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THE CURRENT STATUS, DEVELOPMENT AND FUTURE ASPECTS OF 3D PRINTER TECHNOLOGY IN FOOD INDUSTRY

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ÖZET

3 boyutlu (3B) yazıcılar ilk olarak 1980'lerde polimer, seramik ve metal gibi sert malzemelerin üretiminde kullanılmıştır. Takiben bu teknoloji tıp, eczacılık, gıda alanlarında kullanılmaya başlanmıştır. Gıda marketi Dünya ekonomisini ilk sıralarda etkileyen sektörlerden biridir. Bugün 3B yazıcılar karmaşık işlem koşullarına sahip çeşitli gıda ürünlerinin üretiminde başarıyla kullanılmaktadır. Gıda işleme basamaklarından ötürü gıdalarda bazı önemli bileşenlerin kaybı söz konusudur. 3B yazıcıların ise bu kayıpları önemli oranda azalttığı görülmektedir. 3B yazıcıların gıda ürünlerinde kullanımı ile gıda üretimini tek basamakta yapılmakta ve gıdaya kaliteli bir dizayn kazandırmaktadır. Bu teknoloji gıdanın tüketicinin istediği dizaynda, lezzette ve görünüşte olması sağlamaktadır. 2000'lerin başından beri çikolata, peynir, bazı tahıl ürünleri, jeller, hamur ve şekerli gıdalar 3B yazıcılar ile üretilmektedir. Diğer taraftan güvenli ve sağlıklı gıdaların bu teknik ile üretildiği görülmüştür. 3B yazıcılar 2015'te 3.7 milyar dolarlık bir paya sahip iken bu rakamın 2019 senesinde 6 milyar dolar dolaylarına ulaşması beklenmektedir. Bu çalışmada, gıda sanayindeki 3B yazıcıların şuan ki durumu, kullanım alanları ve en fazla tercih edilen yazıcı çeşitleri tartışılacaktır.

Anahtar Kelimeler: 3B yazıcı, Gıda, Gıda Modelleme, Gıda dizayn

ABSTRACT

3-Dimentional (3D) printers were first used in the early 1980's for the production of rigid materials such as polymers, ceramics and metals. Subsequently, this technology has started to be used in the fields of medicine, food and pharmacy. The food market is one of the most important sectors affecting the world economy in the first place. Nowadays, 3D printer has been successfully used in production of food products with complex production conditions. Important food components are lost due to the food processing technologies. 3D printers seem to have potential to prevent such losses in food products at high rates. Using 3D printers in foodstuffs, in addition to the production of 3D food in just one step, brings a different design quality to food. This technology has the ability to develop food in appearance, design, taste and structure as the consumer desires. Since the early 2000's, a wide sort of food products including chocolate, cheese, some cereal products, gels, dough and candies have been successfully produced by using 3D printers. On the other hand, it is also seen that safe and healthy foods can be produced with this technology. In the future it is clear that this technology will have a significant share in the economy market. It is predicted that 3D printers worldwide market shares of $ 3.7 billion in 2015 will exceed $6 billion by 2019. In this research, the current status of the 3D printer in the food industry and its future, the areas of use and the most commonly used printer types will be discussed.

Keywords: 3D printer; Food; Food design; Food modelling.

1. INTRODUCTION

Technology is a sector that changes and develops every day. Energy has become one of the most important issues that have been discussed in the field of technology for many years. Energy-saving or energy-saving technological devices have always been a field of interest for researchers. 3D printers are an area of research that can be counted according to many technologies. The low energy consumption of 3D printers ensures that work in this area is increased [1]. Nowadays, this technology is used extensively in the fields of plastic medicine and pharmacy. One of the sectors following these areas is food sector. Compared to other areas, using of 3D printers in the food sector is new. In this research, the current status of the 3D printer in the food industry and its future, the areas of use, and the most commonly used printer types will be discussed.

2. DEVELOPMENT OF 3D PRINTERS AND THEIR APPLICATION AREAS

An industrial research centre (Nagoya, Japan) has investigated and published some information about 3D printing technology for the first time in 1981. The names of "additive manufacturing", "rapid prototyping" and "3D printing technology" were mentioned together first time in the same year [2]. First investigation on 3D printer technology was done by Charles W. Hull, who patented the creation of 3D objects from digital data [2,3]. Production with 3D printer is general name of a group of technologies known as additive manufacturing (AM). This technology offers shorter production trails compared with the traditional manufacturing methods. Also, it can generate various complicated shapes by using limited mass of materials with an enhancement of mechanical properties [4,5]. One of the ability of additive manufacturing is to generate materials in small groups. Besides, the allergen, vitamin, nutrient, energy contents and portion size can be automatically established and controlled through the automated manufacture of the food samples [6]. Production food with 3D printer is also named as rapid production, layered production or desktop production in literature.

In last decade, 3D printing technology continued growing, especially in the inventions regarding the material science. Now more than of one hundred raw materials can be used for 3D printing. These materials include thermoplastics, metal, nylon, plaster, ceramics, acrylic and edible materials [7] Also 3D printers are widely used in fields like automotive industry, architecture, construction sector, biotechnology, medicine science, fashion design, industrial design and food sector. Besides, applications of 3D printers contain customized medical surgical tools like dental porcelain, patient specific prostheses, scaffolds and porous ceramic filter production. 3D printers, a rapid prototyping technology, have different operating principles. These principles vary according to the materials used as building raw materials and the design planned to be made at the same time. With the developing technology in recent years, two devices Selective Laser Melting (SLM) and Selective Laser Sintering (SLS) went beyond the concept of prototype and presented the direct use of products from 3D printer. Today it can be said that the production of ceramics using this technology is very new. Many workshops and artists are working on developing this technology and developing projects. These surveys, which are carried out at certain centres, enable the production of leading-edge productions in the field. Some of these projects, which are still being studied, are maintained academically at universities and others are run by independent research groups. In addition to research on the production of functional and artistic forms, various centres and individuals who have been specialized in 3D printers capable of producing advanced ceramics, also offer training on the subject. This allows a greater number of people to both contribute to and benefit from the project simultaneously [8-10]. In last decade, the research and development laboratories of different disciplines have successfully started to draw 3D objects. According to surveys in Belgium, a research centre has started to develop porcelain objects in laboratory conditions [8,11].

3. 3D PRINTERS USED IN FOOD INDUSTRY

Food industry has a big importance for the global economy. This sector produces more than 4 trillion US $ in annual retail sales [12]. Conventional food production systems may be simplified by applying 3D food printers. Also general application of this technique will make the producing activities slowly moving closer to the customers' need and is going to guide to the reduced transport quantity and volume, hereby this situation will reduce high packaging costs and distribution [13].

In the food industry there are food printers with different working principles. The food 3D sample is generally established layer by layer from the bottom-up from computer-assisted design (CAD) drawings by using a large diversity of materials (semi solid, liquid, sheets or powder). This drawing program has facilitated designers to study freely within a digital design environment so that they may elucidate their design thinking and share across platforms [14]. Also this drawing programme is easy to use and many of these designs are becoming so complex that it has become difficult to consider how manufacturing technology can convert them for a physical reality [15,16]. Three printer technologies can be used successfully. These are fused deposition, extrusion deposition and laser sintering. Also these are the 3D printing technologies mostly used to create different food structures [15,17]. Also there are many different patents in 3D printer technology. Producing food with printers was first tested in two dimensions (x and y axis) [18]. 3D (x, y and z) prototypes have begun to be used later. In these patents, there are researches such as printer/printer title designs suitable for food production with 3D printer and printer designs developed according to food type. Today there are some 3D printers in a format suitable for food processing. These are basically four 3D printer types. Foods produced with 3D printers and examples of materials used are given in Table 1.

Table 1. Foods produced with 3D printers and used materials [13,19].

Printer Type	Food Type	Used materials
Extrusion based	Soft foods such as chocolate, cheese and dough and meat puree	Polymers, hydrogels, bio gels
Inkjet printing	Low viscosity materials like fruit puree and pizza sauce	Liquid/solid phase (ink, fruit concentred, fruit juice)
Binder Jetting	Powdered materials like sugar, starch and flour	Sugar and starch mixtures
Selective Laser Sintering	Powdered materials like fat chocolate and sugar	Powdered materials are not sticky and any tendency to agglomerate

Some materials, have easily extruded smoothly with use of a syringe structure. Examples of these materials are humus, chocolate, hydrogel and cheese. The final products are manufactured with diverse taste, nutritional value and texture. Nevertheless, none of these materials is served as main meal. Some printability tests are used for evaluating certain properties of the printable materials. These tests consist of viscosity, consistency and solidifying properties. At the end of the investigations, the most successful pasta dough was found the most successful printable material. On the contrary, foods like meat, rice fruit and vegetables, consumed by consumers mostly, are not printable naturally. There are some ways to give these materials the ability to extrude. Hydrocolloids are the most widely used of these methods. For this purpose, some gums and hydrocolloids are added to give an extrudable character to solid materials [20].

3.1. Extrusion-Based Printing

Extrusion-based printing systems basically withstand dispensing of macromolecules such as hydrogel strands or polymers through a micro nozzle and actual position of them with computer-aided motion either heads of printing or collecting of phases. In these systems, the macromolecules are generally extruded with plastic or metallic syringes with the help of different techniques such as pneumatic, piston-driven or screw-driven onto a building platform. All three techniques have their own advantages and disadvantages. Pneumatic systems are usually works with compressed gas; but their advantage is increasing with highly viscous molten macromolecules. Moreover, the piston-driven techniques usually presents more laminar flow control over macromolecules from the tip of the nozzle. Another side, screw-driven techniques provide more spatial control of macromolecules and this property was more desirable for dispensing of molecules with higher viscosities. Compared with the other printing systems (inkjet-based or laser systems) extrusion based printing systems can be used with printing thickness in the order of 200 mm. Another advantage of this technique is high construction speed with the higher resolutions. Conversely, fabrication speed using this technique is significantly higher and anatomically shaped structures can be generated [21,22].

3.2. Inkjet Printing

In inkjet 3D printing technique, a material-conserving deposition used for liquid stage materials. These inks or liquid phase materials, occurred from a solute, dissolved or dispersed in a solvent. When inkjet printing systems are evaluated, the process starts with distinct amount of ink injected to the chamber, through a nozzle to obtain high resolution as high as possible. After then volume of injected ink reduces because of piezoelectric action, comes from application of external voltage. This fast external voltage provides a shock wave in liquid phase, which finally causes to liquid drop to from the 3D printing nozzle. After that the drop is dried under various conditions such as gravity, air resistance and momentum of motion. Recent investigations show that the final printed shape of 3D food material and drop spreading are mainly coming from viscosity of ink, which in turn is a function of the molarity of the macromolecules used [13,23].

3.3. Binder Jetting

In binder jetting 3D systems, there is a form needed. There are numerous layers which generally come from powders are deployed platform of the construction. A binder mostly liquid form uses for binding two separate consecutive layers. Powders which used in binder jetting 3D printer systems are usually stabilized with sprayed water. There are various studies in food printing with binder jetting 3D printing systems such as utilized sugars and starch mixtures as powder. 3D powder printer as a printer platform, sugar and various flavour binders were used for construct complex shaped cakes for special days and other activities by *Sugar Lab*. This 3D printing system provides different advantages such as fast construction speed, short time and may be most prominent feature is ability to build foods with complex shapes with low budgets [20,24,25]. Researches from the 3D system have composed a binder to manufacture a wide variety of colourful and flavours edible objects, such as various kinds of complex sculptural cakes by varying flavour and colourful binders [26].

3.4. Selective Laser Sintering

This food printer type is mainly uses laser beams for fabrication of 3D objects with the help of scanning layers of powdered materials such as sugars, coffee powders etc. Firstly, computer model was created with different computer modelling programs then created model was transferred to the SLS systems. After that with the help of the created SLS system, it was starting to create 3D objects with laser beam with each separate powder layers. Powder binding techniques of SLS systems are divided into three groups; solid-state sintering which is a thermal operation, liquid phase assisted sintering which is mostly used for higher melting temperatures, and third is full melting process [25].

4. THE SITUATION OF 3D PRINTER IN FOOD INDUSTRY AND USING AREAS

3D printing represents a novel technology in manufacturing which has potential for sustainable development [26]. 3D printing systems also known as AM. This technology was firstly presented for food industry by researchers from Cornell University by use of an extrusion based printer, which was named *Fab@home* in 2001. With 3D food printer machines, producing of the food objects has been proposed as one use of digital AM technologies. 3D printing operates a process whereby products can build on a layer-by-layer basis. Today, many different 3D printed food machines are produced. These machines have been developed to print food products. For this purpose, computer aided design software that can work with a digital manufacturing machine has been used. Research laboratories and some companies have started to develop prototypes to generate food products over ten years [13,27,28].

3D printers, with innovations and advantages have been offered today. Therefore, there is a growing interest for using 3D printers by food producers and customers. The fact that 3D printers do not require special tools and equipments during production; its usage may reduce the work power, affect the quality characteristics (aroma, colour, shape, texture and appearance) of the product and easily adjust the content of raw material when needed [19]. By using 3D printer technologies, it is possible to produce structures with complex geometries, fantastic, detailed textures and special nutritional content. With 3D printer technologies, it is possible to design foods that meet unique feature requests for specific consumer categories, especially for the old people, children and sportsmen [13,29]. One of the advantages of this technology is, some operations that are hard to do by hand nowadays are easy with the use of 3D printers.

The requirement for raw materials that can be used in 3D food printers is that the raw material can flow smoothly from the print cartridge to the printing platform and protect the solid build on the platform. In this direction, substances such as starch and proteins, which can form hydrogel structures, can easily be obtained from cheese, chocolate and humus, which can easily flow from the printer cartridge to the platform. According to a study, sugar, starch and crushed potato were used as raw material and positive result was obtained, too. Compared to conventional food production, there is a serious difference. The fact that the foods produced with the mentioned raw materials belong to the snack or sweet group in general, is that none of them has qualities that can be consumed as the main meal [19,30,31].

Materials such as meat, rice and dried legumes are not suitable for printing due to natural structures. However, some foods can gain printability only after pre-treatment and when hydrocolloids (such as agar, xanthan gum and pectin) are added. According to another study, the transglutaminase enzyme and agar were added to the printable form of turkey meat and the impairments in the physical structure were reduced to a minimum during post-printing cooking. Apart from the materials mentioned, there are also materials available as alternative printer materials. In this project, insects which are seen as an alternative protein source are mixed with powdered insects and melted cheese to produce a printable consistency and high nutritional quality. The present agricultural practices and the production of printable material by obtaining bioactive compounds, enzymes and some aroma substances from the waste materials resulting from food processing are also pointed out as another study for the future. Also according to a recent study, extrusion-based 3D printers were used for the production of complex shaped products. There is a high rate of success. However, extrusion-based 3D printers are affected by parameters such as temperature, food components and additives. In one study, the food ink used for 3D printing was evaluated according to some tests. These tests were dimensional stability test and shear test. As a result of the study, it was stated that methyl cellulose was a suitable printer material. [19,20,32]. Azam et al., (2015) examined some rheological and 3D printing properties when various gums were used as 3D printer material. For this purpose, guar, xanthan, arabic and K-Carrageenan gums were used. In prints using K-Carrageenan gums, it was determined that the objects had the best chewable character. At the end of the research, it was stated that better quality food products could be printed by adding chewing gum to printing materials [33].

Deposition methods based on material extrusion have been used for the printing of liquid or semi-solid foodstuffs. Prototypes of 3D printers have been also developed to manufacture gel-forming samples with use of gelatine and xanthan gum, pieces with complex geometry products, cookie dough and chocolate [34]. In the food industry, it has been seen that food products with a certain textural and rheological character can be successfully produced by 3D printers. Gel structures have an non-dispersible prescription in this technique. There are studies showing that lemon juice gel and surimi are used as food materials. With these materials, 3D printer parameters can be optimized [4,35]. According to another study, a commercially produced cheese variety was used as 3D printing material. The cheese was left to melt for 12 minutes at 75 °C. Cheese was printed at low and high extrusion speeds in 3D printers. It was found that the samples of melted and pressed cheese were 49% less hard ($p < 0.05$) and had higher melting ability. [36].

It seems that the number of 3D printers entering the kitchen after the 2010 year was increased. Specific food printers, such as *ChefJet*^{TM}, began to use in the kitchen in 2014. Existing printing technology, printer cost and food production quantities are very limited. Even a single cookie takes more than an hour to produce. Therefore, it should be noted that 3D printing is not an alternative to traditional food production. It is inevitable to customize and optimize the food so that the aroma and appearance of the advanced food texture can be achieved. [37]. After 2014, it is seen that the price of food printers is lower than $4000. Along with the developing techniques, printer costs have decreased. After 2018, it is thought that 3D food printers can be purchased with much lower cost prices.

Some predicted 3D printer market forecasts for 2018 and beyond have been discussed by various researchers. According to many researchers, people in everyday life will now prepare food, shape, size, flavour, quality and specific demands that they deserve with use of 3D prints. Besides, when examining the global industry analysis reports, it is predicted that 3D printing technology will have an average

economy of $ 3 billion in 2018 [38]. Statistical reports show that 3D technology will have a significant future consumption. 3D printing was expected to reach $ 3.7 billion in 2015. Today, 3D printers seem to pass this value in total. In 2019, this figure is expected to exceed $ 6 billion. 3D hardware costs are falling and operating systems are expected to continue to evolve. [18]. There is an important difference about 3D printers and prototype machines and this difference is cost. While a 3D printer can be purchased for a price of $ 10,000 and below, the price of the prototype machine is $ 500,000 or more. Also, desktop 3D printers can cost more than $ 100,000 today. If the prices of 3D printers go down to $ 300 or less, there will be a significant increase in the amount of printers used in homes. When 3D printer prices go down to these levels, the market penetration of home-based 3D printers will begin to look like small laser printer types. With the growing industrial food market, increased market penetration is going to result in additional 3D home applications. Besides, 3D printer material costs will also expect to reduce as a result of higher market penetration [36].

5. CONCLUSION

It seems that many 3D printers are used in different disciplines. Great progress has been recorded in the field of health. It appears that this technology is also taken into consideration in physics and space studies. In today's conditions, fast food making has become an increasingly important issue. The use of 3D printer may help to cook quickly in kitchens, cafeterias and restaurants. In the future, it is thought that there will be 3D printers available almost everywhere. When compared with traditional food production processes, some deficiencies are striking. It has not been able to catch conventional production processes, but new methods are being developed every day. Against to many advantages, the use of 3D printers in the food industry is still limited. The ability of food printers to make custom design and to produce in a short time will increase the usage of these printers among consumer groups. The development of new alternatives to materials used in current food printers is an important point. It is thought that different fruit purées, fruit concentrates and starch-based cereal products with certain viscosity can be used alternatively. However, future work on this new technology is also needed.

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