DECEMBER 2019 M.Sc. in Food Engineering HATİCE YAPRAK AYDIN

REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

CHOCOLATE AND DELIGHT PRODUCTION WITH 3-DIMENSIONAL PRINTER

M.Sc. THESIS

IN

FOOD ENGINEERING

BY

HATİCE YAPRAK AYDIN

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M.Sc. Thesis

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Supervisor

Prof. Dr. Ali Rıza TEKİN

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FOOD ENGINEERING

Name of the Thesis : Chocolate and Delight Production with 3-Dimensional Printer

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Exam Date :17.12.2019

Approval of the Graduate School of Natural and Applied Sciences

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Hatice YAPRAK AYDIN

ABSTRACT

CHOCOLATE AND DELIGHT PRODUCTION WITH 3-DIMENSIONAL PRINTER

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December 2019
76 pages

3D printer printing technology is a branch of Additive Manufacturing technology which has become widespread in industry in recent years. In this method, the solid / semi-solid raw material is melted from the printer head at certain temperatures and the product is printed in layers with the Fused Deposition Modeling method.3D printer printing technology, which started primarily with the use of polymer based materials as raw materials, has become widespread today with the use of different materials such as metal, ceramics, bone powder and has found its place in the food industry with the use of foodstuffs. In this study, the use of 3D printer printing technology in food field has been studied. The printing of 3 different chocolate types and 2 different types of delights using rheological and mechanical properties were investigated. Two different extruders were designed in Cartesian 3D printer which was produced as prototype and printing experiments were performed. As a result, the printing temperatures for milk, white and dark chocolate types were determined as 29°C, 30°C, 38°C, and printing speeds were 40 mm/s, 50 mm/s, 60 mm/s respectively. In addition, printing temperatures for Turkish delight and custard delight products were determined as 60°C and 65°C, printing speeds of 50 mm/s and 80 mm/s respectively. It has been found that there is a direct proportional relationship between melting temperature, printing temperature and printing speed when printing food products with 3D printer.

Key Words: Food Printer, 3D, Chocolate, Delight, Additive Manufacturing

ÖZET

ÜÇ BOYUTLU YAZICIYLA ÇİKOLATA VE LOKUM ÜRETİMİ

YAPRAK AYDIN, Hatice
Yüksek Lisans Tezi, Gıda Mühendisliği
Danışman: Prof. Dr. Ali Rıza TEKİN
Aralık 2019
76 sayfa

3B yazıcı ile yazdırma teknolojisi son yıllarda endüstride kullanımı hızla yaygınlaşan Eklemeli İmalat teknolojisinin bir dalıdır. Bu yöntemde, katı/yarı katı haldeki hammadde yazıcı başlığından belirli sıcaklıklarda eritilerek, Eriyik Yığın Modelleme yöntemi ile katmanlar halinde ürün yazdırılmaktadır. Öncelikli olarak polimer bazlı maddelerin ham madde olarak kullanımıyla başlayan 3B yazıcı ile yazdırma teknolojisi, günümüzde metal, seramik, kemik tozu gibi farklı maddelerin kullanılmasıyla yaygınlaşmış ve gıda maddelerinin kullanılmasıyla gıda endüstrisinde kendisine yer bulmuştur. Bu çalışmada, 3B yazıcı ile yazdırma teknolojisinin gıda alanında kullanımı üzerine çalışılmıştır. Reolojik ve mekanik özellikleri birbirinden farklı olan 3 farklı çikolata türü ve 2 farklı lokum türünün 3B yazıcı kullanılarak yazdırılması incelenmiştir. Prototip olarak üretilen Kartezyen tipi 3B yazıcıda iki farklı ekstrüder tasarlanarak, yazdırma deneyleri gerçekleştirilmiştir. Sonuç olarak, sütlü, beyaz ve bitter çikolata türleri için yazdırma sıcaklıkları sırasıyla 29°C, 30°C, 38°C, yazdırma hızları sırasıyla 40 mm/s, 50 mm/s, 60 mm/s olarak belirlenmiştir. Ayrıca, Türk lokumu ve Muhallebi lokumu ürünleri için yazdırma sıcaklıkları sırasıyla, 60°C ve 65°C, yazdırma hızları 50 mm/s ve 80 mm/s olarak belirlenmiştir. Gıda ürünlerinin 3B yazıcı ile yazdırılmasında erime sıcaklığı, yazdırma sıcaklığı ve yazdırma hızı arasında doğru orantılı bir ilişki olduğu görülmüştür.

Anahtar Kelimeler: Gıda Yazıcısı, 3B, Çikolata, Lokum, Eklemeli İmalat

''Dedicated to my family''

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Dr. Ali Rıza TEKİN for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to express my love and gratitude to my family and my husband Murat AYDIN for their support, always best wishes.

I would like to thank Dr. Öğr. Üyesi Ali KILIÇ for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to thank Prof. Dr. Mustafa BAYRAM for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to thank Doç. Dr. K. Bülent BELİBAĞLI for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to thank Dr. Öğr. Üyesi Meriç ŞİMŞEK ASLANOĞLU for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to thank Prof. Dr. Ali Coşkun DALGIÇ for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to thank Prof. Dr. Medeni MASKAN for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

This work is supported by Gaziantep University BAP Management Unit Project MF.YLT.17.15) for financial support. I would like to thank Gaziantep University BAP Management Unit.

I also would like to thank the staffs of University of Gaziantep Department of Food Engineering.

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LIST OF SYMBOLS

°C	Degrees Celsius
%	Percent
mm	Millimeter
mm/s	Millimeter/Second
µm	Micrometer

LIST OF ABBREVIATIONS

3D	3 Dimensional
AM	Additive Manufacture
CAD	Computer Aided Design
STL	Stereolithography
FLM	Food Layer Manufacture
3D-FP	3-Dimensional Food Printing
SLS	Selective Laser Sintering
FDM	Fused Deposition Modeling
BJ	Binder Jetting
IJP	Ink Jet Printing
TNO	The Netherlands Organization for Applied Scientific Research
$CaCl_2$	Calcium Chloride
Mg-ST	Magnesium Stearate

CHAPTER I

INTRODUCTION

1.1 General Information

Today, parallel to the development of technology, rapidly developing 3-dimensional (3D) printer technology has become the center of attention of both manufacturers and consumers, thanks to the innovations and advantages it offers. 3D printers are a technology that has gained popularity due to its advantages such as reducing work force, reducing costs, improving product quality standards (color, texture, taste, smell, shape, etc.), minimizing raw material consumption without the need for expensive equipment in production (Değerli, 2017).

3D printer, a branch of Additive Manufacturing (AM) technology, is quite different from traditional manufacturing techniques. It is based on the transformation of the model created using CAD (Computer Aided Design) software into physical product by stacking method in layers. Thus, it is provided to produce 3D concrete objects from an example of a digital model. In this way, 3D printer technology and additive manufacturing technology form the basis of the new industrial revolution (Liu et al., 2019).

Although thermosets and thermoplastics are commonly used in 3D printers, the use of metals, ceramics and food materials has become widespread in addition to polymer materials. 3D printers, which are also used in the food field, enable the production of healthier, longer shelf-life, end-user food products in addition to producing food products from creative design models (Tohic et al., 2018).

AM method which is one of the rapid prototyping methods is based on obtaining the product geometry by stacking a fluid semi-fluid raw material in layers. The raw material used is conveyed into a special mechanism with a heating chamber called extruder and from there passes through an end called a nozzle and the raw material is stacked at the coordinates produced in computer environment. The 3D printer technology used in the food industry differs from robotic-based technologies designed to replicate manual processes in food construction. The first generation of Food Layer Manufacture (FLM) concept designs, prototype equipment and patented food applications have been unveiled to the public. The use of the application has seen more demand outside the food areas. However, the FLM concept has the potential to be used in the creation of new and innovative food recipes and in the production of new food products in individual tastes, colors and textures (Wegrzyn et al., 2011) (Jerez-Mesa et al., 2016).

The use of 3D printer technology in the food sector allows the production of products in new textures and structures, and the development of the concept of digital gastronomy, using traditional and innovative cooking techniques, given the personal nutritional demands of people (Vancauwenberghe et al., 2017).

The first examples of 3D printing technology were made in the early 1980s with the use of metal, ceramic and photo-sensitive polymer materials. The first 3D printer was invented in 1984 by Charles Hull (Guo, Zhang, & Bhandari, 2019). In recent years, it has developed rapidly and started to be applied in automotive, aviation, medical and food fields. 3D food printing (3D-FP) technology helps develop edible products and textures with personalized geometry. It also ensures that nutritional optimization of end products is done according to users' dietary restrictions (Mantihal et al., 2017).

Today, AM technologies are developed on customizable foods for controlled and careful feeding applications in areas of application in high-volume markets. These development efforts on customizable and operational foods have attracted the attention of the confectionery industry, whose commercial activities are high and are seeking to expand its market share. On the other hand, AM technology is an advantageous production method for athletes, patients and the elderly who need special nutritional lists and for people who need to consume high fiber diet products (Slinger et al., 2017).

The use of 3D printer technology in the food industry allows the development of complex, personalized and customized designs. The most widely used 3D printer technology in the food field is the extrusion method. The use of extrusion in food is that fresh foods can be easily converted to semi-liquid (paste) or powder forms in the highest yield. These semi-liquid or powdered food products are extruded through a nozzle with temperature control. For the extrusion process, temperature is an important parameter, especially for printing foodstuffs. Because, the melting and flow behavior of food materials is determined by direct temperature change. The viscosity of the semi-liquid (paste) material or the melting / liquefaction of the powder material is obtained by precise temperature control of the extruder (Mantihal et al., 2019).

On the other hand, because tissues can be designed freely and flexibility in composition, taste and shape designs, various studies have been done recently in the field of food engineering on production with 3D printer technology. Extrusion based AM and 3D printer technology is the most suitable rapid prototyping method to produce foodstuffs. With this technology, foods can be easily shaped by means of complex geometries through the nozzle (Lee et al., 2019).

In contrast to the cooking process in extrusion printing of foods, complex 3D food products are formed in layers and digital control is used in the production of these layers. The digital control mechanisms used provide a precise solution in food shaping for food design and nutrition controlled engineering (Sun et al., 2018).

Nowadays, printers with structural features such as cartesian, delta, polar and scara are used in the printing applications of food products in 3D printers. In addition, piston system, air pressure and screw mechanisms are used as extrusion mechanism (Sun et al., 2018).

With 3D printers, the production of complex geometry products is facilitated, providing economic and environmental advantages. In addition, 3D printer technology offers personalized nutrition opportunities based on calorie intake for individuals who need special nutrition and diet practices. These opportunities from 3D printer technology are especially important for people with specific nutritional needs, such as elderly people and patients who have difficulty eating (Pérez et al., 2019).

Working principles of 3D printing technology used in food industry can be classified; a) Extrusion using pneumatic piston or screwed robotic distribution systems in which hydrogel fluid is continuously supplied, b) thermal inkjet, configured with heater that generates air pressure pulses for generating droplets in the printer head, c) laser-assisted printing system consisting of a laser-absorbing layer, a feed layer of cell-loaded hydrogel, and a receptive substrate (Portanguen et al., 2019).

Patterns made on biscuits and chocolate foods by traditional methods, letters embroidered on cookies, logos embroidered on foodstuffs are costly and time-consuming applications. On the other hand, the production of these special foods creates a great opportunity for the personal gift market. Individuals with special training are currently working in the production of such special foods design. With 3D printer technology, everyone is able to produce such special production foods in their own homes, making it a popular choice among people (Fuh et al., 2015).

The effects of foodstuffs on people's metabolism and health vary from person to person. The concept of personalized nutrition, which aims to prepare individual dietary products to improve the health status of individuals, also benefits the society. 3D food printers have the potential to fill the void of personalized nutrition concept. By combining different food materials easily and quickly, it is easier to produce products suitable for body health through layered production. For most cases, the output from the 3D printer is the final product, but baking is carried out after printing for dough products, cookies and pizza. Thus, healthier products are obtained with lower cost and human-power (Fuh et al., 2015).

The cooking process is the last and most important step before food products are put into use. By combining 3D printer technology with robotic automated systems, robot chefs capable of monitoring food recipes will be widely used in both home users and industrial environments. For example, robotic systems can find the right material to make a cookie in the oven, mix the ingredients, place them in the baking tray by shaping them and put them in the oven, followed by a sequence of automatic processes (Sun et al., 2015).

Furthermore, robotic systems equipped with the necessary and enough information will be able to perform daily tasks such as collecting objects, putting them in place or pouring them. These robotic systems, which are used to allow mass production in traditional food production, are widely designed to automate human labor processes. By combining these robotic systems with 3D printers, manpower, cost, time consumption, waste of raw materials will be significantly reduced and food production efficiency will be increased (Sun et al., 2015).

3D printers are a method of combining 3D printing technique and digital gastronomy to improve food printing, shape, color, texture, flavor and nutritional values, unlike robotic systems found in manufacturing plants. Food printing with 3D printer is a digitally controllable robotic construction process that provides phase transitions by creating complex solid forms. Digital gastronomy is a method that uses the knowledge of production techniques and experience used in food manufacturing. When 3D printer technology and digital gastronomy are combined, food manipulation is digitally visualized. This makes it possible to produce low-cost, innovative food products (Sun et al., 2015).

The use of 3D printer technology in the food sector has started with the need to deliver the product to the end user in a single step, to produce foodstuffs with new textures and high nutritional value. In this context, it is a process produced in layers in which the synergistic composition of nutrients (carbohydrates, proteins, fats) is provided with the essential properties and binding mechanisms. In addition to these features, it is possible to produce complex geometry parts in one step and present them to the user with 3D printer technology (Godoi et al., 2016).

3D food printers consist of a mobile food printing platform (Cartesian coordinate system) on the X-Y-Z axes, a dispensing / sintering unit, and a user interface on a computer. The raw material to be printed is converted into a real manufacturing process in a 3D food printer with a computer controlled system (Fuh et al., 2015).Figure 1.1 shows the chocolate printer and the movement axes used in an exemplary food field.

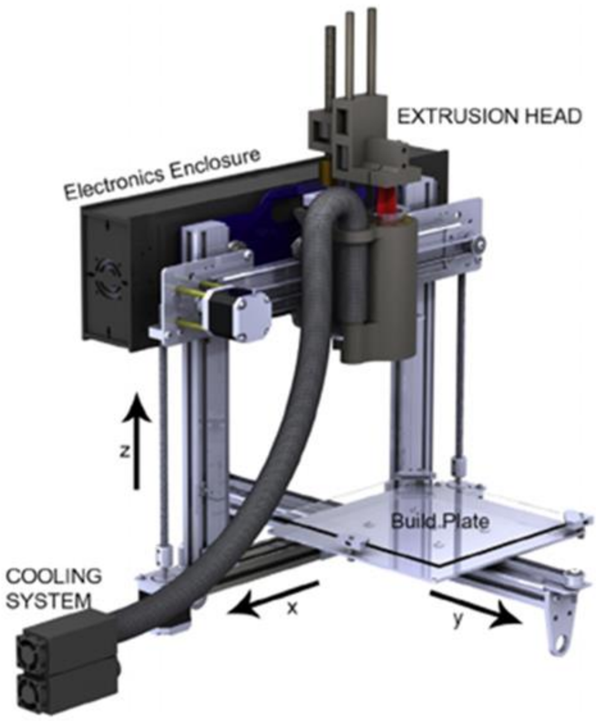


Figure 1.1 The manufactured chocolate printer model (Slinger et al., 2017).

1.2 Food Printer Technology

Using 3D printers, different production techniques are available to produce healthy, personalized and reconstructed products (rich in fiber, protein and starch) and to print according to the desired product recipe. In the food industry, Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Binder Jetting (BJ), Ink Jet Printing (IJP) and Spray Systems are widely used. The most important difference between the techniques used is that the method used for stacking the layers is different. In these techniques, the material is melted, softened and layers are formed. On the other hand, the liquid materials are stacked directly and the material is hardened immediately after the agglomeration process so that the product is finalized (Sun et al., 2015).

1.2.1 3D Printer Technology

The goal of using 3D printer technology in the food industry is to create complex geometries and produce products with detailed textures. Thanks to its advantages, 3D printer technology appears to play an important role in the food industry. With 3D printer technology, some analysis needs to be done in order to observe how food behaves in printing foods. In the light of these analyzes, it is seen that the rational design of food production with 3D printer technology is based on three main factors. These are printability, applicability and post-processing (Godoi et al., 2016).

- **Printability:** The printability factor includes how the material properties should be treated with the 3D printer and what kind of changes will occur in the post-process structure. The printability of additive manufacturing technologies using liquefied raw materials is influenced by drip techniques, material viscosity, or rheological properties. In addition to rheological properties, 3D printers based on extrusion techniques are influenced by the specific gelling mechanism (crosslinking) and thermal properties (melting point and glass transition temperature) of food raw materials. In addition, properties such as particle size, density, wettability, and fluidity affect powder-based 3D printers (Godoi et al., 2016).

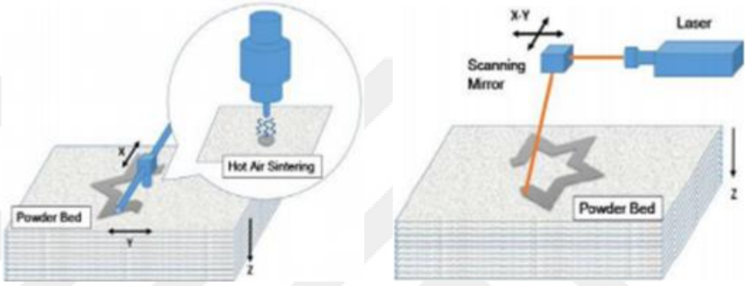
- **Applicability:** The 3D printer technology becomes a flexible production technology when its nutritional value is incorporated into the production of uniquely designed foodstuffs. The applicability of 3D printer technology is determined by the material properties (easy work-ability, shape-ability) of the food raw materials (Godoi et al., 2016).

- **Post Processing:** The food composition printed with the 3D printer must be resistant to baking after printing, such as oven baking, boiling in boiling water or frying in oil. Materials with appropriate physical, chemical, rheological and mechanical properties must be correctly selected in fireproof structures (Godoi et al., 2016).

1.3 3D Printer Techniques Applied in Food Printing

1.3.1 Selective Laser Sintering

In the Selective Laser Sintering (SLS) method, the powder particles of the raw material are spread out in layers and a sintering source is used to fuse the particles in this emitted powder layer. The sintering source used moves along the X and Y axes and the powder particles in the sintered region connect to each other to form a solid layer. After each movement of the sintering head, a second head prepares the raw material as the new powder layer and is then shaped again by heating the raw material on the surface with the sintering head. As each layer is heated, the platform slides down the Z-axis and produces a 3D geometric shape. The sintering head of the 3D printer moves on the X and Y axes, while the printing platform moves on the Z axis (Sun et al., 2015). Hot air or laser method is commonly used for sintering welding. Figure 1.2 (a) shows hot air and Figure 1.2 (b) shows laser sintering.



(a) (b)

Figure 1.2 Working principle of SLS method, (a) Selective hot air sintering (b) Selective laser sintering (Sun et al., 2015).

1.3.2 Fused Deposition Modeling

Fused Deposition Modeling (FDM) method was first developed to produce thermoset and thermo plastic materials. In this method, the melted semi-solid polymer material is conveyed from a moving FDM head and the semi-solid material is deposited in layers on the printer tray. By adapting this method for use in the food industry, print heads moving on the X, Y and Z axes are designed. In these heads, the extruded semi-fluid / fluid food raw material, which is just above the melting point, is rapidly transformed into solid form on the printer platform. The printer platform moves along the Y axis and starts to stack the second layer onto the food raw material, which is transferred to the platform and turned into solid form. In this way, food raw material is converted into product in layers and production is provided. One of the most important points in the FDM method is the relationship between the outdoor temperature and the temperature of the printed food raw material. The printing temperature must be just above the melting point of the food raw material and the outdoor temperature must be lower than the melting point. This enables the printed food raw material to rapidly convert to solid form (Sun et al., 2015). Figure 1.3 shows the working principle of the FDM method.

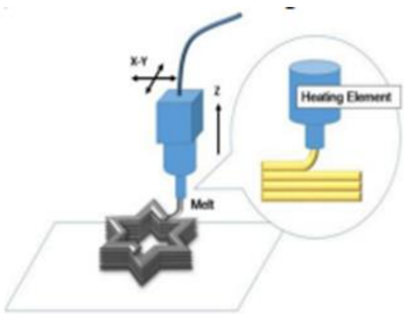


Figure 1.3 Working principle of FDM method (Sun et al., 2015).

1.3.3 Binder Jetting

The printing platform and the form of the raw material used in the Binder Jetting (BJ) method are like the SLS method. Laser melting is not used in the BJ method. In the BJ method, the powdered food raw material is generally stabilized with water mist to minimize problems resulting from discharging the binder. Food raw materials such as sugar and starch are laid in powder form on the printing platform, forming shapes by applying binder liquid along the X and Y axes from the printing head. After the first layer is formed, the second layer is passed back to the powdered food raw material to be laid and re-applied from the binding liquid printing head. While this process is in progress, the printing platform moves down the Z axis (Sun et al., 2015). Figure 1.4 shows the working principle of the BJ method. In the Sugar Lab project carried out by 3D Systems, sugar was produced using the BJ method. This method, which is faster than other printing methods, has a high installation cost (Değerli, 2017).

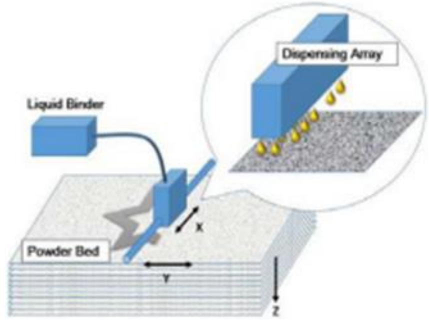


Figure 1.4 Working principle of BJ method (Sun et al., 2015).

1.3.4 Ink Jet Printing

The Ink Jet Printing (IP)method uses a syringe-type print head. The food raw material contained in the printing head is dispensed in fluid droplets and transferred in bulk onto the printing platform. The working principle of classic printers used to print on papers in everyday life is similar. The food raw material to be printed is sprayed in very small droplets. This method, which can be dosed at intervals or continuously according to the desired geometric shape, offers fast and error-free solutions for the completion of pre-prepared products (such as adding tomato sauce on the pizza base, adding chocolate sauce on the baked cookies on the moving tape) (Godoi et al., 2016). Figure 1.5 shows the working principle of the IJP method.

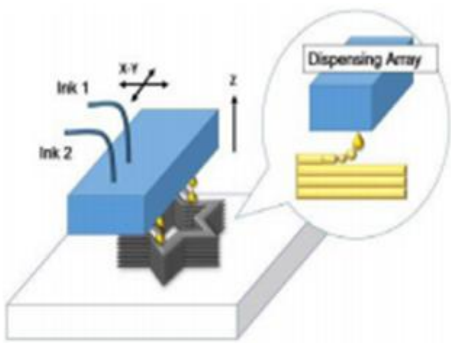


Figure 1.5 Working principle of IJP method (Sun et al., 2015).

Different printing techniques are used according to the characteristics of the food raw materials and the type of product to be produced. Table 1.1 gives examples of food product type, raw materials and 3D printing techniques used in the food field (Değerli, 2017).

Table 1.1 Product type and used 3D printing techniques (Değerli, 2017)

Food Products	Raw Materials Used	Printer Type Used
Cookie	Sugar, flour, eggs, butter	FDM
Pasta	Durum wheat semolina, water	FDM
Chocolate	Cocoa butter, sugar, cocoa, butter, lecithin	FDM
Cheese, sauces and coatings	Cheese, chocolate, tomato, gums, sugar, salt	IJP
Meat and seafood	Clam, turkey meat	FDM, Bio-printer

1.4 CAD Software for 3D Printers

When printing with 3D printers, a 3D model of the product to be produced is required. This model can be created by solid model or surface modeling with various CAD software. In the CAD software used, the modeled product is saved in STL (Stereolithography) format and transferred to the 3D printer control program and the product is printed. The most common CAD software used today is the transfer of the sample to a three-dimensional printer control program and printing. Nowadays, CAD software which is widely used in part modeling for printing on 3D printers, SolidWorks, AutoCAD, Fusion 360, 3DS Max, Rhino, Maya, ZBrush, Blender, Mudbox, Creo, Inventor, Modo, LightWave, Mathematica, SketchUp, OpenSCAD, Cinema4D, FreeCAD (Çelik, 2015).

1.5 Three-Dimensional Object Slicing Programs

In 3D printing, the model file is transferred to the control program to be saved in STL format after the product is modeled with CAD software on computer. In order to print in layers on the model transferred to the control program, slicing is required. Slicing process is the process of converting the model file into layers by determining the parameters such as surface quality, fill rate, printing speed, which are required for printing the product to be shaped in layers. After this conversion, G codes are generated, which include the path of the printer header as coordinates when printing layers as stacking. The G code file created is transferred to the 3D printer by using a memory card or directly by computer connection and the product is printed (Çelik, 2015).

There are many slicing and control programs for 3D printers considering their body structure and print head. The slicing software used in production are Cura, Repetier and Makerware (Çelik, 2015).

1.5.1 Three-Dimensional Object Slicing Program–Cura

Easy to use and free of charge for slicing 3D printers, Cura software is widely used. Figure 1.6 shows the user interface of the Cura software.

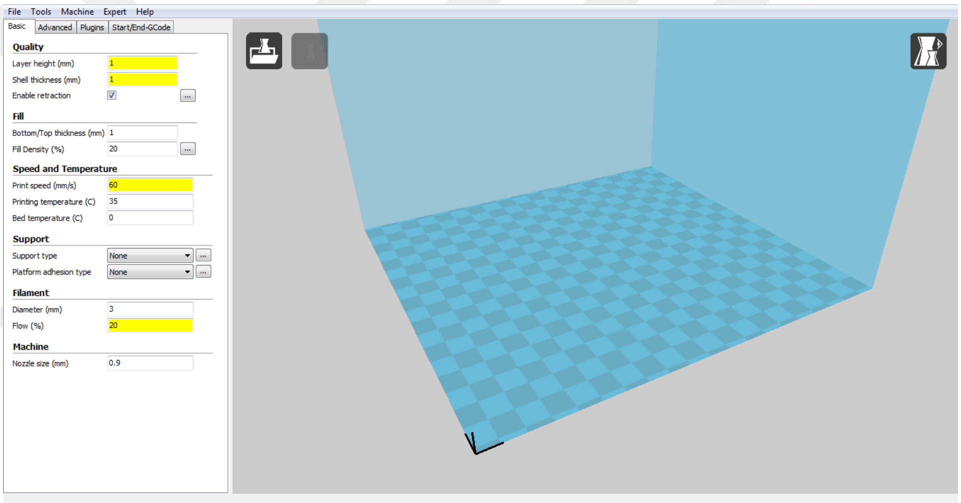


Figure 1.6 Cura software user interface.

The product file designed in CAD software is transferred to Cura software and converted into STL format. The Cura software reads the surface geometries in the STL file and creates the model file. Figure 1.7 shows the model file that is converted to STL format and transferred to Cura software.

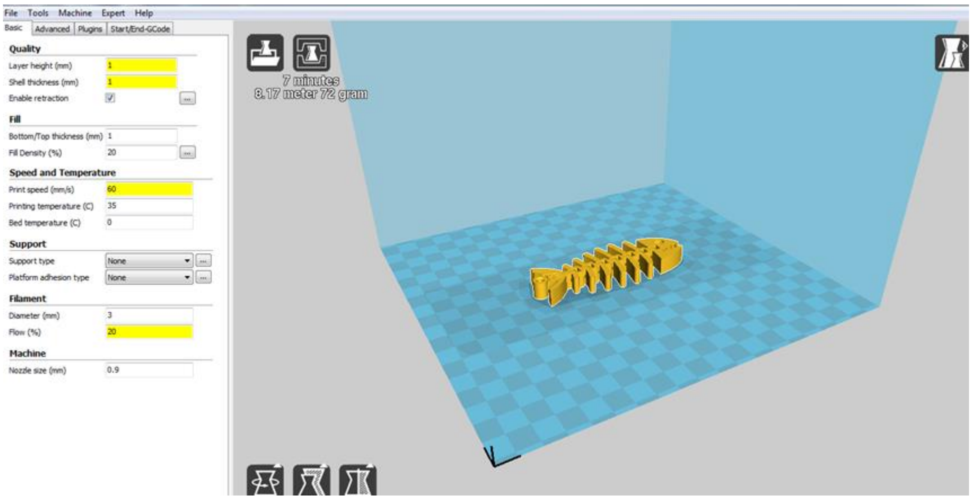


Figure 1.7 Product model transferred to Cura software in STL format.

Some parameters must be entered when slicing in Cura software. These parameters directly affect the printing, the quality and the geometric dimension of the product. Incorrect or incomplete parameters result in incorrect production. The parameters to be entered in the Cura software are classified below. Figure 1.8 shows the screenshot in which the basic parameters are entered in the Cura software.

1. **Quality Settings**
   - Layer height: Height of each layer in millimeters during printing
   - Shell thickness: Thickness of the printed product in millimeters
   - Enable retraction: The parameter used to make the extruder withdraw
2. **Fill Settings**
   - Bottom / Top thickness: The value of the top and bottom thickness of the printed product in millimeters
   - Filling density: The amount of material that should be used for the printed product, in percentage terms
3. **Speed and Temperature Settings**
   - Print speed: The value of the speed of the printed product in millimeters of how far it travels in a second
   - Printing Temperature: The temperature value of the printed product used in ideal conditions
4. **Support Settings**
   - Support type: Parameter used to indicate the type of support selected

- ➢ Adhesion to the platform type: Creating additional platform type

5. **Filament Settings**
    - ➢ Diameter: The parameter that gives the diameter of the filament used in millimeters.
    - ➢ Flow: Parameter that gives the flow rate of the filament used in percentage terms
6. **Machine settings**
    - ➢ Nozzle size: The value of the nozzle diameter used for printing in millimeters

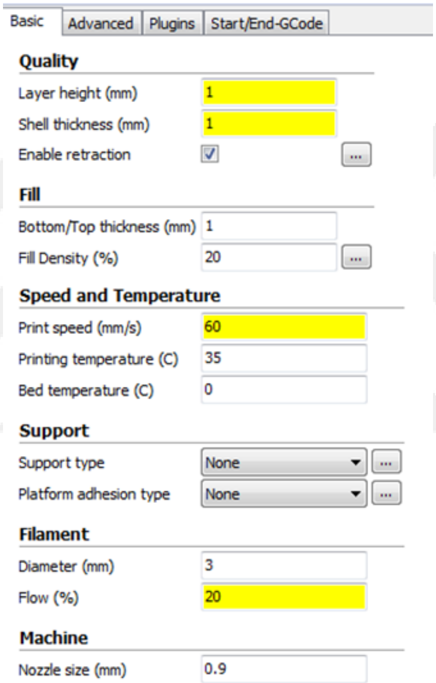


Figure 1.8 Cura software basic printing parameters.

In addition to the basic parameters mentioned above, the advanced settings section of the Cura software enters the precise printing parameters. The precise printing parameters required to achieve quality production are classified below. Figure 1.9 shows the screen display where the fine print parameters are entered in the Cura software.

1. **Retract Settings**
   - Speed: Withdrawal speed rate per second
   - Distance: 1-millimeter retraction distance
2. **Quality Settings**
   - Initial layer thickness: The thickness of the first layer created during printing
   - Initial layer line width: The line width of the first layer created during printing
3. **Speed Settings**
   - Travel speed: Moving speed of the extruder in millimeters divided by seconds during printing
   - Bottom layer speed: Moving speed of the bottom layer created during printing in millimeters divided by seconds
   - Infill speed: Speed of product occupancy during printing
   - Top/Bottom speed: The value of the speed at which you create the bottom and top layers during printing, in millimeters divided by seconds
   - Outer shell speed: The value of the speed required to create the outer shell of the printed product, in millimeters divided by seconds
   - Inner shell speed: The value of the speed required to create the inner shell of the printed product, in millimeters divided by seconds
4. **Cooling Settings**
   - Minimal layer time: Minimal layer per second during printing time
   - Enable cooling fan: The button used to activate the cooling fan during printing

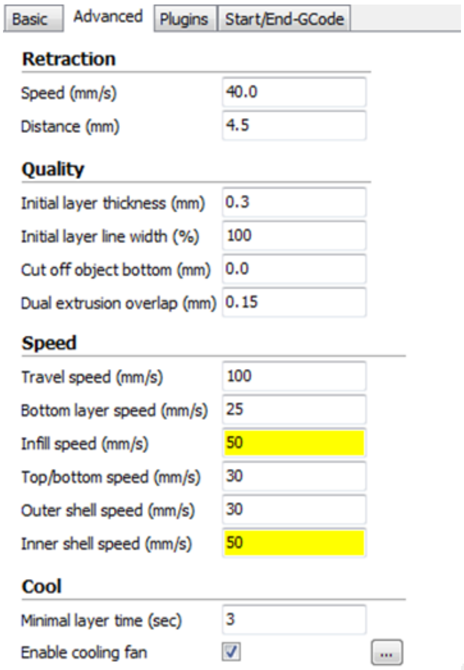


Figure 1.9 Cura software precision printing parameters.

1.6 Chocolate Production

The main raw material used in chocolate production is cocoa beans. The cocoa beans are firstly cleaned and roasted and separated from the shell to obtain cocoa liquor or chocolate mass. Then, in order to produce the desired chocolate type, chocolate liquor, cocoa butter and sucrose are mixed in certain proportions. The mixed chocolate mass is subjected to thinning. This thinning process is also called grinding. The prepared mixture is thinned up to 30 µm using steel cylinders. The main purpose of the thinning process is that the chocolate particles become too small to be noticed in the mouth. The sufficiently thinned mixture is subjected to conching in the next step. Conching is carried out to remove unwanted acidic taste and moisture in the chocolate. At this stage, the chocolate is placed in a tank, mixed at high temperature, at a low speed, and the volatile components that evaporate are removed by a fan on the tank. After conching, the chocolate is shaped by cooling to 27°C (Sökmen, 2005). Chocolate samples produced are shown in Figure 1.10.

Figure 1.10 Types of chocolate produced on the market (İTO, 2019).

1.7 Delight Production

1.7.1 Turkish Delight Production

Turkish Delight is a type of confectionery that is unique to Turkish culture. Sugar is used as sweetener; starch is used as binder and tissue-forming agent in Turkish delight. Turkish Delight is a food obtained by cooking the raw materials it contains in appropriate proportions by mixing in open boilers or steam jacketed, automatic mixing boilers at a certain temperature and time. Cooking time varies between 1-2 hours depending on the type of boiler. After the production, Turkish Delight is poured into low-edge wooden or steel trays sprinkled with starch and sprinkled with starch and cut into small pieces (Batu, 2016). Figure 1.11 shows a type of traditional Turkish delight.

Figure 1.11 Turkish delight (Yeni Şafak, 2015).

1.7.2 Custard Delight Production

Unlike traditional Turkish delight, custard delight contains milk, sugar, starch, vanilla, margarine and flour as raw materials. The mixture obtained by adding these raw materials in certain proportions is cooked. The cooked pudding is poured into molds and left to cool. When the cooling process is completed, the desired sizes are cut and coconut or different products are added (Batu, 2016). Figure 1.12 shows a type of custard delight.

Figure 1.12 Turkish delight with custard (Habereses, 2018).

CHAPTER II

LITERATURE REVIEW

2.1 Studies in the Literature

3D printer technology was first developed by Chuck Hull in 1970. However, it has not received much attention in its time frame and has not been as popular as it is today. In 1986, Chuck Hull founded 3D Systems and developed a patent for stereolithography (Kaya, 2017).

The introduction of 3D printers to the public was first made by Cody Wilson at the University of Texas, announcing the first 3D printed gun and sharing the manufacturing codes. With this technology, the fact that everyone can buy their own printer at an affordable price and produce their own weapons has increased the interest in 3D printer technology (Kietzmann et al., 2015).

The first desktop 3D printer was developed by Adrian Bowyer at the University of Bath, when he launched the Replicating Rapid Prototyper initiative, known as RepRap (Jerez-Mesa et al., 2016). With the 3D printer produced by the RepRap project, 3D printing machines that can produce about half of their parts were produced (Pearce, 2014).

The first 3D printer was used in the food field was developed about 10 years ago. A 3D printer prototype was developed and patented by Nanotek Instruments to manufacture a custom-designed birthday cake. Nico Kläber produced customized food prints using a robot arm at the Electrolux Design Lab 2009 competition. Using food cartridges in various food production process, Philips Design has proposed the development of a 3D printer prototype with a user interface that individuals can easily determine their shape, texture and characteristic features (Fuh et al., 2015).

Fuh et al. created a user interface to design a 3D model on the platform they developed. They created all public template libraries and opened them to web-based access to design food. Thanks to these interfaces, everyone has been able to make custom designs for their own food printing or download and use previously designed models (Fuh et al., 2015).

The production of food directly with a 3D printer without using any mold has attracted the attention of many companies. Stratasys, the world's largest 3D printer company, has worked on the development of a 3D chocolate printer. On the other hand, 3D Systems has announced that they have developed a printer capable of 3D chocolate printing. The 3D System company's ChefJet series printer has used Z Corp's inkjet technology to produce food objects using sugar, powder and cocoa (Lipton et al., 2015). In addition, ChefJet printers use natural food dyes to give color to printed products. In the printing process where food dyes are used, the materials spreading in powder layers are combined with binder chemicals and laser sintering and hot air sintering techniques are used during production (Slinger et al., 2017). Using the 3D printer, Candy Labs worked to print customized and personalized candy products. Cornell Creative Machines Lab worked on cookie printing using a 3D printer. Choco Edge and PIQ companies have worked on the design and production of custom-made chocolates designed by their customers and designed with 3D printers (Lipton et al., 2015). Developed by Choco Edge, Choco Creator uses an extruder system that can reshape melted chocolate. In this way, they have significantly reduced raw material consumption and costs. In addition, studies have been conducted at Cornell University on the use of 3D printers in bakery and frying. With the Digital Chocolatier 3D printer, printing of chocolate and sugar foods was successfully achieved with blends containing chocolate and sugar components (Pallottino et al., 2016).

In 2006, Fab @ Home developed a 3D printer that can produce using different printing materials. They used the previous model of the developed device to freeze Nutella and shape the chocolate. In addition, researchers from TNO, Stratasys, Exeter University and many countries have worked on 3D printers to print different types of food. They used different techniques in order to make food pressure by using powder and liquid foods. They melted the chocolate powders by heating them with laser and produced chocolate using SLS technique. They also produced sculptures using candy in 3D printers. They applied the inkjet technique to print the produced sculptures and used alcohol as binders (Lipton et al., 2015). The recipes of food products to be produced with 3D printers must be different from normal recipes. It is an important factor that pre-treatment of selected materials and ensuring thermal stability for post-processing. For this reason, the ChocALM machine 3D printer developed in another study was used for printing chocolate products in a manner that could provide the rheological and post-production thermal stability of the chocolate material. In addition, food materials such as pastry, cheese, humus and chocolate, which are naturally suitable for printing with a 3D printer, have been printed using a piston mechanism. While some of these materials have thermal stability enough to take their final shape without printing after printing, some of these materials do not produce the desired geometry (Fuh et al., 2015).

It is necessary to prepare suitable recipes for printing of 3D raw materials and food raw materials and many studies have been made on the determination of these recipes. In these studies, selective sintering, melt extrusion, room temperature extrusion, electric bed binder jetting and inkjet printing techniques were used to print the prepared recipes (Fuh et al., 2015).

Within the PERFORMANCE project, TNO and Biozoon companies worked on the development and production of special food for the elderly using 3D printers. In their work, they used 3D printers to produce personalized, creative designs. NASA worked on the Small Business Innovation Research project to print food using 3D printer technology at the International Space Station (Lipton et al., 2015). In addition to food printing, NASA has studied vaccines that can be produced with 3D printer technology in the event of an infectious virus outbreak or in general situations (Kietzmann et al., 2015).

Lipton et al. have worked on the creation of new formulations to print cookies with a 3D printer. The cookies that were printed with the printer they used, were fried and managed to keep their final shape after the frying process (Lipton et al., 2010).

In their studies, Van Bommel and Spicer used algae and insects to mix beef and chicken-like products for protein and carbohydrate printing on a 3D printer. They presented their work as an environmentally friendly and sustainable solution to meet growing food demand (van Bommel et al., 2011).

In addition to the traditional chocolate producers such as Dove, Cadbury, Hershey and Ferrero, 3D chocolate printer prototype was produced at Exeter University, and the production of digital products was carried out by going beyond the traditional methods (Jia et al., 2016).

At EXPO 2015, the first 3D pasta printer prototype developed by Barilla Group and TNO was presented. The prototype printer was able to print pasta shapes every 3 minutes at the speed of four items every 3 seconds (Pallottino et al., 2016).

In the study, he developed an appropriate ink composition from citrus fruits using the inkjet technique. The compositions he developed had the ability to penetrate the waxed surfaces of foods such as citrus fruits and succeeded in printing these compositions with a 3D printer. In the study of youth, she developed a 3D printer to print a product with an edible substrate. In the printer he developed, he realized colorized food printing by using a jet printer head containing food colorant. Shastry et al. patented the printer to produce edible food with low-viscosity inks modified with high polarity and water-based glue. In the Inkedibles study, he developed a device prototype that allows printing and edging all edible sheets manually. In their work, they performed printing of products such as edible pens, food signs, cheese leaves, sticky papers, wafer sheets with 3D printer (Fell, 1978).

Lipton et al. used transglutaminase to successfully print a mixture of turkey, scallop and celery food on a 3D printer and to perform cooking and frying after printing, and successfully achieved printing. In his study, Lin worked on the printing of food products made of pizza-like complex materials with a 3D printer and determined the technical printing characteristics required for the printing process (Lipton et al., 2010). In another study, Lipton et al. aimed to produce meat-like products and print them with a 3D printer in order to meet increasing food demand and reduce the use of livestock. In their study, they created a modern Meadow study on stem cells to form a matrix similar to meat (Lipton et al., 2015).

There are studies showing that extrusion-based techniques are more efficient in the production of food products such as chocolate, pasta, pork, cheese and pizza. In these studies, it was emphasized that the products produced should have a smooth structure and prevent the deposition of foodstuffs in the printing process (Slinger et al., 2017). Another study on the extrusion system was conducted at Cornell University. In this study, a printing head based on extrusion system was used to print cake ice cream, processed cheese and sugar cookies with 3D printer and printing of these materials with extrusion was realized. The Netherlands Organization for Applied Scientific Research (TNO) used the extrusion method to print algae and insect mixtures with a 3D printer. Using the Foodini 3D printer, extrusion printer header, the filling and graphic decoration of the surfaces of the food materials have been performed successfully. In their study, performed quality inspection using processed cheese printed with 3D printer. In their study, they showed that hardness of printed cheeses decreased by 49% and showed a higher degree of melting than untreated cheese samples (Liu et al., 2017). Extrusion method, as well as other printer head systems are used in the studies. In the study carried out by TNO, sugar and NesQuik powders were used to print with a complex 3D printer. In their study, they used the sintering method. They also used SLS in the CandyFab project to produce complex geometry pieces from sugar powders. On the other hand, in their study, Southerland and Walters used sugar and starch mixtures to be printed using binding jet technology. Grood and Grood developed a 3D printer using ink jet spraying technique to distribute liquids to the surface of foods and produced prototypes. With the FoodJet printer developed by another company, they used pneumatic membrane nozzles to allow the pouring of edible foods onto a moving object. Willcocks et al. developed edible inks that were harmless to human health and developed printing using 3D ink in order to improve the surfaces of foods such as biscuits, cakes and crackers (Liu et al., 2017).

Chen and Mackley in their study showed that chocolate material can be printed by cold extrusion. In their work, drawn chocolate rolls and sticks have a similar shape (Chen et al., 2006). In their study, Hao et al. used melt stacking modeling method to print chocolate material. In their study, they stated that extrusion speed, nozzle speed and nozzle height parameters from the printer table were effective in product quality in chocolate printing process (Hao et al., 2010). Severini et al. suggested that grain based support structures should be used to prevent precipitation during dough presses (Severini et al., 2016).

As in the printing of chocolate material, various gelling additives must be added to produce complex products using cookie dough, meat and vegetable puree. The most common gelling agents added during 3D printing are gelatin, xanthan gum, starch and alginate. On the other hand, it is suggested that the printing parameters should be optimized during the printing of chocolate, cookie dough, powdered sugar, processed cheese, meat puree, fruit and vegetables with 3D printer and different parameters are used for each product (Dankar et al., 2018). In addition, there are studies on the printing of foodstuffs with variable microstructure and texture properties using 3D printer using pectin-based food inks. In the studies, $CaCl_2$ (Calcium chloride) was added in the pectin and the concentration of the pectin produced was stated to be an important parameter in determining the firmness and strength of the printed object. As a result, it has been shown that sugar and pectin concentrations increase the viscosity and the structure of the product is affected (Vancauwenberghe et al., 2017).

Miller et al. have developed a printing method that uses a 3D printer to create artificial vascular networks in sugars. They have shown that these natural structures are of complex geometry with thick textures. Thus, they were able to produce candy glass filaments ranging in diameter from 0.15 to 1.2 mm (Kinstlinger et al., 2016).

Lille et al. were able to print high-nutritional snack products with a 3D printer in terms of protein, starch and fiber. PepsiCo has started using 3D printers in potato chips manufacturing to reduce costs and produce healthier products (Lille et al., 2018). Bocusini has developed print recipes specific to their designs. They printed products such as octopus mashed potatoes with a 3D printer. In addition, they were able to print soy and gluten-based ingredients with a 3D printer that tasted meat-like for vegetarian individuals (Dankar et al., 2018).

While the first 3D printer was developed with a single extruder system, 8 extruder heads were added, and it was developed to allow printing of products such as chocolate and cheese. In addition, Cadbury and Hao from the University of Exeter have studied the use of chocolate on a 3D printer. They were able to provide all the controls from the tempering of the chocolate to the storage accuracy, thus producing the first 3D chocolate printer according to the demands of the customers. In the prototype they developed, they produced production using extrusion type 3D head which melted under temperature (Lille et al., 2018).

In addition, studies have been made to make pizza printing with 3D printer. In these studies, a special pizza recipe was created for pizza production. For pizza printing on a 3D printer, instead of adding water when preparing the pizza dough, the product prepared from paste-like tomato sauce was added. Before the extrusion process, the cheese was melted by heating at 150°C and allowed to cool on the sauce surface. In this way, instead of traditional methods for pizza production, 3D printing technology has been used to produce production in a shorter time (Lille et al., 2018).

Goyanes et al., using melt agglomeration modeling technique, produced tablets containing patient-specific drug doses. In addition, in the medical field, studies are being carried out on bio-printers in order to produce new ones instead of disrupted tissues. In these studies, dome-shaped porous adipose tissue structures, called biomimetic 3D tissue printing, were produced with 3D printer technology (Goyanes et al., 2014).

Boland et al. have worked on the ability to produce customized foods for personalized nutrition and have developed and patented the POSIFood system. In their study, Van Cauwenberghe et al. showed that by adding bovine serum albumin during 3D printing, the pores in the printed products increased. Severini et al. succeeded to produce cereal based food products with 3D printer and showed that printing parameters were important in determining the properties of the food such as structure and rheology after production (Vancauwenberghe et al., 2017).

In the printing studies using wheat dough with 3D printer, the necessity of optimizing the dough formula was emphasized. They showed that the dough formulation affects the rheological structure, texture and shape of the product after printing. Therefore, they have optimized the formulation of wheat dough primarily by changing the wheat flour type, moisture content and proportions of the additives used in the mixture. They compared the changes in the viability, color, texture and moisture content of probiotics in wheat flour and determined the development parameters for printing probiotic dough type products with 3D printers (Liu et al., 2018). Studies have shown that lemon juice gel should be used in 3D printer printing of mashed potatoes and fruit-based snacks, a starch-containing product (Liu et al., 2018).

Takagishi et al. worked on printing 3D edible film and chocolate products. In their study, they stated that 3D electrostatic inkjet technique is suitable for these products and they realized prototype production (Takagishi et al., 2018).

Puscha et al. have designed a large volume extruder design and prototype for printing biopolymers, hydrogels, pastes and epoxy materials in 3D printers (Puscha et al., 2018).

Sun et al. classified the printability of foodstuffs in 3D printers into three categories. They have identified these as natural printable foodstuffs, traditional non-printable foodstuffs and alternative components (Fuh et al., 2015). Natural printable materials have been identified as materials which do not require the addition of flowability enhancing materials when exiting the extruder nozzle tip. They stated that materials such as cream cheese, cheddar cheese, vegemite and marmite have enough hardness to maintain their structure during printing and are suitable for printing with a 3D printer. On the other hand, materials such as Greek yogurt and ketchup are not suitable for printing with 3D printer since they cannot keep their shape after printing. Soy and Forkes, in the Au Gratin project of Insect food, worms, crickets and insect protein-based flour made from pupae of flour, butter, chocolate, cream cheese and spices, such as food, successful 3D printing process has been completed (Dick et al., 2019). Severini et al. showed that 1% fish collagen should be added in the printing process of fruits and vegetables to increase fluidity. In addition, Severe et al., In another study, worked by producing milled larvae of yellow maggots and enriched wheat flour dough to produce snacks with 3D printers. They stated that the addition of milled insects at a certain micro value softens the dough, the dough swells over time and the size of the printed products increases (Derossi et al., 2018).

One of the most important problems when printing chocolate material on a 3D printer is that chocolate flows very quickly through the nozzle tip in fluid form. Mantihal et al, by adding magnesium stearate (Mg-ST) into the grated chocolate, managed to reduce the sliding effect of chocolate in the extruder. They also added different additives such as natural plant sterols in powder form to the chocolate. In this way, they showed that the benefits of vegetable sterols are very high and the chocolate's printability and nutritional value are increased by adding vegetable sterols to chocolate (Mantihal et al., 2019).

Zeleny and Ruzicka have developed a commercial 3D printer using the melt stack modeling technique for thermoplastics for printing foodstuffs (Zeleny et al., 2017). Bégin-Drolet et al. have developed the design and prototype of an ultra-fine pitch screw with a worm gear mechanism for printing food, and a print head that will deliver the syrup into the piston. They added an air cooling system to the extruder tip they developed to solidify the sugar material they use quickly (Bégin-Drolet et al., 2017). Zhao and his colleagues have developed a software and 3D printer system design and prototype production that can print face to face using photos of individuals on food (Zhao et al., 2018).

In the light of the information given above, there are many studies in the national and international literature on the use of 3D printers in the food field, production of foods such as chocolate, pastry, cake, pizza, determination of ideal parameters and 3D printer performances in the production of food products. However, there are few studies on the printability of different chocolate types with a single 3D printer, the printing of the traditional delight types with a 3D printer and the comparison of the extruder types used for food products.

The aim of this thesis is to be able to print the Turkish delight dessert and chocolate derivatives with 3D printer, to determine the ideal parameters for the printing of foodstuffs and to determine the printing performances of different extruder types.

CHAPTER III

MATERIALS AND METHODS

3.1 Material

The materials used in the thesis are listed below.

- Mold chocolate types (Dark / Milky / White)
- Delight (Turkish delight, Custard delight)

3.1.1 Composition of Chocolate Varieties

The composition of the chocolate varieties used in this study are given in the Table 3.1.

Table 3.1 Dark, milk and white chocolate compositions

Component	**Dark chocolate (%)**	**Milk chocolate (%)**	**White chocolate (%)**
Sugar	39-41	47-49	47-49
Cocoa mass	53-60	7-8	-
Cocoa butter	6-7.5	25-26.5	31-33
Milk powder	-	21-21.5	22-29
Lecithin	0.25-0.3	-	0.49-0.50
Sodium carbonate	0.15	-	
Vanilla Extract	0.03	-	0.01

3.1.2 Composition Properties of Delight Varieties

The compositions of the types of delight used in this study are given in the Table 3.2.

Table 3.2 Turkish and custard delights compositions

Component	Turkish delight (%)	Custard delight (%)
Sugar	48-50	12-13
Water	45-50	-
Lemon juice	0.2-03	-
Starch	6-7	4-5
Gypsum	1.2	-
Milk	-	75-77.5
Vanilla	-	0.3-0.35
Flour	-	4.5-5
Margarine	-	3-3.5

3.1.3 Choice of Chocolate Samples

The chocolates used in the study were ready-made chocolates produced by brands such as Nestle / Ülker / Milka sold in the market and can be supplied from any food market or supermarket. These molds were melted and reshaped with the help of the 3D printer.

3.1.4 Delight Production

In this study, delight was supplied from a local market (İmren Lokumları) as dough of delight and custard delight, which means, ready-made doughs were used.

3.2 Method

The methods used in this study were the constructed 3D printer together with two different extruders.

3.2.1 Method Specifications

3.2.1.1 3-Dimensional Food Printer

The 3D printer used in the thesis was the 3D printer using FDM technique. Ideal for the use of solid and semi-liquid foods, the FDM printer features a precision temperature-controlled extruder system.

The technical specifications of the 3D printer where the experimental work performed were listed below.

- 3D printer size: 425mmx445mmx455mm
- 3D printer weight: 20 kg
- Nozzle diameter: 1.5 mm
- Nozzle volume: 50 ml
- 4 Nema17 stepper motor
- 1 pc 40x40mm 20W 12V fan

The 3D printer's construction design consists of an aluminum-cooled printer tray, cooling fan, cable carrying system, gantry rail system, digital display unit and plexi glass covering the perimeter of the device. The body of the printer is made of 7075 and 6061 series aluminum profiles and has a completely closed production area. The 3D printer used includes a high propulsion, hot-cold zone design and a homogeneous flow profile filament extrusion system. Core XY gantry system was used in the motion system of the 3D printer used. The Core XY system features high accuracy and precise positioning. In addition, with double belt drive system and precision linear rail and slide mechanism, head and table movement was achieved with high precision and accuracy. The actual view of the 3D printer used in Figure 3.1 is shown in Figure 3.2.

Figure 3.1 The 3D printer used in this study

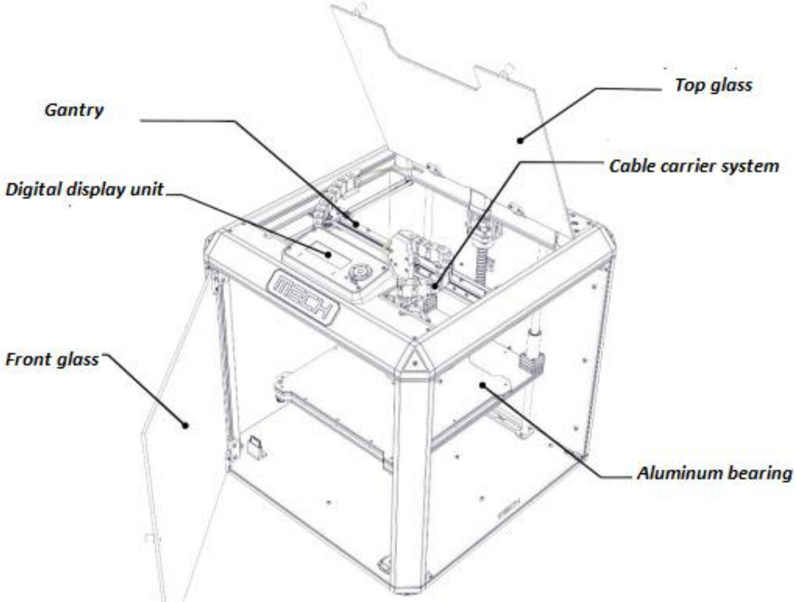


Figure 3.2 Schematic view of the 3D printer.

3.2.1.2 Development of the Extruder Types

In this study, two types of extruder systems were designed and produced for the printing of chocolate and delight products in 3D printer. The first extruder system consists of a glass body, a plunger, a screw shaft and a high-resolution motor based on the operating principle of the piston mechanism. In this design, semi-fluid chocolate and delight products were placed in the glass piston body and fixed in a steel body. In the glass piston body, the piston head compresses the semi-fluid food product by converting the rotational movement from the motor to linear movement with the screw shaft, creating pressure and allowing the food product to flow through the nozzle at the end of the glass tube. Figure 3.3 shows a schematic illustration of the first extruder design, and Figure 3.4 shows parts of the first extruder design.

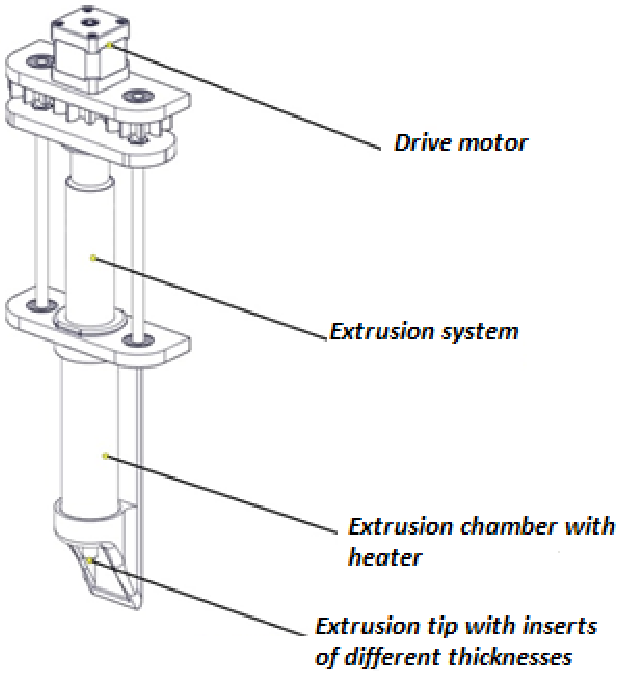


Figure 3.3 Schematic view of the first extruder design.

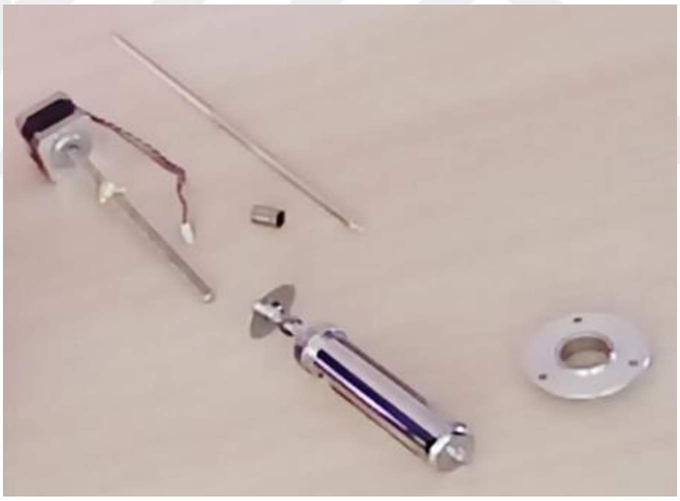


Figure 3.4 The first extruder design real parts.

The second extruder design has the same working principle as the extruder systems in conveying products by auger shaft or in plastic injection molds. The second extruder design consists of plastic chamber, pre-cut blades, metal heated nozzle, high resolution stepper motor, cooling fan, brass nozzle parts. In the second extruder design, chocolate was cut into small pieces and homogeneously melted in the extruder. The pre-cut blades used cut the large chocolate pieces into smaller pieces and make the heating process faster. After the heated chocolate melts, it was carried by gravity by ball screw to the brass nozzle at the end of the extruder. The product coming out of the nozzle is then transferred to the printer tray and the food product is printed. One of the biggest problems in printing food products with a 3D printer is the precipitation after printing. To prevent this, a cooling fan was installed at the end of the extruder. Furthermore, to speed up the cooling process, the tray of the 3D printer was replaced with an aluminum plate and a cooling fan which was added to the bottom of the printer. Thus, the problem of precipitation of the product after printing was eliminated. Figure 3.5 shows the model view of the parts of the second extruder design and Figure 3.6 shows the assembly of the second extruder design.

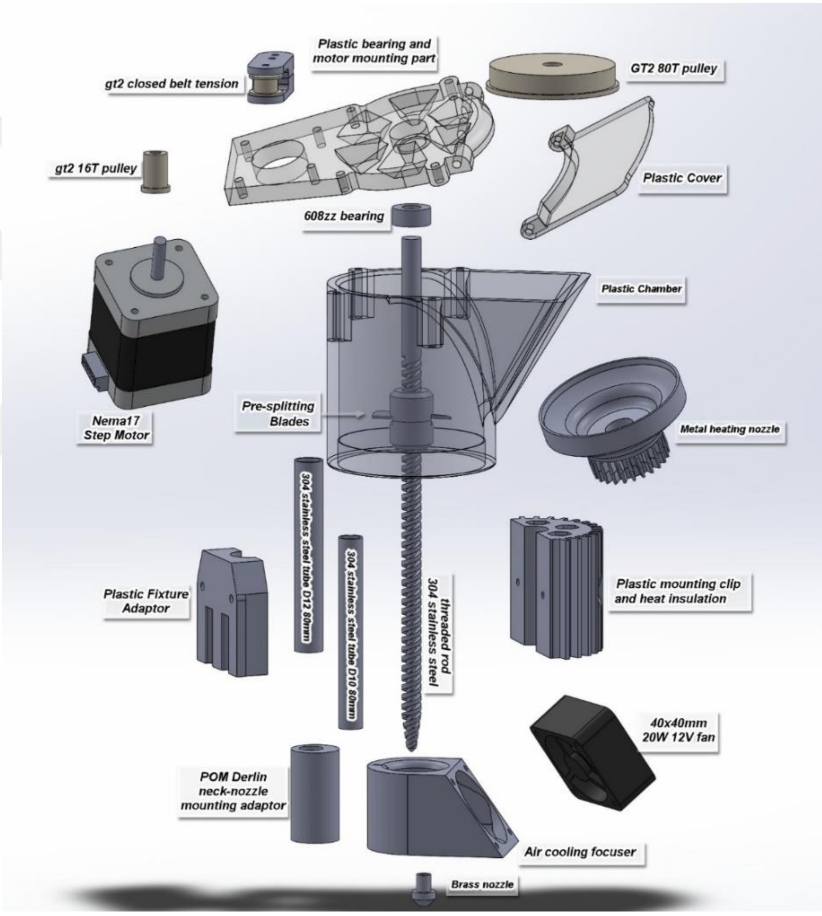


Figure 3.5 Second extruder design parts model view.

Figure 3.6 Second extruder design assembly appearance.

3.3 Analysis

3.3.1 Sensory Analysis of Chocolate Products

In this study, sensory analysis of chocolate printed with a 3D printer was performed with 10 pre-determined panelists. Chocolate samples produced by traditional methods and chocolate samples printed with a 3D printer were given to panelists and asked to compare them. Panelists tried chocolates produced by both types of production methods and stated their opinions in pre-prepared questionnaires. Panelists were asked to rate chocolate samples according to texture, appearance, taste, smell and color characteristics in the surveys. According to the scoring results, the differences between chocolate produced by traditional methods and chocolate products printed with a 3D printer were determined.

3.3.2 Sensory Analysis of Delight Products

In this study, sensory analysis of delights printed with a 3D printer was performed with 10 pre-determined panelists. Samples of delights produced by traditional methods and samples of delights printed with a 3D printer were given to panelists and asked to compare them. Panelists tried both types of delight and produced their opinions in pre-prepared questionnaires. Panelists were asked to rate the samples of the delight in the questionnaires according to their texture, appearance, taste, smell and color characteristics. Based on the scoring results, the differences between traditional delights and delights products printed with a 3D printer were determined.

3.4 Preparation of the 3D Printer for Printing

The 3D food printer of this thesis was adjusted according to the parameters determined for the printing of chocolate and delight products. The printing parameters used in the printing of chocolate and delight products are given in Table 3.3. These parameters have a direct impact on the quality and geometric shape of the printed products.

Table 3.3 Printing parameters for 3D printer

Nozzle temperature
Melting temperature of chocolate
Printing temperature of delight dough
Print speed
Extrusion temperature
Diameter of nozzle
Bed temperature
Freezing temperature of printed food
Movement speed
Layer thickness
Nozzle flow rate
Cooling fan temperature

The values of the parameters used, which are given in Table 3.3, vary in the geometric shape to be printed due to the variety of raw materials to be used. When printing chocolate and delight products on a 3D printer, the printing parameters are different for each product. In addition, the models used as geometric shapes are available from the Thingiverse software, which is a free website used for sharing user-generated digital design files. The solid models used in this study were downloaded from the Thingiverse site. It was then transferred to Cura software and used.

3.5 Preparation of Printing Materials

3.5.1 Chocolate Samples

In his thesis, 3 different types of chocolate were used, including milk, dark and white chocolate, for printing chocolate products on a 3D printer. These chocolates, which are obtained from supermarkets, are divided into small pieces and placed in beaker. The chocolates placed in the beaker were melted in a hot water bath until the melting temperatures reached 46°C and mixed homogenously. Then the melted chocolate product was placed in the extruder of the 3D printer. Figures 3.7, 3.8, and 3.9 show the melting process of milk chocolate, dark chocolate and white chocolate respectively.

(a) (b)

Figure 3.7 Melting process of milk chocolate, a) dividing into small pieces, b) Melt state after hot water bath.

(a) (b)

Figure 3.8 Melting process of dark chocolate, a) dividing into small pieces, b) Melt state after hot water bath.

(a) (b)

Figure 3.9 Melting process of white chocolate, a) dividing into small pieces, b) Melt state after hot water bath.

The melting process with hot water bath was used for the first extruder design. Since this extruder has a piston mechanism in its design, the extruder has been melted out of the glass chamber by the process of melting, and the extruder has been placed in the glass chamber manually. Figure 3.10 shows the first extruder design mounted on a 3D printer and placed melted chocolate into extruder. In the second extruder design, the heating system was carried out directly within the extruder and since the cutting process was done with the front blade, the melting process was not applied with a hot water bath.

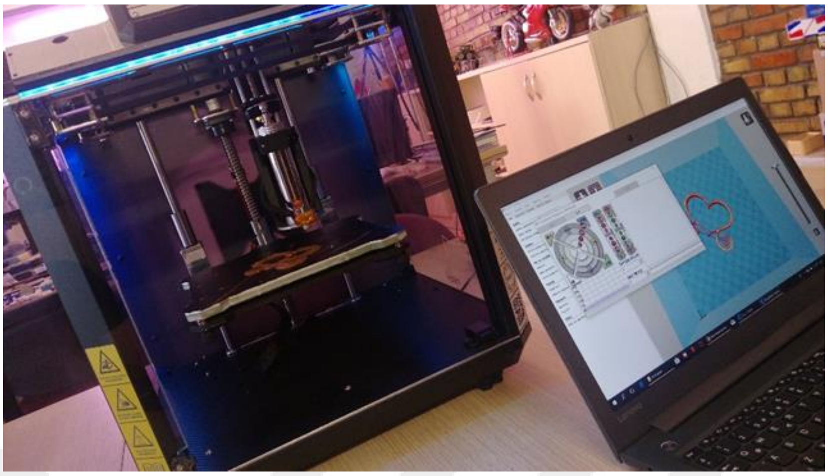


Figure 3.10 The first extruder design as assembled to the 3D printer.

Printing parameters are entered in the Cura software screen to print the melted chocolate placed in the extruder. After the printing parameters are entered, the feed is fed directly into the system for production. Figure 3.11 shows the print parameters screen of the Cura software and the manual move 3D printer screen.

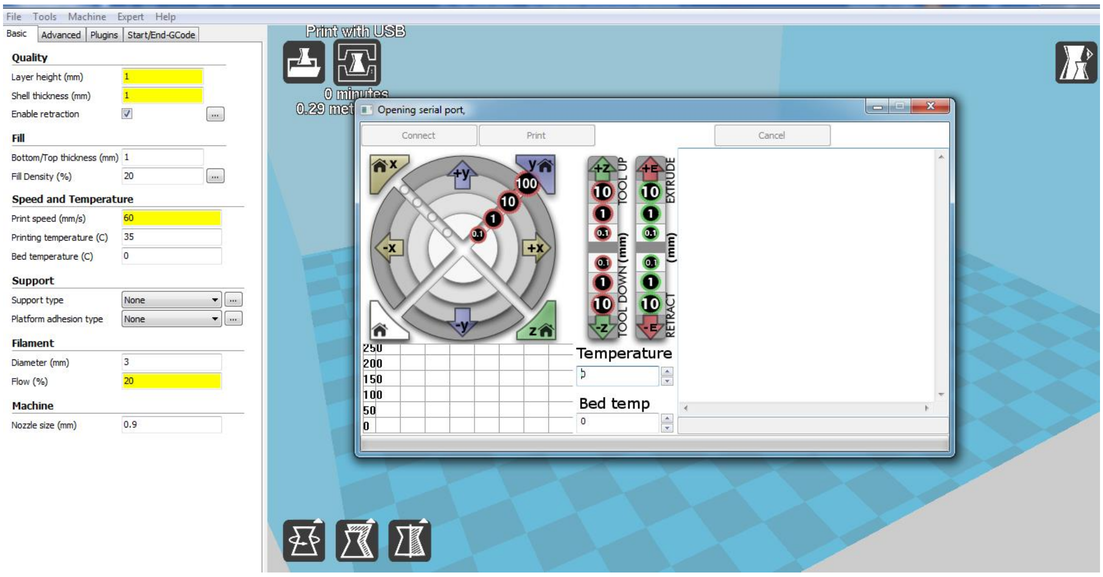


Figure 3.11 Cura software print screen.

3.5.2 Delight Samples

3.5.2.1 Turkish Delight Samples

It was observed that the Turkish delight dough was suitable for printing at approximately 60°C and was then placed in the extruder chamber. The same process procedure was repeated for the first and second extruder designs. The Turkish delight dough used is shown in Figure 3.12. In addition, food additive dyes were added to color the delight. These are yellow (E107), green (E142), blue (E133), red (E128) food additive dyes.

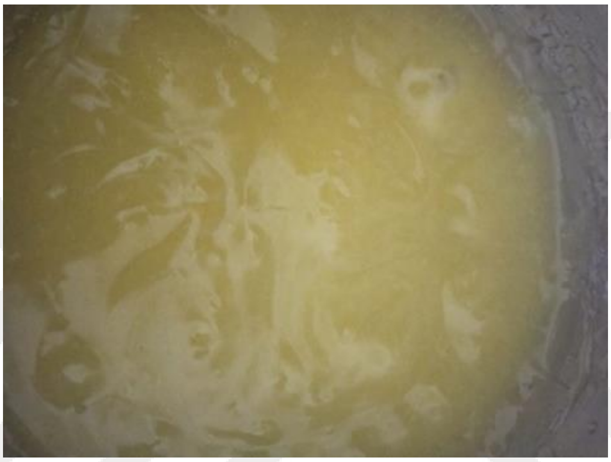


Figure 3.12 Turkish delight dough used.

3.5.2.2 Custard Delight Samples

The other type of delight used in the study is custard. It was observed that the custard delight dough was suitable for printing at approximately 65°C and was then placed in the extruder chamber. Figure 3.13 shows the custard delight dough used. In addition, food additive dyes were added to color the delight. These are yellow (E107), green (E142), blue (E133), red (E128) food additive dyes.

Figure 3.13 Used custard delight dough.

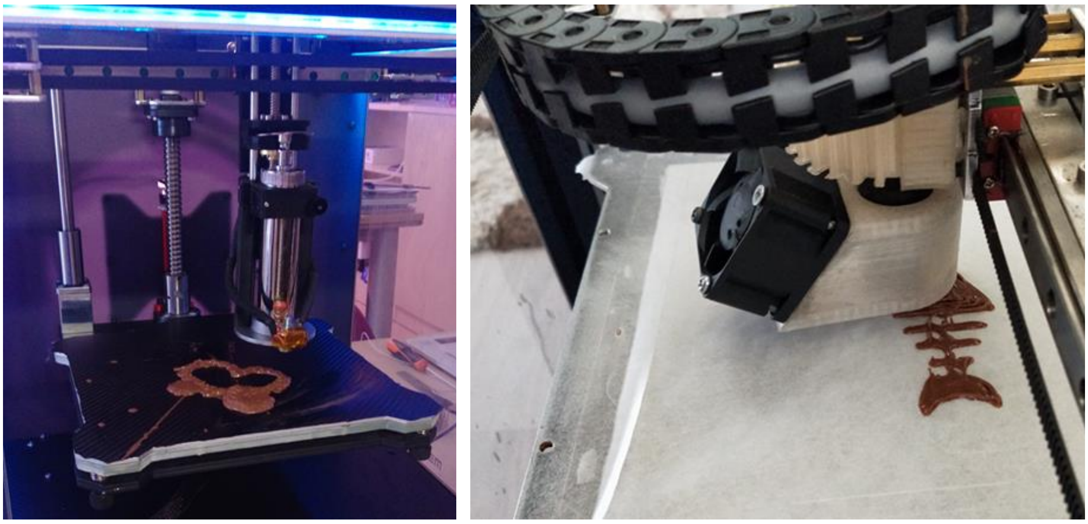
CHAPTER IV

RESULTS AND DISCUSSION

4.1 Experimental Results

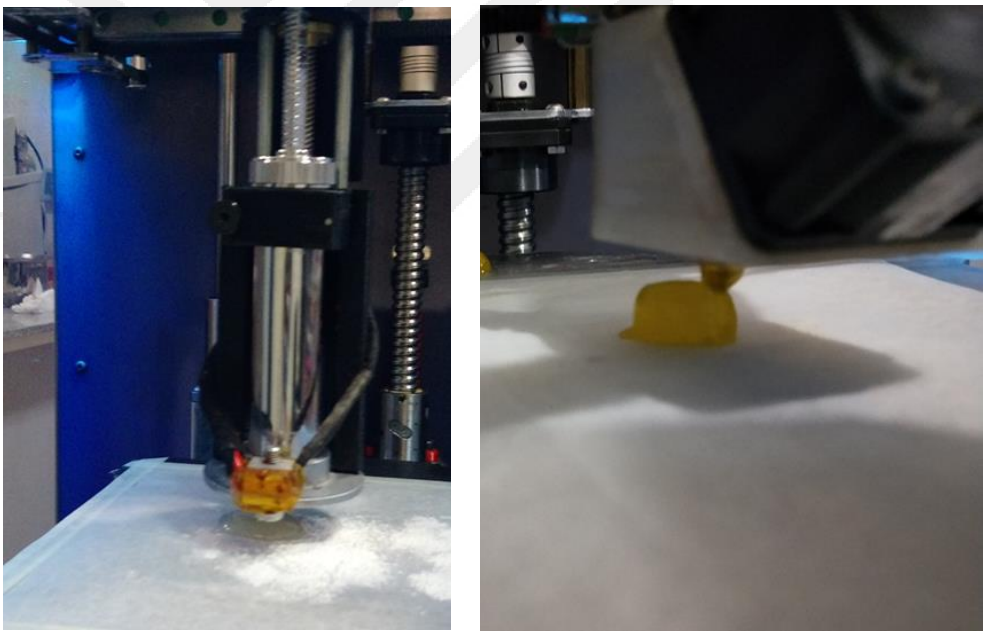
Because the rheological and mechanical properties of chocolates and delights are very different, different printing parameters were tested and pre-experiments were carried out to determine the ideal parameters and to determine which extruder design should be used for these food products.

In the pre-printing experiments with 3D printer, extruder of the first design with piston mechanism was used to determine the fluidity of the products at ideal temperature and viscosity ranges. While the first design extruder used to print dark chocolate and custard delight successfully, errors occurred in milk and white chocolate and Turkish delight products. The first design extruder type with piston mechanism was used to determine the fluidity of products at ideal temperature and flow ranges in the preliminary printing experiments with a 3D printer. While printing only dark chocolate and custard delight with the first design extruder is performed successfully, errors occurred in printing milk and white chocolate and Turkish Delight products. Because the extruder system with piston mechanism was not enough for the printing of these products, whose structure and contents are different. The reason is both the deficiencies in the mechanism and the failure of flow control due to these deficiencies. These deficiencies include the lack of enough sensors to control temperature change, the lack of cooling system, the freezing of the product in the chamber and the lack of an apparatus to ensure homogenous mixing. Due to these deficiencies, some important problems occurred during the printing of the products. These are: problems such as freezing the product in the chamber while waiting for the product to come to the appropriate consistency for printing and causing clogging at the nozzle end, deposition and accretion of the product because it cannot be cooled during printing. Moreover, chocolate varieties had to be used by melting in order to be printed. Furthermore, we did not have the chance to use the product by melting it homogenously in the chamber. Because when we heated the chamber, only the part at the tip of the nozzle melted and the other parts took longer to melt. For this reason, increasing the temperature has been tried, but this has caused the product to flow more from the nozzle end and create clutter during printing. There was also no cooling system in the first mechanism. Therefore, printing of foods was studied by reducing the pressure speed and ambient temperature in order to be able to shape. In this case, healthy shapes made it difficult to obtain. Because of these, processing and re-solidification time is fast, while only dark chocolate and custard delight printing can be obtained in the piston mechanism, printing of other products was not possible. So, it was necessary to develop the second extruder system. In the screw system intended to be designed, the product would not freeze in the chamber and would not cause clogging. For this reason, pre-cutting blades were added in order both to mix homogenously and to use the product by melting it into pieces. This allows easier flow control without subjecting the product to high temperatures and disrupting the structure of the product. Another criterion for printing foods was that there was no deposition and accretion in the product during printing of food products in this new system. To avoid these problems, a cooling fan was added to the end of the screw extruder system to allow the product layers to freeze in a controlled manner. And this fan was operated by gradually reducing the ambient temperature due to the waiting time of the product in the chamber. In this way, shapes in the desired structures could be obtained and prints of Turkish delight and milk and white chocolate could be obtained. In Figures 4.1 and 4.2, print trials of milk chocolate and Turkish delight in both extruder types are given. The pictures here show that the trials in the first mechanism failed and the trials in the second mechanism succeeded.



(a) (b)

Figure 4.1 Milk chocolate printing in the two types of extruders.
(a) Piston type extruder (b) Screw type extruder.



(a) (b)

Figure 4.2 Turkish delight printing sample in the two types of extruders,
(a) Piston type extruder, (b) Screw type extruder.

Many printing experiments have been carried out to print chocolate and Turkish delight with the 3D printers. The ideal printing parameters were determined from these experiments and these parameters are given in Tables 4.1 through 4.5.

4.1.1 Printing Results of Chocolate Varieties

4.1.1.1 Milk Chocolate

The most important parameter to be determined in the 3D printer printing tests for milk chocolate is the printing temperature. After conducting various experiments, a melting temperature of 38°C and solid factor temperature 29°C were determined to be ideal for chocolate printing. By cooling the chocolate product to 29°C, it was observed that the product obtained in the 3D printer printing experiments did not cause precipitation and stable product geometry was obtained.

Another important parameter is the print speed. In the printing of the milk chocolate, precipitation was the case for high speeds while freezing within the extruder was observed for low speeds printing. Therefore, the ideal print speed parameter has been determined using various print speeds. Show in Table 4.1.

Another parameter that affects the geometry of the product is the freezing time, which varies entirely with the composition of the chocolate used. For these reasons, considering the printing gaps that may occur after each layer during the printing process, the operating capacity of the cooling fans is gradually reduced, to obtain the most favorable printing.

In addition to the basic parameters for milk chocolate, precise printing parameters such as layer height, fill rate, shell thickness were also tried at different values. After serial trials, the ideal printing parameters determined for milk chocolate are given in Table 4.1. The example of milk chocolate printed with 3D printer using the basic and precise printing parameters given in Table 4.1 is shown in Figure 4.3.

Table 4.1 Print parameters for milk chocolate

Parameter	**Unit**	**Value**
Layer height	*mm*	0,9
Shell thickness	*mm*	1
Bottom/Top thickness	*mm*	1
Print speed	*mm/s*	40
Printing temperature	*°C*	29±2
Bed temperature	*°C*	18
Nozzle size	*mm*	0,9
Retraction speed	*mm/s*	30
Initial layer thickness	*mm*	0,3
Travel speed	*mm/s*	100
Bottom layer speed	*mm/s*	25
Infill speed	*mm/s*	50
Top/Bottom speed	*mm/s*	30
Outer shell speed	*mm/s*	30
Inner Shell speed	*mm/s*	50
Cooling fan	*%*	100-50

Figure 4.3 Milk chocolate print sample.

4.1.1.2 Dark Chocolate

After milk chocolate experiments, printing experiments of dark chocolate with 3D printer were performed. It differs from milky and white chocolates due to different compositions.

The melting temperature of the dark chocolate is lower than the white chocolate variety but a few degrees higher than the milk chocolate. This is because it contains less sugar and cocoa butter. This causes a difference in both the viscosity and the melting temperature of the product.

As a result of the experiments, it was determined that melting up to 42°C and cooling to 30°C were the most suitable values for dark chocolate printing. By cooling the chocolate to 30°C, it was found that the product obtained in the 3D printer printing experiments did not cause precipitation and stable product geometry was obtained.

At the same time, the cooling fan at the extruder outlet was gradually lowered and it was initially operated at 80% capacity, reduced to 50% during the printing process. Gradual lowering of the cooling fan prevented the settling or agglomeration of the product printed with the 3D printer.

After various experiments, the ideal printing parameters, determined for dark chocolate, are given in Table 4.2. Dark chocolate printed with the 3D printer using the basic and precise printing parameters given in Table 4.2 is shown in Figure 4.2.

Table 4.2 Print parameters for dark chocolate

Parameter	Unit	Value
Layer height	*mm*	0,9
Shell thickness	*mm*	1
Bottom/Top thickness	*mm*	1
Print speed	*mm/s*	50
Printing temperature	*°C*	30±2
Bed temperature	*°C*	18
Nozzle size	*mm*	0,9
Retraction speed	*mm/s*	30
Initial layer thickness	*mm*	0,3
Travel speed	*mm/s*	100
Bottom layer speed	*mm/s*	25
Infill speed	*mm/s*	50
Top/Bottom speed	*mm/s*	30
Outer shell speed	*mm/s*	30
Inner Shell speed	*mm/s*	50
Cooling fan	*%*	80-50

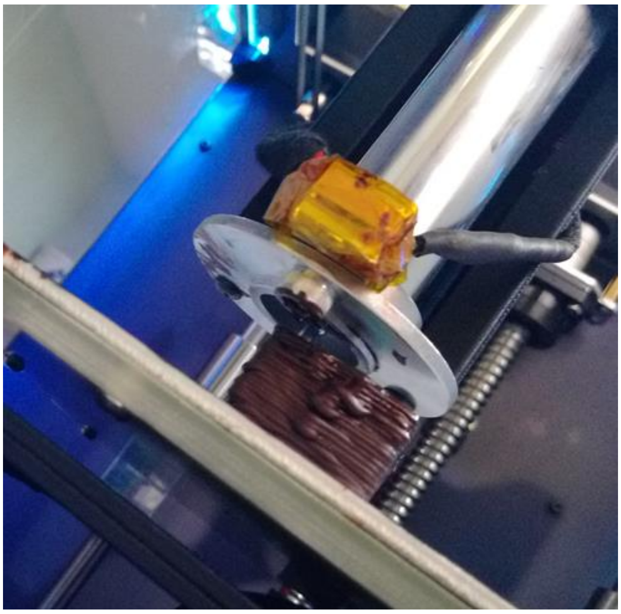


Figure 4.4 Dark chocolate print sample.

4.1.1.3 White Chocolate

Finally, white chocolate samples were printed with 3D printer. Since white chocolate contains higher quantity of cocoa butter than other chocolate varieties, it melts at higher temperatures. On the other hand, while melting at high temperature, the melting temperature was increased in a controlled manner in order to prevent the burning of dairy products.

The ideal melting temperature for white chocolate was 48°C and the printing temperature was 38°C. In addition, white chocolate freezes quickly due to the high fat it contains. Therefore, waiting for cooling in other chocolate types was not performed for white chocolate and was placed directly in the extruder.

Another important point when printing white chocolate with a 3D printer is the freezing temperature. Due to the high fat content, the freezing process is quick. For this reason, the capacity of the cooling fans in the 3D printer was started at 60% and gradually reduced to 30% during the printing process. The printing speed used for white chocolate is faster compared to other types of chocolate due to its rapid freezing.

As a result of various trials, the ideal printing parameters were determined for white chocolate (given in Table 4.3). White chocolate printed with the 3D printer using the basic and precise printing parameters, (given in Table 4.3) is shown in Figure 4.5.

Table 4.3 Print parameters for white chocolate

Parameter	**Unit**	**Value**
Layer height	*mm*	0,9
Shell thickness	*mm*	1
Bottom/Top thickness	*mm*	1
Print speed	*mm/s*	60
Printing temperature	*°C*	38±2
Bed temperature	*°C*	18
Nozzle size	*mm*	0,9
Retraction speed	*mm/s*	30
Initial layer thickness	*mm*	0,3
Travel speed	*mm/s*	100
Bottom layer speed	*mm/s*	25
Infill speed	*mm/s*	50
Top/Bottom speed	*mm/s*	30
Outer shell speed	*mm/s*	30
Inner Shell speed	*mm/s*	50
Cooling fan	*%*	60-30

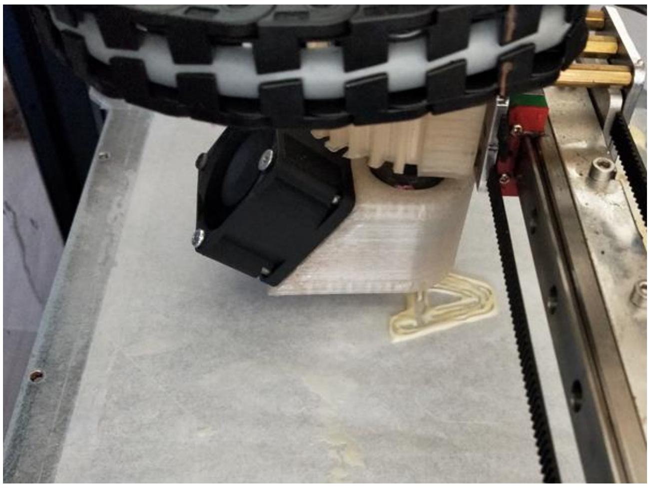


Figure 4.5 White chocolate print sample.

4.1.2 Printing Delight Varieties

4.1.2.1 Turkish Delight

After the printing of the chocolate varieties, the experiments for printing the Turkish delight with the 3D printer were started. In these experiments, traditional Turkish delight was first printed with 3D printer. Turkish delight could not be printed in the experiments carried out with the first extruder design piston mechanism extruder. Since Turkish delight flows through the nozzle end of the piston system quickly, we failed in printing. However, in the screw system, the product flow was slower and could be controlled by providing control.

Turkish delight printing experiments were performed by converting the extruder system to the second design ball screw system. In Turkish delight production, the dough of Turkish delight is cooked in open custard and therefore it can be heated up to 140°C while mixing. The dough of Turkish Delight produced in local market is manufactured at 140°C. The delight dough produced at this temperature was taken and kept until the temperature was lowered to 80°C. Then, the temperature of the delight dough placed in the extruder chamber was reduced to approximately 60°C with continuous stirring and printed at 60°C with 3D printer.

The most important parameter in the printing of Turkish delight with 3D printer is the cooling, as no melting is applied, as is the case with chocolate. Due to the high temperature of the dough, the cooling fans both at the extruder end and under the table were operated with 100% capacity. As a result of the different experiments, the ideal printing parameters determined for Turkish delight are given in Table 4.4. The example of Turkish delight printed with 3D printer using the basic and precise printing parameters given in Table 4.4 is shown in Figure 4.6.

Table 4.4 Turkish delight printing parameters

Parameter	Unit	Value
Layer height	*mm*	0,9
Shell thickness	*mm*	1
Bottom/Top thickness	*mm*	1
Print speed	*mm/s*	50
Printing temperature	*°C*	60±2
Bed temperature	*°C*	18
Nozzle size	*mm*	0,9
Retraction speed	*mm/s*	30
Initial layer thickness	*mm*	0,4
Travel speed	*mm/s*	100
Bottom layer speed	*mm/s*	25
Infill speed	*mm/s*	50
Top/Bottom speed	*mm/s*	30
Outer shell speed	*mm/s*	30
Inner Shell speed	*mm/s*	50
Cooling fan	*%*	100-60

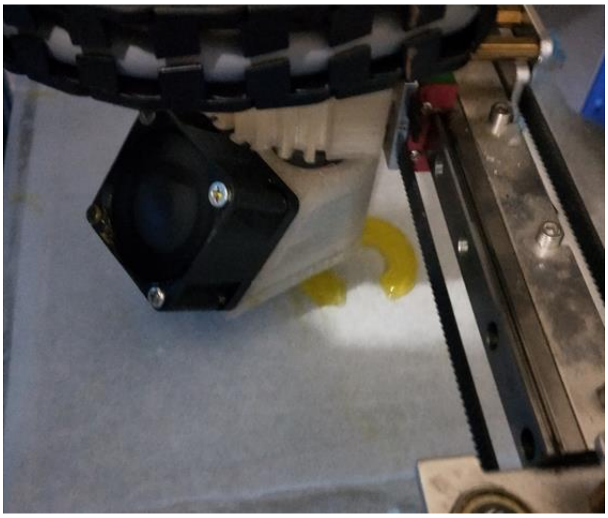


Figure 4.6 Turkish delight print sample.

4.1.2.2 Custard Delight

After the printing of the traditional Turkish delight with a 3D printer, printing experiments of the custard delight (also known as Sultan delight) were started. The temperature of about 65°C is enough for the printing with 3D printer of the custard delight. At 65°C, the dense custard delight was placed directly in the extruder and started printing at a 3D printer. A piston extruder system was used for custard delight printing and successful prints were obtained.

The most important parameter for the custard delight, which has an intense consistency like putty, is the cooling parameter. The printing speed is higher than that of Turkish delight, as the tempering temperature is low and goes into cooling immediately on the tray. In addition, no heating was required during the printing process, and the cooling fans were used at the lowest capacity since they cool down quickly.

As a result of different experiments, the ideal printing parameters determined for custard delight are given in Table 4.5. An example of a custard delight printed with a 3D printer using the basic and precise printing parameters given in Table 4.5 is shown in Figure 4.7.

Table 4.5 Custard delight printing parameters

Parameter	Unit	Value
Layer height	*mm*	0,9
Shell thickness	*mm*	1
Bottom/Top thickness	*mm*	1
Print speed	*mm/s*	80
Printing temperature	*°C*	65±2
Bed temperature	*°C*	18
Nozzle size	*mm*	0,9
Retraction speed	*mm/s*	30
Initial layer thickness	*mm*	0,4
Travel speed	*mm/s*	100
Bottom layer speed	*mm/s*	25
Infill speed	*mm/s*	50
Top/Bottom speed	*mm/s*	30
Outer shell speed	*mm/s*	30
Inner Shell speed	*mm/s*	50
Cooling fan	*%*	50-30

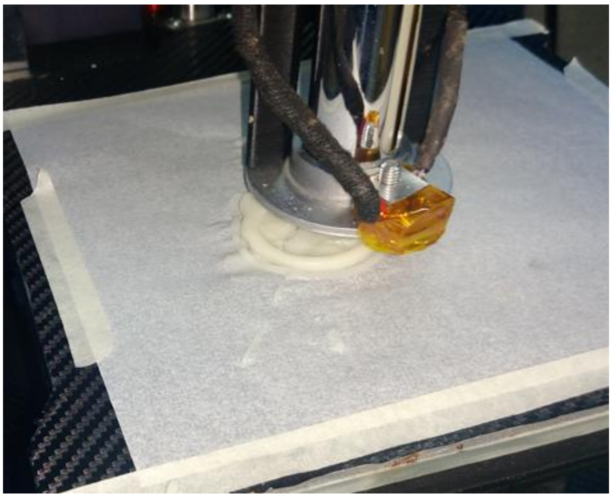


Figure 4.7 Custard delight printed sample.

4.2 Discussion

4.2.1 Discussion of Chocolate Varieties

4.2.1.1 Milk Chocolate

Milk chocolate contains sugar, cocoa liquor, cocoa butter and milk powder (Glicerina et al., 2016). Due to the milk, it becomes hypersensitive to heat and easily burns into a perishable product. Therefore, more controlled temperatures need to be used to melt-reshape the milk chocolate. In addition, milk chocolate melts more quickly than dark and white chocolate. Due to its composition, the printing temperature for white chocolate was to determine as 29°C, and the printing temperature is lower than those of dark and white chocolate.

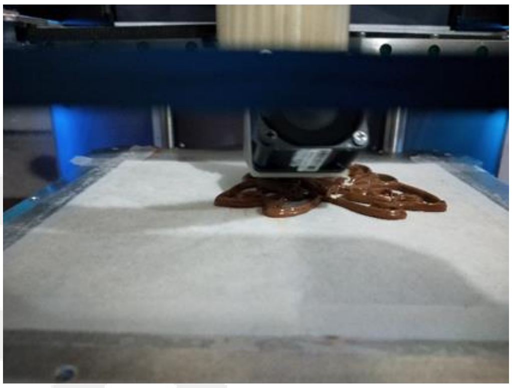
Milk chocolate has a high viscosity due to its high content of sugar (Glicerina et al., 2016). The first design piston extruder system was used for the printing of milk chocolate, but the result was the production of defective products. This is because precise pressure control cannot be achieved in the first design piston extruder system for milk chocolate with high viscosity and fluidity and the flow rate of milk chocolate cannot be controlled by the piston system. Due to the lack of precise pressure control, milk chocolate was kept inside the extruder to reduce viscosity, but the holding process caused the chocolate to start freezing from the center, and at the end of the freezing process, the nozzle at the end of the extruder became clogged..

On the other hand, chocolate is not a food product suitable for very fast cooling and heating. This is because, if the temperature change is fast, the heat released in the chocolate during the printing process with the 3D printer cannot be removed, it stays inside, and then it emerges on the surface and causes fat-bloom. This is not preferred for chocolate because of its bad appearance. For all these reasons, the first design piston mechanism extruder system is not suitable for printing milk chocolate with 3D printer and the second system is the most suitable system for milk chocolate extruder.

As milk chocolate is a soft chocolate, the ambient temperature is lowered as much as possible during printing and the cooling fans are operated at maximum capacity to achieve the desired final geometric shape. The most successful results for printing milk chocolate with a 3D printer were achieved with the second design screw type extruder.

Figure 4.8 shows the appearance of the butterfly motif at the time of printing on a 3D printer using milk chocolate. The butterfly motif shown in Figure 4.8 was obtained by using the basic and precise printing parameters given in Table 4.1. In addition, although the butterfly motif used was of complex geometry, the ideal printing parameters were determined, and the printing process was performed with high geometric accuracy. Figure 4.9 shows the image of milk chocolate with butterfly model after printing.

(a)



(b)

Figure 4.8 Printing butterfly motif with 3D printer using milk chocolate.

Figure 4.9 Butterfly model produced using milk chocolate.

Similarly, printing experiments were performed with 3D printer for the product with complex geometry in the form of stars using milk chocolate. Figure 4.10 shows the images of the star model printed with the 3D printer during printing. Figure 4.11 shows the finished version of the star model printed with milk chocolate.

(a) (b)

Figure 4.10 Printing star motif with 3D printer using milk chocolate.

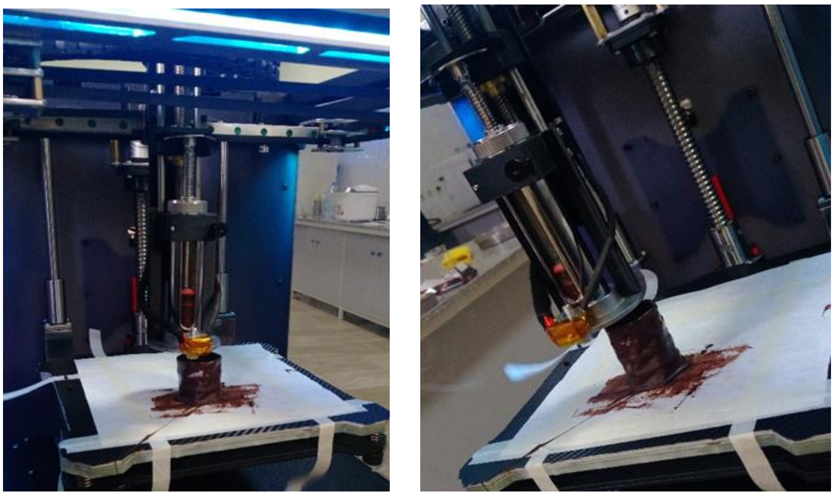
Figure 4.11 Star model produced using milk chocolate.

Sensory analyzes were performed for butterfly and star model products printed with milk chocolate. Ten panelists who participated in sensory analysis were asked to taste the piece chocolates used before printing with 3D printer and the motif chocolates printed with 3D printer. The panelists stated that there was no difference in taste between piece chocolates and chocolates printed with 3D printer motifs. They also emphasized that the shapes of chocolates printed with 3D printer would be more creative and preferred as a priority.

4.2.1.2 Dark Chocolate

Dark chocolate contains sugar, cocoa liquor and cocoa butter. Unlike other chocolate varieties, it does not contain dairy products (Glicerina et al., 2016). Therefore, it is harder structure than other chocolates. This property makes the dark to be printing easily with 3D printer. When printing with a 3D printer, the dark chocolate cools down quickly, resulting in a higher geometric accuracy. Due to the low sugar content, its viscosity is lower that of chocolates (Mantihal et al., 2019). Because of this, the first design piston pressurized extruder was used to obtain products with high geometric completeness.

Dark chocolate is a type of chocolate in which higher levels of layers can be extracted and other layers are fully interconnected. In this way, dark chocolate and complex geometry pieces can be printed easily with 3D printer. Figure 4.12 shows the vase model printed with a 3D printer using dark chocolate during printing. Figure 4.13 shows the finished version of the vase model printed with 3D printer using dark chocolate. The layers of the dark chocolate were fully connected to each other and the height of the vase model was increased to 75 mm (Mantihal et al., 2017). In Figure 4.14, a rose printed product is given using dark chocolate.



(a) (b)

Figure 4.12 Printing the vase model with 3D printer using dark chocolate.

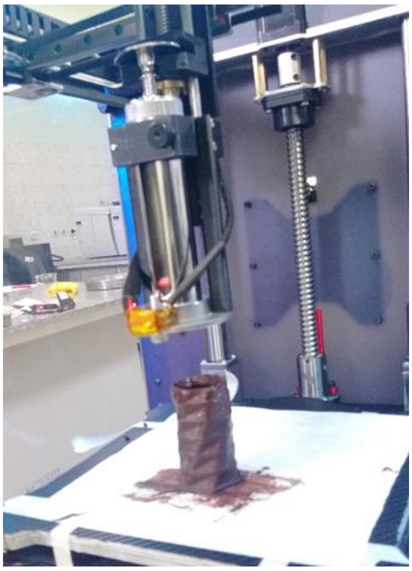


Figure 4.13 Vase model produced using dark chocolate.

Figure 4.14 Rose model produced using dark chocolate.

Figure 4.15 shows sample products printed with dark chocolate of different heights.

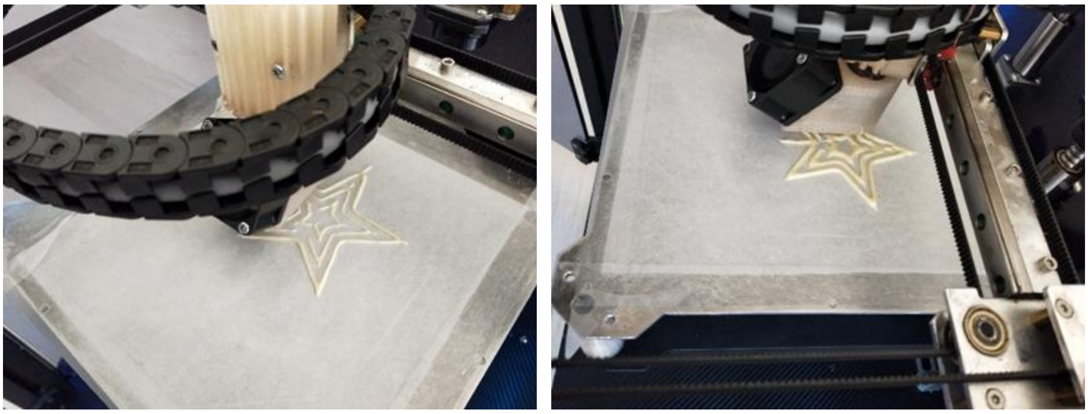
Figure 4.15 Products with different heights produced using dark chocolate.

Sensory analyzes were performed for vases, roses and other products printed with dark chocolate. Ten panelists who participated in sensory analysis were asked to taste the piece chocolates used before printing with 3D printer and chocolate products printed with 3D printer. The panelists stated that there was no difference in taste between piece chocolates and 3D printed chocolate products. They also emphasized that the shapes of chocolate printed with 3D printer would be preferred.

4.2.1.3 White Chocolate

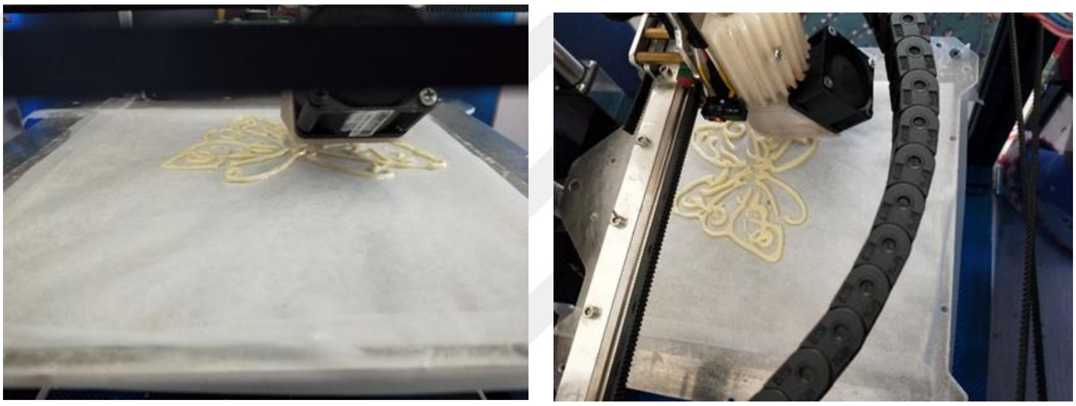
White chocolate contains only cocoa butter, sugar and milk. It is a kind of chocolate that melts at higher temperatures and freezes more quickly than other chocolate types due to the amount of cocoa butter it contains (Glicerina et al., 2016). In addition, the temperature control must be performed very precisely in order to prevent the white chocolate from burning at high temperatures. Because, like milk chocolate, the composition contains heat-sensitive milk products.

Successful printing results have not been achieved with the first design piston mechanism extruder in the printing of white chocolate. Because the product contains a high percentage of cocoa butter, white chocolate inside the piston mechanism starts to freeze. Like milk chocolate, white chocolate started to freeze in the extruder causing blockages at the nozzle tip. The most successful results in printing white chocolate with 3D printer were obtained with the second design screw type extruder. The best printing temperature for white chocolate was obtained at 38°C. As the structure freezes quickly, the 3D printer's cooling systems are operated with 60% capacity. Figure 4.16 shows the appearance of the product with star motif during printing, printed with a 3D printer using white chocolate. Figure 4.17 shows the view of the butterfly model printed on 3D printer using white chocolate during printing. Figure 4.18 shows the finished version of the butterfly motif printed using white chocolate.



(a) (b)

Figure 4.16 Printing a star model with a 3D printer using white chocolate.



(a) (b)

Figure 4.17 Printing a butterfly model with a 3D printer using white chocolate.

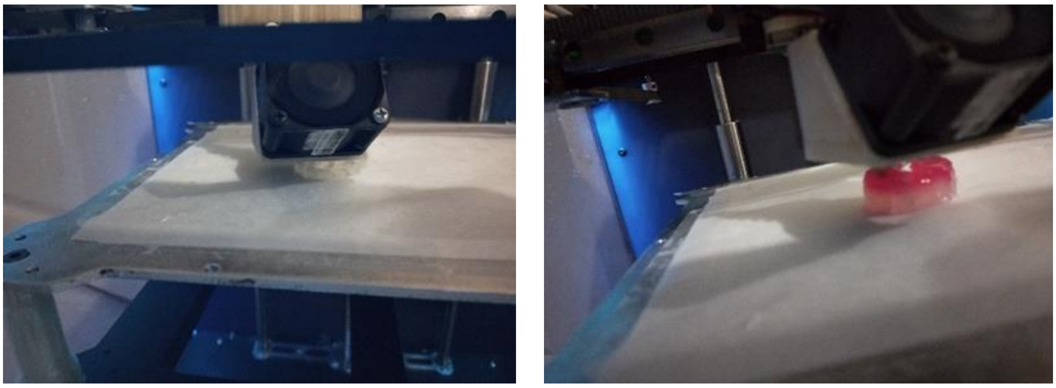
Figure 4.18 Butterfly model produced using white chocolate.

Sensory analyzes were performed for star and butterfly products printed with white chocolate. Ten panelists who participated in sensory analysis were asked to taste the piece chocolates used before printing with 3D printer and chocolate products printed with 3D printer. The panelists stated that there was no difference in taste between piece chocolates and 3D printed chocolate products. They also stated that the shapes of chocolate printed with 3D printer are more creative and emphasized that preference will be priority.

4.2.2 Discussion of Delight Varieties

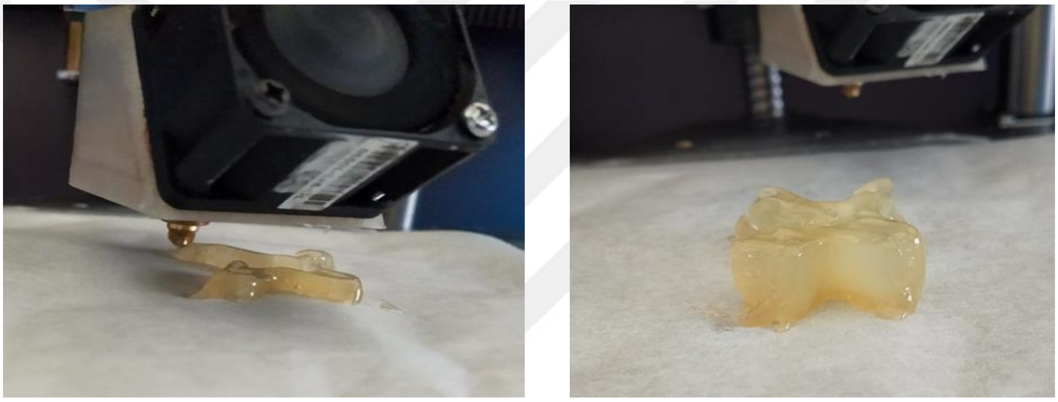
4.2.2.1 Turkish Delight

Traditional Turkish delight is a Turkish dessert prepared with water, sugar, starch, citric acid or tartaric acid or potassium tartaric acid and prepared in accordance with the technique with the addition of condiments, dried fruits or similar substances to the delight mass when necessary (Kirmaci et al., 2009). Since Turkish Delight is not a re-melted product like chocolate products, printing with a 3D printer is difficult. In addition, Turkish delight dough is obtained at very high temperatures, it needs to be put on hold to bring it to suitable temperatures for printing. Furthermore, due to the high amount of sugar it contains, controlled flow cannot be achieved with the first design piston mechanism extruder because of its high viscosity. On the other hand, when it starts to cool, the product freezes in the extruder and clogs the nozzle tip even under high pressure. The second design spiral type extruder system was used to ensure that the Turkish Delight was mixed in a continuous homogenous manner in the nozzle and that it could be printed before it started to cool. Because the mechanical properties of Turkish delight dough differ from chocolate and the problems experienced in printing with a 3D printer, more simple geometrical products were obtained instead of complex geometrical products. Figure 4.19, Figure 4.20 and Figure 4.21 illustrate the appearance of various letter-model products printed with a 3D printer using traditional Turkish delight during printing. Plain Turkish delight, food-based coloring additive is added to clearly understand the geometric properties during printing. Figure 4.22 shows the appearance of the cylindrical product during printing, and Figure 4.23 shows the printing experiment with rose Turkish delight.



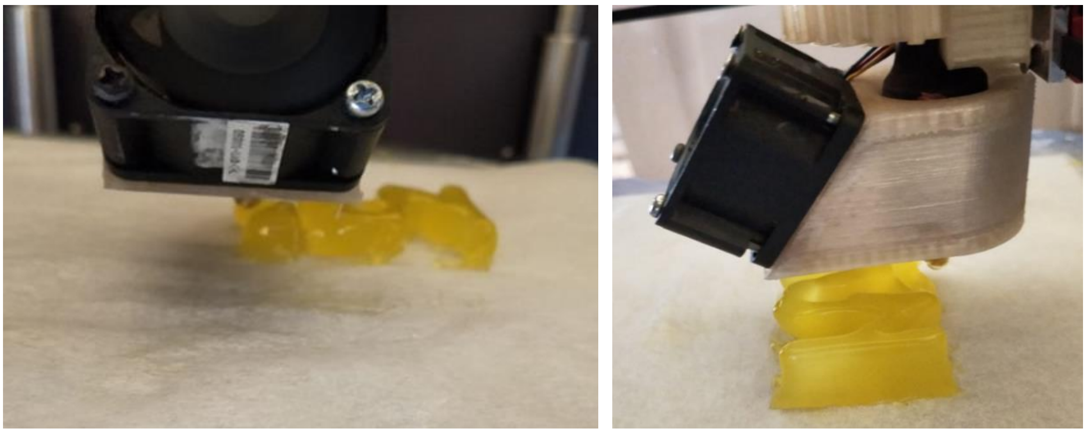
(a) (b)

Figure 4.19 Printing the letter model with 3D printer using Turkish delight dough (Model 1).



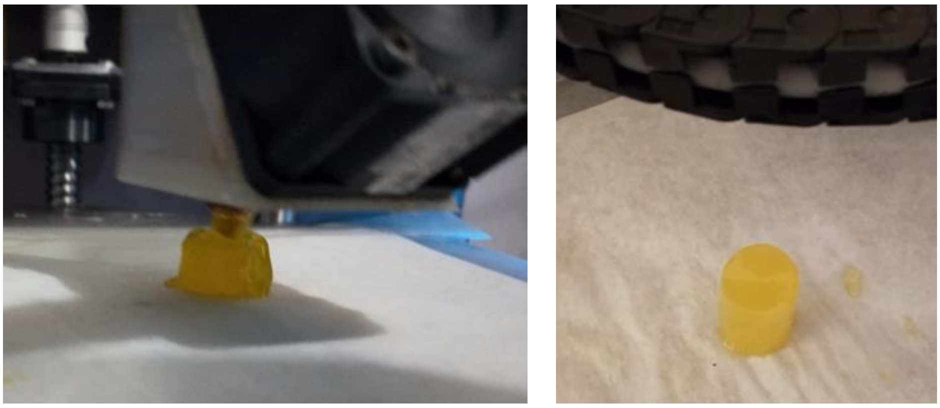
(a) (b)

Figure 4.20 Printing the letter model with 3D printer using Turkish delight dough (Model 2).



(a) (b)

Figure 4.21 Printing the letter model with 3D printer using Turkish delight dough (Model 3).



(a) (b)

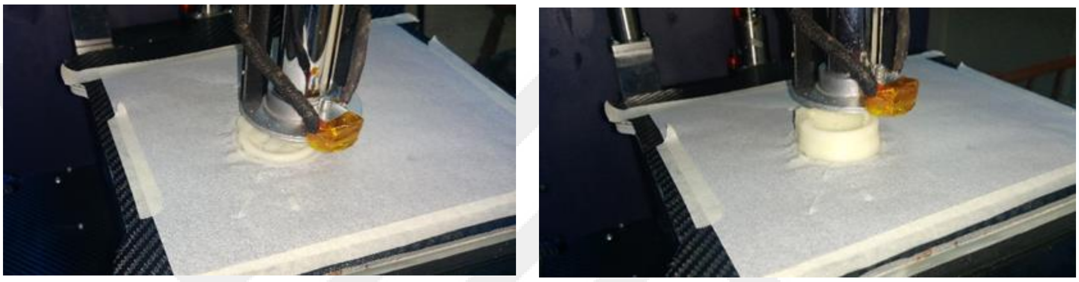
Figure 4.22 Printing the cylinder model with 3D printer using Turkish delight dough.

Figure 4.23 Printing the letter model with 3D printer using rosy Turkish delight dough.

Sensory analyzes were performed for products with different geometries printed with Turkish delight. Ten panelists who participated in sensory analysis were asked to taste Turkish delight products produced by traditional method and Turkish delight products printed with 3D printer. The panelists stated that Turkish delight products printed with 3D printer were softer. They also emphasized that Turkish delight products, printed with 3D printer, will be preferred as they are more creative in shape.

4.2.2.2 Custard Delight

Custard delight or Sultan delight is known as a milky dessert of Afyon region. Due to the milk it contains, it is softer and custard-like, as compared to other delights. It can easily be shaped due to its soft structure. Like Turkish delight, the dough is prepared at once and cannot be re-melt and used again. For this reason, it should immediately be fed to the extruder without waiting for it to cool and printed with a 3D printer. The cooling rate is high due to the margarine content. For this reason, the cooling capacity of the extruder and the tray was operated to a minimum during printing with 3D printer. The printing temperature was determined as 65°C in 3D printing experiments using custard delight. The first type extruder with piston mechanism was enough for printing because of the soft and semi-fluid structure of custard delight. Figure 4.24 shows the view of the cylindrical geometry of the product printed with the 3D printer using custard delight. Figure 4.25 shows the finished version of the cylindrical geometry of the product at the end of printing.



(a) (b)

Figure 4.24 Printing of the cylindrical geometry model with 3D printer using custard delight dough.

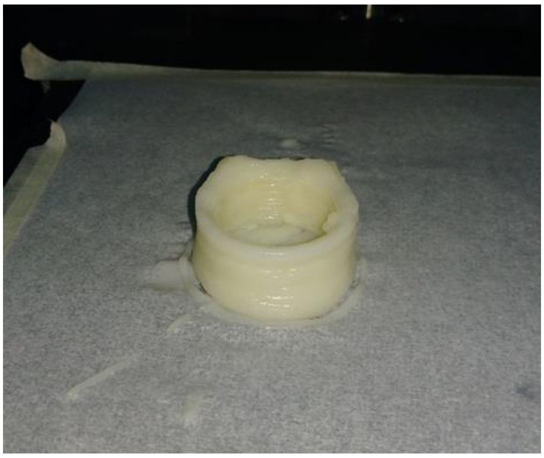
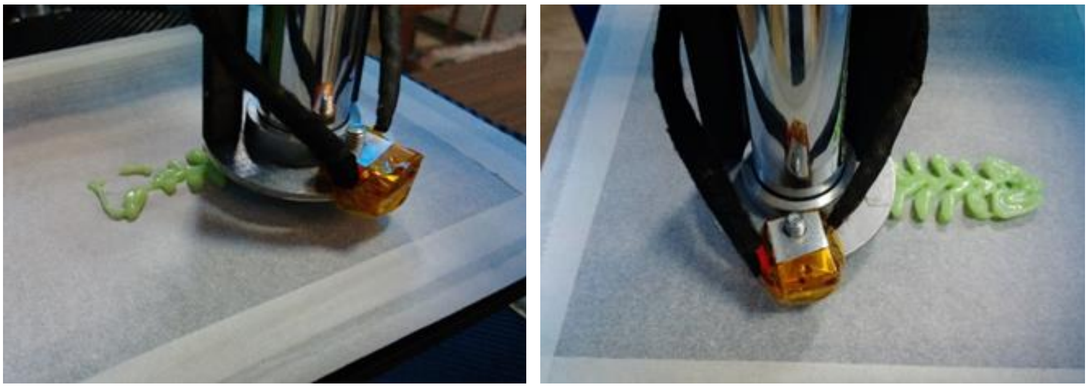


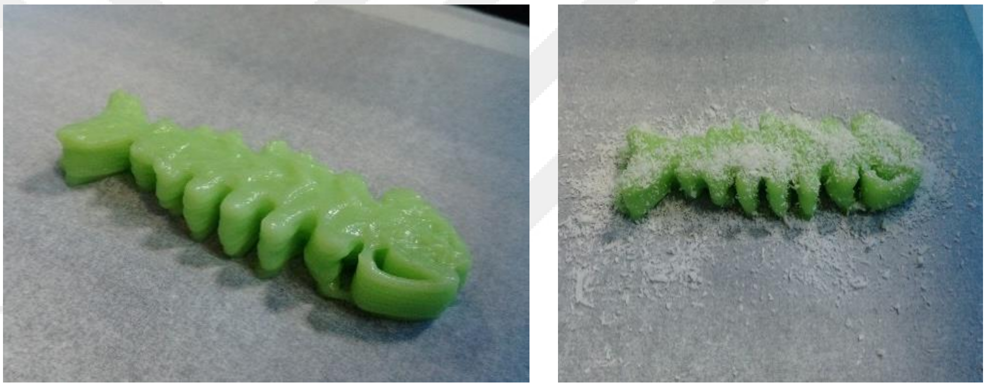
Figure 4.25 Custard delight dough using 3D printer with cylindrical geometry product.

Figure 4.26 shows the fish geometry product printed with 3D printer using custard delight during printing, and Figure 4.27 shows the finished product at the end of printing. To color the custard delight, green food color was added to the fish geometry product, and coconut was added after 3D printing.



(a) (b)

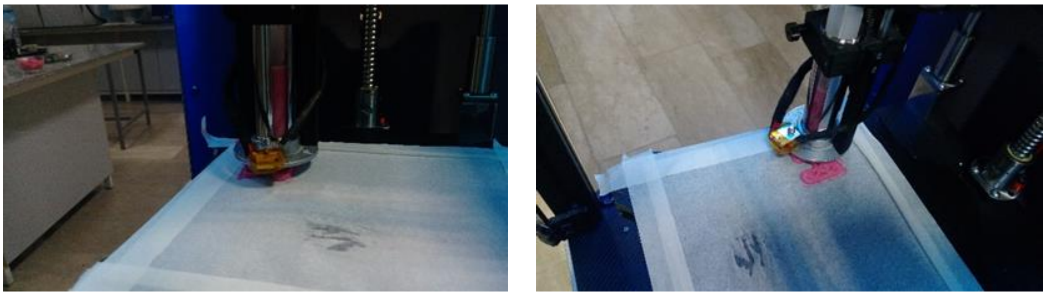
Figure 4.26 Printing of fish geometry model with 3D printer using custard delight dough.



(a) (b)

Figure 4.27 Fish geometry product with 3D printer using custard delight dough.

Figure 4.28 shows the appearance of the letter-shaped product printed by 3D printer using custard delight during printing, and Figure 4.29 shows the finished product at the end of the letter-shaped product. Red colored food coloring was added to the letter-shaped product to color the custard delight.



(a) (b)

Figure 4.28 Printing the letter-shaped model with 3D printer using custard delight dough.

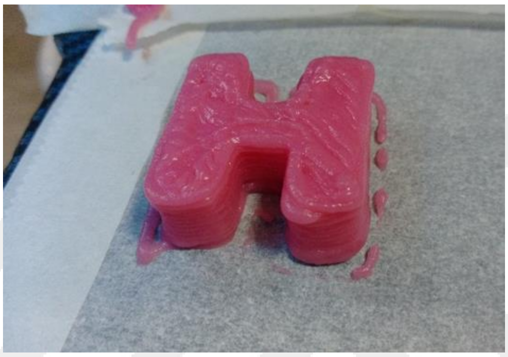
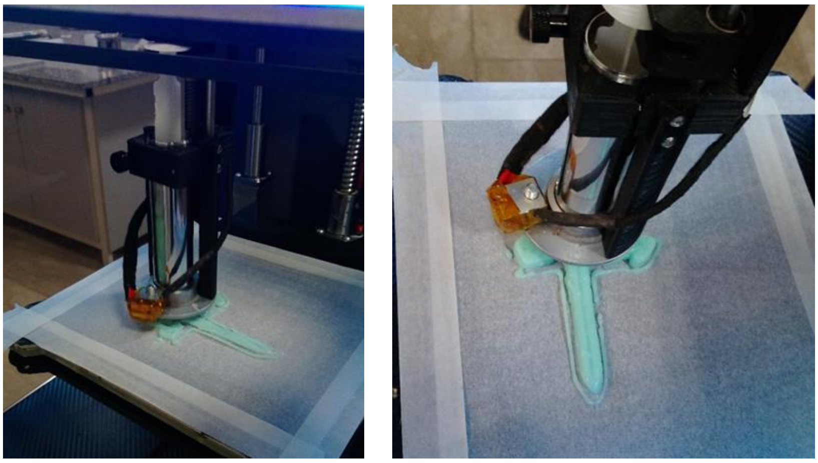


Figure 4.29 Letter-shaped product with 3D printer using custard delight dough.

Figure 4.30 shows the view of the product with flower model printed during printing with 3D printer using custard delight, and Figure 4.31 shows the finished version of the product with flower model at the end of printing. Blue colored food coloring was added to the product with floral model for coloring of custard.

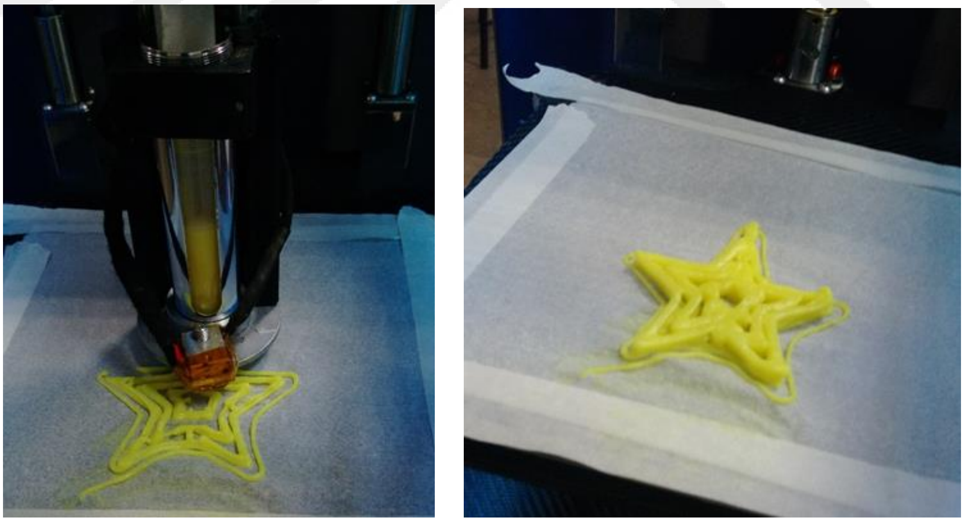


(a) (b)

Figure 4.30 Printing of flower pattern with 3D printer using custard delight dough.

Figure 4.31 Product with flower motif with 3D printer using custard delight dough.

Figure 4.32 shows the star geometry printed with 3D printer using custard delight during printing. Figure 4.33 shows the finished version of the star geometry product at the end of printing. To color the custard, a yellow food color was added to the star geometry product, and coconut was added after 3D printing.



(a) (b)

Figure 4.32 Printing the star geometry model with 3D printer using custard delight dough.

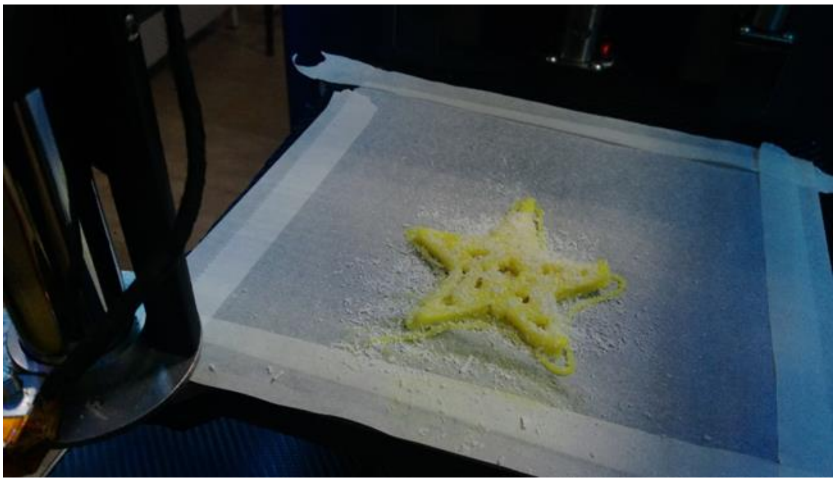


Figure 4.33 Star geometry with 3D printer using custard delight dough.

Sensory analyzes were performed for products with different geometries printed with custard delight. Ten panelists who participated in the sensory analysis were asked to taste the custard delight products produced by traditional method and the custard delight products printed with 3D printer. The panelists stated that the custard delight products printed with 3D printer were softer. They also emphasized that custard delight products, which are printed with 3D printers, will be preferred as they are more creative in shape.

CHAPTER V

CONCLUSION

3D printer is one of the innovative technologies that have been used in many branches of the industry. With the growing demand for personalized and customized foods in recent years, 3D printers have begun to be used in the food industry. Within the scope of this thesis, milk, bitter, and white chocolate varieties were printed, Turkish delight and custard delight were also printed with the 3D printer to determine their ideal printing parameters. The prototype of the 3D printer was prepared and then it was designed, according to the structural properties of the food products used. As a result, two different extruders were developed and used in the printing experiments. The following printing parameters were observed to be useful to print the products in questions:

- The melting temperature for milk chocolate was 38°C and the ideal printing temperature was 29°C. Furthermore, the printing speed is 40mm/s and the most suitable extruder type is the second design spiral type extruder.

- The melting temperature for the dark chocolate was 42°Cand the ideal printing temperature was 30°C. Furthermore, the printing speed is 50mm/s and the most suitable extruder type is designated as first design piston mechanism extruder.

- The melting temperature for white chocolate was 48°C and the ideal printing temperature was 38°C. Furthermore, the printing speed is 60mm/s and the most suitable extruder type is the second design screw type extruder.

- The ideal printing temperature for Turkish delight is 60°C. Furthermore, the printing speed is 50mm/s and the most suitable extruder type is the second design screw type extruder.

- The ideal printing temperature for custard delight was 65°C. Furthermore, the printing speed is 80mm/s and the most suitable extruder type is designated as first design piston mechanism extruder.

- Furthermore, when comparing the first and second design extruders, it has been found that for the food products having high viscosity and viscosity, the first type piston mechanism extruder is suitable for use in food products where precise temperature control of the second design screw type extruder is required.

- On the other hand, in the printing experiments of food products with 3D printer, it is observed that there is a direct correlation between melting temperature, printing temperature and printing speed. It has been observed that the printing temperature increases with increasing melting temperature of the food product. In addition, the relationship between print temperature and print speed has been found to increase as the print temperature increases.

- The ability to print chocolate and delight products, which are widely consumed in daily life, has been shown to be printed with 3D printer, and it has been proved that personalized and customized designs can be produced more economically and creatively in the food industry.

REFERENCES

Batu, A. (2016). Türk Lokumu Üretim Tekniği ve Kalitesi, *Gıda Teknolojileri Elektronik Dergisi*. **1(1)**, 35-46.

Batu, A., Batu, H. S. (2016). Türk Tatlı Kültüründe Türk Lokumunun Yeri, *Journal of Tourism and Gastronomy Studies*. **4(1)**, 42-52.

Batu, A., Kirmacı, B. (2009). Production of Turkish delight (lokum), *Food Research International*. **42 (1**), 1-7.

Bégin-Drolet, A., Dussault, M. A., Fernandez, S. A., Larose-Dutil, J., Leask, R. L., Hoesli, C. A., Ruel, J. (2017). Design of a 3D Printer Head for Additive Manufacturing of Sugar Glass for Tissue Engineering Applications, *Additive Manufacturing*.**15(1)**, 29-39.

Chen, Y. W., Mackley, M. R. (2006). Flexible Chocolate, *Soft Matter*.**2(1)**, 304-309.

Çelik, D. (2015). Üç Boyutlu Yazıcı Tasarımı Prototipi ve Tersine Mühendislik Uygulamaları, Yüksek Lisans Tezi, *Karabük Üniversitesi Fen Bilimleri Enstitüsü.* 100-110.

Dankar, I., Haddarah, A., Omar, F. E. L., Sepulcre, F., Pujolà, M. (2018). 3D Printing Technology: The New Era for Food Customization and Elaboration, *Trends in Food Science and Technology*.**75(1)**, 231-242.

Değerli, C., El, S. N. (2017). Üç Boyutlu (3D) Yazıcı Teknolojisi ile Gıda Üretimine Genel Bakış, *Türk Tarım – Gıda Bilim ve Teknoloji Dergisi.***5(6)**, 593-599.

Derossi, A., Caporizzi, R., Azzollini, D., Severini, C. (2018). Application of 3D Printing for Customized Food. A Case on The Development of a Fruit-Based Snack for Children, *Journal of Food Engineering*.**220(1)**, 65-75.

Dick, A., Bhandari, B., Prakash, S. (2019). 3D Printing of Meat, *Meat Science*.**153(1)**, 35-44.

Fell, D. A. (2006). Videojet Ink for Printing on Food Products, *United States Patent.* US 7,051,654 B2.

Fuh, J. Y. H., Hong, G. S., Zhou, W., Huang, D., Sun, J. (2015). An Overview of 3D Printing Technologies for Food Fabrication, *Food and Bioprocess Technology*.**8(8)**, 1605-1615.

Glicerina, V., Balestra, F., Rosa, M. D., Romani, S. (2016). Microstructural and rheological characteristics of dark, milk and white chocolate: A comparative study, *Journal of Food Engineering***.** **169(1)**, 165-171.

Godoi, F. C., Prakash, S., Bhandari, B. R. (2016). 3d Printing Technologies Applied for Food Design: Status and Prospects, *Journal of Food Engineering.***179(1)**, 44-54.

Goyanes, A., Buanz, A. B. M., Basit, A. W., Gaisford, S. (2014). Fused-Filament 3D Printing (3DP) for Fabrication of Tablets, *International Journal of Pharmaceutics.***476(1)**, 88-92.

Guo, C. F., Zhang, M., Bhandari, B. (2019). A Comparative Study Between Syringe-Based and Screw-Based 3D Food Printers by Computational Simulation, *Computers and Electronics in Agriculture.***162(1)**, 397-404.

HaberESES. 2018. Saray lokumu tarifi. https://www.gazetees.com/yasam/saray-lokumu-tarifi-h13359.html, 20.09.2019.

Hao, L., Mellor, S., Seaman, O., Henderson, J., Sewell, N., Sloan, M. (2010). Material Characterisation and Process Development for Chocolate Additive Layer Manufacturing, *Virtual and Physical Prototyping.***5(2)**, 57-64.

İTO. İstanbul Ticaret Odası. 2019. Perakende sektöründe çikolata-çiçek mutluluğu. https://www.itohaber.com/haber/sektorel/209692/perakende_sektorunde_cikolata-cicek_mutlulugu.html, 20.09.2019.

Jerez-Mesa, R., Travieso-Rodriguez, J. A., Corbella, X., Busqué, R., Gomez-Gras, G. (2016). Finite Element Analysis of The Thermal Behavior of a Reprap 3D Printer Liquefier, *Mechatronics.***36(1)**, 119-126.

Jia, F., Wang, X., Mustafee, N., Hao, L. (2016). Investigating the Feasibility of Supply Chain-Centric Business Models in 3D Chocolate Printing: A Simulation Study, *Technological Forecasting and Social Change.***102(1)**, 202-213.

Kaya, G. (2017). Vidalı Basınçlı Transfer Sistemine Sahip Çift Nozullu Kartezyen Tipi Üç Boyutlu Gıda Yazıcısı Tasarımı ve Prototipi, Yüksek Lisans Tezi, *Karabük Üniversitesi Fen Bilimleri Enstitüsü.* 25-33.

Kietzmann, J., Pitt, L., Berthon, P. (2015). Disruptions, Decisions, and Destinations: Enter the Age of 3-D Printing and Additive Manufacturing, *Business Horizons.***58(2)**, 209-215.

Kinstlinger, I. S., Miller, J. S. (2016). 3D-Printed Fluidic Networks as Vasculature for Engineered Tissue, *Lab on a Chip.***16(11)**, 2025-2043.

Le Tohic, C., O'Sullivan, J. J., Drapala, K. P., Chartrin, V., Chan, T., Morrison, A. P., Kelly, A. L. (2018). Effect of 3D Printing on The Structure and Textural Properties of Processed Cheese, *Journal of Food Engineering.***220(1)**, 56-64.

Lee, J. H., Won, D. J., Kim, H. W., Park, H. J. (2019). Effect of Particle Size on 3D Printing Performance of the Food-Ink System with Cellular Food Materials, *Journal of Food Engineering.***256(1)**, 1-8.

Lille, M., Nurmela, A., Nordlund, E., Metsä-Kortelainen, S., Sozer, N. (2018). Applicability of Protein and Fiber-Rich Food Materials in Extrusion-Based 3D Printing, *Journal of Food Engineering.***220(1)**, 20-27.

Lipton, J., Arnold, D., Nigl, F., Lopez, N., Cohen, D., Norén, N., Lipson, H. (2010). Mutli-Material Food Printing with Complex Internal Structure Suitable for Conventional Post-Processing. *21st Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference.* 809-815.

Lipton, J. I., Cutler, M., Nigl, F., Cohen, D., Lipson, H. (2015). Additive Manufacturing for the Food Industry, *Trends in Food Science and Technology.***43(1)**, 114-123.

Liu, Y., Liang, X., Saeed, A., Lan, W., Qin, W. (2019). Properties of 3D Printed Dough and Optimization of Printing Parameters, *Innovative Food Science and Emerging Technologies*.**54(1)**, 9-18.

Liu, Z., Zhang, M., Bhandari, B., & Wang, Y. (2017). 3D printing: Printing Precision and Application in Food Sector, *Trends in Food Science and Technology*.**69(1)**, 83-94.

Liu, Z., Zhang, M., Yang, C. H. (2018). Dual Extrusion 3D Printing of Mashed Potatoes/Strawberry Juice Gel, *Lwt - Food Science and Technology*.**96(1)**, 589-596.

Mantihal, S., Prakash, S., Bhandari, B. (2019). Textural Modification of 3D Printed Dark Chocolate by Varying Internal Infill Structure, *Food Research International*.**121(1)**, 648-657.

Mantihal, S., Prakash, S., Godoi, F. C., Bhandari, B. (2017). Optimization of Chocolate 3D Printing by Correlating Thermal and Flow Properties With 3D Structure Modelling, *Innovative Food Science and Emerging Technologies*.**44(1)**, 21-29.

Mantihal, S., Prakash, S., Godoi, F. C., Bhandari, B. (2019). Effect of Additives on Thermal, Rheological and Tribological Properties of 3D Printed Dark Chocolate, *Food Research International*.**119(1)**, 161-169.

Pallottino, F., Hakola, L., Costa, C., Antonucci, F., Figorilli, S., Seisto, A., Menesatti, P. (2016). Printing on Food or Food Printing: A Review, *Food and Bioprocess Technology*.**9(5)**, 725-733.

Pérez, B., Nykvist, H., Brøgger, A. F., Larsen, M. B., Falkeborg, M. F. (2019). Impact of Macronutrients Printability and 3D-Printer Parameters on 3D-food Printing: A review, *Food Chemistry*.**287(1)**, 249-257.

Portanguen, S., Tournayre, P., Sicard, J., Astruc, T., Mirade, P. S. (2019). Toward the Design of Functional Foods and Biobased Products by 3D Printing: A review, *Trends in Food Science and Technology*.**86(1)**, 188-198.

Puscha, K., Hintonb, T. J., Adam W. Feinberga, B. (2018). Large Volume Syringe Pump Extruder for Desktop 3D printers, *HardwareX*.**3(1)**, 49-61.

Severini, C., Derossi, A., Azzollini, D. (2016). Variables Affecting the Printability of Foods: Preliminary Tests on Cereal-Based Products, *Innovative Food Science and Emerging Technologies.***38(1)**, 281-291.

Slinger, D. J., Scheurer, S., Woodruff, M. A., Lanaro, M., Powell, S. K., Liao, S., Forrestal, D. P. (2017). 3D Printing Complex Chocolate Objects: Platform Design, Optimization and Evaluation, *Journal of Food Engineering.***215(1)**, 13-22.

Sökmen, A. (2005). Bazı Sükroz İkamelerinin Çikolatanın Reolojik Özelliklerine Etkileri, Yüksek Lisans Tezi, *İstanbul Teknik Üniversitesi Fen Bilimleri Üniversitesi.* 3-10.

Sun, J., Peng, Z., Zhou, W., Fuh, J. Y. H., Hong, G. S., Chiu, A. (2015). A Review on 3D Printing for Customized Food Fabrication, *Procedia Manufacturing.***1(1)**, 308-319.

Sun, J., Zhou, W., Yan, L., Huang, D., Lin, L. Y. (2018). Extrusion-Based Food Printing for Digitalized Food Design and Nutrition Control, *Journal of Food Engineering.***220(1)**, 1-11.

Takagishi, K., Suzuki, Y., Umezu, S. (2018). The High Precision Drawing Method of Chocolate Utilizing Electrostatic Ink-Jet Printer, *Journal of Food Engineering.***216(1)**, 138-143.

Bommel, K.V., Spicer, A. (2011). Hail the Snail: Hegemonic Struggles in the Slow Food Movement, *Organization Studies.***32(12)**, 1717-1744.

Vancauwenberghe, V., Katalagarianakis, L., Wang, Z., Meerts, M., Hertog, M., Verboven, P., Nicolaï, B. (2017). Pectin Based Food-Ink Formulations for 3-D Printing of Customizable Porous Food Simulants, *Innovative Food Science and Emerging Technologies.***42(1)**, 138-150.

Yeni Şafak. 2015. Türk lokumu hakkında bilinmeyenler. https://www.yenisafak.com/foto-galeri/hayat/turk-lokumu-hakkinda-bilinmeyenler-2013799?page=1, 20.09.2019.

Wegrzyn, T., Golding, M., Archer, R. (2012). Food Layered Manufacture: A New Process for the Construction of Solid Foods, *Trends in Food Science & Technology.***27(1)**, 66-72.

Zeleny, P., Ruzicka, V. (2017). The Design of the 3D Printer for Use in Gastronomy, *MM Science Journal*.**1(1)**, 1744-1747.

Zhao, H., Wang, J., Ren, X., Li, J., Yang, Y. L., Jin, X. (2018). Personalized Food Printing for Portrait Images, *Computers and Graphics (Pergamon)*.**70(1)**, 188-197.