Chapter 9

# Novel Soft Meals Developed by 3D Printing

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Additional information is available at the end of the chapter

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### Abstract

Recently, 3D printing is being applied to various fields. 3D printing of foods has been developed; however, there are many challenges. To overcome the challenges, we have started a new research group named "Yonezawa Itadakimasu Research Group," to focus on the development of 3D printing applications for manufacturing food. We have developed Novel jelly foods that are shaped by 3D printed molds. Fused deposition modeling (FDM) 3D printer for food manufacturing makes the 3D printed molds. First step of making 3D printing mold is to print a cast. Then, food grade silicone is poured into the cast to make a mold. This type of 3D printed mold can be used widely, such as making sweets, restaurant menus, and care foods by changing the design depending on the use of application. Secondly, we started to develop 3D food printers. This type of challenge to develop future foods by 3D printing technology may have a major impact on the care food because the looks of foods are important and will be improved by 3D printing.

**Keywords:** 3D printer, food printer, FDM, care food, mold

## 1. Introduction

3D printing finds its application in medicine, manufacturing, sensors, micro-and nanotechnology, and custom-made art and design. Most widely used application of 3D printing is in industrial equipment such as production of prototype parts of industrial products and confirmation of shape. Over the last decade, application of 3D printers has increased, and free-formable 3D printers are becoming widely used. Now 3D printers can be purchased from electronic retail stores to online retail stores such as Amazon. Many low-cost compact and portable 3D printers have been developed, but large-scale 3D printers that can output furniture to homes have also been developed. Varieties of 3D printers exist, such as 3D printing of foods, medicines, and organs. Two distinct types of Product Data Management (PDM) printers are being developed for 3D printing of foods: (1) Fused deposition modeling (FDM) type of 3D food printers that directly output foods; and (2) FDM type which makes 3D printing mold, i.e., to print a cast for food molding.

To increase the awareness and use of 3D printers, we have set up locations where ordinary people can use 3D printers such as "Yonezawa Itadakimasu Research Group" and "Eki Fab." Yonezawa Itadakimasu Research Group is researching and developing new foods utilizing 3D printers. Eki Fab is a fabrication space inside the station building, and anyone can freely use a 3D printer. We have held food events at the Eki Fab.

This paper describes the principle of 3D printers, application of 3D printing in food manufacturing, "Yonezawa Itadakimasu Research Group," "Eki Fab," and the future of foods made by 3D printer.

## 2. Principle of 3D printer

3D printer is a device for manufacturing a three-dimensional object that stacks materials based on 3D data. 3D printers can be roughly classified into lamination methods such as fused deposition modeling (FDM), powder lamination method, inkjet and bathtub stereolithography (**Figure 1**).

- Fused deposition modeling (FDM)

FDM is the most inexpensive and major modeling method as a 3D printer for public because patent has expired. In the FDM 3D printer, a string-like resin called a filament is melted by a heater and discharged from a nozzle, so that it is shaped. It is necessary to introduce support structure because structures floating in the air cannot be shaped in principle of modeling. The main resins currently used are various resins refer to thermoplastic ABS and PLA. ABS is a resin obtained by copolymerizing acrylonitrile, butadiene, and styrene in general. In addition, the use of various resins such as super engineering plastics such as is beginning to be studied such as polycarbonate (PC) and polyphenol sulfone (PPSU).

As an example of application to foods, FDM type printers are used to make food molds such as chocolate and jelly molds.

- Powder lamination method

In the powder lamination method, the surface of a bed containing powder is thinly compacted at an arbitrary place, and this is repeatedly laminated as one layer. It can handle a wide range of materials such as metal powder, resin powder, and ceramic powder. It is an expensive device which is difficult to purchase for individuals because it has higher modeling precision than FDM. Also, since the material is powdery, management and safety considerations are necessary. This method is further classified into two methods: selective laser sintering, which locally heats with laser to melt and consolidate powder, and powder fixing method that fixes with adhesive.

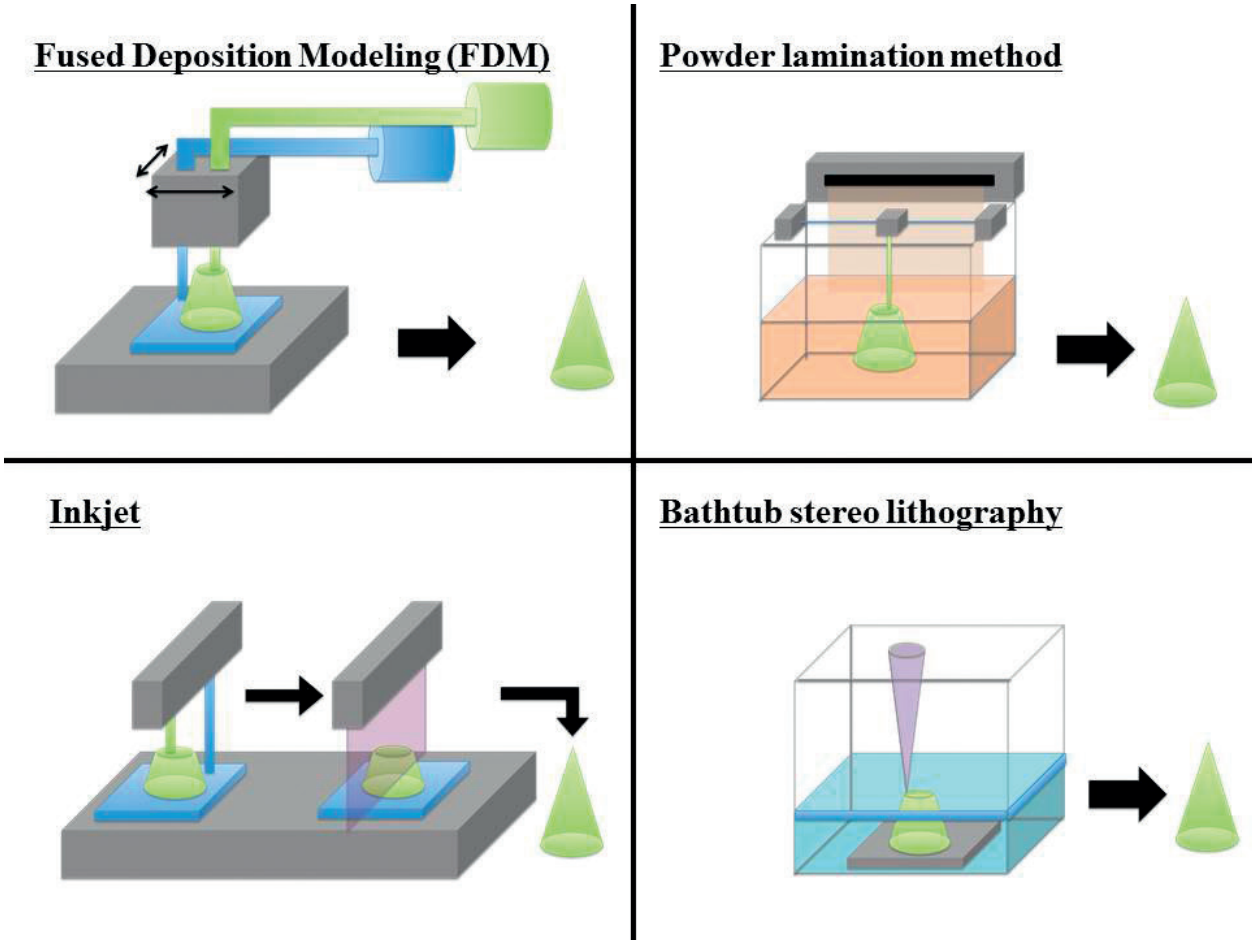


**Figure 1.** Modeling methods of 3D printer.

Powder sintering method is like FDM, but among thermoplastic resins, powder of crystalline polymer such as nylon 11, 12, polyamide 11, 12 is mainly used, and metal powders and ceramics powder can also be handled. Powder is a support structure; hence, there is no need to design the support structure.

Powder fixing method is chemical energy is given to ceramics powder such as gypsum, and this chemically combines the powders and solidifies. As an example, calcium sulfate causes a hydration reaction when water is added, it solidifies into dihydrate gypsum. Full color printing is also possible if coloring is charged in water. In addition, there are cases in which polymer is sprayed on natural sand or artificial sand as an adhesive. Particularly, 3D printers for producing sand mold for casting using furan type or phenol type resins become conspicuous in the market. This powder fixing method is sometimes called inkjet, described later, because liquid (ink) is ejected from a nozzle.

- Inkjet

As a 2D printer, a method of ejecting ink from a nozzle and solidifying the material is called an inkjet lamination method. The point that the fine particles of the photo-cross-linkable resin used as a material is solidified by irradiating ultraviolet rays is different from the powder fixing method. Thickness of a layer stacked by a 3D printer is called stacking pitch. While the stacking pitch of a typical FDM is 0.2 mm, the stacking pitch of inkjet is as fine as 0.01 mm, so it becomes a beautiful and smooth shaped object. Materials often used for inkjet are urethane acrylate type (acrylic resin) of radical polymerization. Photo-cross-linkable resins are important for ink control to determine shaping accuracy. Since the reaction rate is also important, radical polymerization with a high polymerization rate is used.

As an example of application to foods, there are cases where dispensers are used to serve food in a restaurant or to make pizza and utilization in events.

- Bathtub stereolithography

Bathtub stereolithography is a type that performs 3D modeling while polymerizing macromolecules like inkjet. Modeling is performed by irradiating a tank filled with photo-cross-linkable resins with ultraviolet laser. Acrylic resin is similar to inkjet printing inks. Viscosity and surface tension in uncured state are related to molding accuracy. As a different feature, the material is contained in a liquid bath called a bathtub, and the structure is supported by the uncured liquid, so that a support structure is not required.

## 3. Examples of utilizing 3D printers

3D printers are widely used in industrial applications, while at the same time efforts are being made to utilize 3D printers in new fields. We will introduce numerous examples that have been done so far.

- 3D printer restaurant

Food Ink opened the world's first pop-up 3D print food restaurant. The food printer used in this project is a portable 3D printer "by Flow" developed by a startup company in the Netherlands. It is a 3D printer that can support various materials (PLA, ABS, polyethylene terephthalate (PET), nylon, bronze, silicon, food, etc.) by replacing the extruder. When used as a food printer, it is shaped by a method of extruding a food paste from a syringe pump.

- 3D printed pizza

Bee Hex has developed a 3D printer that outputs pizza. Pizza dough, tomato sauce, and cheese are made by dissolving the powder in water attached to the material tank of the printer. The material is extruded at high pressure and stacked from the pizza dough in turn. The basic structure is almost the same as the 3D printer, but the pressure mechanism and the print head are different. In addition, they are applying for a patent with technology to prevent dripping. Powder material was developed to accommodate the long-term stay of the space.

- 3D printed meal for elderly people

Biozoon developed a 3D printer powder mix for elderly and those with dysphagia. It is a material that solidifies when printed and dissolves when placed in the mouth as usable with general extruder-type 3D printers. This powder mix can form various shapes and it is possible to look and taste like real food using colorants.

- Food 3D printer that can output food in image form

XYZ Printing Japan has developed a food 3D printer “XYZ Food Printer.” Traditional food 3D printers could output decorations to cookies but XYZ Food Printer is a new printer “output food in image shape.”

- Introducing food 3D printer in fine restaurants

The Spanish fine restaurant “La Enoteca” has introduced a food 3D printer. Printed mashed potatoes in coral shape were developed. It is almost impossible to shape the mashed potatoes in the shape of corals with human hands. La Enoteca’s expectations are that it can quickly respond when complex shaped orders come in.

- Gummy 3D printer

German confectionary manufacturer Katjes developed Gummy 3D printer “The Magic Candy Factory.” We can make your own customized gummy from selfie and images in a few minutes. We can make original gummy by choosing your favorite one from 8 assorted flavors and 10 different shapes. The gummy liquid is squeezed out from the syringe warmed to 70–90°, and the gummy is stacked.

- Screw type chocolate

Confectionery store Grandujour has developed screw type chocolate. Chocolate is molded using molds made with 3D printers, and it looks like a real screw.

- Sugar 3D printer

MIT graduate students developed 3D printers of sugar at the robot workshop. The 3D printer can melt the sugar at 150°C and shape candy.

- Cake made with 3D modeling and 3D printing

Ukrainian artist Dinara Kasko made beautiful cake using 3D modeling and 3D printer. She shapes geometric configuration with FDM 3D printers, and made various cakes with silicon type model based on them.

- 3D printer capable of printing 100 types of meals

The Netherlands Organization for Applied Scientific Research (TNO) has developed a 3D printer that can provide 100 types of meals customized for 20 residents of German care facilities. Developed food 3D printers can make personalized foods according to individual needs.

## 4. YONEZAWA *Itadakimasu* Research Group

“YONEZAWA *Itadakimasu* Research Group” is conducting research and development of new food using YONEZAWA regional foods and 3D printer since 2014. *Itadakimasu* is the word Japanese people use before eating, to thank the ingredients, the people involved, and the nature. This research group is aimed at development and promotion of local economy through development of new food. Participating members are Yamagata University and some other local companies and universities.

We have suggested "The three points of Yonezawa *Itadakimasu* Research Group" and provided an idea based on those.

The three points of "YONEZAWA *Itadakimasu* Research Group" are:

1. Shape of food related to famous items of Yonezawa.
2. Yonezawa related ingredients.
3. Utilizing university facility such as 3D printer, laser cutter, or food gel to introduce the activities of the YONEZAWA *Itadakimasu* Research Group.

### 4.1. Food 3D printer "E-Chef"

"E-Chef" is a food 3D printer that can print a picture on a tablet or a cookie (**Figure 2**) [5]. Ink uses jam made from local fruits. E-Chef was exhibited at the local festival and is now in actual use. E-Chef was popular with children and well taken up in local newspapers. However, we found it difficult to introduce it in the restaurants as there are such problems as slow forming speed, costly, and difficulty in mastering. So, we should think of what type of food and which method we should make how to make with the 3D printer. This is described in next section.

### 4.2. Development of food using 3D printer

Yonezawa has famous food "ABC." A is Tateyama apple, B is Yonezawa beef, and C is Yonezawa carp. We developed new foods using these local foods and 3D printer. Developed foods are "3D Tateyama apple JELLY," "3D Tateyama apple RAKUGAN," "3D Yonezawa beef hot jelly," and "3D carp jelly." These are made with 3D printing mold using a FDM 3D printer. We introduce how to make 3D printing mold using 3D printer and features of each food.

**Figure 2.** 3D printing by E-Chef.

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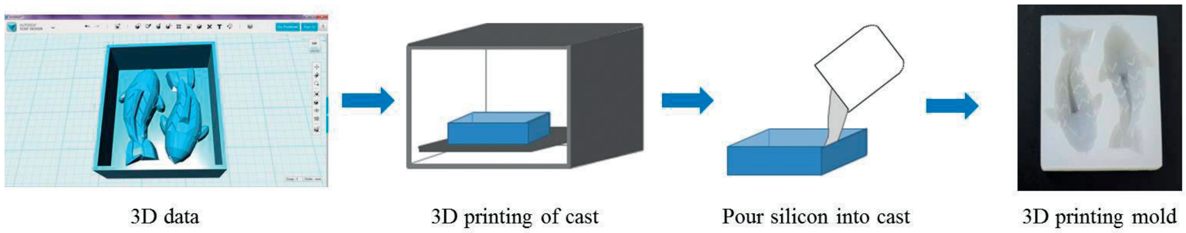




**Figure 3.** Manufacturing process of 3D printing mold.

### *4.2.1. Method of manufacturing 3D printing mold using 3D printer*

3D printing mold of "3D Tateyama apple JELLY," "3D Yonezawa beef hot jelly," and "3D carp jelly" were made using FDM 3D printer. Stacking pitch was 0.2 mm and polylactic acid (PLA) was used as the filament. For making 3D printing mold, at first, we printed a cast. Then, food-grade silicone was poured into the cast to make a mold (**Figure 3**).

3D printing mold of "3D Tateyama apple RAKUGAN" was made with a FDM 3D printer and a laser cutter. RAKUGAN is a Japanese traditional confection made by adding a little moisture to the sugar and pushing it to the mold and drying it. Although the original mold is wooden, an acrylic plate processed with a laser cutter at the handle part, and parts for pushing the material were made with a 3D printer (**Figure 4**).

**Figure 4.** 3D printing mold of "3D Tateyama apple RAKUGAN".

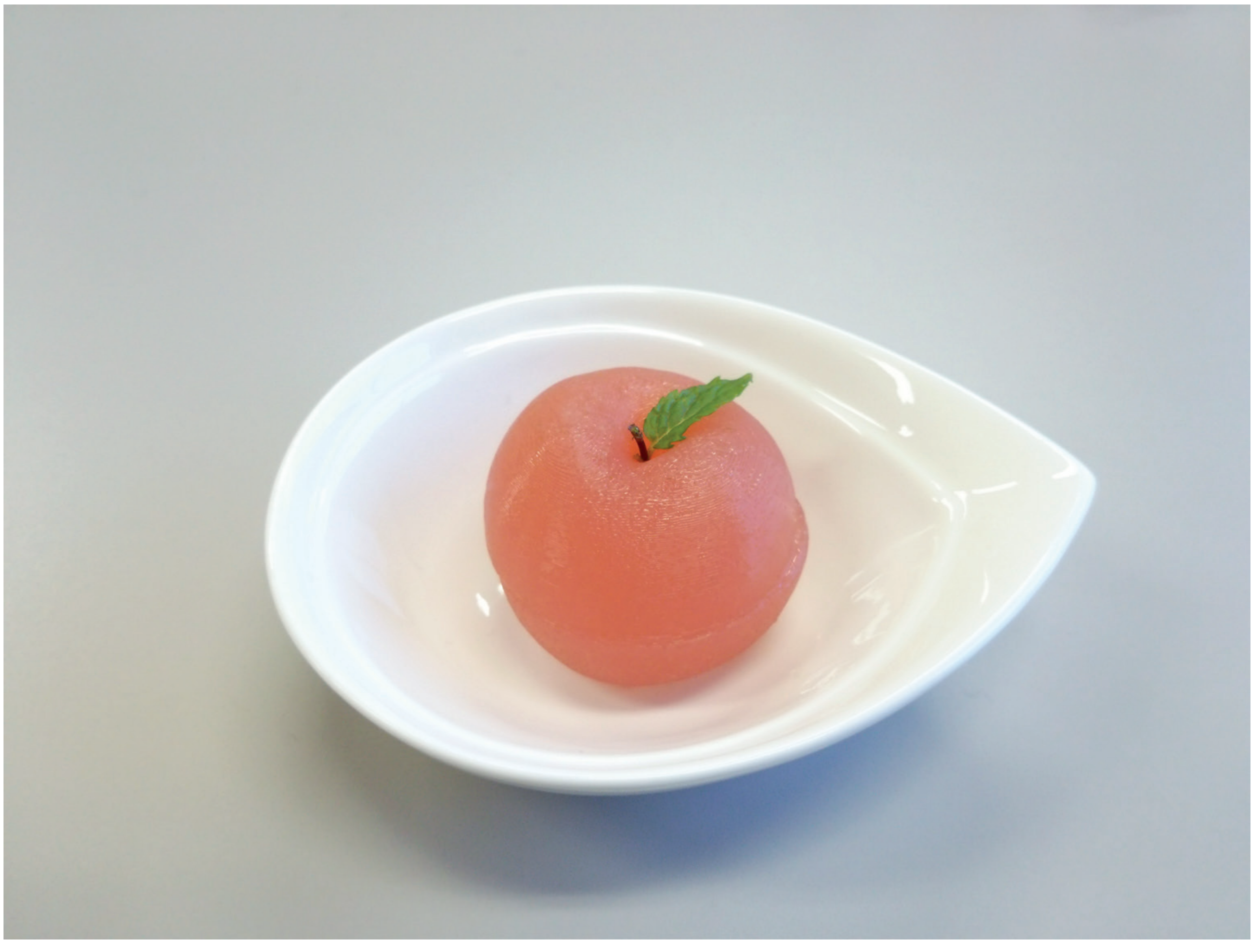

**Figure 5.** 3D Tateyama apple JELLY.

#### *4.2.2. 3D Tateyama apple JELLY*

3D Tateyama apple JELLY is a jelly made from juice and powder of Taneyama apple (**Figure 5**). 3D printing mold is made from a 3D scan of a real Tateyama apple (**Figure 6**). The size of the jelly is 4.5 cm in diameter and 5.0 cm in height.

3D Tateyama apple JELLY is served as a dessert in the local Italian restaurant.




**Figure 6.** 3D Tateyama apple JELLY mold.

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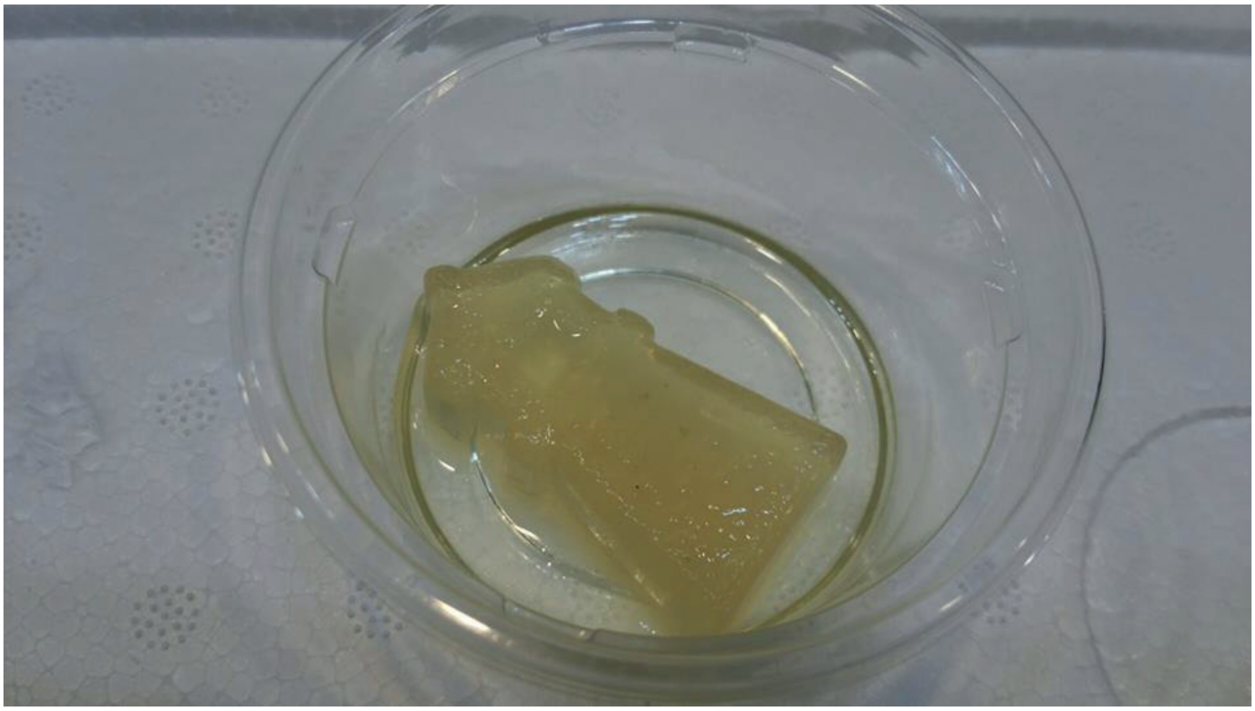

**Figure 7.** 3D Yonezawa beef hot jelly.

*4.2.3. 3D Yonezawa beef hot jelly*

"3D Yonezawa beef hot jelly" is made from Yonezawa beef consommé soup and agar (**Figure 7**). It is a rare jelly which is hard to dissolve when warmed, because it uses agar as a coagulant. Agar [1] made from seaweed usually forms into jelly at 0.7 wt.%. Jelly made from agar has a high melting temperature (68–84°C), keeps the shape in hot soup. 3D printing mold of the jelly has been designed in the motif of a snow lantern (**Figure 8**). The size of the jelly is 4.5 cm in length, 2.4 cm in width, and 1.7 cm in height.

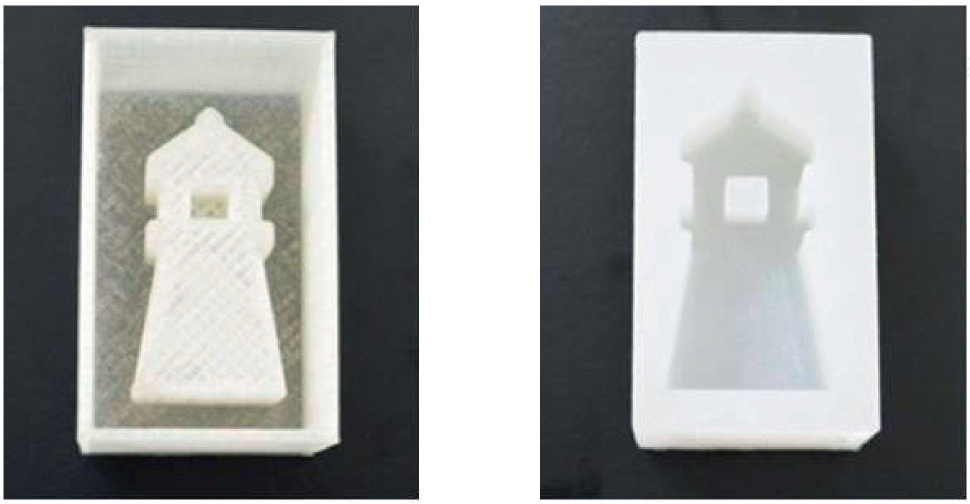


**Figure 8.** 3D Yonezawa beef hot jelly mold.

**Figure 9.** Restaurant menu 3D Yonezawa beef hot jelly.

"3D Yonezawa beef hot jelly" is served in the local Italian restaurant as appetizers or soup garnishes (**Figure 9**).

### *4.2.4. 3D carp jelly*

3D carp jelly is a jelly in the shape of Yonezawa carp (**Figure 10**). "3D carp jelly" is served in the local carp restaurant as "3D carp hot pot." Jelly is made from soy milk, dried carp flakes, and gelatin. This Jelly melts easily and becomes soy milk soup when heated (**Figure 11**). Because the jelly contains heart-shaped konjac, konjac comes out when the jelly melts. Gelatin [2] made from collagen, contained in the skin of cows and pigs, usually forms into jelly at 2.0 wt.%. Jelly made from gelatin melts at room temperature (20–30°C). The size of the jelly is 6 cm in length, 2.7 cm in width, and 1.5 cm in height.

### *4.2.5. 3D Tateyama apple RAKUGAN*

RAKUGAN is traditional Japanese confection made by adding a little moisture to the sugar and pushing it to the mold and drying it. RAKUGAN mold is originally wooden (**Figure 12**) and made

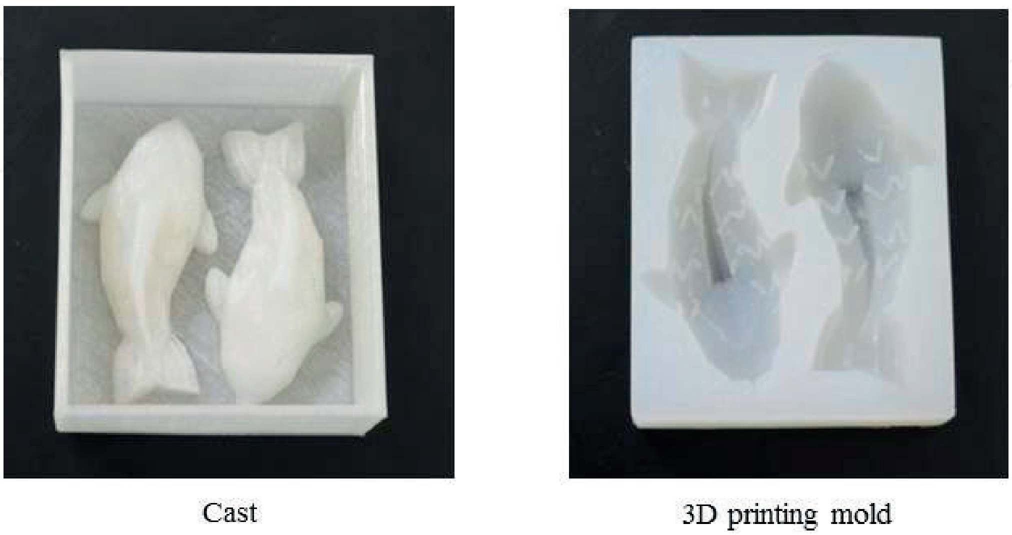


**Figure 10.** 3D carp jelly mold.

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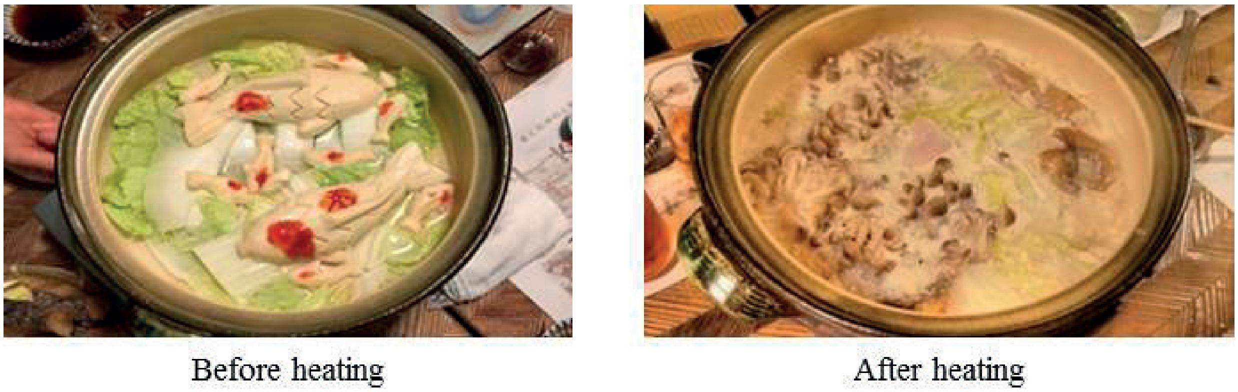


Figure 11. Restaurant menu 3D carp hot.

by craftsmen, but the number of craftsmen are decreasing. Therefore, an acrylic board processed with a laser cutter, and parts for pushing the material were made with a 3D printer (**Figure 13**). 3D printing mold of RAKUGAN has been designed in the motif of a snow lantern. 3D Tateyama apple RAKUGAN is mainly composed of the powder of Tateyama apple and Wasanbon, which is fine-grained Japanese sugar (**Figure 14**). The size of the RAKUGAN is 3 cm in length, 1.5 cm in width, and 0.7 cm in height. 3D Tateyama apple RAKUGAN is sold at a local sweets shop.

**Figure 12.** Wooden mold.



**Figure 13.** 3D printing mold of 3D Tateyama apple RAKUGAN.

**Figure 14.** 3D Tateyama apple RAKUGAN.

## 5. Eki Fab

Eki Fab is a manufacturing space installed in the station building. 3D printers and laser cutters are installed, so that anyone can use them. Although this activity is open only every Saturday, many people use it when waiting for train at the station, including children and elderly people.

Eki Fab has held various events in the past. Among them, we have introduced events related to food.

### 5.1. Original jelly making class

We conducted an event "Let's make original jelly with 3D printer" for junior high school students. It is a part of the program of Japan Society for the Promotion of Science. The event was divided into three sections, (i) creation of jelly mold data, (ii) modeling a jelly mold with a 3D printer, and (iii) eating jellies made with original jelly mold.

i. Creation of jelly mold data

Jelly mold 3D data was created using AUTODESK 123D Design free CAD software. There are various operation methods for 3D CAD, and it is hard to master it. However, if it is a simple form like a jelly mold, it can be made with few steps so that data can be created in a relatively brief time. Junior high school students who participated in the event could finish creating jelly type data in about 2 h (**Figure 15**).

ii. Modeling a jelly mold with a 3D printer

Eki Fab has an FDM 3D printer. In FDM 3D printers, either filament of ABS or PLA is basically used. But we used a filament called PET+ which was approved by FDA (Food and Drug Administration) to touch foods (**Figure 16**).

iii. Eating jellies made with original jelly mold

Figure 15. Making 3D data with CAD.

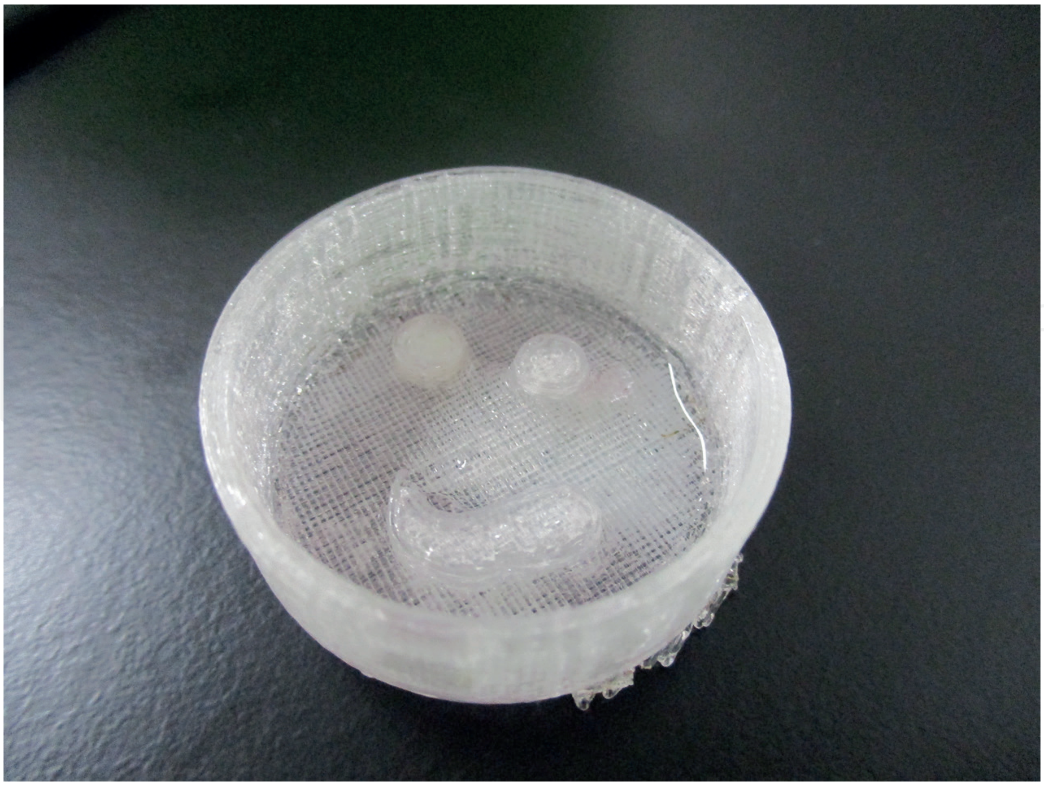

Figure 16. Jelly mold.

**Figure 17.** Eating jelly.

Even though most of the participants were seeing a 3D printer first time, everyone could create the original mold and make the jelly. Participants had a serious look during data creation and modeling, but a smile was seen when eating the finished original jelly (**Figure 17**).

## 6. Measurement of physical property of edible material for 3D food printer

We developed 3D food printer named "Food-y" after the E-Chef (**Figure 18**). Food-y is a printer developed jointly by MIRICE Co., Ltd., SEIKI Co., Ltd., and Yamagata University. In Food-y, shape of the food can be given by filling a syringe with a paste-like material such as bean paste or rice flour cookie and pressing it with a piston to eject the materials (**Figure 19**). However, other materials may not be able to shape depending on physical properties. Therefore, we have analyzed the texture and viscoelasticity of the material to ascertain conditions of lamina table material.

### 6.1. Materials for texture and viscoelasticity analyses

Materials were Mochi prepared by mixing rice flour and water and heating. Four Mochi were prepared by mixing 100, 125, 150, and 200 ml of water with 50 g of rice flour (Mochi 33 (rice flour 33%), Mochi 28 (rice flour 28%), Mochi 25 (rice flour 25%), and Mochi 20 (rice flour 20%), respectively).

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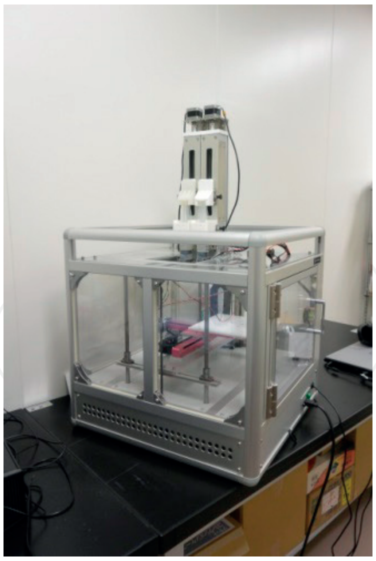

Figure 18. 3D food printer “Food-y”.



### 6.2. Modeled object and volume

Modeling was carried out at the material temperature kept at 25°C. **Figure 20** shows the 3D data of the apple recessed in the center used for molding. **Figure 21** shows what was molded in Food-y. **Table 1** shows the volume of the modeled objects.

### 6.3. Measurement of texture

Food has characteristics of texture. The texture as a dynamic property includes factors such as hardness, cohesiveness, and adhesiveness. Cohesiveness represents the easiness of cohesion


**Figure 19.** Bean paste and rice flour cookie by 3D printed.

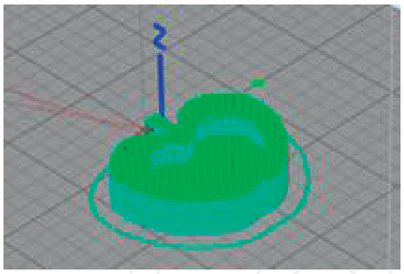


**Figure 20.** 3D data of apple.

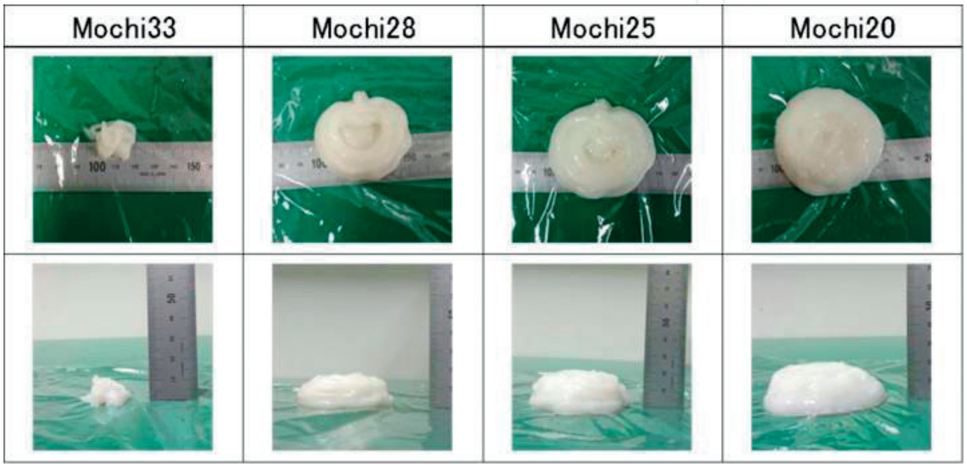


**Figure 21.** Printed Mochi by Food-y.

when the food is eaten, and adhesiveness represents the force to attach and separate from teeth, tongue, and oral cavity when the food is eaten [3].

We measured the texture before modeling for Mochi 33, 28, 25, 20. We used EZ Test (SHIMADZU CORPORATION) (**Figure 22**) as a texture analyzer. For the test, hardness, cohesiveness, and adhesiveness were measured nine times for each sample, and the results are shown in **Figures 23–25**, respectively.

### 6.4. Measurement of viscoelasticity

Mochi has a viscoelastic body. Therefore, we evaluated the workability of Mochi by measuring viscoelasticity. Measurement of viscoelasticity by a rheometer is technically established, and it can be said that it is appropriate because it is excellent in quantitative aspects [4].

For the Mochi 33, dynamic viscoelasticity measurement in the linear region was carried out as measurement of viscoelasticity before modeling. We used MCR 301 (Anton Paar Co., Ltd.) (**Figure 26**) as a rheometer. Cone plate ϕ 25 mm Angle 2 degrees and ϕ 50 mm Angle 1 degree

| Sample | Mochi 33 | Mochi 28 | Mochi 25 | Mochi 20 |
|---|---|---|---|---|
| Volume (ml) | 2 | 21 | 43 | 44 |

**Table 1.** Volume of the modeled objects.

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**Figure 22.** Texture analyzer EZ Test.

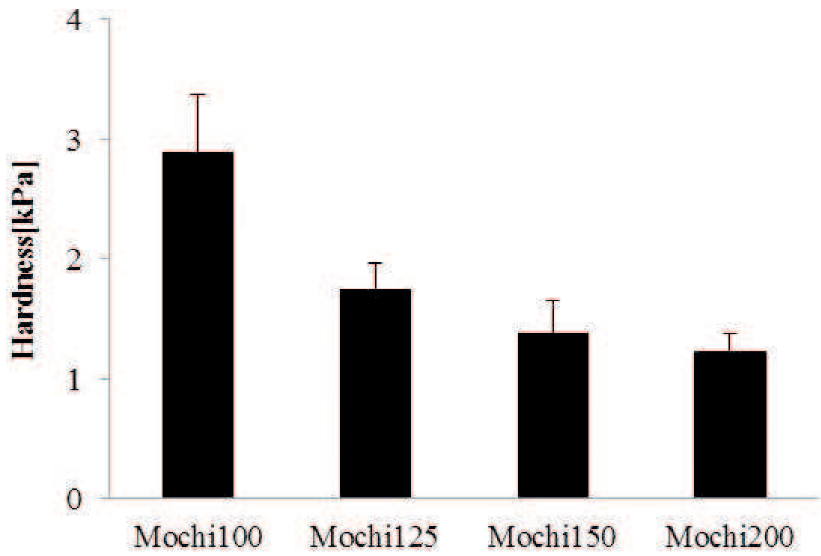


**Figure 23.** Hardness of Mochi.

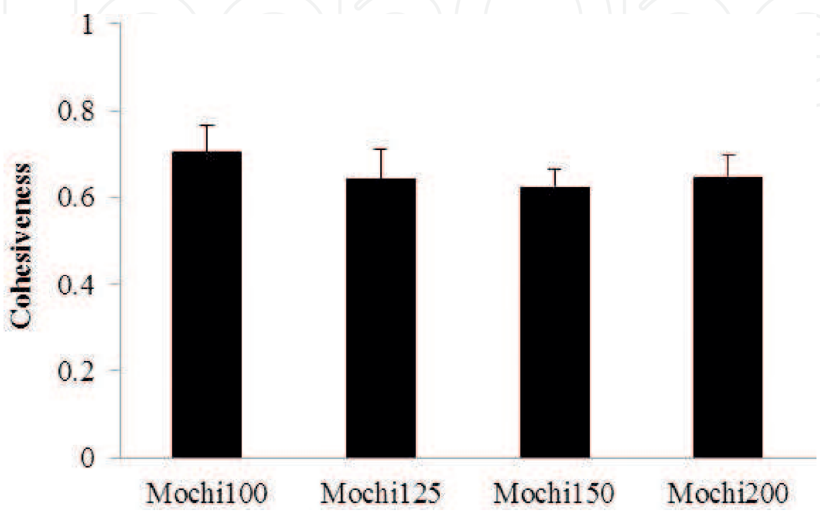


**Figure 24.** Cohesiveness of Mochi.

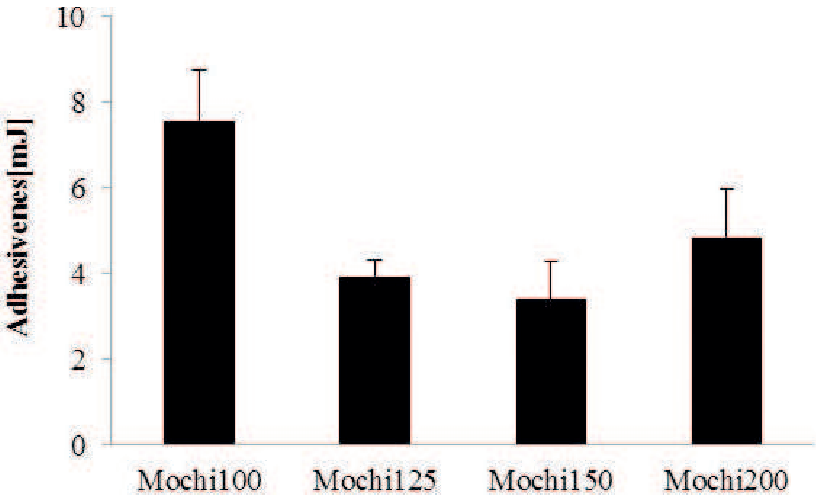


**Figure 25.** Adhesiveness of Mochi.

were used (**Figure 27**). The results of storage elastic modulus G′ and loss elastic modulus G″ are shown in **Figure 28**. Also, storage elastic modulus G′ and loss elastic modulus G″ at an angular frequency of 1 rad/s and the hardness measured by a texture analyzer are shown in the same graph (**Figure 29**).

### 6.5. Results

Mochi 28 could make beautiful shapes enough to easily understand the shape of the apple (**Figure 21**). Therefore, consider Mochi 28 as a reference. Mochi 33 is deficient in ejection and Mochi 25 and Mochi 20 are ejected excessively (**Table 1**).

Hardness decreases as the proportion of rice flour becomes smaller (**Figure 23**). Cohesiveness is almost constant regardless of the sample (**Figure 24**). Adhesiveness is variable (**Figure 25**).

G′ and G″ becomes smaller as the amount of rice flour decreases (**Figure 28**).

From Mochi 33 to Mochi 25, hardness, G′ and G″, tends to be similar (**Figure 29**).

**Figure 26.** Rheometer MCR301.

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Figure 27. Cone plate of rheometer.

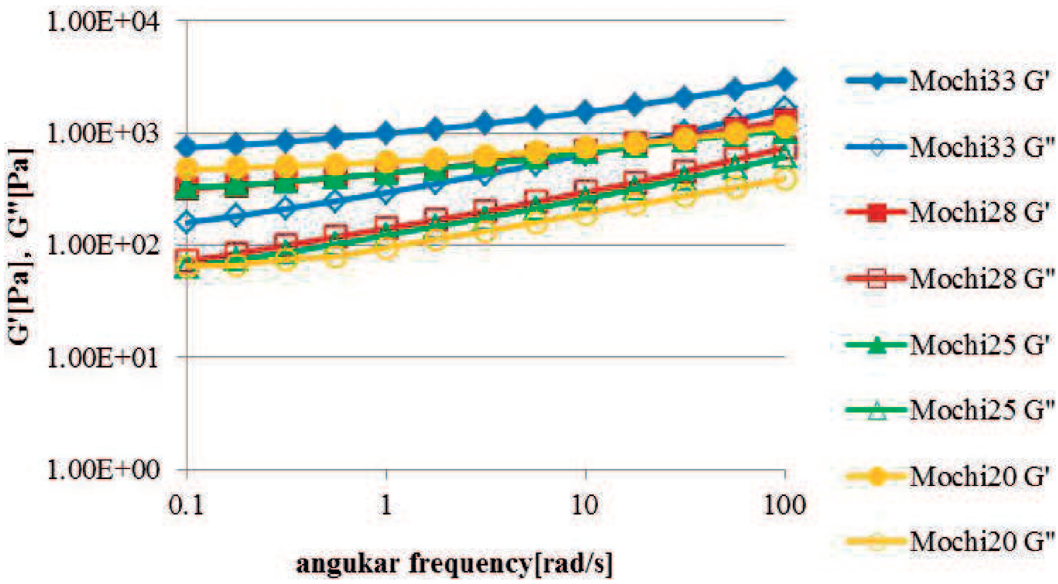


Figure 28. G′ and G″ of Mochi.

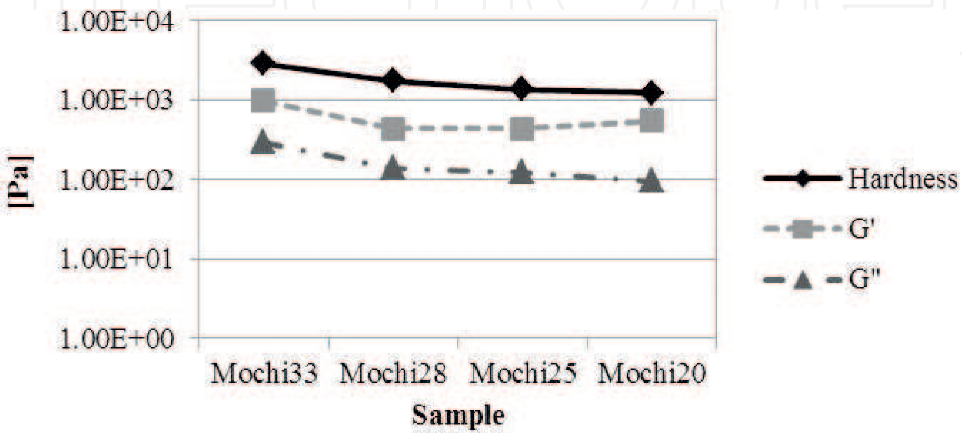


Figure 29. Hardness, G′, and G″ of Mochi.

### 6.6. Consideration

From the texture test, we can see that the sample is hard if volume is small and if the sample is soft volume becomes excessive. Easiness of 3D laminate modeling can be determined from the hardness measured by the texture analyzer.

From the comparison of the texture test and the viscoelasticity test, the hardness of the storage elastic modulus and the loss elastic modulus of the sample tend to be similar.

### 6.7. Conclusion

The simplicity of 3D laminate modeling by food-3D printers can be determined by the hardness measured by a texture analyzer. The texture analyzer is standardized in the laboratory of food and considered to be useful as a discrimination method. In addition, the hardness measured by the texture analyzer agrees well with the viscoelasticity measured by the rheometer. In the laboratory of soft material engineering, it is possible to evaluate the viscoelasticity by a rheometer and advance the research to predict the ease of 3D laminate modeling.

Future work will involve conducting similar research on food samples other than Mochi and investigate the generality of the above conclusion. We will also develop a method to judge easiness of 3D laminate modeling from measured values of viscoelasticity. This will ultimately establish a methodology for finding the optimum 3D lamination condition from the physical properties of soft materials.

## 7. 3D printing and future foods

As discussed, there are many applications of 3D printers in the field of food. Common to all cases is that the producer is using 3D printers considering "appearance" of food. "Appearance" of food is very important; it is one of the key factors to make delicious meals. Especially, it is said that care foods are so soft that they look bad and it also affects the amount of meals. Therefore, using a 3D food printer or 3D printing mold, "looks" can be greatly improved.

3D food printing has many challenges, such as shortage of edible material, less-accuracy during modeling, and difficulty in real use. However, we can expand the possibilities of food shaping by advancing what we can do now such as make a 3D printing mold with 3D printer etc.

One of the features of 3D printers is that materials can be shaped if there is only 3D data. As the development of food 3D printers progresses, it may be possible to adjust the shape, taste, nutrition, etc. according to individual's physical condition automatically based on the digital data of the food, and cooking can be done with one click of operation.

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