Three-dimensional food printer design and production

İbrahim Karaman[1], Dilşad AKGÜMÜŞ GÖK[2,*], Serkan GÖK

[1] *Istanbul Aydin University, Engineering Faculty, Departmen of Mechanical Engineering, 34295, Istanbul, Turkey*

[2*] *Istanbul Aydin University, Engineering Faculty, Departmen of Mechanical Engineering, 34295, Istanbul, Turkey, https://orcid.org/0000-0003-3403-3815*

[3] *Istanbul Aydin University, Machine and Metal Technologies Department, Istanbul, Türkiye, 34295, Istanbul, Turkey, https://orcid.org/0000-0003-3238-6705*

Abstract

The aim of this study is to design and produce a 3D food printer that can provide innovative and customised food solutions, especially for groups with special nutritional needs such as patients with swallowing difficulties, the elderly and children. It also aims to provide innovations in terms of reducing food waste, optimising material use and sustainability. Solidworks and Creo Parametric were used for the design and .STL files were sliced with Ultimaker Cura. The outer body of the prototype is made of aluminium sigma profiles and plastic parts are made of ABS material with FDM type 3D printer. In the printer, which has a special extruder and thermistor equipped injection system, successful printing trials were carried out in different geometric shapes consisting of chocolate, pancake batter and vegetable puree in the laboratory environ-ment. The 3D food printer has created an infrastructure that will be used for gelatin, chicken and meat printing in the future. The results of the study show that 3D food printer technology can make significant contributions to sustainability by increasing efficiency in food production pro-cesses as well as providing solutions to personal nutrition needs.

Keywords: Three-dimensional printer, food printer, customized nutrition, food design.

1. Introduction

This study focuses on 3D food printers that bring an innovative approach to food production processes. 3D food printers offer customised food solutions, especially for groups with special dietary requirements such as individuals with swallowing difficulties, the elderly and children. These printers also have the potential to improve the quality of nutrition by presenting proteins and vegetables in attractive and consumable forms. They also support sustainability by reducing food waste and optimising material use. In this study, a 3D food printer suitable for food production was designed and manufactured. This 3D food printer, whose design and production stages are detailed in the study, was tested with chocolate, pancake batter and leek puree. In the study, 3D printers and 3D food printers are discussed first. In the continuation of the study, the design, production and testing processes of the prototype 3D food printer are given.

1.1. 3D Printer Technology

3D printers are devices that transform computer models into real objects layer by layer. These devices create physical products by using a wide variety of materials and slicing digital designs. Thanks to the developing technology, the materials used can be found in a wide range from plastics to food, and the production process can be carried out with fewer errors and material waste compared to traditional methods. In recent years, the use of this technology has increased worldwide because people can produce the objects they need at home or in the office at lower cost. 3D printers work using digital files in .STL format, creating each layer of an object in turn. The 3D printing process starts from a computer-aided design (CAD) model and this model is transformed into three-dimensional objects with the Additive Manufacturing technique. The American Society for Testing and Materials (ASTM) divides the 3D printing process into seven main categories: powder bed welding, directed energy deposition, material extrusion, binder spraying, material spraying, sheet lamination and pool photopolymerisation (ASTM, 2015). The advantages of 3D printers are manifested in various aspects such as customised manufacturing, rapid prototyping, cost-effectiveness and easy production of complex designs. With customised manufacturing, 3D printers give users the ability to make personalised products according to specific needs. This capability is used in many industries, especially in agriculture, healthcare, automotive, locomotive and aerospace (Shahrubudin et al., 2019). With rapid prototyping, 3D printers accelerate the product development process, helping to quickly turn ideas into tangible objects, thus speeding up the design and iteration processes (Aimar et al., 2019). In terms of cost-effectiveness, 3D printers reduce material wastage and consume less energy compared to traditional manufacturing methods. It also provides economic benefits with reduced inventory needs and low logistics costs (Shahrubudin et al., 2019). At the point of production of complex designs, 3D printers can simply create complex geometries that cannot be produced by conventional methods. This feature has great potential, especially in areas such as medical implants and personalised medicine production (Aimar et al., 2019). From an ecological point of view, a study shows that 3D printer technology saves time and cost, and environmental impacts can be reduced with less toxic, biodegradable and recyclable materials (Behm et al., 2018). The usage areas of 3D printers have spread to a wide range from electronics to automotive, from medical applications to architecture. In the medical field, 3D printer technology revolutionises the production of special prostheses, implants and anatomy models; it develops personalised treatments with tissue and organ fabrication (Aimar et al., 2019). In the electronics industry, 3D printers produce prototypes of components such as circuit boards and sensors quickly and cost-effectively, accelerating the production of personalised electronic devices and industrial design processes (Bozkurt and Karayel, 2021). In the automotive industry, 3D printers have found a wide range of use from prototypes of vehicle parts to complete cars, enabling the development of lighter and more efficient parts and enabling customised vehicle designs (Bozkurt and Karayel, 2021). In the aviation industry, 3D printers play a role in the production of aircraft parts and engine components, increase fuel efficiency and reduce costs with lightweight materials, and encourage innovation by facilitating the production of parts with complex geometries (Bozkurt & Karayel, 2021). In architectural design, 3D printers are used in the fast and cost-effective production of prototypes of buildings and structures, and provide advantages in the production of complex structural elements (Jandyal et al., 2022). The impact of 3D printer technology is not limited to the applications listed above, but also extends to the food industry. This emerging technology offers innovative ways of working in the food industry, from the personalisation of foods that cater to specific dietary needs to the production of complex cake and confectionery designs. This can be seen as the beginning of a new era in food production, where flavour, nutrition and presentation can be tailored to personal preferences and brought to life with 3D food printers.

1.2. 3D Food Printer Technology

3D food printers are an innovative technology used in food production to create three-dimensional shapes by adding material layer by layer. This technology is capable of creating food products with customised nutrient contents and complex geometries (Sun et al., 2015). First developed by researchers at Cornell University, this technique offered the possibility to mould liquid food materials with Fab@Home Model 1, an open source 3D printer (Malone and Lipson, 2007; Periard et al., 2007). Compared to traditional methods, 3D food printers provide advantages such as reducing waste and innovating food design. It has a wide range of applications from space exploration to military operations and special dietary needs of elderly or sick individuals (Lipton et al., 2010). It also has the capability to produce foods in small batches to meet customised dietary requirements (Lipton et al., 2015; Severini et al., 2016; C. Severini et al., 2018). The advantages offered by this technology include shaping food products into desired shapes, personalised food preparation, aesthetic and artistic designs, discovery of new flavours, healthier products, online recipe and design sharing, food presentation in desired sizes and layers, design competence and reduction of material waste. With these features, 3D food printers are increasingly in demand due to the freedom of design customisation and the potential to create new textures (Dankar et al., 2018; Severini et al., 2018).

1.3. 3D Food Printing Techniques

The manufacturing process starts by creating a digital model with 3D design software, which is converted into .STL format. Specialised instructions for the printer are then created using G-code software. The 3D printer adds the food layer by layer according to these instructions and creates the final product. In the final stage, the printed object is made ready for consumption by going through processes such as cooling, drying or cooking. Before and after the printing process, parts in contact with food need to be cleaned or coated. The integration of food into 3D printing technology can present challenges due to the wide variations in physio-chemical properties (Godoi et al., 2016; Sun et al., 2018). Studies classify 3D food printer technologies into three main categories: liquid bonding (LB), selective laser sintering (SLS)/hot air sintering (HAS) and hot melt extrusion method (Cohen et al, 2009; Dankar et al., 2018; Godoi et al., 2016; Hao et al., 2010; Hopkinson et al., 2006; Huang et al., 2012; Lipson and Kurman, 2013; Lipton et al., 2015; Liu et al., 2017; Oskay and Edman, 2006; Sher and Tut'o, 2015).

1.3.1. Liquid binder spraying (LB) method

The liquid binder spraying (LB) method is the process of manufacturing 3D food materials by adding a thin layer of food powder to a surface and then combining it with a specified liquid binder (Godoi et al., 2016). This method is particularly suitable for powder-based food materials and was first used by the ChefJet 3D printer (3D System, 2013; iReviews, 2014). Liquids with added flavours and colours are used to hold powdered materials such as sugar together, and complex confectionery products can be produced quickly (Sher and Tut'o, 2015).

1.3.2. Selective Laser Sintering (SLS) / Hot Air Sintering (HAS)

Selective Laser Sintering (SLS) and Hot Air Sintering (HAS) utilise powder-based materials to rapidly create 3D objects. In these processes, the model defined by a 3D software is applied to the material in the powder bed using a laser or hot air stream, forming a solid structure (Sun et al., 2015; Godoi et al., 2016). In SLS, the laser combines the powder material layer by layer by scanning specified cross-sections. As each layer is completed, the powder bed is lowered slightly and a new layer of powder is added. This process continues until the 3D object is complete and can create layers containing multiple food substrates (Diaz et al., 2014). SLS technology used for metal sintering fuses solid cores together by melting the surface of the particles (Mellor et al., 2014; Periard et al., 2007). In HAS, a stream of hot air is directed into powdered media such as sugar and applied in layers until a 3D object is formed (Oskay and Edman, 2006; Godoi et al., 2016). The advantages of these technologies include speed and the ability to sinter powder materials. However, printing fresh food ingredients is not suitable with these methods and additional post-processing is required to remove excess powder from the sintered product (Liu et al., 2017). SLS has been used to fabricate complex 3D structures, especially with sugar-rich powders such as sugar (Gray, 2010), but the process is limited to powder-based materials (Lai and Cheng, 2007).

1.3.3. Hot Melt Extrusion Method

Hot Melt Extrusion (HME) is a technology in which melted material is passed through a nozzle to form 3D structures. For example, it has been used to print 3D chocolate structures by melting chocolate between 28°C and 40°C (Chen and Mackley, 2006). During the HME process, heat is applied to adjust the viscosity of the material and ensure smooth flow through the nozzle (Tadmor and Klein, 1970). This method has been used in the production of plastics and rubber as well as food products (Chokshi and Zia, 2004). The HME concept has also been applied to semi-liquid materials and used in 3D food printers with devices such as Choc Creator, Foodini and Porimy. Since most fresh food ingredients can be mixed and liquefied, extrusion is an ideal method for such materials (Godoi et al., 2016; Hao et al., 2010). Fruit and vegetable purees, dough, pectin-based formulations, meat and gel-based materials have been successfully extruded (Severini et al., 2018; Yang et al., 2018; Vancauwenberghe et al., 2018; Dick et al., 2019; Wang et al., 2018; Yang et al., 2018a). Furthermore, pre-tempered chocolate powder can also be 3D printed by extrusion with food additives (Porimy, 2014). However, it may be a problem that some foods do not solidify immediately when forming layered structures by extrusion. Therefore, enhancement agents such as food additives and hydrocolloids may be required to improve printability, flowability and solidification properties.

1.4. Printable Foodstuffs

Printable food materials play an important role in 3D printing and the rheological properties of these materials such as fluidity, gelation, melting and glass transition temperatures are critical factors for successful 3D printing (Zhang et al., 2018; Liu et al., 2017; Godoi et al., 2016).

1.4.1. Sugar

Sugar can be used in binder spraying, SLS and HAS technologies because it can easily melt or dissolve with heat or moisture. The properties of sugar, such as compressibility and powder density, affect powder fluidity and model building when a heat source is applied (Ber-retta et al., 2013). The adhesion force of the sugar or the powder and binder interface associated with the chemical reaction is also important. The fluidity of liquid binders determines the solubility and mechanical properties of the printed output, indicating that sugar is a suitable material for SLS and HAS (Sher and Tut'o, 2015).

1.4.2. Gelatin

Gelatin is a protein obtained by the breakdown of collagen fibres and is a suitable substrate for 3D printing with its melt-in-the-mouth texture (Diaz et al., 2015; Nocera et al., 2015). The properties of gelatin, such as viscosity and shear rate, affect the extrusion process and can improve food viscosity and increase printability (Cohen et al., 2009; Yang et al., 2018).

1.4.3. Dough

Dough is a carbohydrate macronutrient that exhibits viscoelastic properties when mixed with water. The interaction between gluten protein and water determines the viscoelastic properties of the dough. The dough material can hold gas, which allows it to retain its shape during baking and frying. Variations in the amount of butter, eggs and sugar are also important, affecting the extrusion rate and structure retention of the dough (Lipton et al., 2010; Yang et al., 2018b).

1.4.4. Chocolate

Chocolate is a material that can melt and solidify rapidly at a certain temperature and is sensitive to temperature thanks to cocoa butter. With appropriate tempering, it is possible to produce quality chocolate by obtaining a more stable crystal polymorph (Afoakwa et al., 2007-2009; Chen and Mackley, 2006). The semi-solid state of chocolate at room temperature and its viscous state at body temperature are ideal for 3D printing. It also contains soya lecithin, an emulsifying agent (Hao et al., 2010; Sood et al., 2010).

2. Materials and Methods

2.1.Electronic Materials Used in Three Dimensional Food Printer

There are electronic parts that control the stepper motors that enable the movement mechanism of the 3D food printer, control of the temperature to be given to the heater tray, control of the extruder system for the injector to print, temperature control of the flare resistance system, control of the movement and orientation commands of the printing tray. All electronic parts used within the scope of the study must work properly with each other. The parts used in the production of 3D food printer are as follows:

- Arduino Mega 2560 Control Card: This open source and easy-to-use board has 54 digital input/output pins, 15 PWM outputs, 16 analogue inputs and USB connection.
- Ramps 1.4 Control Board: This board, used with Arduino, provides power unit control and has the technical features of 3 Mosfet outputs, 3 Thermistor outputs, 2 headers and 5 stepper motor driver connections.
- A4988 Stepper Motor Driver Board Pololu: This board with microstepping and bipolar stepper motor driving capabilities has adjustable current limiting, over-current and over-temperature protection and 5 different microstep resolutions up to 1/16 step. The driver circuit requires a 3V-5.5V connection between VDD-GND terminals for logic supply and a connection between VMOT and GND terminals between 8-35V for motor supply.
- NTC Thermistor: It is a circuit element whose resistance decreases as the temperature increases and is placed in series with the motor.
- NEMA 17 Stepper Motor: These are motors that convert electrical energy into rotational motion and provide very precise control. The structures of the stepper motors used in the study consist of rotor, stator and bearings.

Plastic materials used in 3D food printer were obtained from FDM type 3D printer and metal materials were obtained from a private company. ABS (Acryloni-trile Butadiene Styrene) material was selected as the plastic part because of its strength, surface quality and working structure at high temperatures, and the metal materials used were stainless steel in order to be suitable for food materials.

As a result of the researches carried out before starting the 3D food printer design; it was determined that 3D food printers are similar to FDM type 3D printers in terms of both design and operation. Based on this similarity, aluminium sigma profiles were designed as shown in Figure 1 Aluminium sigma profiles were preferred because they are light, durable and easy to assemble. The design of the body obtained as a result of the assembly of sigma profiles is shown in Figure 2.

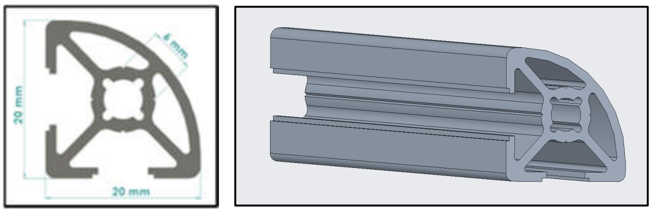
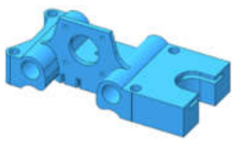
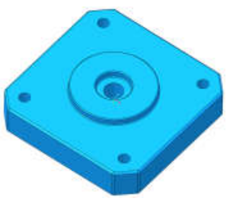


Figure 1. Sigma profile design used in the study


Figure 2. Main body design

In this printer, 4 stepper motors, 14 pulleys, 5 belts, 1 polypropylene 60 ml injector, nozzles of different diameters, 4 fans, 2 thermistors, 1 Arduino Mega 2560 control card, 1 Ramps 1.4 control card, 1 A4988 stepper motor driver card pololu, 3 Limit switches, 1 power supply and plastic parts suitable for stepper motors were used. The stepper motor in the 3D food printer produced within the scope of the study applies force to the injector at a certain step number by means of commands from the Ar-duino software, and then shapes the mash-like material in the injector with the help of the heat given by the thermistor according to the G codes specified in the .STL file on the heater table with the nozzle tips. In the study, an extruder system suitable for the materials used was designed. The plastic parts used in the assembly of the extruder system and designed in Solidworks programme were produced in the FDM type 3D printer in Istanbul Aydın University 3D Printer Laboratory. Table 1 shows the part designs and descriptions used in the extruder system of the 3D food printer.

Table 1. Extruder part design and descriptions.

Axis Parts	Descriptions
	**Shaft and Injector Holder** It is the part where the shafts on the Z axis pass and where the injector enters, allowing the belts to move.
 	**Engine Holder and Anti-Vibration** Nema 17 brand Stepper motor is used. Strain and malfunctions may occur when the motor is exposed to vibration and vibrations under pressure and stress. It is the part responsible for protecting the motor against these and impacts from the

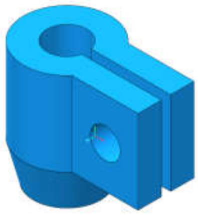
	external environment.
	**Injector and Fan Stabilizer** It is the part that connects one injector and two cooling fans in the system.
	**Replaceable Nozzle** It is a part that can be mounted on the end part of the injector and can be used and changed in different thicknesses and can provide nozzles in desired thicknesses.
	**Flare Resistor** It is the part that wraps the injector in the aluminum band and reaches the desired temperature and ensures that the fluid in the injector flows at the appropriate viscosity values.

Figure 3 shows the assembled extruder and injector system. The injector used in the extruder system is equipped with a thermistor and flare resistance system in aluminium foil. This system prevents the freezing of chocolate, pancake batter and pureed foods in the injector and allows the injector pusher to move more easily. The material coming out of the nozzles solidifies in the desired products thanks to two Rhino 30x30 fans with four specially designed 45-degree angles. The main task of the extruder in the 3D food printer is to inject the chocolate, pancake batter and mash consistency products into the heater table under appropriate pressure and conditions. The main reason for using a polypropylene injector in this printer is that it is healthier in terms of food printing and can pressurise better due to the lack of air flow. The injector used in the study is shown in Figure 4.

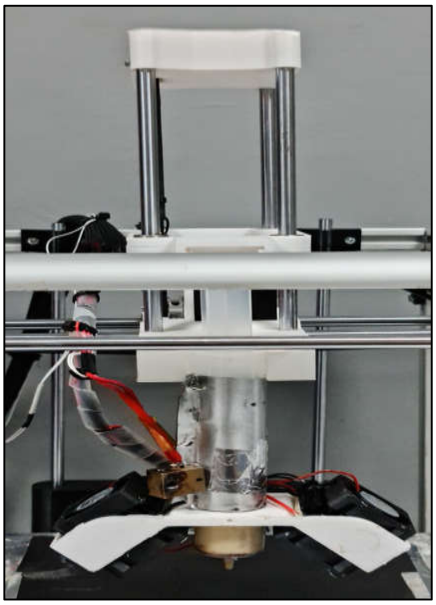


Figure 3. Extruder and injector assembly

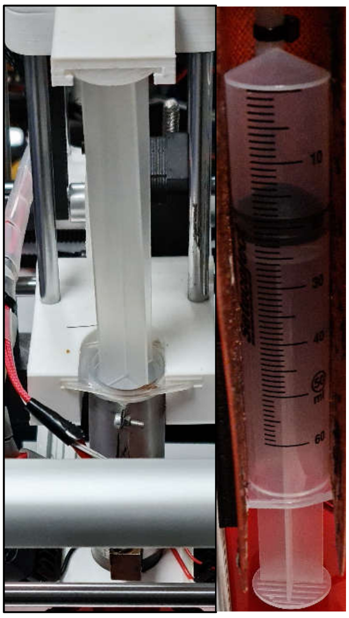


Figure 4. Polypropylene 60 ml injector

The table preferred within the scope of the study and shown in Figure 5 is made of aluminium sheet metal plate, which is widely used in the market. During the food printing process, the thermistor can reach a temperature of 220°C and the heating table can reach a maximum temperature of 110°C.

Figure 5. Heating table

Injector and stepper motor holder consists of 4 stainless steel shafts. The movement of the extruder system is provided by a stepper motor. The extruder system has the ability to move in the desired direction in X, Y and Z axes. In Tables 2, 3 and 4, the designs and descriptions of the parts in the X, Y and Z axes, respectively, are given.

Table 2. X axis part design and descriptions.

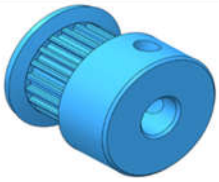
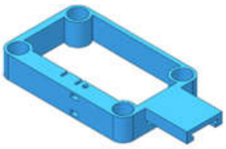
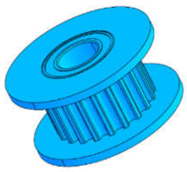
Axis Parts	Descriptions
	**Stepper Motor Pulley** The Nema 17 stepper motor on the X axis ensures that the toothed belts work in harmony with each other.
	**Shaft and Injector Holder** It is the part that connects the shafts, injector and stepper motor on the X axis to each other and ensures that they work in a coordinated manner.
	**Pulley** Two GT2 pulleys were used for the motion transmission of the belt in the X-axis direction.

Table 3. Y axis part design and descriptions.

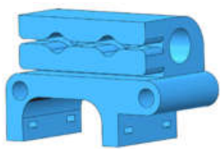
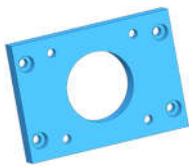
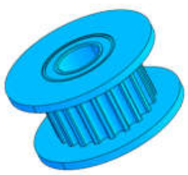
Axis Parts	Descriptions
	**Belt and Shaft Holder** It is the part with two pieces on the Y axis, through which the belts that provide movement pass, and at the same time it is used for mounting the shafts.
	**Motor Holder** It is used to fix the motor to the sigma profiles on the Y axis and to prevent the motor from vibrating in motion.
	**Pulley** Two GT2 pulleys were used to transmit the motion of the belt in the Y-axis direction.
	**Belt** In the Y axis, a 340 mm long closed belt was used in accordance with GT2 pulleys.

Table 4. Z axis part design and descriptions.

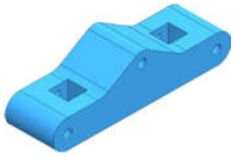
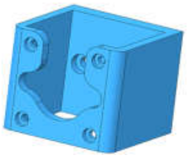
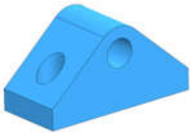
Axis Parts	Descriptions
	**Z-Axis Elevator** It provides the ability to hold and assemble the Z-axis ball screw, the trapezoidal shaft acting as an elevator, and the heated printing sheet.
	**Motor Holder** There is a motor holder on the Z axis. It ensures that the motor remains stationary and does not move in case of strain. It provides a buffer against impacts from the external environment.
	**Shaft Holder** It is the part that connects the Z axis carrier shafts with the X axis and prevents movement and vibration that may occur during operation.
	**Trapezoidal Shaft** It is the part that provides movement along the Z axis thanks to the teeth on it. It realizes the movement process with the help of one stepper motor and coupling.

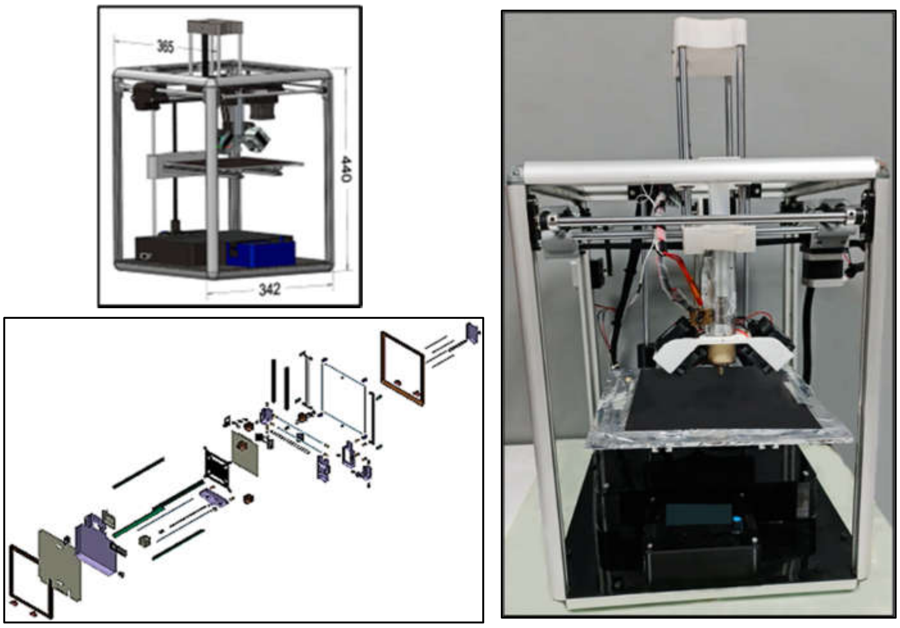
Table 5 shows the technical specifications of the 3D food printer produced within the scope of the study.

Table 5. Technical specifications of the 3D food printer.

Feature	Description
Model	FDM type 3D food printer
Device language	Turkish
Machine dimensions	365x342x440 mm
Number of axes	X, Y, Z
Print area dimensions	215x215x200 mm
Injector diameter	3.81mm
Layer height	2 mm
Wall thickness	3 mm
Filling density	%100
Print speed	10 mm/sec
Operating temperature	15°C-30°C
Heater table temperature	110°C
Extrusion temperature	90°C
Number of extruders	1 piece
Injector size	60 ml
Injector material	Polypropylene
Chassis material	Aluminum
Power	220 volts, 60 watt

Maximum speed of the device	100 mm/sec
X – Y axis drive system	GT2 Belt with minimal backlash
Connectivity	USB and SD cart
File extension	.STL
Cost	500 USD

Figure 6 (a) shows the completed design of the 3D food printer produced within the scope of the study, and Figure 6 (b) shows the prototype of this printer.

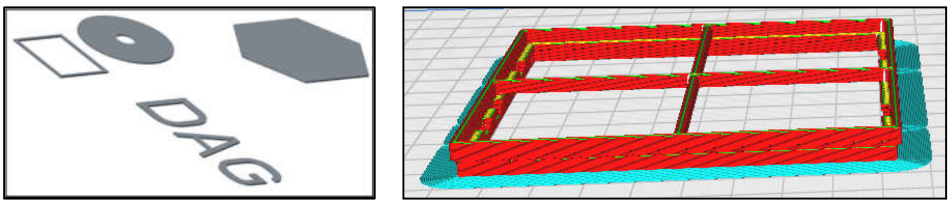


(a) **(b)**

Figure 6. (a) Three-dimensional food printer design **(b)** Printer prototype

3. Results and Discussion

The drawings shown in Figure 7 (a) were designed in Creo Parametric 3D program for the printing trials of the 3D food printer, whose design and prototype production was completed. The created design was transferred to the Ultimaker Cura program in .STL format and the slicing process of the part shown in Figure 7 (b) was started. After the slicing process (G codes) are transferred to the 3D food printer via flash memory or USB.



(a) **(b)**

Figure 7. (a) Designs created in Creo Parametric program; **(b)** Slicing in Ultimaker Cura program

Within the scope of the study, the design and production of a 3D food printer was carried out to enable patients who are intubated due to diseases during the pandemic period, the elderly and children with dysphagia to consume protein and vegetables that they cannot consume and to make these foods attractive. In the study, chocolate, pancake batter and leek puree trials were carried out. First of all, in the experiments with chocolate printing, 45°C temperature was evenly distributed to the injector by the heater flare resistance system. In this way, freezing, strain, etc. in the injector was prevented. During the production with chocolate, the table temperature was set to 0oC since the chocolate was desired to solidify, not melt. After the printing process was completed, the chocolates were frozen in the refrigerator to preserve their shape. Figure 8 shows the printing trials performed with melted instant chocolate.

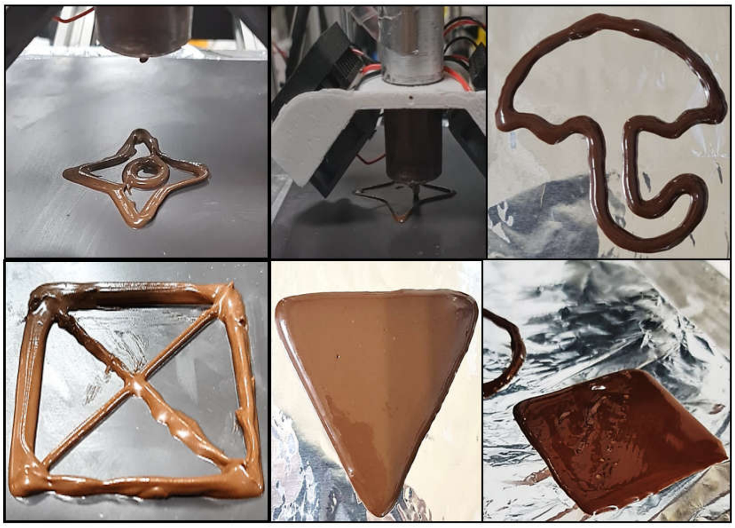


Figure 8. Printing experiments with chocolate

The second experiment was carried out at an ambient temperature of 25°C and with the pancake batter whose recipe (ingredients used and weights) is given in Table 6. During the production with pancake batter, the table temperature was set at approximately 60°C. Thus, the pancake dough, which was cooked on one side, was removed with the help of a spatula, turned upside down and placed on the printer table again and the other side was cooked. Figure 9 shows the printing trials performed with pancake batter.

Table 6. Pancake batter recipe.

No	Material
1	2 eggs
2	3 tablespoons of sugar
3	1 glass of milk
4	3,5 cups flour
5	1 packet of baking powder
6	Half a packet of vanilla

Figure 9. Printing experiments with pancake batter

Leek is a healthy vegetable that is beneficial for heart, intestine and skin health and should be consumed by people, but it is a vegetable that is not preferred by children. With the 3D food printer produced within the scope of the study, it is possible to produce this food in different shapes and flavors that will appeal to children and make them eat it. The recipe of the puree prepared from leek vegetable as the last experiment of the study (ingredients used and their weights) is given in Table 7. During the production of leek puree, the plate temperature was set to approximately 60oC and both sides were cooked. Figure 10 shows the printing trials performed with leek puree.

Table 7. Leek puree recipe

No	Material
1	200 g leek
2	1 glass of water
3	2 cups flour
4	3 tablespoons olive oil
5	1 packet of starch

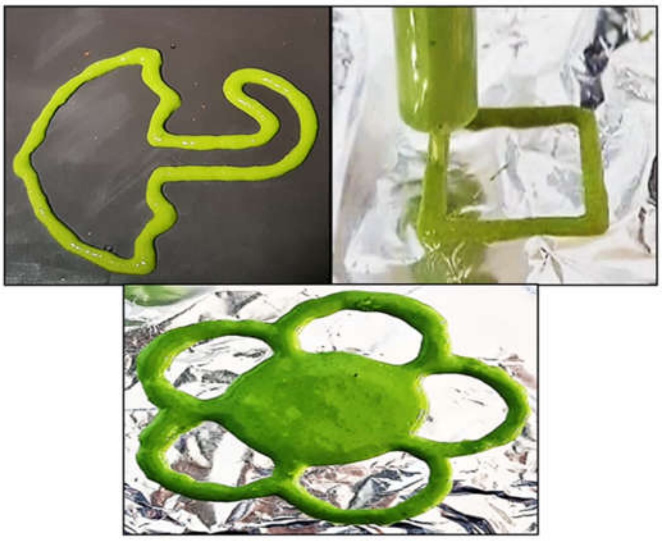


Figure 10. Printing experiments with leek puree

4. Conclusion

Within the scope of this study, a 3D food printer that can be suitable for creative food presentation, design, prototyping and customized nutrition has been designed and produced. In particular, it is aimed to enable patients with swallowing difficulties, the elderly and children to take proteins and vegetables that they cannot / do not consume in their bodies in different shapes, flavors and compositions.

The 3D food printer parts were designed in Solidworks and printing trial designs were made in Creo Parametric program. Ultimaker Cura program was used for slicing .STL files. The design stages are discussed in detail in the study. In the prototype stage, the main housing was made of 20x20 aluminum sigma profiles and the other plastic parts of the printer were made of ABS material with an FDM type 3D printer. The most important part of the 3D food printer is the extruder and injection system. The injection part is completed with a thermistor and flare resistance system. This system prevents freezing and coagulation in the injector. In the study, two special fans with a 45-degree angle were designed for the solidification to take place in a regular and controlled manner. The dimensions of the 3D food printer produced in the study are 365x342x440 mm and the printing area (heater table size) is 215x215x200 mm. The heater table temperature can reach a maximum of 110OC. Arduino-based Marlin software was used in the software part of the device. The printing trials on the 3D food printer were carried out in a la-boratory environment, and direct intervention was performed when mechanical or electronic problems were realized during printing. Special recipes were used for the other food ingredients (pancake batter and leek puree) except for chocolate in order to achieve efficient printing trials. Printing trials with different geometric shapes and compositions of chocolate, pancake batter and leek puree were successfully obtained.

As a result, a 3D food printer was produced in this study to be used in multidisciplinary studies with Bioengineering and Food Engineering departments. This printer has also created an infrastructure for gelatin, chicken and meat printing, which are planned to be tested in future studies. It is predicted that 3D food printers will pave an impressive way in the preparation and presentation of gastronomic foods in the future by improving the shape and composition of foods with the technology it has.

Implications for gastronomy

The implications for gastronomy stemming from the development of a 3D food printer are manifold. Firstly, this technology offers a revolutionary approach to catering to specific dietary requirements, particularly benefiting individuals with swallowing difficulties, the elderly, and children who often require customized food solutions. By enabling the creation of intricate and personalized food structures, the 3D food printer opens doors to culinary innovation, allowing chefs to experiment with novel textures, flavors, and presentations.

Moreover, the printer's capability to utilize various ingredients, including chocolate, pancake batter, vegetable puree, gelatin, chicken, and meat, signifies its versatility in gastronomic applications. This versatility extends beyond conventional cooking methods, potentially leading to the development of entirely new food forms and gastronomic experiences. Additionally, the integration of sustainable practices into food production, facilitated by the reduction of food waste and optimization of material use, aligns with contemporary gastronomic trends emphasizing environmental responsibility. Furthermore, the efficiency gains achieved through 3D food printing hold promise for addressing broader sustainability challenges within the food industry, contributing to the conservation of resources and reduction of carbon emissions associated with traditional food manufacturing processes. Overall, the adoption of 3D food printing technology has the potential to revolutionize gastronomy by fostering creativity, enhancing accessibility to tailored nutrition, and promoting sustainability throughout the food supply chain.

AUTHOR CONTRIBUTIONS

İ. Karaman: Investigation; writing - original draft; visualization. **D. Akgümüş Gök:** Methodology; conceptualization; writing - review & editing; validation. All the authors read and approved the final manuscript.

FUNDING INFORMATION

No funding was received for this study.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from thecorresponding author upon reasonable request.

ETHICS STATEMENT

This study does not involve any human or animal testing.

INFORMED CONSENT STATEMENT

Written informed consent was obtained from all study participants.

REFERENCES

Afoakwa, E.O., Paterson, A., Fowler, M. and Vieira, J. (2009). Comparison of rheological models for determining dark chocolate viscosity. *International Journal of Food Science & Technology*, 44, 162–167.

Aimar, A., Palermo, A. and Innocenti, B. (2019). The role of 3D printing in medical applications: A state of the art. *Journal of Healthcare Engineering*, 5340616.

ASTM. Standard Terminology for Additive Manufacturing Technologies, ASTM International: West Conshohocken, PA, 2015. https://doi.org/10.1520/F2792-12

Behm, J.E., Waite, B.R., Hsieh, S.T. and Helmus, M.R. (2018). Benefits and limitations of three-dimensional printing technology for ecological research. *BMC Ecology*, 18, 1-13.

Berretta, S., Ghita, O., Evans, K.E., Anderson, A. and Newman, C. *Size, shape and flow of powders for use in selective laser sintering (SLS). In High Value Manufacturing: Advanced Research in Virtual and Rapid Prototyping*. Proceedings of the 6th International Conference on Advanced Research in Virtual and Rapid Prototyping, Leiria, Portugal, 2013.

Bozkurt, Y. and Karayel, E. (2021). 3D printing technology; methods, biomedical applications, future opportunities and trends. *Journal of Materials Research and Technology*, 14, 1430-1450.

Chen, Y.W. and Mackley, M.R. (2006). Flexible chocolate. *Soft Matter*, 2, 304–309.

Chokshi, R. and Zia, H. (2004). Hot-melt extrusion technique: A review. *Iranian Journal of Pharmaceutical Research*, 3, 3–16.

Cohen, D.L., Lipton, J.I., Cutler, M., Coulter, D., Vesco, A. and Lipson, H. *Hydrocolloid printing: A novel platform for customized food production.* In Proceedings of Solid Freeform Fabrication Symposium, Austin TX, 2009.

Dankar, I., Haddarah, A., Omar, F.E., Sepulcre, F. and Pujola, M. (2018). 3D printing technology: The new era for food customization and elaboration. *Trends in Food Science & Technology*, 75, 231–242. doi: 10.1016/j.tifs.2018.03.018.

Diaz, J.V., Bommel, K.J.C.V., Noort, M.W., Henket, J. and Brier, P. *Preparing edible product, preferably food product including bakery product, and confectionary product, involves providing edible powder composition, and subjecting composition to selective laser sintering*. Nede-C: Nederlandse Org Toegepast Natuurwetensch, 2014.

Diaz, J.V., Noort, M.W. and Bommel, K.J.C.V. *Producing edible object used in food product, comprises subjecting edible powder composition comprising water-soluble protein, hydrocolloid and plasticizer to powder bed printing by depositing edible liquid onto powder in a layer-wise manner*. Nede-C: Nederlandse Org Toegepast Natuurwetensch, 2015.

Dick, A., Bhandari, B. and Prakash, S. (2019). 3D printing of meat. *Meat Science*, 153, 35–44.

Godoi, F.C., Prakash, S. and Bhandari, B.R. (2016). 3D printing technologies applied for food design: Status and prospects. *Journal of Food Engineering*, 179, 44–54. doi: 10.1016/j.jfoodeng.2016.01.025.

Gray, N. Looking to the future: creating novel food using 3D printing. Available online: http://www.foodnavigator.com/Science/Looking-to-the-future-Creating-novel-foods-using-3D-printing (accessed on 08.06.2025).

Hao, L., Mellor, S., Seaman, O., Henderson, J., Sewell, N. and Sloan, M. (2010). Material characterisation and process development for chocolate additive layer manufacturing. *Virtual and Physical Prototyping*, 5, 57–64.

Hopkinson, N., Hague, R. and Dickens, P. *Rapid Manufacturing: An Industrial Revolution for the Digital Age*, John Wiley & Sons: W.Sussex, England, 2006.

Huang, S.H., Liu, P., Mokasdar, A. and Hou, L. (2012). Additive manufacturing and its societal impact: A literature review. *The International Journal of Advanced Manufacturing Technology*, 67, 1191–1203.

iReviews. 3D system ChefJet pro 3D food printer. Available online: http://3d-food-printers.ireviews.com/3d-systems-chefjet-pro-review (accessed on 08.06.2025).

Jandyal, A., Chaturvedi, I., Wazir, I., Raina, A. and Haq, M.I.U. (2022). 3D printing–A review of processes, materials and applications in industry 4.0. *Sustainable Operations and Computers*, 3, 33-42.

Lai, W.-H.and Cheng, C.-I. Manufacturing Method of Three-Dimensional Food by Rapid Prototyping. U.S. Patent Application No: 11/785,930, 2008.

Lipson, H. and Kurman, M. *Fabricated: The New World of 3D Printing*, John Wiley & Sons: Indiana, USA, 2013.

Lipton, A.D., Nigl, F., Lopez, N., Cohen, D., Nor´en, N. and Lipson, H. *Multimaterial food printing with complex internal structure suitable for conventional post-processing*. In Proceedings of the Solid Freeform Fabrication Symposium, Austin TX, 2010.

Lipton, J.I., Cutler, M., Nigl, F., Cohen, D. and Lipson, H. (2015). Additive manufacturing for the food industry. *Trends Food Science & Technology*, 43, 114–123. doi: 10.1016/j.tifs.2015.02.004.

Liu, Z., Zhang, M., Bhandari, B. and Wang, Y. (2017). 3D printing: Printing precision and application in food sector. *Trends Food Science & Technology*, 69, 83–94. doi: 10.1016/j.tifs.2017.08.018.

Malone, E. and Lipson, H. (2007). Fab@Home: The personal desktop fabricator kit. *Rapid Prototyping Journal*, 13, 245–255.

Mellor, S., Hao, L. and Zhang, D. (2014). Additive manufacturing: A framework for implementation. *International Journal of Production Economics*, 149, 194–201.

Nocera, A.D., Salvatierra, N.A. and Cid, M.P. (2015). Printing collagen 3D structures. *Food Hydrocoll*, 49, 136–139.

Oskay, W. and Edman, L. The Candy Fab project. Available online: http://candyfab.org/ (accessed on 08.06.2025).

Periard, D., Schaal, N., Schaal, M., Malone, E. and Lipson, H. *Printing Food*. In Proceedings of the 18th Solid Freeform Fabrication Symposium, Austin TX, 2007.

Porimy. Porimy kunshan bo mai three-dimensional printing technology Co., Ltd. Available online: http://www.porimy.com/ (accessed on 08.06.2025).

Severini, C., Derossi, A. and Azzollini, D. (2016). Variables affecting the printability of foods: preliminary tests on cereal-based products. *Innovative Food Science & Emerging Technologies*, 38, 281–291.

Severini, C., Derossi, A., Ricci, I., Caporizzi, R. and 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. doi: 10.1016/j.jfoodeng.2017.08.025.

Shahrubudin, N., Lee, T.C. and Ramlan, R.J.P.M. (2019). An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manufacturing*, 35, 1286-1296.

Sher, D. and Tutó, X. (2015). Review of 3D food printing. *Temes Disseny*, 31, 104–117.

Sood, A.K., Ohdar, R. and Mahapatra, S.S. (2010) Parametric appraisal of the mechanical property of fused deposition modelling processed parts. *Materials & Design*, 31, 287–295.

Sun, J., Peng, Z., Yan, L., Fuh, J.Y.H. and Hong, G.S. (2015) 3D food printing: An innovative way of mass customization in food fabrication. *International Journal of Bioprinting*, 1, 27-38.

Tadmor, Z. and Klein, I. *Engineering Principles of Plasticating Extrusion*, Van Nostrand Reinhold Co.: New York, USA, 1970.

Vancauwenberghe, V., Delele, M.A., Vanbiervliet, J., Aregawi, W., Verboven, P., Lammertyn, J. and Nicolaï, B.(2018). Model-based design and validation of food texture of 3D printed pectin-based food simulants. *Journal of Food Engineering*, 231, 72–82.

Wang, L., Zhang, M., Bhandari, B. and Yang, C. (2018). Investigation on fish surimi gel as promising food material for 3D printing. *Journal of Food Engineering*, 220, 101–108. doi: 10.1016/j.jfoodeng.2017.02.029.

Yang, F., Zhang, M., Bhandari, B. and Liu, Y. (2018). Investigation on lemon juice gel as food material for 3D printing and optimization of printing parameters. *Food Science & Technology*, 87, 67–76. doi: 10.1016/j.lwt.2017.08.054.

Yang, F., Zhang, M., Prakash, S.and Liu, Y. (2018). Physical properties of 3D printed baking dough as affected by different compositions. *Innovative Food Science & Emerging Technologies*, 49, 202–210.

Zhang, H., Fang, M., Yu, Y., Liu, Q., Hu, X., Zhang, L. and Tian, F. *Application Prospect of 3D Printing Technology in the Food Intelligent Manufacturing*. In Recent Developments in Mechatronics and Intelligent Robotics, ICMIR 2018, Deng, K., Yu, Z., Patnaik, S., Wang, J. Eds.; Springer: Cham, Switzerland, 2019.