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REVIEW

Printing on Food or Food Printing: a Review

F. Pallottino[1] · **L. Hakola**[2] · **C. Costa**[1] · **F. Antonucci**[1] · **S. Figorilli**[1] · **A. Seisto**[2] · **P. Menesatti**[1]

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Abstract The processes of printing foodstuffs or imaging on an unconventional surface deserve extra attention in comparison with conventional techniques especially in relation with the substrate interested that will or should say a lot about the concept behind the design. Indeed, while printing on food, designers are required to consider carefully both, the appropriate edible inks and the production processes. Moreover, printing on food packaging requires almost as much care. However, the concept of food printing represents nowadays a new frontier in food processing and industry to realize new food products of complex shapes and colour and with particular mixtures. At the moment, many current research projects and products related to food printing are being developed. In 2011, a European Cooperation in Science and Technology action named "New possibilities for print media and packaging, combining print with digital" was created with the aim to promote an interdisciplinary interaction among European research partner with several different research backgrounds. Among the aims of the project, a crucial aspect regards the combination of food expertise with printing using new technologies in order to print on food or food printing. In light of this scenario, image processing and machine control occupy a very important part of the research: a number of programs were written or modified as part of the research into food printing. This review aims to produce an updated analysis on the current developments regarding the technology for food printing and printing on food. In this sense, the work starts giving an overview of the 2D and three-dimensional (3D) printer technology and moves on the food media, edible substrate used by 3D printers and a print of food chapter, related to the substrates used by the 2D printers.

Keywords Printing · Food processing · Print media · Edible ink · Packaging · 2D and 3D printers

✉ C. Costa
corrado.costa@entecra.it

[1] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA), Unità di ricerca per l'ingegneria agraria, Via della Pascolare 16, 00015 Monterotondo scalo, Rome, Italy

[2] VTT Technical Research Centre of Finland, Tietotie 3, P.O. Box 1000, 02044 VTT Espoo, Finland

Introduction

Printing or imaging on an unconventional surface means committing to feeding a specific concept: the substrate will or should say a lot about the concept behind the design. About printing on food, designers are required to carefully consider proper edible inks and production processes. Printing on food packaging requires almost as much care. Meanwhile, for the concept of food printing, a new frontier in food processing and industry could be reached realizing and producing new foods, shapes, colour and particular mixtures. In this case, different patents (e.g. three-dimensional (3D) printers with deposition and for rapid prototyping) (Ben-Yoseph et al. 2009; Fork and Hantschel 2010; Von Hasseln 2011; Batchelder 2012), researches on edible ink printing, edible fluids/semi-solid or gel to be used as food component and extruding and printing technologies for fluid or semi-solid products are commercially available.

As reported by Millen (2012), in recent years, foods are becoming more customized and consumers require food that tastes great, looks great and is healthy. To be able to create completely customized foods, there are two options. Using a material set that is large enough to satisfy all consumers' wants or using a small material set that can be combined in varying ratios. As the former has limited capabilities, especially on a small scale, the latter option has been explored. Food printing is a method to distribute food in a personalized manner, and it represents one way to satisfy this demand. There are many current research projects and existing products related to food printing. In 2011, a European Cooperation in Science and Technology (COST) action (FP1104) called "New possibilities for print media and packaging, combining print with digital" was started with the scope to promote an interdisciplinary interaction among European research partner with several different research backgrounds. Among the aims of the project has been suggested to combine food technology with print and media to develop using new technologies to print on food or food printing. Another example is given by the interest shown by NASA and a Texas company which are at the moment exploring the possibility to print food on deep space mission using a 3D printer. Indeed, NASA has financed a Small Business Innovation Research (SBIR), at the moment at its phase, to Systems and Materials Research Consultancy of Austin, Texas, to study the practicability of the project. Systems and Materials Research Consultancy will conduct the study with the aim to develop a 3D-printed food system for long-duration space missions. Research projects in the area of rapid prototyping with food materials are at present in varied stages of progress. The existing research ranges from concept ideas (some of which could be achievable and some being futuristic ideas) right through to in-depth material and flow research for extrusion deposition.

The direct printing on agricultural raw products and/or food processed permits no label in foreign material interposition reducing packaging waste. Direct contact between plastic packaging materials and food can result in migration of low-molecular-weight additives from packaging materials into foodstuffs (Figge 1996). Castle et al. (1989) have been demonstrated that on storage of a tightly wound reel of polypropylene packaging film, specially printed for experimental purposes, transfer can occur of components from the ink on the outer surface of the film on to the inner food contact surface.

In this scenario, image processing and machine control occupy a very important part of the research: a number of programs were written or modified as part of the research into food printing. For example, as reported by Millen (2012), two programs were written in Visual Basic and one in Matlab to process images so that colour distribution information could be determined. In this case, if a discontinuous flow regime is used in the food printing process, there is a valuable opportunity to distribute voxels (volume element representing a value on a regular grid in three-dimensional space; it is a combination of volume and pixel where pixel is a combination of picture and element). For example, voxels of similar colour could be printed in sequence to avoid changing colour so much. About this, as reported by Yam and Papadakis (2004), in food engineering research, it is often necessary to analyze the surface colour of food samples both qualitatively and quantitatively. For example, qualitative analysis may involve visual inspection and comparison of the food samples. Moreover, the most obvious application of the printing of food is for manufacture of edible objects that would be difficult to produce by hand. This could include pieces that are made up of different materials or even simply different colours of the same material (i.e. frosting) (Periard et al. 2007).

The direct printing on food processed permits a new direct message to consumer (product promotion and/or new marketing) regarding the following: product, production health, cultural and social information.

This review aims to produce an updated analysis on the current developments regarding the technology for food printing and printing on food. In this sense, the work starts giving an overview of the 2D and 3D printer technology and moves on the food media, edible substrate used by 3D printers and a print of food chapter, related to the substrates used by the 2D printers. The last chapter points out the possibilities given by the use of food printers (e.g. 2D, bar codes) for a correct food traceability.

Food Printer

2D Printer

Two-dimensional printing on food is decoration of food surfaces by using printing methods. Because food as a printing substrate is a very demanding one, typically, only inkjet printing is considered a suitable printing method. Figure 1 shows the EdiJET printer, a machine that prints edible ink directly

Fig. 1 EdiJET represents an example of an inkjet food printer able to print on several surfaces. Available at http://www.uglyduckclothing.co.uk

onto different food surfaces such as cookies, cakes and sweets. The printer was designed in order to be compact and fit inside a bakery or a sweet store to add a sense of customization to their products. Traditionally, food surfaces are decorated by using stamping, moulding, edible labels or wafers, or removable labels or stickers. These technologies do not offer possibility for cost-effective personalization which is possible with, e.g. inkjet printing. For printing on food, one important aspect of inkjet printing is also that it is a non-contact method, thus protecting food from contamination during printing. Inkjet printing is also easily automated, is suitable for mass production, offers possibility for customised and personalized marking and can be integrated into existing food production lines. The drawbacks of inkjet printing for food decoration are short marking distances (<1 cm) and ink compatibility issues since theoretically every food product would require a specific ink to have good enough print quality and adhesion.

Inkjet printing has been widely accepted for food decoration purposes by both EU and FDA, and there are commercially available suitable printing systems and edible inks. For example, in 2012, EC passed a regulation permitting the use of food additive E445 (glycerol esters of wood rosins) as an emulsifier in water-based inks used for inkjet printing on confectionary after a request from Mars Chocolate UK (William Reed Business Media 2012). EU Regulation No 472/2012 issued 4.6.2012 states that additives can be used for personalized and/or promotional products consumed in small quantities for a restricted number of occasions.

Besides inkjet printing, also laser marking is a potential method for 2D printing on food products. It is based on a use of laser beam to locally engrave or discolour the surface. Figure 2 shows the PLS laser printer made by Universal Laser Systems, a machine with a dual laser configuration able to print at high speed on food and many other uneven surfaces. The benefits of laser marking include long marking distance and compatibility with a wide variety of surfaces. Drawbacks include the limited use of different colours and local burning of the marked surface (Hakola et al. 2013). Inkjet printing and laser marking are compared with the conventional food decoration method in Table 1 (Hakola et al. 2012). Hakola et al. (2013, 2015) describe decoration of meat and bakery products by inkjet printing and laser marking. Both methods have been evaluated to be suitable for making temporary or durable markings on food. End uses include both security and decoration solutions. Figure 3 shows some example of foodstuffs that can be printed/marked in relationship with the technologies presented in Table 1.

Fig. 2 PLS dual laser printer made by Universal Laser Systems able to print on several surfaces among which foodstuffs. Available at http://www.ulsinc.com

Inkjet printing is a digital printing technology based on small ink drops that form the printed image. There are different inkjet technologies that differ in the way that drops are generated. Continuous inkjet is based on continuous drop generation, drops needed for images are guided to substrate, and other drops are re-circulated. It is mainly used for coding and marking applications as well as high-speed publication printing. In drop-on-demand technology, drops are generated only when needed based on either deformation of piezo-electric crystal (piezo-electric inkjet) or heating element (thermal inkjet). Besides home and office printing, drop-on-demand technologies are used for industrial applications such as package printing, surface decoration, 3D printing and printed intelligence applications such as printed electronics, diagnostics and displays.

Most of the inkjet printers intended for edible ink printing are at the moment based on continuous inkjet printing technique. Manufacturers include Linx (Linx Printing Technologies 2015), Leibinger (Leibinger Group 2015), Domino (Domino Printing Sciences plc 2015), Markem-Imaje (Markem-Imaje 2015) and Citronix (Citronix Inc. 2015). The printer manufacturers also offer compatible edible inks for their systems. The drop-on-demand inkjet printing systems have not become common in food-grade ink printing for some reason. Several factors might have affected this, e.g. low speed, easily clogging nozzles, shorter lifetime of printheads and more demanding maintenance and adjustment procedures. In addition, third-party edible inks are not directly available for drop-on-demand printheads, although the ink selection is otherwise very wide. Some ink manufacturers mention on their websites that edible inks are available on request. Manufacturers for drop-on-demand edible ink printers include Matthews Marking (Matthews Marking Systems 2015), Dotjet (Dotjet Inc. 2015), MapleJet (MapleJet Co. 2015), Hewlett-Packard (iJet) (Hewlett-Packard Development Company 2015) and RN Mark (RN Mark Inc. 2015) with Xaar printheads.

Table 1 Comparison between digital and conventional food decoration methods

Method	Inkjet printing (Fig. 1)	Laser marking (Fig. 2)	Conventional methods (Fig. 3)
Principle	Small ink drops generated and placed on substrate to form an image from digital file	Colour change or engraving, contactless, no additives, image from a digital file	Stamping, labels/stickers, moulding, edible wafers
Suitable product groups	Medical products, bakery products, sweets, egg	Medical products, bakery products, sweets, meat products, cheese, eggs	All
Personalization	Yes	Yes	No
Colours	Full colour	Single colour	Full colour
Accuracy	Smallest detail in the range of 10 μm	In the case of CO_2 laser in the range of 100 μm	Depending on technology
Durability	Depending on substrate from low to high	Permanent	From removable (stickers) to permanent (moulding)
Marking distance	Preferably 1–5 mm, potentially even 3 cm	Depending on optics used and focus spot size wanted up to 1 m	Contact
Time to make the marking	Typical printing speed 10–1000 mm/s: 5 cm logo → 0.05–5 s	Typical scanning speed, for example, 1 m/s (possible up to 50 m/s), Vaasan logos contour width 20 mm, scanned 1 m/s, took 0.4 s	
Contact with substrate	No	No	Yes
Maintenance	During printing and when not printing	Expected tube lifetime in a CO_2 laser 10,000 h	
Device price	For this purpose approximately 30,000–50,000 euro (printer only)	A laser plus a scanner head, 20,000–60,000 euro	
Consumables	Printheads, ink, ink tubings	In the long run, some optical components and the laser tube may have to be changed.	

Fujifilm Dimatix is one of the few companies to offer edible inkjet inks for drop-on-demand inkjet (Fujifilm Corporation 2015). Tapestry™ FEC inks are designed to be printed on porous food surfaces. Printing can be done before or after baking, thus making inks suitable also for raw products. Fujifilm Dimatix states that inks have no impact to product shelf life or flavour and the colorants used are FDA and EU certified. However, inside Europe, there are some countries that do not approve some of the colorants including Sweden, Norway, France, Denmark and Germany. The inks are glycol and dye based. CMYK and spot colours are available on request. Colorants are typical food colorants such as E129 (Allura Red, Red 40), E127 (erythrosine), E122 (carmoisine), E133 (brilliant blue), E132 (indigo), E102 (tartrazine) and E104 (quinoline yellow).

In addition to inks, Fujifilm Dimatix also has Merlin product line for printing systems that can be integrated into existing production lines. Merlin printers are configured to support many jetting fluid types, thus making them suitable for printing, deposition and decorative food and non-food applications. One of the first installations around 2004 was at Procter & Gamble for printing on Pringles chips. Merlin printers have 4–48 printheads designed for four-colour printing, printing speed of 150 m/min and 50–76-cm print width.

Generally, any home/office printer could be modified to print edible ink on edible substrates if a suitable ink cartridge is available. The most popular application is personalized birthday cake decoration inkjet printed on rice sheet with edible inks. These inks typically contain water as a solvent and

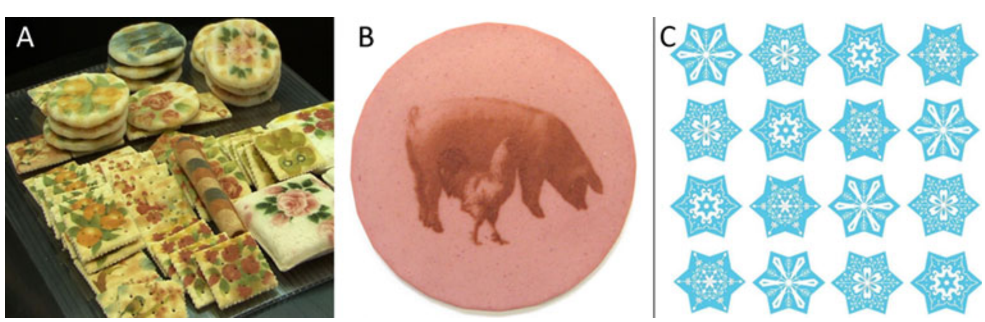

Fig. 3 The picture represents some example of different food stuffs printed with different technologies cited in Table 1. From *left* to *right*, **a** example of bakery products printed through an inkjet food printer (available at http://www.diginfo.tv), **b** example of meat etched with a laser printer (available at http://www.neatorama.com) and **c** example of edible wafer for cupcake pre-printed and pre-cut using conventional methods (available at http://www.amazon.com)

food colorants. Suitable printers can be purchased with approximately 500 euros and ink cartridges that contain edible ink with approximately 50 euros. With some substrate handling modification, the same printers could be used for printing on other food products. These kinds of systems designed to print single items have low printing speed and thus are not compatible with industrial production environments.

Typical edible ink composition consists of water, ethanol, glycol and/or glycerol as solvents and an edible colorant. There are many patents for edible inks. Some of the ink recipes are designed to give visual images, but some recipes additionally provide flavour. Toyo Ink (Furuno and Nishida 2011; Nishida et al. 2011a, b, c) describes an edible ink consisting of 65 wt% water, 23 wt% ethanol, 12 wt% glycerine and 6 wt% gardenia blue pigment designed for food decoration. The viscosity of the ink is 3.5 mPas. Hebrew University and Steam Coffee Culture Ltd. describe a coffee-based ink for food consisting of coffee, propylene glycol, glycerol and Tween 80 (Eliav et al. 2008). Procter & Gamble Company has a patent for an inkjet ink that adds flavour (Wen et al. 2008). The composition is based on lecithin, glucose, lemon juice, bitterness suppressor and toner flavour, as well as solvents.

Besides ink composition patents, there are also some patents describing additional areas related to inkjet decoration of food products. Unilever has a patent for inkjet printing on chocolate products, especially chocolate-covered ice cream products (Xu 2011). Printing is done on frozen chocolate and after printing stored preferably at −5 to −20 °C, thus indicating that edible inks tolerate temperatures below 0 °C. The ink described in the patent is water based and contains, among others, sunflower oil and cocoa fat. Japanese companies Sanryu and Tanizawa Kaki Kogyo have a patent where inkjet-printed images are fixed to the white chocolate surface by spraying cocoa butter (Tobita and Tanisawa 2009). This could be one solution for edible inks having poor adhesion to certain substrates. General Mills describes a digital imaging printer that is designed to print on food products at a temperature of at least 75 °C (Smith 2007). The patent describes especially inkjet printing on fruit food snack with fruit-based paste or confection slurry.

3D Printer

Bringing the food industry to the digital age is one of the essential and revolutionary applications of 3D printing. Figure 4 shows a prototype of pasta printer co-developed by Barilla Group and TNO and presented at EXPO2015 in Milan (Italy). The printer is capable of printing 3D pasta shapes at the speed of four elements every 2 min. Applying this technology enables fast automated and repeatable processes and freedom in design, as well as allows large and easy variability of the cooking process, which can be customized for each region or individual. Using robotic layer-based food printing systems allows the recipe of the food to be digitized and saved in order to prepare very repeatable and high-quality dishes without any margin for operator error. In addition, the shape and decoration of the food can be individualized based on the customer or the occasion (des Aufsatzes et al. 2013).

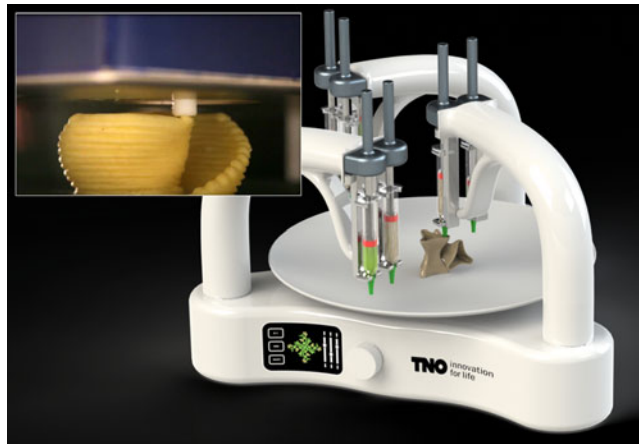

Fig. 4 Examples of a filament six-head 3D printers and the resulting final product. Available at http://3digitalcooks.com/ and https://www.tno.nl

In this scenario, a company called Choc Edge is currently marketing “the world’s first commercial 3D chocolate printer”, the Choc Creator. It uses a nozzle to dispense molten chocolate into any pattern and shape. Researches in University of Cornell have demonstrated new materials suitable for baking, broiling and frying for use with food 3D printers. In this case, printed objects were deep fried and retained their shape with minimal loss of detail due to deep frying. Cornucopia is another program working on specialized 3D printers for the food industry and so far has designed four prototypes. The digital Chocolatier allows for the design of chocolate and candies which even has a “carousel” of ingredients, and the digital fabricator combines selected ingredients and turns them into “flavors and textures that would be completely unimaginable with other cooking techniques” (des Aufsatzes et al. 2013).

Three-dimensional printing technology could revolutionize and reshape the world. Advances in 3D printing technology can significantly change and improve the way that we manufacture products and produce goods worldwide. An object is scanned or designed with computer-aided design software and then sliced up into thin layers, which can then be printed out to form a 3D product. As previously described, the importance of an invention can be appraised by determining which of the human needs it fulfils. As shown, 3D printing can have an application in almost all of the categories of human needs. While it may not fill an empty unloved heart, it will provide companies and individuals fast and easy manufacturing in any size or scale limited only by their imagination. One of the main advantages of the industrialization revolution was that parts could be made nearly identically which meant that they could be easily replaced without individual tailoring. Three-dimensional printing, on the other hand, can enable fast, reliable and repeatable means of producing tailor-made products which can still be made inexpensively due to automation of processes and distribution of manufacturing needs. If the last industrial revolution brought us mass production and the advent of economies of scale, the digital 3D printing revolution could bring mass manufacturing back a full circle to an era of mass personalization and a return to individual craftsmanship.

Inkjet printing food ingredient is a one way to make 3D-printed food. Other 3D printing approaches include powder printing, selective laser sintering (SLS) and hot-melt extrusion technologies. In powder printing, an inkjet printhead moves across a bed of powder and selectively deposits a liquid-binding material. Afterward, a thin layer of powder is spread across the section. This process is repeated until all layers are completed. Unbound powder is removed. Powder printing has some potential in food printing for powder type of foods similar to pharmaceutical applications (Ventola 2014). Hot-melt extrusion has the similar potential since it has also been used for printing pharmaceuticals (Goyanes et al. 2015). In hot-melt extrusion, hot material is pushed through a die of the desired cross section. SLS is not a familiar technology with 3D food printing since it is typically used for attaching different metals together. In SLS, a laser beam is used to bind materials together to create a solid structure. Selective laser melting (SLM) uses also a laser beam, but in this case, the materials are melted together. SLM might be suitable for 3D food printing for attaching food components together.

Print on Food

No available literature describes procedures or researches on printing on food matrices. However, since 1970, many international patents have been registered. Fell (1979) registered an ink composition suitable for ink jet printing on a variety of substrates and particularly food products, for example citrus fruit, and method of marking such products. The compositions are characterized by their ability to penetrate the waxed surfaces of such foods as citrus fruits to provide markings therein. Young (2000) registered a machine adapted to print an image as hereinbefore defined onto a surface of an edible substrate, the machine including a bubble-jet printer head assembly and the machine including a container for containing a liquid food colorant. This invention also included a method of printing an image onto an edible substrate. Shastry et al. (2006) registered a patent which modifies the surface of an edible with a high-polarity water-based glaze or polishing gum which improves the printing of images on the edibles with low-viscosity inks typically used in inkjet printing. The methods described here are suitable for printing high-resolution images on edible substrate, such as a hard panned sugar shell confectionery, using inkjet systems. One of the oldest edible media and, still today, one of the most used for its low cost and easy utilization are represented by edible paper. Both, the firsts made of rice and the modern ones mainly represented by icing sheets, are used nowadays as substrate for printing writings and/or pictures using edible ink. Most edible papers have little or no flavour and reduced texture. Edible papers can normally be printed on by a standard printer and, upon application to a moist surface, dissolve maintaining a high resolution. These substrates are present in a wide variety such as fondant paper, frosting sheets, wafer paper and sugar paper. Edible papers and ink are nowadays a well-established reality counting tons of patents and applications, many of which created many years ago (Huang et al. 2014) and now even sold at low price through internet or specialized shops (Goodall and Ceurstemont 2006). Examples are represented by the inks produced by Gateway Technology Industry (2015) especially made for the food printing industry including cookie, biscuit, marshmallow, cotton candy, rice paper, chewing gum, cupcake, etc. for printing and free head clogging in the CMYK colour space. Lately, even commercial applications sold to retailers are being developed such us the Barista Bot created by Hypersonic Studio (2015). This machine represents an interactive robotic experience for the consumers to experience the possibility to buy a truly personalized cup of coffee. Indeed, utilizing a simple web cam, the Barista Bot acquires a real-time facial picture and draws your likeness on top of your own latte/cappuccino/coffee. This represents an example of an innovative application even if not directly innovating in terms of printable substrate. Inkedibles™ (2015) made a step forward with respect to just printing offering a whole set of instruments to print and manually decorate any kind of edible substrate. Indeed, Inkedibles™ besides producing printable inks, cheese sheets, frosting sheets, wafer sheets pre-printed design, etc., becoming lately more and more conventional, does offer: edible paper cutters, chocolate transfer, edible pens and food markers and dedicated airbrush. Moreover, printing on food requires as well appropriate software able to accomplish the task, not always easy, to print on different media. Deco Enterprises Ltd (2015) sells the proprietary Edible Artist in order to make such process easier. This is one rare example of software customized for food applications. Indeed, being able to adapt even a normal printer to print on food sheets, e.g. using the Canon MG6620 or the MG5520, often dedicated software is not needed yet for 2D printing.

Food Media (i.e. Media to Eat)

At the moment, a very interesting and crucial aspect of food printing is represented by the substrates which are being developed or already used to print food throughout a 3D printer. While such concept was unthinkable, until few years ago, it is now possible due to the recent creation of even consumer-accessible 3D printer and getting today a rapidly developing reality. Indeed, different printer models, adopting different substrates, are lately appearing on the net and starting to be promoted. Unfortunately, now, there are not many sources about the materials used besides few exceptions.

An example is given by a company called Choc Edge is currently producing and marketing what they claim to be "the world's first commercial 3D chocolate printer", the Choc Creator V1 using a nozzle to lay down molten chocolate into any drawing and shape (Chocedge Ltd 2015).

Hod Lipson and Evan Malone from Cornell University Creative Machines Lab started the Fab@Home project (Fab@Home 2015) in 2006 with the aim to develop an open-source mass-collaboration personal fabricator (3D printer) that everybody will be able to use at home. Such an open-source device is nowadays produced in different ways and gives the possibility to print several things among which food. The open-source nature of the system gives the chance, to the entire community working on the project all over the world, to experiment loading up the printer's syringes with any raw food of liquid consistency within reach. Sun et al. (2015a, b) classified the available printing materials in (i) natively printable which include all those materials that can be extruded smoothly from a syringe like hydrogel, cheese, cake frosting, hummus, chocolate, etc.; (ii) traditional food material normally not printable including most of the food normally consumed such as fruit, vegetables, meat, etc. but that can be extruded thanks to a fine-tuning of hydrocolloid concentration in order to create a material with the desired structural strength (Lipton et al. 2010; Cohen et al. 2009); (iii) alternative kind of ingredients reported to be e.g. extrudable materials mixed with insect powder (Soares 2011). Lipton et al. (2010) tested with success the possibility to print a variety of multi-material food among which turkey, scallop and celery that were processed and modified using transglutaminase to enable them to be cooked or fried after printing. Many peculiar applications are seen around such as e.g. the Burritobot (2014), a 3D printer developed by Marko Manriquez, a New York University graduate student that developed a thesis project that he calls "A 3-D printer that assembles made-to-order burritos via a custom iPhone app". Sun et al. (2015c) report the possibility of printing cookies sugar teeth without the need of further post-processing (cooking) made from a mixture of sugars, starch and mashed potato. Lin in 2015 reported the possibility to print even complex food materials such as pizza without, however, explaining the technical printing aspects. Periard et al. (2007) report as to build 3D objects using a Fab@Home printer (Fab@Home project 2015) requires that the materials have high enough viscosity to be self-supporting and stackable in layers with appropriate resolution. In their experiment, different materials were chosen and tested including cake frosting, chocolate, processed cheese and peanut butter, some of which needing a temperature-controlled syringe tool to accomplish the task. Moreover, the research reports that the material properties involve the need for a fine manual calibration process which involves selecting the appropriate syringe tip for each material, iteratively depositing test paths, tuning the flow rates and delays and, in the end, recording the height and width of the paths. Normally, higher consistency liquid requires the use of thicker tips.

The material set requirements suitable for 3D printing can represent a serious barrier for solid freeform fabrication (SFF) of food (Lipton et al. 2010). While such a barrier can be partially overcome through manual adjustments, such as in the case of the Fab@Home printer (Fab@Home project 2015), other printers do not allow the use of such varieties of substrates. Moreover, the work carried out by Lipton et al. (2010) underlines another crucial aspect represented by the compatibility of printable food material with traditional cooking techniques such as broiling, baking or frying. They specify as previous work used unmodified traditional foods relying on the direct fabrication of the final food shapes where the only post processing required was cooling (e.g. chocolate). For such reason, the work proposes the use of simple additives and modifications with respect to traditional recipes showing the possibility to create complex geometries which can be cooked like ordinary food in order to obtain product with retained rheology. In details, transglutaminase allows turkey and scallop to be 3D printed for the first time through SFF while agar was used for creating printing vegetables after obtaining a purée from the initial materials.

Another work (Cohen et al. 2009) created and studied the reaction of different and much more complex extrudable materials Cohen et al. (2009) created a new combination of hydrocolloids such as xanthium gum and gelatin as a starting point showing the possibility to produce printing materials that could replicate a wide range of food. Furthermore, they set up a two-dimensional mouthfeel rating system, with the help of expert panel and expert testers, with the aim to evaluate the hydrocolloid mixtures used for food printing in comparison with standard food. The work concludes asserting the possibility to recreate a very broad range of mouthfeel using only xanthan and gelatin. While the authors describe hydrocolloids as a next future implementation, Lipton et al. (2010) describe SFF of hydrogels as a technique allowing for the complete control of the final product taste, nutritional value and texture, but as well as being a highly controlled material would not be easily and immediately adopted for the personal use by most individuals.

Concerning the software used for 3D food printing, there are many commercial and open-source ones available nowadays. These software are mainly just the same software utilized for 3D modelling; therefore, complex and not accessible to everybody, rare solutions are being developed in order to overcome the problem of file preparation. The Bocusini platform (Bocusini 2015), raising money on Kickstarter, is becoming reality now not only supplying the printer and 30 different ingredients (just marzipan and chocolate until now, more to come) but also giving the opportunity to download ready-to-print file from their website. We obviously must consider as if from one side, this makes the technology available for everybody and, on the other, leave the consumer less degree of freedom.

Conclusions

The present review describes the technology and applications available nowadays for food printing and printing on food emphasizing on 2D and 3D printers and relative substrates used. At the moment, new technologies are developing incredibly fast in this sector, making hard to predict future trends. Indeed, the food print sector appears very difficult to describe. However, while new printers and substrates are being developed, we are witnessing the start of a real marketing of such devices. Despite the sales, the number of applications and the degree of freedom in the use seem to be still limited for the end user. It must be said that many printers (especially 3D) present a large number of settings to adjust on the base of the material used. It would be desirable to reduce their number in order to simplify their use.

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