Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Food Science

Formulated food inks for extrusion-based 3D printing of personalized foods: a mini review

Yizhou Ma and Lu Zhang

3D food printing is an emerging technology to structure foods from digital designs. A number of food inks are formulated to 3D/4D print foods with customized appearance. This mini review focuses on the recent developments in 3D printing of personalized foods with modified sensorial properties (e.g. texture and flavor). Varying sensory perceptions of printed food could lead to eating behavior changes among consumers and potentially achieve personalized nutrition. Modifying geometric designs and varying spatial distributions of ingredients are common techniques to alter sensorial properties of printed foods. The high degree of customization of 3D food printing indicates its potential as an on-demand production tool for personalized foods. Nevertheless, we suggest that longitudinal consumer insights and robust printers are needed to further achieve 3D printing of personalized foods.

Address
Laboratory of Food Process Engineering, Wageningen University and Research, P.O. Box 17, 6700 AA Wageningen, The Netherlands

Corresponding author: Zhang, Lu (lu1.zhang@wur.nl)

Current Opinion in Food Science 2022, **44**:100803

This review comes from a themed issue on **Food chemistry & biochemistry**

Edited by **Zhili Wan**

https://doi.org/10.1016/j.cofs.2021.12.012

Introduction

3D printing, also known as additive manufacturing, refers to the construction of 3-dimentional objects from digital designs. Since 2007, researchers attempt to develop 3D food printing technology to customize food designs, personalize nutrition, simplify the food supply chain, and broaden future food sources [1•]. Extrusion-based 3D printing is the most common technology to print food materials, compared to other technologies such as laser sintering or inkjet printing. In extrusion-based printing, a motorized syringe extrudes food materials onto a platform, and the object is built layer by layer based on a predesigned digital model. A variety of food materials has been formulated as food inks for 3D printing purposes. The food inks are often viscoelastic, to provide necessary structural integrities while remain extrudable through the printing nozzle [2•].

To develop such food inks, researchers adopted existing food materials (i.e. chocolate and cookie dough) into 3D printing applications [3,4]. Also, various food hydrogels, protein dispersions, and emulsion gels were formulated to be 3D-printable [5]. These adopted and formulated food inks are often studied for their 3D-printability (e.g. extrudability and self-supporting stability). Successful printing of those inks into stable shapes showcased 3D printing as a way to customize food designs. Customizable foods can assist designing personalized diets which could lead to eating behavior improvement and better nutritional well-being for long-term health of individuals [6,7]. The increased degree of customization can also adjust functional nutrient dosage, release profile, and duration similar to 3D-printed medicine [8]. Therefore, 3D food printing shows its potential use to produce on-demand and personalized foods that meet preferences and nutrition needs from consumers.

In previous reviews, authors have discussed a wide range of food materials in terms of printing feasibility, formulations, printing parameters, and post-processing techniques for 3D printing [5,9]. In this mini review, we focus on various extrusion-based food inks that are developed for producing personalized foods. We discuss food personalization via 3D printing from three aspects, that is, appearance customizations, flavor and texture modifications, and eating behavioral influences. The common personalization strategies are listed and discussed to provide guidelines for future sensorial modifications. Finally, we point out several challenges and opportunities to further realize personalized foods through 3D printing.

The food ink evolution for personalized foods

Food inks have been developed to enable various degrees of customization for 3D food printing. An evolution of food inks with increasing technical complexity and consumer involvement is observed from the recent research outcomes. In this section, we discuss the food ink evolution for personalization based on appearance customizations, texture and flavor modifications, and satiety and eating behavioral influences.

Appearance customization

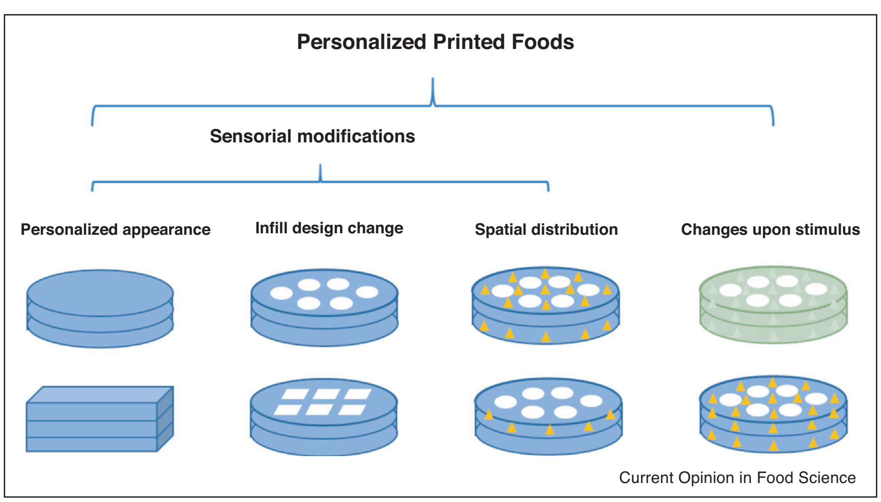
The early attempts of extrusion-based 3D food printing focused on printing food inks into customizable shapes. Those food inks were often adopted from ready-to-eat or prepared recipes. Lipton *et al.* listed then-available food inks such as chocolate, meat pastes, vegetable purees, and cookie dough [4]. Because of chocolate's unique material properties and popularity among consumers, specialized chocolate printers were developed and commercialized for confectionary design and manufacturing purposes. Several fundamental studies also investigated how chocolate compositions and processing influence its printability [10]. In recent studies, a variety of printable food inks has been developed such as protein gel, starch gel, and emulsions. Godoi et.al. reviewed the 3D printability of food inks as influenced by their compositions (ratios of macronutrients), which is strongly linked to the rheological properties of the inks [11]. In some other studies, additives such as hydrocolloids are often formulated into food inks to improve their 3D-printability [9]. These food inks were generally developed to showcase 3D printing as a tool to fabricate foods with a stable and customized shape (see Figure 1), rather than providing certain functionalities.

Moving beyond printing food into customizable and stable shapes, researchers utilized 4D printing to further modify appearance of printed foods. Over time, 3D-printed food materials can have color, shape, or flavor transformations (i.e. the 4th dimension) induced by internal or external stimulus such as pH, the availability of water (e.g. hydration or dehydration), and heat (e.g. microwave cooking) (see Figure 1) [12]. As reviewed by Teng *et al.*, functional ingredients such as colorants, dielectric regulators (i.e. salts and syrup), flavors, and bioactive compounds are formulated into the base inks for 4D food printing. For example, a color change of printed food was achieved by dual-extruding layers of two types of potato starch gels containing either anthocyanin (as the functional material) or lemon juice (as a pH stimulus) [13]. Over a period of 30 min, the color of the printed layers of anthocyanin-containing gel intensified due to change of its pH which is caused by the redistribution of hydrogen ions within the matrix. In another study, shape changes of starch-based foods were induced by microwave dehydration. He *et al.* investigated the degree of shape changes as controlled by changing ink formulations, microwave power, and infill patterns [14]. This study suggested that the addition of syrup and salts can influence both the rheological properties of the food ink and structural changes induced during microwave cooking. To summarize, in the case of 4D printing, functional properties of the food inks are specifically developed to showcase appearance customizability of 3D printing for personalized food designs.

Textural and flavor modifications

As a structuring tool, 3D printing can alter micro-structure and macro-structure of foods. By using digital design software, the infill density and pattern for a 3D object can be controlled. The change in infill can subsequently impact the texture of the printed food structure (see Figure 1). Derossi *et al.* structured bigger pores in cereal cubes via 3D printing compared to those produced by conventional processing methods. As a result of the microstructure changes, the hardness, chewiness and cohesiveness of 3D-printed samples after baking were higher than the manual-shaped ones. The authors further conducted textural modifications through a controlled generation of pores in the food matrix, to 'program' the texture of cereal-based foods [15]. A similar approach was found in developing 3D-printed potato snacks varying in

Figure 1



Schematic illustrations of 3D/4D printed foods that are personalized at different levels: white cycles and rectangles indicate different infill designs in the structure; orange triangles indicate functional ingredients that are distributed differently in structures; and color change is indicated by the change from green to blue color as an example of stimulus-responsive transformations of 3D-printed foods.

texture by changing infill patterns and densities during printing [16,17]. Modifying the infill of a food design has become the common method to alter food texture, providing opportunities for customizable food texture via 3D printing.

While texture modifications of printed foods are often characterized by instrumental analysis (e.g. texture profile analysis), data obtained from sensory panels are still limited in literature. Therefore, it is sometimes difficult to confirm texture modifications would result in actual changes of consumer perceptions. Mantihal *et al.* evaluated the sensorial properties of 3D-printed chocolate with different levels of infills [18]. Although the hardness of samples with various infill levels differed significantly as measured by a texture analyzer, the sensory study found no significant difference in hardness perceived by 30 semi-trained panelists. In a different study [19•], the authors modified the infill patterns of 3D-printed protein bars to examine the hardness perceived by 70 untrained panelists. This study showed that the concentric infill pattern resulted in higher perceived hardness compared to the rectilinear and layered patterns, which agreed to the instrumental analysis. Meanwhile, the authors found that modifying infill patterns did not impact consumer liking of the protein bars and suggested that 3D printing can be a viable technique for textural modifications of solid foods. For future research, combining instrumental analysis with sensory tests could provide further knowledge about how changes in food structure could impact its texture.

Flavor modifications were also attempted in previous studies by controlling the spatial distribution of ingredients in a food matrix using 3D printing (see Figure 1). Modifying flavor perceptions can potentially improve consumer preferences and achieve sugar, salt, and fat reductions in food formulations. For example, a chocolate layer with varied levels of thickness (as a way to change sugar content) was deposited onto rice waffles using 3D inkjet printing to create bite-to-bite difference of sweetness [20]. The sensory evaluation showed that the bite-to-bite variation created by 3D printing affected sweetness, expected fullness, and liking of the samples. The study concluded that the flavor modifications by 3D food printing can contribute to healthier food designs, creating similar sensory perceptions with less undesirable ingredients such as sugar. In a different study, dual-extrusion was used to stack salted and unsalted layers to structure starch snacks [21]. Based on results from a trained sensory evaluation, the inhomogeneous distribution of salt enhanced the saltiness perception, which can be used as a strategy for salt reduction in real food applications. Similarly, different lemon mousse formulations were layered into one structure to provide layer-by-layer variations in sweet and sour perceptions [22]. Although no significant difference in preference was found between the multisensory layered and control samples, the authors suggested that the multisensory layered design can be tailored towards preferences of specific consumer groups. Also, flavor modifications can be achieved using 4D printing. A controlled release of encapsulated cinnamaldehyde and pepper red pigments was developed for 3D-printed buckwheat snacks by microwave heating [23]. Upon microwave cooking, the buckwheat snacks released spicy flavors from cinnamaldehyde and changed color. Combining functional food inks with different 3D printing strategies (e.g. dual-extrusion or coaxial-extrusion of multiple materials), we can summarize sensorial modifications of 3D-printed personalized foods through altering appearances, textures, and flavors (see Table 1).

The available sensory studies provided empirical data to show the impact of food designs via 3D printing on texture and flavor perceptions. However, 3D food printing's specific influence on consumer preferences still remains challenging to characterize due to the lack of longitudinal consumer studies. On the individual level (i.e. consumer studies), a feedback loop for consumer preferences is needed to fully test the concept of personalized food produced by 3D printing. In an exploratory study, the authors collected consumer insights from 12 Dutch soldiers after consuming 3D printed foods for four weeks [24]. The soldiers consumed and rated personalized snack bars based on texture (crunchy or soft) and flavors (distribution of fillings). The study reported that an increase of personalization improved the overall liking of the snack bars, indicating that 3D printed foods can tailor their sensory profiles based on consumer needs. To further advance food personalization, consumer involvement is needed to test whether texture and flavor modifications based on 3D printing can fulfill consumer needs and improve food liking.

Satiety and eating behavioral influences

Changing food perceptions may lead to positive changes in eating behavior among consumers. To study such effect, consumer involvement is needed. A food personalization system named 'FoodFab' offered a proof-of-concept for personalizing calory intakes on the individual level [25••]. The system aims to alter the food's internal structure and overall appearance (i.e. size) to influence chewing time, which can subsequently determine the perceived satiety. Based on the calorie requirement of the user, the system calculates the necessary chewing time and print a specific cookie by altering the infill patterns and density. This study shows the infill density and size significantly affected both the chewing time and perceived satiety of the participants, when the infill pattern and overall calory/mass of the samples were kept the same. Specifically, the sample with the lowest infill density hence the largest size required the longest chewing time and was perceived with the highest increase of satiety. FoodFab served personalized foods based on

Table 1

Representative studies that achieved sensorial modifications of food through 3D printing

Modifications	Modification aim	Printing materials	Modification strategies	References
Appearance	Color changes	Starch gels	Dual-extrusion to achieve acid fusion among anthocyanin-containing layers	[13]
Appearance	Shape changes	Purple sweet potato purees	Controlling infill patterns and dielectric properties during microwave heating	[14]
Appearance/Flavor	Color and aroma changes	Buckwheat dough	Controlled release of aroma and color compounds by microwave heating	[23]
Texture	Hardness and chewiness changes	Cereal-based snacks	Infill densities and patterns to generate different porous structures	[15]
Texture	Hardness and fracturability changes	Potato snacks	Infill densities and patterns modifications	[16,17]
Texture/Preference	Hardness and overall preference	Dark chocolate	Infill densities modifications	[18]
Texture/Preference	Hardness, chewiness, and overall preference	Protein bar filled with chocolate	Infill patterns modifications	[19•]
Flavor/Preference	Sweetness, expected fullness, and overall preference	Chocolate on rice waffle	Spatial distribution of chocolate on a single layer	[20]
Flavor	Saltiness	Starch-based snacks	Dual-extrusion of salted and unsalted layers	[21]
Flavor	Sweetness and sourness	Lemon mousse	Dual extrusion to create layer-by-layer flavor variations	[22]
Texture/Flavor	Customizable texture & flavor	Snack bar (biscuit with fillings)	Varying the combinations of types of dough and fillings; Varying post-printing treatment	[24]

individual's calorie needs and created the feedback loop by asking the perceived satiety level. Although with limited food options and only targeting satiety, the concept provided in this study may be expanded to other personalization objectives such as reducing sugar and fat intakes and dosing nutraceuticals.

Challenges and outlooks

While the variety and functionality of food inks keep expanding, applications of 3D food printing to prototype and produce personalized foods remain at the conceptual stage. Here, we propose a road map to produce scalable and deployable personalized foods based on 3D printing (see Figure 2).

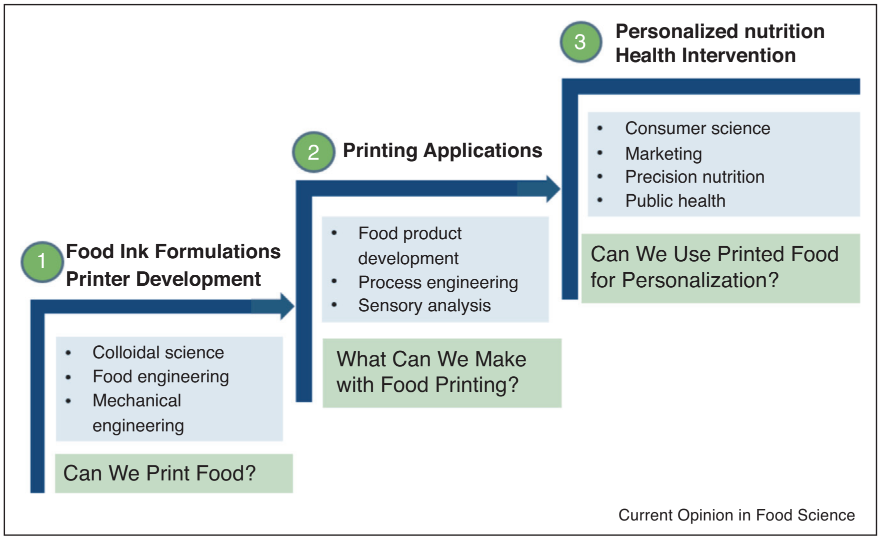
On Stage 1, studies have leveraged insights from colloidal science and food engineering to develop food ink formulations with good 3D printability. However, most of the 3D food printers used in current studies are either custom-built or modified from a plastic printer. Limited commercial printers are available to 3D print food materials. Unlike printing plastics, food materials are diverse and complicated in rheological properties, requiring a wide range of printing conditions to achieve proper structuring [2•]. Currently, due to the complexity in the rheological properties of food materials, extensive trail-and-error experiments are needed to find the proper printing conditions for a chosen food ink. The lack of quantitative printability evaluation made it difficult to achieve automated food printing. In some recent studies, vision sensors (e.g. optical/thermal cameras) are used to study the extrusion-based 3D printing of food materials. The data acquired by these sensors during printing experiments are used to quantitatively evaluate 3D printability of food materials [26,27]. Structured database of sensor and image data can further develop predictive models to link the printability of food inks to their rheological properties and printing conditions.

In addition, the current 3D food printers featured in literatures were either modified from plastic or bioprinters which operate at relatively low throughput for proof-of-concept applications. Food material properties (e.g. elasticity and solidification) set certain limits to the printing speed in current food printers, which make it difficult to use 3D printing as on-demand food production tools for consumer studies. To facilitate the production of personalized foods, robust food printers combined with integrated software controls are needed to adapt printing conditions based on food material properties [28]. The future development of personalized foods well depends on the robustness of food printers to accurately and timely produce food products as requested by individual users.

On Stage 2 (Figure 2), 3D food printing has been experimented as a product development tool to provide customizations and modifications discussed in earlier sections. Also, 3D bio-printing or food-printing has been used to prototype and produce meat alternatives such as cultured meat or plant-based meat replacers, which may contribute to the sustainable development of food production.

To advance towards food personalization (Stage 3, Figure 2), we also need more insights from consumer and nutritional studies. Consumer studies focusing on individual customizations should be performed to examine the current 3D food printing capabilities and the consumer acceptance of 3D-printed foods. Meanwhile,

Figure 2



A proposed road map for 3D food printing as a tool to produce personalized foods. Stage 1: Food ink formulation and printer development. Expertise from colloidal science, food engineering, and mechanical engineering can help us to answer the question whether we can print food. Stage 2: Printing applications. Expertise from product development, process engineering, and sensory analysis can help us to find out what we can make using 3D food printing. Stage 3: Food personalization and health intervention. Expertise from consumer science, marketing, precision nutrition, and public health can understand whether printed foods can achieve food personalization.

recent studies have shown that 3D-printed foods can achieve sugar, salt, and fat reductions with the potential to maintain the original sensory profile [19•,20,29]. Therefore, longitudinal studies may be needed to link long-term consumption of 3D-printed foods with potential health benefits. Similarly, food inks were formulated to act as delivery systems for other bioactive compounds. Customizing nutrient delivery to fulfill specific nutritional needs can be a subsequent study topic for personalized foods based on 3D printing. Moreover, food for special consumer groups such as dysphagia patients can also be produced by 3D food printing. Several studies have explored the formulations and potential health benefits of using 3D food printing to produce texture-modified foods for dysphagia patients [30,31]

Conclusions

The extrusion-based 3D food printing technology suits the needs for producing personalized foods. Thanks to the extensive development of functional food inks, 3D printing can alter appearance and sensorial properties of foods, to potentially meet consumer preferences and impact consumer eating behaviors. Controlling printing infills and the spatial distribution of ingredients are the common strategies to modify texture and flavor perceptions of printed foods. Future research is needed for longitudinal studies in terms of consumer acceptance of 3D food printing and potential health impacts by consuming printed foods. To further advance personalized food productions, robust 3D food printers are also needed to timely and accurately fabricate food designs using a wide range of food inks.

Conflict of interest statement

Nothing declared.

Acknowledgement

The authors would like to acknowledge the financial support from Sectorplan Techniek Mechanical Engineering (NWO).

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. • Derossi A, Caporizzi R, Paolillo M, Oral MO, Severini C: **Drawing the scientific landscape of 3D Food Printing. Maps and interpretation of the global information in the first 13 years of detailed experiments, from 2007 to 2020**. *Innov Food Sci Emerg* 2021, **70**:102689
This review provides an overview of 3D food printing development for the last 15 years. The paper applies a meta-analysis to showcase the research development of 3D food printing and the current key research focus.

2. • Wilms P, Daffner K, Kern C, Gras SL, Schutyser MAI, Kohlus R: **Formulation engineering of food systems for 3D-printing applications – a review**. *Food Res Int* 2021, **148**:110585
This review provides fundamental engineering principles of 3D food printing. It covers rheological properties that are key to extrusion-based food printing, extrudability of food materials, and buildability of the 3D food structures.

3. Hao L, Mellor S, Seaman O, Henderson J, Sewell N, Sloan M: **Material characterisation and process development for chocolate additive layer manufacturing**. *Virtual Phys Prototyp* 2010, **5**:57-64.

4. Lipton JI, Cutler M, Nigl F, Cohen D, Lipson H: **Additive manufacturing for the food industry**. *Trends Food Sci Technol* 2015, **43**:114-123.

5. Siacor FDC, Chen Q, Zhao JY, Han L, Valino AD, Taboada EB, Caldona EB, Advincula RC: **On the additive manufacturing (3D printing) of viscoelastic materials and flow behavior: from composites to food manufacturing**. *Addit Manuf* 2021, **45**:102043.

6. Celis-Morales C, Livingstone KM, Marsaux CF, Macready AL, Fallaize R, O'Donovan CB, Woolhead C, Forster H, Walsh MC, Navas-Carretero S *et al.*: **Effect of personalized nutrition on health-related behaviour change: evidence from the Food4Me European randomized controlled trial**. *Int J Epidemiol* 2017, **46**:578-588.

7. Zeevi D, Korem T, Zmora N, Israeli D, Rothschild D, Weinberger A, Ben-Yacov O, Lador D, Avnit-Sagi T, Lotan-Pompan M *et al.*: **Personalized nutrition by prediction of glycemic responses**. *Cell* 2015, **163**:1079-1094.

8. Tan YJN, Yong WP, Kochhar JS, Khanolkar J, Yao X, Sun Y, Chi Kit A, Soh S: **On-demand fully customizable drug tablets via 3D printing technology for personalized medicine**. *J Control Release* 2020, **322**:42-52.

9. Zhang JY, Pandya JK, McClements DJ, Lu J, Kinchla AJ: **Advancements in 3D food printing: a comprehensive overview of properties and opportunities**. *Crit Rev Food Sci Nutr* 2021:1-18.

10. Rando P, Ramaioli M: **Food 3D printing: effect of heat transfer on print stability of chocolate**. *J Food Eng* 2021, **294**:110415.

11. Godoi FC, Prakash S, Bhandari BR: **3D printing technologies applied for food design: status and prospects**. *J Food Eng* 2016, **179**:44-54.

12. Teng X, Zhang M, Mujumdar AS: **4D printing: recent advances and proposals in the food sector**. *Trends Food Sci Technol* 2021, **110**:349-363.

13. Ghazal AF, Zhang M, Liu Z: **Spontaneous color change of 3D printed healthy food product over time after printing as a novel application for 4D food printing**. *Food Bioprocess Technol* 2019, **12**:1627-1645.

14. He C, Zhang M, Devahastin S: **Investigation on spontaneous shape change of 4D printed starch-based purees from purple sweet potatoes as induced by microwave dehydration**. *ACS Appl Mater Interfaces* 2020, **12**:37896-37905.

15. Derossi A, Caporizzi R, Paolillo M, Severini C: **Programmable texture properties of cereal-based snack mediated by 3D printing technology**. *J Food Eng* 2021, **289**:110160.

16. Liu Z, Dick A, Prakash S, Bhandari B, Zhang M: **Texture modification of 3D printed air-fried potato snack by varying its internal structure with the potential to reduce oil content**. *Food Bioprocess Technol* 2020, **13**:564-576.

17. Liu Z, Zhang M: **Texture properties of microwave post-processed 3D printed potato snack with different ingredients and infill structure**. *Future Foods* 2021, **3**:100017.

18. Mantihal S, Prakash S, Bhandari B: **Texture-modified 3D printed dark chocolate: sensory evaluation and consumer perception study**. *J Texture Stud* 2019, **50**:386-399.

19. • Zhu S, Ruiz de Azua IV, Feijen S, van der Goot AJ, Schutyser M, Stieger M: **How macroscopic structure of 3D printed protein bars filled with chocolate influences instrumental and sensory texture**. *LWT* 2021, **151**:112155

This paper provides a good application case of altering sensory perceptions (flavor and texture) using extrusion-based 3D printing. The article found that 3D printing can be a viable method to change texture and flavor perception of chocolate-filled protein bars.

20. Zhu S, Ribberink M, de Wit M, Schutyser M, Stieger M: **Modifying sensory perception of chocolate coated rice waffles through bite-to-bite contrast: an application case study using 3D inkjet printing**. *Food Funct* 2020, **11**:10580-10587.

21. Fahmy AR, Amann LS, Dunkel A, Frank O, Dawid C, Hofmann T, Becker T, Jekle M: **Sensory design in food 3D printing – structuring, texture modulation, taste localization, and thermal stabilization**. *Innov Food Sci Emerg* 2021, **72**:102743 http://dx.doi.org/10.1016/j.ifset.2021.102743.

22. Chow CY, Thybo CD, Sager VF, Riantiningtyas RR, Bredie WLP, Ahrné L: **Printability, stability and sensory properties of protein-enriched 3D-printed lemon mousse for personalised in-between meals**. *Food Hydrocoll* 2021, **120**:106943.

23. Guo C, Zhang M, Devahastin S: **Color/aroma changes of 3D-printed buckwheat dough with yellow flesh peach as triggered by microwave heating of gelatin-gum Arabic complex coacervates**. *Food Hydrocoll* 2021, **112**:106358.

24. Caulier S, Doets E, Noort M: **An exploratory consumer study of 3D printed food perception in a real-life military setting**. *Food Qual Prefer* 2020, **86**:104001.

25. •• Lin Y-J, Punpongsanon P, Wen X, Iwai D, Sato K, Obrist M, Mueller S: **FoodFab: creating food perception illusions using food 3D printing**. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*; *Association for Computing Machinery: 2020:1-13*

This is the first study to implement a consumer feedback loop to produce snacks with customizable calory intakes. The authors applied infill changes to create illusions and impacted perceived satiety of participants.

26. Ma Y, Schutyser MA, Boom RM, Zhang L: **Predicting the extrudability of complex food materials during 3D printing based on image analysis and gray-box data-driven modelling**. *Innov Food Sci Emerg* 2021, **73**:102764.

27. Fahmy AR, Becker T, Jekle M: **3D printing and additive manufacturing of cereal-based materials: quality analysis of starch-based systems using a camera-based morphological approach**. *Innov Food Sci Emerg* 2020, **63**:102384.

28. Jayaprakash S, Paasi J, Pennanen K, Flores Ituarte I, Lille M, Partanen J, Sozer N: **Techno-economic prospects and desirability of 3D food printing: perspectives of industrial experts, researchers and consumers**. *Foods* 2020, **9**:1725.

29. Shahbazi M, Jäger H, Ettelaie R: **Application of Pickering emulsions in 3D printing of personalized nutrition. Part II: functional properties of reduced-fat 3D printed cheese analogues**. *Colloids Surf A Physicochem Eng Asp* 2021, **624**:126760.

30. Pant A, Lee AY, Karyappa R, Lee CP, An J, Hashimoto M, Tan U-X, Wong G, Chua CK, Zhang Y: **3D food printing of fresh vegetables using food hydrocolloids for dysphagic patients**. *Food Hydrocoll* 2021, **114**:106546.

31. Lee AY, Pant A, Pojchanun K, Lee CP, An J, Hashimoto M, Tan UX, Leo CH, Wong G, Chua CK, Zhang Y: **Three-dimensional printing of food foams stabilized by hydrocolloids for hydration in dysphagia**. *Int J Bioprinting* 2021, **7**.