Elongation Optimization of Bioplastic using Response Surface Methodology

Trisita Novianti, Issa Dyah Utami and Heri Awalul Ilhamsah
Department of Industrial Engineering, University of Trunojoyo, Jl. Raya Telang Kamal, Bangkalan, Indonesia

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Abstract: Bio plastics are derived from plant sources such as corn starch, cassava, sugarcane, soybean, banana peel. Bio plastics are environmental friendly and biodegradable, which is a material that can return to its natural state when buried in the ground or soaked in the water. Microorganisms will break down into carbon dioxide and water. The aim of this study was measuring elongation optimization in bio plastic, which made of glycerin and cornstarch as the base material. For calculation, this study was using the surface response method with experimental design with 2 factors (22), and experimental design were 13 experiments. Based on the calculation results, the desirability value for elongation was 18.4. Moreover, the combination of the optimal parameters produced was 0.5 ml glycerin and 3.81 g starch with the optimum elongation was 17.3%. The elongation of commercial plastic bag is 222.5%. The elongation of bioplastic sample in this research were below this number. Moreover, the bioplastic sample, which was made of corn starch, cannot be used as commercial plastic bag. However, it can be used in food packaging, pharmacy, and cosmetic which do not need high elongation, which is around 20%.

1 INTRODUCTION

Bioplastics are derived from plant sources such as corn starch, cassava, sugarcane, soybean, banana peel. Bio plastics are environmental friendly and biodegradable, which is a material, returns to its natural state when buried in the ground or soaked in the water (Ghayebzadeh et al., 2020). Microorganisms will break down into carbon dioxide and water. Bags are made of bio plastic can be thrown away and buried (Zhang et al., 2020). This can reduce plastic waste in the world, especially in the ocean (Andrady, 2017). The fact, Indonesia has the second rank for plastic waste in the ocean after China. This condition can cause animal death, which is accidentally eat plastic waste (Lestari and Trihadiningrum, 2019). Bio plastics can be used for shopping bag, food packaging, gardening, sanitary products, medical product (Jambeck et al., 2015).

Urbanization and industrialization combined an increasing in the population has led to the accumulation of boundless quantities of non-biodegradable waste in the environment. Plastics have turned to be an expected part of day-to-day life. Deceleration in accessibility of petrochemical residues has led to the dependence and development of eco-friendly and biodegradable plastics of commercial stuff, with improved worldly properties than their synthetic (Umesh et al., 2018). Using non-renewable packaging make a serious ecological problem caused by their non-biodegradability. The development of biodegradable edible film can replace synthetic materials, thus protecting environment and improving product quality (Araújo et al., 2018a). Biodegradable films may be made of natural polymers, for instance proteins, polysaccharides, lipids, or a combination of these compounds (Abbas et al., 2017).

In this study was used cornstarch for basic material, because of its large availability, easily available in Indonesia, and the price is cheap. For making bio plastic, first this study had to assess the mechanical properties of the bio plastic. This can be indicated by measuring elongation which is one of indicators of the flexibility of the material (Domene-López et al., 2019). In accordance to Japanese Industrial Standard, the percent extension or flexibility is categorized as good if above 10% and will be categorized very well if it exceeds 50% (Miyamoto et al., 1984). The surface response methodology was used to measure the optimum composition for glycerine and corn starch to form bio plastic material which has maximum elongation. This response surface method is an optimization method

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that is devoted to research using experiments (Gaspersz, 1992, Akinoso et al., 2012).

2 METHODOLOGY

2.1 The Process of Making Bioplastics

The concentration of cornstarch and glycerin was used in accordance pre-determined coding. Added 0.8 g carrageenan, then distilled r with 100 ml water. The next process was heated using a hotplate with a temperature of 95 ºC while stirring for 30 minutes. Next step was preparing a mold made of square glass with a size of 10 cm x 10 cm, after going through the stirring process for 30 minutes, the bio plastic was taken 15 ml and printed in the mold. Then the mixture was dried in an oven at 65 ºC for 8 hours.

Furthermore, observations were made by forming bio plastics which be tested using a Texture Analyzer (de Azêvedo et al., 2020). A bio plastics sample, which was analysed, was 1cm x 5 cm. The measurement process by clamping the bio plastic sample with the tool and stretch it until broke up. When the biopassicator was broke, the tool automatically stops pulling (Novianti et al., 2019)

2.2 Data Retrieval

Data retrieval process was carried out using the Texture Analyzer tool. The tool can be used to measure the elongation of bio plastics. The process of retrieving data for elongation is as follows:

a. Making bio plastic sample, the size is 1 cm x 5 cm;
b. make initial settings with distance around 4 cm between clamp 4 cm;
c. clamping the two ends of the bio plastic on the clamp in the Texture Analyzer tool;
d. do the Running Texture Analyzer Tool
e. the tool will automatically stop when the object (bio plastic) will be disconnected;
f. the results are the output peak force.

2.3 Elongation Assessment

Cornstarch has a level of elasticity in bio plastics. Starch has amylase content and high plasticize in glycerin which cause bio plastics are having a high flexibility. The levels of amylopectin have an effect to make bio plastic stable in flexibility (Ibrahim et al., 2019, Reyes et al., 2020). Elongation testing in this study by taking bio plastic samples by cutting 1 cm x 5 cm x 0.1 cm. Then it was tested and obtained the maximum pull until the bio plastics break up. For calculating elongation using a formula as follows:

$$\text{Elongation}=\left(\frac{b-a}{a}\right)100\% \quad (1)$$

where are:
Elongation = Bio plastics elasticity (%)
b = additional length of sample when torn (cm)
a = sample length before it is pulled out (cm)

The following is a sample size of the bio plastic to be tested using a texture analyzer:

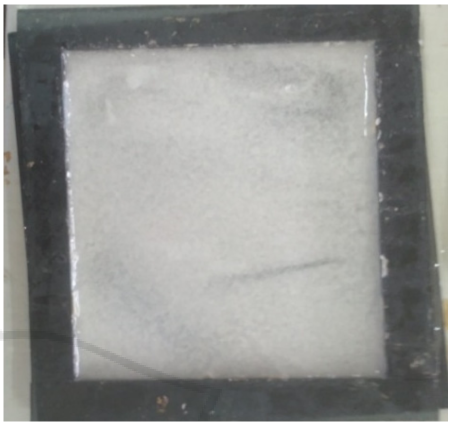

Figure 1: Bioplastic sample.

The completion method that will be used is the surface response method, which is a collection of statistical and mathematical techniques that are useful for analyzing problems about several independent variables that affect non-independent variables (Montgomery, 2017). The response surface method has the goal of finding the optimum response (Biglari et al., 2018). In this study identified the optimum response from bio plastics to the concentration of cornstarch.

The response surface method has the advantage of the other methods, which is the number of experiments is less so that the experimental costs can be reduced, and can be used for multiple responses. Then the output produced is an equation which will be used to predict the response with different independent variable values (Mäkelä and Management, 2017).

The results of the response surface method are countur plot and surface plot. Both will show the optimal area and can determine the level of influence of the independent variable on the response variable (Dean et al., 2017). Next is the D-Otimaly Response curve, which is a curve that will show the value of desbirability from optimal conditions for both responses. The equation as follows:

$$Y = B_0 + B_1 X_1 B_2 X_2 + B_3 X_1^2 + B_4 X_2^2 + B_5 X_1 X_2 \quad (2)$$

From the data that has been obtained from the experimental results, the data will be processed with the calculation of the matrix, so that the coefficients from the above equation will be obtained. The steps of the response surface method to be carried out are as follows (Sarabia et al., 2019):

a. Look for response surface coefficients by doing matrix calculations (in this study was used minitab for calculation);
b. assess model significance (ANOVA);
c. if the result is a significant, then the test will continue to determine the optimal parameters

The following hypothesis on a significant test that was conducted:

H_0 = Significant Model is proven

H_1 = Significant Model is not proven

If $F_{count} > F_{table}$ and *Sig* < 0.05, then accept H_0.

Furthermore, the test can be continued to next step which is optimal parameter assessment. The next step is to determine the optimum parameters by using the response optimizer in the Minitab application. The output of the process is calculated plot, surface plots and D-Optimal Response curves (Myers et al., 2016).

To determine the optimum area, it can be seen from the contour of the plot, while the surface plot will show the parameters that most influence to the response (Baş and Boyacı, 2007). D-Optimaly response can show its optimum point. In this study will show bio plastic parameters from the composition of glycerin and cornstarch (Yolmeh et al., 2017). Experimental design as follows:

Table 1: Experimental design.

Experimental Design	Factors (k)			
	2	3	4	5
Factorial Design	2^2	2^3	2^4	2^5
α ($2^{(k/4)}$)	1.414	1.682	2	2.378
Number of central repetition	5	6	7	10

α value can be derived as follow:

$$a = 2^{k/4} \quad (3)$$

Whereas:

k = Number of factors

α = Error

Table 2: Treatment code of glycerin and starch.

Treatments	Treatments Codes				
	-1.414	**-1**	**0**	**1**	**1.414**
Glycerin (ml)	1	0.5	1	1.5	2
Starch (g)	2	2	3	4	5

The research was conducted using response which was elongation optimal solution and using two factors. By using the Central Composite Design method, the number of experiments were 13 with the following details.

$$\begin{aligned} N &= 2^n + 2n + m \\ N &= 2^2 + 2(2) + 5 \\ N &= 4 + 4 + 5 \\ N &= 13 \end{aligned} \quad (4)$$

Whereas:

N : Number of experiments

n : Number of factors

m : number of centre point repetition

The experimental data were generated using the response surface method. The independent variable used in this experiment were glycerine and corn starch composition. While the dependent variables was elongation. The complete experimental design is as follows.

1. Factor:
   a) X_1 for glycerin experimental code
   b) X2 for cornstarch experimental code
   c) G for glycerin real composition from 0.5 ml to 2 ml
   d) T for cornstarch real composition from 2 g to 5 g
2. Response:

Y for bio plastic elongation code

The values of T and G for α and - α which were used as follows:

a. Value of cornstarch for α code (1.414)

$T = x_i (\Delta x_{+1,-1} / 2) + x_{original}$

$T = 1,414 ((4-2) / 2) + 3$

$T = 1,414 (1) + 3$

$T = 4,414 \approx 5$ gram

b. Value of cornstarch for -α code (-1.414)

$-T = x_i (\Delta x_{+1,-1} / 2) + x_{original}$

$-T = -1,414 ((4-2) / 2) + 3$

$-T = -1,414 (1) + 3$

$-T = -2,414 \approx 2$ gram

c. Value of glycerin for α code (1.414)

$G = x_i (\Delta x_{+1,-1} / 2) + x_{original}$

$G = 1,414 ((1,5-0,5) / 2) + 1$

$G = 1,414 (0.5) + 1$

$G = 1,707 \approx 2$ ml

d. Value of glycerin for -α code (-1.414)

$-G = x_i (\Delta x_{+1,-1} / 2) + x_{original}$

$-G = -1{,}414 ((1{,}5-0{,}5) / 2) + 1$

$-G = -1{,}414 (0{,}5) + 1$

$-G = 0{,}293 \approx 1$ ml

3 RESULT AND DISCUSSION

The higher of elongation, the elasticity of the bio plastics will have more elastic and not easily broken (Araújo et al., 2018b). The following was a recapitulation of the elongation test:

Table 3: Elongation assessment.

No	Factor				
	Code		Composition		Response
	X_1	X_2	G (ml)	T (g)	Y (%)
1	0	0	1	3	10
2	0	0	1	3	12
3	0	0	1	3	14
4	0	0	1	3	11
5	0	0	1	3	9
6	-1,414	0	1	3	7
7	1,414	0	2	3	11
8	0	-1,414	1	2	7
9	0	1,414	1	5	6
10	-1	-1	0,5	2	8
11	1	-1	1,5	2	10
12	-1	1	0,5	4	9
13	1	1	1,5	4	9

Whereas:

X_1 = Treatment code for glycerin

X_2 = Treatment code for corn starch

G = Composition of glycerine (ml)

T = Composition of corn starch (g)

Y = Bio plastic elongation (%)

The following were the results of the coefficient model output from the calculation of Minitab:

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.017237	0.003447	3.95	0.051
Linear	2	0.007899	0.003950	4.52	0.055
X1	1	0.007108	0.007108	8.14	0.025
X2	1	0.003285	0.003285	3.76	0.094
Square	2	0.009762	0.004881	5.59	0.035
X1*X1	1	0.005391	0.005391	6.17	0.042
X2*X2	1	0.004390	0.004390	5.03	0.060
2-Way Interaction	1	0.002552	0.002552	2.92	0.131
X1*X2	1	0.002552	0.002552	2.92	0.131
Error	7	0.006112	0.000873		
Lack-of-Fit	2	0.002172	0.001086	1.38	0.334
Pure Error	5	0.003940	0.000788		
Total	12	0.023349			

Figure 2: The calculation result.

$$Y = -0{,}084 - 0{,}141\, X_1 + 0{,}1845\, X_2 + 0{,}0974X_1^2 - 0{,}02085X_2^2 - 0{,}0505\, X_1X_2 \tag{5}$$

Whereas:

Y = Maximum optimal solution for elongation bioplastic

X_1 = Glycerin

X_2 = Cornstarch

Table 4: The result of Analysis of Varian (ANOVA).

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	22.1318	4.43	8.7	0.006
Error	7	3.5613	0.508		
Lack of fit	3	2.5842	0.8614	3.53	0.127
Pure error	4	0.9771	0.2443		
Total	12	25.69			

Based on the table, an elongation test of cornstarch model, obtained F count was 8.7 then F table obtained by the distribution table F with df model was 5 and df error was 7. From the lack of fit, test obtained p value = 0.127 which is greater than the significance level α = 0.05, then the model accept H_0 . It can be interpreted that the regression model was suitable and can be continued with the next model.

The next step was the optimal parameter determination stage. The optimal area was derived by using contour plots, surface plots on elongation tests, and then the optimal combination of parameters for elongation test using D-Otimaly Response, where the two plots will show the range of parameters and response. In this study there were two factors. The following were plot contours and surface plots for elongation test:

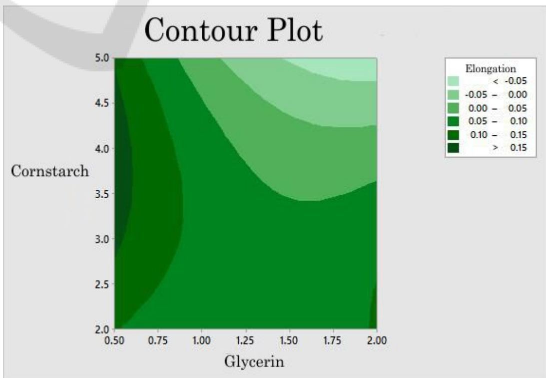

Figure 3: Elongation contour plot.

It can be shown in figure 3 that optimal solution is between 2.0 g to 5.0 g of corn starch and 0.5 ml to 2.00 ml glycerine.

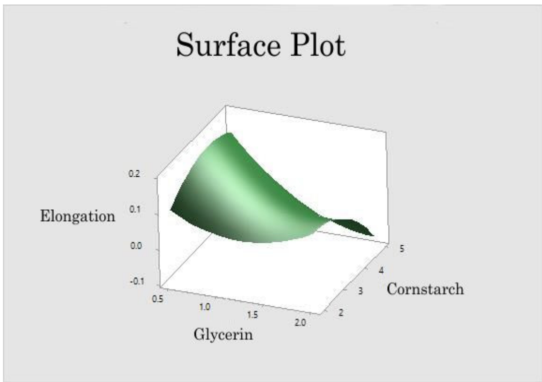

Figure 4: Elongation surface plot.

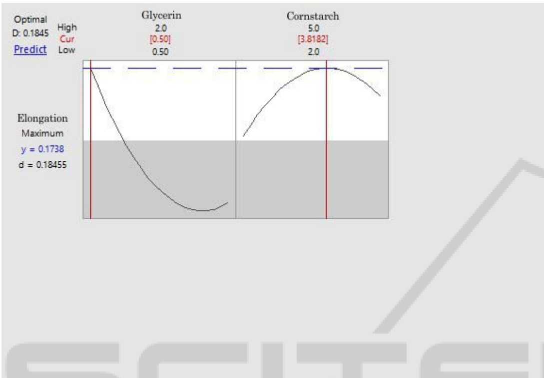

Figure 5: Elongation optimal solution area.

Based on the figure, elongation D-Optimaly response was obtained by the value of the desibrability function. Desirability value for elongation was 18.4, then the combination of the optimal parameters were 0.5 ml glycerin and 3.81 g cornstarch along with the optimum elongation result was 17.3%.

Elongation of this study also has met the standard, according to the Japanese Industrial Standard, elongation is categorized as good if above 10% and will be categorized very well if it exceeds 50%. The elongation of commercial plastic bag is 222.5%. The elongation of bioplastic sample in this research were below this number. Moreover, the bioplastic sample, which was made of corn starch, cannot be used as commercial plastic bag. However, it can be used in food packaging, pharmacy, and cosmetic which do not need high elongation, which is around 20% (Gozan and Noviasari, 2018). Moreover, using biodegradable packaging in the commercial or daily usage can protect ecological system and save habitat in the environment.

4 CONCLUSIONS

The optimal solution was derived by using the surface response methodology which had 2 factors (2^2) of experimental design. Moreover, the study design was using 13 experiments. Based on the figure, elongation D-Optimaly response was obtained by the value of the desibrability function. Desirability value for elongation was 18.4, then the combination of the optimal parameters were 0.5 ml glycerin and 3.81 g cornstarch along with the optimum elongation result was 17.3%. Elongation of this study also has met the standard, according to the Japanese Industrial Standard, elongation is categorized as good if above 10% and will be categorized very well if it exceeds 50% (Rudnik, 2019). The elongation of commercial plastic bag is 222.5%. The elongation of bioplastic sample in this research were below this number. Moreover, the bioplastic sample, which was made of corn starch, cannot be used as commercial plastic bag. However, it can be used in food packaging, pharmacy, and cosmetic which do not need high elongation, which is around 20%. The combination responses of tensile strength, elongation, modulus young optimizing can be done in the future research for improving edible film properties. Using biodegradable packaging in the commercial or daily usage can protect ecological system and save habitat in the environment.

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REFERENCES

Abbas, H. K., Accinelli, C. & Shier, W. T., 2017. Biological control of aflatoxin contamination in US crops and the use of bioplastic formulations of Aspergillus flavus biocontrol strains to optimize application strategies, *Journal of agricultural and food chemistry,* 65, 7081-7087.

Akinoso, R., Adeyanju, J. A. J. F. & Technology, B., 2012. Optimization of edible oil extraction from ofada rice bran using response surface methodology. 5, 1372-1378.

Andrady, A. L. J. M. P. B., 2017. The plastic in microplastics: A review. 119, 12-22.

Araújo, C., Rodrigues, A., Joele, M. P., Araújo, E. & Lourenço, L., 2018a. Optimizing process parameters to obtain a bioplastic using proteins from fish byproducts through the response surface methodology, *Food packaging and shelf life,* 16**,** 23-30.

Araújo, C., Rodrigues, A., Joele, M. P., Araújo, E., Lourenço, L. J. F. P. & Life, S., 2018b. Optimizing process parameters to obtain a bioplastic using proteins from fish byproducts through the response surface methodology. 16**,** 23-30.

Baş, D. & Boyacı, I. H. J. J. O. F. E., 2007. Modeling and optimization I: Usability of response surface methodology. 78**,** 836-845.

Biglari, N., Dashti, M. G., Abdeshahian, P., Orita, I., Fukui, T. & Sudesh, K. J. B., 2018. Enhancement of bioplastic polyhydroxybutyrate P (3HB) production from glucose by newly engineered strain Cupriavidus necator NSDG-GG using response surface methodology. 8**,** 330.

De Azêvedo, L. C., Rovani, S., Santos, J. J., Dias, D. B., Nascimento, S. S., Oliveira, F. F., Silva, L. G., Fungaro, D. A. J. J. O. P. & Environment, T., 2020. Study of Renewable Silica Powder Influence in the Preparation of Bioplastics from Corn and Potato Starch. 1-14.

Dean, A., Voss, D. & Draguljić, D., 2017. Response surface methodology. *Design and analysis of experiments.* Springer.

Domene-López, D., Delgado-Marín, J. J., Martin-Gullon, I., García-Quesada, J. C. & Montalbán, M. G. J. I. J. O. B. M., 2019. Comparative study on properties of starch films obtained from potato, corn and wheat using 1-ethyl-3-methylimidazolium acetate as plasticizer. 135**,** 845-854.

Gaspersz, P. J. T. B., 1992. Teknik Analisis dalam Perancangan Percobaan. 719.

Ghayebzadeh, M., Aslani, H., Taghipour, H. & Mousavi, S. J. M. P. B., 2020. Estimation of plastic waste inputs from land into the Caspian Sea: A significant unseen marine pollution. 151**,** 110871.

Gozan, M. & Noviasari, C. The effect of glycerol addition as plasticizer in Spirulina platensis based bioplastic. E3S Web of Conferences., 2018. EDP Sciences, 03048.

Ibrahim, M., Sapuan, S., Zainudin, E. & Zuhri, M. J. I. J. O. B. M., 2019. Potential of using multiscale corn husk fiber as reinforcing filler in cornstarch-based biocomposites. 139**,** 596-604.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R. & Law, K. L. J. S., 2015. Plastic waste inputs from land into the ocean. 347**,** 768-771.

Lestari, P. & Trihadiningrum, Y. J. M. P. B., 2019. The impact of improper solid waste management to plastic pollution in Indonesian coast and marine environment. 149**,** 110505.

Mäkelä, M. J. E. C. & Management 2017. Experimental design and response surface methodology in energy applications: A tutorial review. 151**,** 630-640.

Miyamoto, H., Kobayashi, H. & Ohtsuka, N., 1984. Standard method of test for elastic-plastic fracture toughness JIC recommended in Japan. *Mechanical Behaviour of Materials.* Elsevier.

Montgomery, D. C., 2017. *Design and analysis of experiments*, John wiley & sons.

Myers, R. H., Montgomery, D. C. & Anderson-Cook, C. M., 2016. *Response surface methodology: process and product optimization using designed experiments*, John Wiley & Sons.

Novianti, T., Anna, I. & Cahyadi, I. Optimization of bioplastic's tensile strength. Journal of Physics: Conference Series., 2019. IOP Publishing, 012048.

Reyes, J. D. C., Tungol, J. M., Musngi, P. P., Magarro, A. S., Guevarra, K. F., Santos, J. S. J. J. O. H. & Development, E., 2020. Three Experimental Phases of Cornstarch-Based Biodegradable Plastic. 2**,** 81-89.

Rudnik, E., 2019. *Compostable polymer materials*, Newnes.

Sarabia, L. A., Ortiz, M. C. & Sánchez, M. S., 2019. Response surface methodology.

Umesh, M., Mani, V. M., Thazeem, B. & Preethi, K., 2018. Statistical Optimization of Process Parameters for Bioplastic (PHA) Production by Bacillus subtilis NCDC0671 Using Orange Peel-Based Medium. *Iranian Journal of Science and Technology, Transactions A: Science,* 42**,** 1947-1955.

Yolmeh, M., Jafari, S. M. J. F. & Technology, B., 2017. Applications of response surface methodology in the food industry processes. 10**,** 413-433.

Zhang, C., Wang, C., Cao, G., Wang, D. & Ho, S.-H. J. J. O. H. M. 2020. A sustainable solution to plastics pollution: An eco-friendly bioplastic film production from high-salt contained Spirulina sp. residues. 388**,** 121773.