLS techniques are shown in (Plate VIII, Fig. 1 D, E).

Jetting based techniques

Printed objects in jetting based techniques show a higher resolution, compared to the extrusion based printing, the matrix is applied in smaller batches. The dosage amount of matrix can be better controlled (Vadodaria et Mills, 2020).

Binder jetting

The binder jetting method is beneficial in printing using bulk mixtures. It is considered to be very efficient in terms of production speed, construction of complex structures and low material costs (Liu et al., 2017), though, equipment costs are relatively high (Le-Bail et al., 2020). A low viscosity liquid binder is applied to a thin layer of the powder mixture to form a 2D profile (Godoi et al., 2016). Gradually, additional layers of powder mixture and liquid binder are applied to form the desired structure (Le-Bail et al., 2020). Post-processing involves the removal of binder and unbound powder (Vadodaria et Mills, 2020). Food structures are printed in high resolution (Dankar et al., 2018). This method uses sugar and polymeric materials such as cellulose, xanthan gum, corn starch, dextran and gelatin as a matrix (Vadodaria et Mills, 2020). Though, the most common raw material is sugar (Plate VIII, Fig. 1 F). A number of colored sugar structures were printed using a ChefJet printer. A mixture of water, alcohol, glycerin and salt is used as a binder (Holland et al., 2019).

Inject printing

In 3D injection molding, low viscosity materials are usually used, meaning that this method is mainly used for surface filling and decoration (Liu et al., 2017; Foodjet, 2020). Inkjet printing uses the accumulation of material droplets. This technique uses thermal and piezoelectric printing. Matrices used in the injection technique, include chocolate, liquid dough, sugar icing, jams, meat pastes, etc. (Godoi et al., 2016). There are drop-on-demand (DoD) printers on the market that have been used for hot printing (Vadodaria et Mills, 2020). The DoD printer can be used to create patterns for decorative purposes (Holland et al., 2019). Inkjet technology is used by FoodJet (Foodjet, 2020).

Pneumatic jetting

In the pneumatic jetting technique, the printing is caused by the air pressure on the die in the dispenser, which opens or closes according to the piezoelectric movement caused by the electrical signal. Higher viscosity matrices can be used in this technique (Vadodaria et Mills, 2020). This technique can be relatively fast and inexpensive; though, it is less accurate compared to the inkjet printing (Gao et al., 2016).

Electrostatic jetting

Electrostatic jetting uses higher viscosity matrices. This method uses for printing the electrostatic force induced by the stress toward the matrix to print (Vadodaria et Mills, 2020). In the study conducted by Takagishi et al., (2018), chocolate was used as a matrix. High stress was applied to the matrix in the dosing device and to the base plate. Using electrostatic force, the chocolate was dosed in very small amounts. The printing is enabled by linear movement of the phase and the base plate. A pressure is also used to facilitate printing (Takagishi et al., 2018; Suzuki et al., 2019). The width of the printed line can be regulated by the applied voltage. This technique is relatively slow (Vadodaria et Mills, 2020).

Matrices intended for 3D food printing are mostly applied in liquid form (liquid, powder). These matrices should be able to maintain their shape during and after application. The liquid consistency of the matrix is ensured by softening or melting. In order for the structure to be self-supporting, additives are added to the matrix. Temperature changes, gelation, or reverse processes also have a large effect. In multicomponent structures, the behavior of the matrice is also affected by the presence of proteins, carbohydrates and fats. The used matrices and 3D printing techniques are overviewed in Table 1 (Godoi et al., 2016).

Table 1. An overview of 3D food printing techniques and used matrices

Technique		Application-material	Aditivum	Reference
Extrusion based printing		Milk protein	Sodium casenate	(Liu et al., 2019)
		Fish surimi gel	Microbial transglutaminase	(Dong et al., 2020)
		Meat paste	NaCl, xanthan gum/ guar gum	(Dick et al., 2020)
		Meat mass	Transglutaminase	(Lipton et al., 2010)
		Lemon juice gel	Potato starch	(Yang et al., 2018)
		Biscuit dough		(Pulatsu et al., 2020)
		Mushroom paste	Wheat flour,NaCl, CaCl2, Na2S2O5	(Keerthana et al., 2020)
		Egg paste	Rice starch	(Anukiruthika et al., 2020)
		Potato, corn and rice starch		(Liu et al., 2020b; Chen et al., 2019)
		Chocolate		(Lanaro et al., 2017
		Chocolate	Magnesium stearate, Plant sterols	(Mantihal et al., 2019)
		Processed cheese mass		(Le Tohic et al., 2018)
Selective sintering	SLS	Nesquik powder		(Lanaro et al., 2019)
	SHASAM	Sugar powder		(Lanaro et al., 2019)
Jetting based techniques	Binder jetting	Sugar powder		(Southerland et al., 2011)
		Cocoa powder	Maltodextrin/sugar	(Von Hasseln, 2013)
		Cocoa powder		(Holland et al., 2019)
	Inject jeting	Chocolate mass		(Lanaro et al., 2019)
		Jams, sauces, creams		(Foodjet, 2020)
	Electrostatic jetting	Chocolate		(Suzuki et al., 2019; Takagishi et al., 2018)

Conclusion

3D food printing is a technique that can meet the nutritional and visual needs of consumers. Though, it brings with it a number of complications that will be certainly the objects of further studies. Various design techniques of 3D food printing are described in the review. The overview of 3D food techniques indicated that the most investigated technique is 3D printing by extrusion. 3D printing is used both for printing the structures themselves and to supplement the decorative element of pre-prepared food.

References

Anukiruthika T, Moses JA, Anandharamakrishnan C 2020: 3D printing of egg yolk and white with rice flour blends. Journal of Food Engineering **265**.

Dankar I, Haddarah A, Omar FE, Sepulcre F, Pujolà M 2018: 3D printing technology: The new era for food customization and elaboration. Trends in food science & technology **75**: 231-242

Derossi A, Paolillo M, Caporizzi R, Severini C 2020: Extending the 3D food printing tests at high speed. Material deposition and effect of non-printing movements on the final quality of printed structures. Journal of Food Engineering **275**

Dick A, Bhandari B, Dong X, Prakash S 2020: Feasibility study of hydrocolloid incorporated 3D printed pork as dysphagia food. Food Hydrocolloids **107**

Dong X, Pan Y, Zhao W, Huang Y, Qu W, Pan J, Prakash S 2020: Impact of microbial transglutaminase on 3D printing quality of Scomberomorus niphonius surimi. LWT **124**

Fina F, Goyanes A, Gaisford S, Basit AW 2017: Selective laser sintering (SLS) 3D printing of medicines. International journal of pharmaceutics **529(1-2)**: 285-293

Foodjet: Precision depositing solutions. Available at: https://www.foodjet.com/. Accessed June 01, 2020

Gao Q, He Y, Fu JZ, Qiu JJ, Jin YA 2016: Fabrication of shape controllable alginate microparticles based on drop-on-demand jetting. Journal of Sol-Gel Science and Technology **77(3)**: 610-619

García-Segovia P, García-Alcaraz V, Balasch-Parisi S, Martínez-Monzó J 2020: 3D printing of gels based on xanthan/konjac gums. Innovative Food Science & Emerging Technologies

Gholamipour-Shirazi A, Norton IT, Mills T 2019: Designing hydrocolloid based food-ink formulations for extrusion 3D printing. Food Hydrocolloids **95**: 161-167

Godoi FC, Prakash S, Bhandari BR 2016: 3d printing technologies applied for food design: Status and prospects. Journal of Food Engineering **179**: 44-54

Holland S, Foster T, Tuck C 2019: Creation of Food Structures Through Binder Jetting. In: Godoi FC, Bhandari BR, Prakash S, Zhang M (Ed.): Fundamentals of 3D Food Printing and Applications. Academic Press, pp. 257-288

Chen H, Xie F, Chen L, Zheng B 2019: Effect of rheological properties of potato, rice and corn starches on their hot-extrusion 3D printing behaviors. Journal of food engineering **244**: 150-158

Keerthana K, Anukiruthika T, Moses JA, Anandharamakrishnan C 2020: Development of fiber-enriched 3D printed snacks from alternative foods: A study on button mushroom. Journal Of Food Engineering **287**

Kouzani AZ, Adams S, J Whyte D, Oliver R, Hemsley B, Palmer S, Balandin S 2017: 3D Printing of Food for People with Swallowing Difficulties. Kne Engineering **2(2)**: 23-29

Lanaro M, Forrestal DP, Scheurer S, Slinger DJ, Liao S, Powell SK, Woodruff MA 2017: 3D printing complex chocolate objects: Platform design, optimization and evaluation. Journal of Food Engineering **215**:13-22

Lanaro M, Desselle M R, Woodruff M A 2019: 3D Printing Chocolate: Properties of formulations for extrusion, sintering, binding and ink jetting. In: Godoi FC, Bhandari BR, Prakash S, Zhang M (Ed.): Fundamentals Of 3D Food Printing And Applications. Academic Press, pp151-173

Le Tohic C, O'Sullivan JJ, Drapala KP, Chartrin V, Chan T, Morrison AP, Kelly AL 2018: Effect of 3D printing on the structure and textural properties of processed cheese. Journal of Food Engineering **220**: 56-64

Le-Bail A, Maniglia BC, Le-Bail P 2020: Recent advances and future perspective in additive manufacturing of foods based on 3D printing. Current Opinion in Food Science **35**: 54-64

Lille M, Nurmela A, Nordlund E, Metsä-Kortelainen S, Sozer N 2018: Applicability of protein and fiber-rich food materials in extrusion-based 3D printing. Journal of Food Engineering **220**: 20-27

Lipton J, Arnold D, Nigl F, Lopez N, Cohen DL, Norén N, Lipson H 2010: Multi-material food printing with complex internal structure suitable for conventional post-processing. In: Solid freeform fabrication symposium, pp. 809-815

Lipton, 2017 Lipton JI 2017: Printable food: the technology and its application in human health. Current opinion in biotechnology **44**: 198-201

Liu Y, Yu Y, Liu C, Regenstein JM, Liu X, Zhou P 2019: Rheological and mechanical behavior of milk protein composite gel for extrusion-based 3D food printing. Lwt **102**: 338-346

Liu Z, Bhandari B, Zhang, M 2020: Incorporation of probiotics (Bifidobacterium animalis subsp. Lactis) into 3D printed mashed potatoes: Effects of variables on the viability. Food Research International **128**

Liu Z, Chen H, Zheng B, Xie F, Chen L 2020: Understanding the structure and rheological properties of potato starch induced by hot-extrusion 3D printing. Food Hydrocolloids **105**

Liu Z, Zhang M, Bhandari B, Wang, Y 2017: 3D printing: Printing precision and application in food sector. Trends in Food Science & Technology, **69**: 83-94

Lupton D, Turner B 2018: Both fascinating and disturbing: Consumer responses to 3D food printing and implications for food activism. In Digital Food Activism. New York: Routledge.

Mantihal S, Prakash S, Godoi FC, Bhandari B 2019: Effect of additives on thermal, rheological and tribological properties of 3D printed dark chocolate. Food research international **119**: 161-169

Pérez B, Nykvist H, Brøgger AF, Larsen, MB, Falkeborg MF 2019: Impact of macronutrients printability and 3D-printer parameters on 3D-food printing: A review. Food chemistry **287**: 249-257

Piyush Kumar R, Kumar R 2020: 3D printing of food materials: A state of art review and future applications. Materials Today: Proceedings

Portanguen S, Tournayre P, Sicard J, Astruc T, Mirade PS 2019: Toward the design of functional foods and biobased products by 3D printing: A review. Trends in food science & technology **86**: 188-198

Pulatsu E, Su JW, Lin J, Lin M 2020: Factors affecting 3D printing and post-processing capacity of cookie dough. Innovative Food Science & Emerging Technologies **61**

Severini C, Derossi A, Ricci I, Caporizzi R, Fiore A 2018: Printing a blend of fruit and vegetables. New advances on critical variables and shelf life of 3D edible objects. Journal of Food Engineering **220**: 89-100

Severini C, Azzollini D, Albenzio M, Derossi A 2018: On printability, quality and nutritional properties of 3D printed cereal based snacks enriched with edible insects. Food Research International **106**: 666-676

Singh et al. 2017 Singh S, Ramakrishna S, Singh R 2017: Material issues in additive manufacturing: A review. Journal of Manufacturing Processes **25**: 185-200

Southerland D, Walters P, Huson D 2011: Edible 3D printing. NIP & Digital Fabrication Conference **2011(2)**: 819-822

Sun J, Zhou W, Yan L, Huang D, Lin LY 2018: Extrusion-based food printing for digitalized food design and nutrition control. Journal of Food Engineering **220**: 1-11

Sun J, Peng Z, Yan L, Fuh JYH, Hong GS 2015: 3D food printing -an innovative way of mass customization in food fabrication. International Journal of Bioprinting **1(1)**: 27-38

Suzuki Y, Takagishi K, Umezu S 2019: Development of a high-precision viscous chocolate printer utilizing electrostatic inkjet printing. Journal of food process engineering **42(1)**

Takagishi K, Suzuki Y, Umezu S 2018: The high precision drawing method of chocolate utilizing electrostatic ink-jet printer. Journal of food engineering **216**:138-143

Vadodaria S, Mills T 2020: Jetting-based 3D Printing of Edible Materials. Food Hydrocolloids, 106

Von Hasseln KW 2013: Apparatus and method for producing a three-dimensional food product. U.S. Patent Application No. 13/196,859

Wang L, Zhang M, Bhandari B, Yang C 2018: Investigation on fish surimi gel as promising food material for 3D printing. Journal of Food Engineering **220**: 101-108

Yang F, Guo C, Zhang M, Bhandari B, Liu Y 2019: Improving 3D printing process of lemon juice gel based on fluid flow numerical simulation. Lwt, **102**: 89-99

Yang F, Zhang M, Bhandari B, Liu Y 2018: Investigation on lemon juice gel as food material for 3D printing and optimization of printing parameters. Lwt **87**: 67-76

Zhu S, Stieger MA, van der Goot AJ, Schutyser MA 2019: Extrusion-based 3D printing of food pastes: Correlating rheological properties with printing behaviour. Innovative Food Science & Emerging Technologies **58**

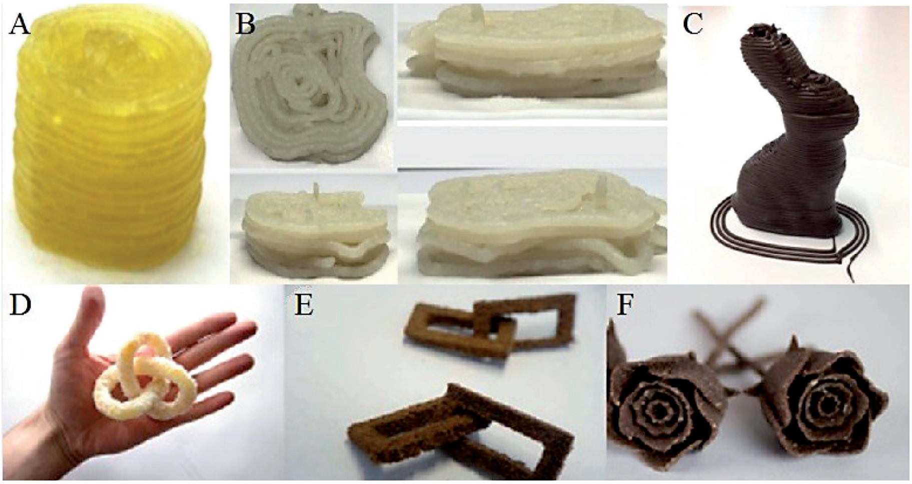

Fig. 1. The examples of 3D printed objects. A: Cylindrical structure of lemon juice with a starch concentration of 15 g/100 g (Yang et al., 2018). B: Geometric shapes of 3D printed surimi gel samples with a salt concentration of 1.0 g/100 g (Wang et al., 2018). C: Chocolate 3D structure in the form of a hare with cooling used during printing (Lanaro et al., 2017). D: sugar 3D structure created by SHAZAM technique. E: 3D object from Nesquik powder created by SLS technique. F: Structures created by the binder blasting technique using the ChefJet 3D system. The object D was taken from the following web site: https://candyfab.org/. The object E was taken from the following link: https://ec.europa.eu/jrc/sites/jrcsh/files/20150225-presentation-jan-sol.pdf. The object F was taken from the following web site: http://3dinsider.com/3d-printing-chocolate/.