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A study of parameter affecting cookie model by using a 3D printing technology

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Abstract

The objective of this research was to study the parameters affecting the injection molding of cookies to the desired size. The initial variables in the study were the nozzle travel speed at 200 mm/min and 300 mm/min, the height between the nozzle and the workpiece base at a height of 5.5 mm and 6.5 mm., and the amount of butter, which was reduced by 40 g and increased by 40 g from the original recipe. The dependent variable was the width of the cookie line in 3 positions: head, middle and tail. The control variable was the size of the nozzle at 4 mm in diameter. From the experimental results, it was found that the factors that significantly influenced the width of the cookie dough were the speed of the nozzle movement, the amount of butter in the cookie recipe, and the co-influence between the amount of butter in the cookie recipe and the height between the nozzle and the base. When analyzing the consistency of the cookie patties, it was found that the amount of butter in the recipe was reduced by 40 g or 20% from the original recipe, the nozzle movement speed was at 300 mm/min., and the height between the nozzle and the workpiece base was 5.5 mm. This will make the width of the cookie line at the head, middle and tail positions to be the most similar.

Keywords

fused deposition modeling; syringe base extruder; 3D food printing technology; parameter optimization

1. Introduction

3D printing technology, or additive manufacturing, is being used in a wide variety of industries such as jewelry, automobiles, medical parts and human organs. The principle of printing is based on a layer-by-layer method of fabrication. The advantages of this technology are its ability to design complex products that conventional manufacturing processes are not able to achieve with the above technology and its ability to be applied in a wide range of fields including medicine, aerospace, automotive. Moreover, it is increasingly being used in the food industry [1].

3D printing technology applied to the food industry has many benefits, such as the food design that can be personalized nutrition [2]. By using this technology, the complex-shaped food design that cannot be done with simple labors or molds can be produced using a 3D shape design data file with the specified G code file extension. It can also be used to shape desserts and colorful images onto food surfaces, such as hot coffee. In addition, 3D food printing provides the scaling and adaptation of individual's nutritional and energy needs according to their physical and nutritional needs. The application of this technique brings food creation closer to the customer and reduces the transport volume, thereby reducing packaging, distribution and cost [3].

3D food printing technology is divided into three main techniques [4]: Extrusion-based printing, Powder Bed Fusion printing, and Binder Jetting printing. Food safety and regulatory compliance are integral considerations in addition to formulation. All food contact parts including the nozzle, syringe barrel, tubing, and build platform should be manufactured from materials such as 304 stainless steel and certified food grade polymer that meet food contact standards.

As Fig. 1 shows Extrusion-based printing, a very popular technique. The working principle is to continuously extrude solid or semi-solid material from the nozzle. The nozzle set or base will move up and down depending on the design of the machine. Food printing has been experimented on a variety of materials, for example pasta, chocolate, cheese, lemonade gel, and elderly food. As Fig. 2 shows Powder Bed Fusion printing. This technique prints a work piece by spreading a thin layer of powdered food material and then using a laser beam to the desired printing position to make the powder melt and blend together, then spread the new powder. For the next layer, a laser beam is repeatedly fired at the desired position until the product is as designed. This technique is used to design confectionery products made from sugar to specific or complex sizes and shapes. It also reduces the amount of materials in the production process.

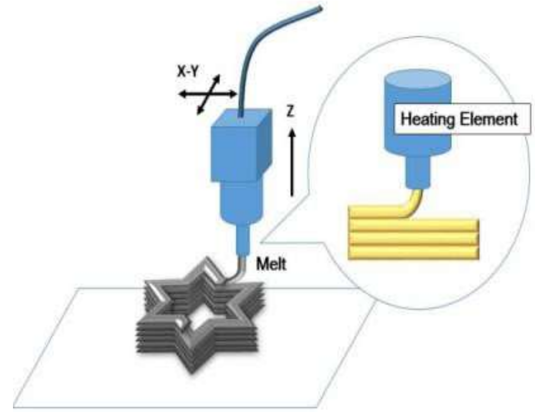


Figure 1 Extrusion-based printing

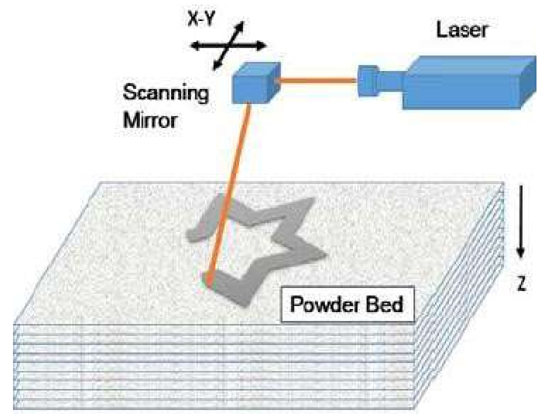


Figure 2 Powder Bed Fusion printing

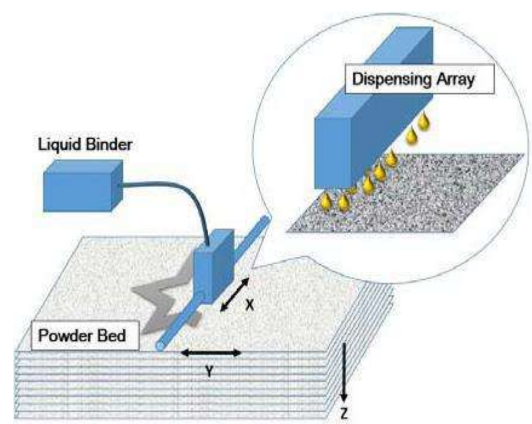


Figure 3 Binder Jetting printing

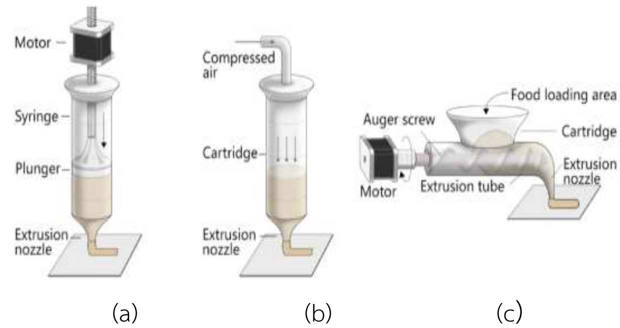


Figure 4 Extrusion-based printing mechanisms: (a) Syringe-Based Extrusion, (b) Air Pressure Driven Extrusion, (c) Screw-Based Extrusion

As Fig. 3 shows Binder Jetting printing. This technique is similar to Powder Bed Fusion printing, but uses a water-based liquid spray or another food ingredient known as a binder to bind the powder together in the desired position. This process is repeated with the required number of layers until a product is embedded in the powder similar to a fossil. The material that does not adhere to the binder is then removed from the product, but the removed material can be reused for future printing. The resulting products are processed in the final step using suitable processes such as baking. This technique can be used to design products in the bakery and confectionery industries.

There are three mechanisms of the Extrusion-based printing used for food printing as shown in Fig. 4 [5]. As Fig. 4 (a) the syringe-based extrusion consists of a needle cylinder for collecting the material and a motor to drive the extrusion process. The motor is used to push the material out of the syringe through the nozzle. The extrusion speed can be increased or decreased by setting the rotation speed of the motor. This type of extrusion is suitable for extrude solid or semi-solid and liquid materials. As Fig. 4 (b) air pressure driven extrusion is the printing of food without the food touching the top of the nozzle. The system will release air at the specified pressure, which the air is the medium to push the material out of the nozzle, so the air must be well filtered and cleaned. This type of extrusion is suitable for liquid or low viscosity materials. As Fig. 4 (c) screw-based extrusion is the printing using a rotating screw to drive the material out of the nozzle. This type of printing is not suitable for liquid materials with high viscosity and mechanical strength. Throughout the process of Screw-Based Extrusion, the material can be filled into the hopper at any time due to continuous printing, which is different from syringe printing and pneumatic printing that cannot print continuously. Cookie is a popular snack for many people and cookie texture is one of the texture that can be molded, therefore it is widely used in 3D printing in the food industry. [6] studied the changes in recipes that affect the ability in the printing and forming of food. In the case of sugar cookies, the concentration of sugar, egg yolk and butter, studies have shown that egg yolk and sugar concentrations affect the shape stability of cookies after baking as measured by width, length and height. The yolk and sugar concentrations were able to maintain the shape of cookies in width and length after baking, but only butter reduced the shape of cookies and reduces their height after baking. [7] compared study of the printability of egg yolk (EY) and egg white (EW) with blending of rice flour, focusing on optimizing various extrusion printing parameters, including printing element, nozzle height, nozzle diameter, rolling motor printing speed, extrusion speed and rate. In addition, they also studied the different physical, mechanical and fluid properties of materials. The results of the study showed that the addition of the filler (Rice flour 1:1 and 1:2 w/w) had a significant effect on improving the stability and strength of EY and EW. The printing position of EY 1:2

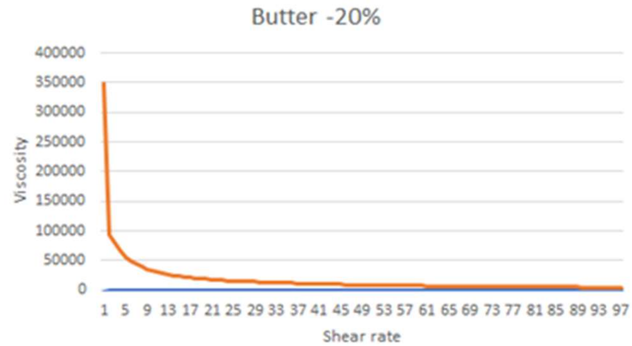
(EY: rice flour) could print in 3D with fine precision and higher layer clarity with minimal color shift.

Therefore, this project aims to study the parameters that affect the extrusion-based of cookies to the desired sizes. The independent variables in the study are the nozzle displacement speed of 200 mm/min and 300 mm/min, the height between the nozzle and the base at a height of 5.5 mm and 6.5 mm, the decreased amount of butter by 40 g and the increased amount of butter by 40 g from the original recipe. The dependent variable is the width of the cookie line in 3 positions which are head, middle, and tail.

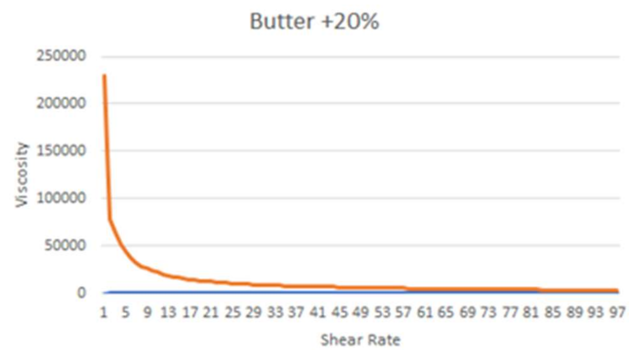
2. Experiment

2.1 Analysis of the rheological property of the material

The mechanical property and the flow behavior of the food play an important role during extrusion-based. During extrusion-based, the cookie texture gets relatively high mechanical stress and shear. Therefore, the rheological property of the cookie texture is an important index to determine the extrusion-based ability as shown in Fig. 5. The viscosity of the cookie texture decreases markedly as the shear rate increases, indicating that the cookie is a pseudoplastic liquid. The increase in butter decreases the viscosity which affects the molding of cookie texture. The decrease in butter increases the viscosity, which affects the shape retention of cookie texture.



(a) The decreased amount of butter by 40 g



(b) The increased amount of butter by 40 g

Figure 5 The rheological behavior graphs of cookies with different butter amounts

Table 1 Experimental variables

Independent Variables	Control Variables	Dependent Variables
The nozzle speed	4 mm. of nozzle	The width of the cookie lines is measured at three positions along each line.
The height between the nozzle and the base	Tested at room temperature 28°c	
The amount of butter	Cookie recipe	

2.2 Printing variables

Determine the variables in the experiment as shown in Table 1. The interactions between the nozzle speed, the height between the nozzle and the base, and the amount of butter are studied. This is 2k factorial design experiment with completely randomized design.

2.3 Material

The amount of butter: The ideal cookie texture should have a suitable viscosity and be able to be molded into an attractive shape. The decreased amount of butter (under 40g or 20% from the original recipe) creates an unsuitable material and is highly viscous. The material is hard and has low fluidity, resulting in broken lines and difficult for molding to the desired shape as shown in Fig. 6. On the other hand, the increased amount of butter (more than 40 g or 20% from the original recipe) leads to a low viscosity material. The material has good fluidity, resulting in the greater extrusion-based width than the specified value, and resulting in maintaining the shape of the cookie line sizes as shown in Fig. 7.

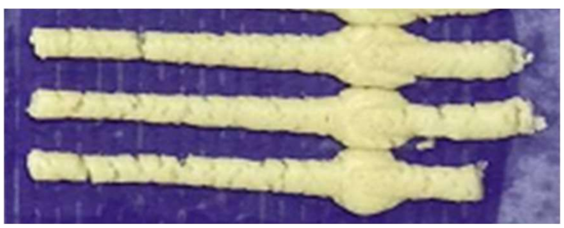


Figure 6 The cookie line sizes of the decreased amount of butter by 40 g

Figure 7 The cookie line sizes of the increased amount of butter by 40 g

Figure 8 3D Extrusion-based cookies with the nozzle height 5.5 mm.

Figure 9 3D Extrusion-based cookies with the nozzle height 6.5 mm.

From the test of the amount of butter between 120 g and 200 g, the appearance of the extrusion-based cookie lines has slight defects and deformation. Based on these observations, the level of the amount of butter is reduced by 40 g and increased by 40 g from the original recipe. The height between the nozzle and the base is the distance between the tail of the nozzle of the extrusion-based machine and the base used for extruding the workpiece. The nozzle height has a great influence on the forming geometry, in the same case with the extrusion-based of the cookie lines. According to the experiment, it was found that the lower height will result in the cookie line being unshaped and flat as shown in Fig. 8. And the higher height will result in the cookie line being rounded, and when it is molded by 3D extrusion-based, the cookie texture does not stick together, affecting the good appearance as shown in Fig. 9.

Based on these observations, the heights between the nozzle and the base are 5.5 and 6.5 mm.

The nozzle speed is the running speed of machine, greatly affecting the size of the molded line. According to the experiment, the high nozzle speed will result in smaller line sizes as shown in Fig. 10. On the other hand, the low nozzle speed will result in larger and wider line sizes as shown in Fig. 11. It was observed that the level of the nozzle speed factor that makes the sizes of the cookie lines are 200 mm/min and 300 mm/min. As the analysis of the experimental variables, the experimental table can be as shown in Table 2. Design of Experiment (DoE) method was applied to analyze the effect of input parameters (factors) on the width of the extruded cookie line (response variable). Analysis of variance (ANOVA) and mean comparison were processed with Minitab software. Differences of $p < 0.05$ were determined to be significant.

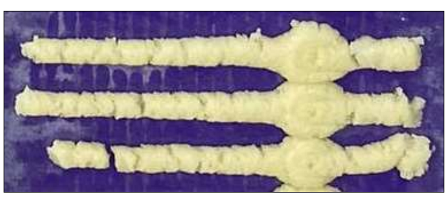


Figure 10 The size of the cookie line using the nozzle speed 300 mm/min.

Figure 11 The size of the cookie line using the nozzle speed 200 mm/min

Table 2 Experimental design

Order	The nozzle speed (mm/min)	The height between the nozzle and the base (mm)	The amount of butter (g)
1	200	5.5	-40g
2	200	5.5	+40g
3	200	6.5	-40g
4	200	6.5	+40g
5	300	5.5	-40g
6	300	5.5	+40g
7	300	6.5	-40g
8	300	6.5	+40g

2.4 Experimental hypothesis

Hypothesis 1

H_0 : The nozzle speed does not affect the size of cookie lines.

H_1 : The nozzle speed affects the size of cookie lines.

Hypothesis 2

H_0 : The height between the nozzle and the base does not affect the size of cookie lines.

H_1 : The height between the nozzle and the base affects the size of cookie lines.

Hypothesis 3

H_0 : The amount of butter does not affect the size of cookie lines.

H_1 : The amount of butter affects the size of cookie lines.

3. Analysis

3.1 Experimental results

Analysis of the data normalization, according to the analysis of the data proportion as shown in Fig. 12, the Residual distribution is the normal distribution scattered as residual points aligned on the line, tends to be linear and independent. In addition, the graph between the residual values and experimental sequences were not trending. It can be concluded that it is independent and not depend on the experiment, so this experiment is valid. When considering the distribution of the data on the chart based on Histogram Test, Residual distribution is independent, non-definite or not approximate, indicating that residual values are independent.

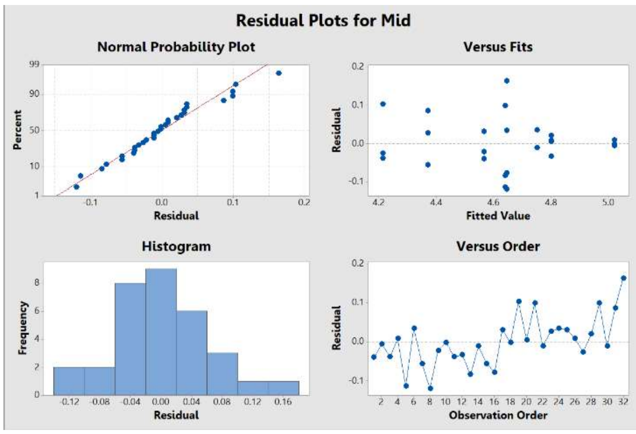


Figure 12 Residual plot

Factorial Regression: Mid versus Butter, Nozzle Speed, Nozzle Height

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	1.77980	0.25426	49.33	0.000
Linear	3	1.49650	0.49883	96.77	0.000
Butter	1	1.02567	1.02567	198.98	0.000
Nozzle Speed	1	0.45196	0.45196	87.68	0.000
Nozzle Height	1	0.01887	0.01887	3.66	0.068
2-Way Interactions	3	0.28279	0.09426	18.29	0.000
Butter*Nozzle Speed	1	0.04448	0.04448	8.63	0.007
Butter*Nozzle Height	1	0.21797	0.21797	42.29	0.000
Nozzle Speed*Nozzle Height	1	0.02035	0.02035	3.95	0.058
3-Way Interactions	1	0.00050	0.00050	0.10	0.757
Butter*Nozzle Speed*Nozzle Height	1	0.00050	0.00050	0.10	0.757
Error	24	0.12371	0.00515		
Total	31	1.90351			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0717955	93.50%	91.61%	88.45%

Figure 13 The result of analysis of variance

3.2 Analysis of the variance of two-level of factorial data

According to the analysis of variance of factors affecting the width of the cookie lines using Minitab program, it is found that the main factors influencing the width of the cookie lines significantly ($p < 0.05$) are the nozzle speed, the amount of butter in the recipe, and the interaction between the amount of butter in the recipe and the height between the nozzle and the base as shown in Fig. 13.

Consider the main factors that affect the width of the cookie lines: The amount of butter shows that the graph is significantly positive, meaning that the line size increases according to the increased amount of butter. The nozzle speed shows that the graph is significantly negative, meaning that the line size increases according to the increased speed of the nozzle. The height between the nozzle and the base shows that the graph is significantly negative and almost linear, meaning that no matter how high or low the nozzle height is adjusted, the line size of cookie does not change that much. Therefore, the height between the nozzle and the base does not affect the width of the cookie line. As the consideration of the two-factors, it is found that the combined influences between the factors, the amount of butter and the height between the nozzle and the base, nozzle speed and nozzle hight significantly affect the width of the cookie lines. If the adjustment of the amount of butter is at the high level and the height between the nozzle and the base is high, the cookie lines is wide. If the adjustment of the amount of butter is at the low level and the height between the nozzle and the base is low, the cookie lines is narrow.

4. Results and discussion

As the results of finding the optimal value of factors to find the optimal level for adjusting the extrusion-based machine and to provide the closest width to the target width at 4 mm. according to the diameter of the nozzle, the optimal factors can be summarized in Table 3. In this study, there is a dependent variable, Y is the width of the cookie line, and there are three independent variables, X_1 is The amount of butter, X_2 is The nozzle speed, and X_3 is The height between the nozzle and the base. The regression equation is

$$\begin{aligned} Y = {} & 7.024 + 0.0611X_1 - 0.00843X_2 - 0.301X_3 \\ & - 0.000010X_1X_2 - 0.01024X_1X_3 \\ & + 0.001009X_2X_3 + 0.000008X_1X_2X_3 \end{aligned} \quad (1)$$

The correlation coefficient of this equation is R-Sq = 93.50%, which is greater than the accepted percentage of 70%. It can be accepted that this regression equation can be used to predict the width of the cookie line from the significant factors.

Table 3 The optimal value of factors

Factors	Suitable Parameters
The amount of butter	Reduces 40 g from the original recipe
The nozzle speed	300 mm/min

5. Conclusions

To investigate a capability material deposition of the extrusion-based machine, the amount of butter, the nozzle speed and the height between the nozzle are parameters that were verified. As the experimental design and the experimental operation, including the analysis of the response variables, the research results of the amount of butter, the nozzle speed and the height between the nozzle and the base at the significance level (α= 0.05) can be concluded using Response Optimization to find the optimal value of each factor. The optimum values for extrusion-based are the reduced amount of butter by 40 g from the original recipe, the nozzle speed at 300 mm/min, and the height between the nozzle and the base at 5.5 mm. For this reason, the width of the cookie line and the positions of head, middle, tail have the closest value to 4 mm.

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