Analysis of Extrusion Process Parameters in The Manufacture of Bioplastic Pellets on Water Resistance and Biodegradation Test

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Abstract. One source of isolated or frequently extracted vegetable protein is soybean. Using an extruder, a method of extrusion is used to create mixed bioplastics. Biodegradable plastic seeds are produced by extrusion following the drying and pelting stages. A mixing process that tries to make the material homogenous and evenly distributed can be carried out using an extruder machine. Because of the characteristics of bioplastics with low water resistance and plastics that disintegrate easily This work aims to identify the ideal parameter variations for water resistance and biodegradation in extrusion machines, as well as the impact of parameter changes in the production of LDPE-soybean seeds on bioplastic seed yield products. This study's primary materials are Low-Density Polyethylene (LDPE) and biodegradable plastic made of tapioca, protein-rich soybeans, and glycerol. It blends in the extruder machine and then uses compression molding to print the specimen, which has the following dimensions: 20 mm in length, 20 mm in width, and less than 1 mm in thickness. The specimen then measures the water resistance test results and the irreversible bioplastic pellet's biodegradation values. Taguchi method was used to conduct the experiment design and to achieve the data processing. Three variables used are barrel temperature, composition, and screw rotational speed. Based on the conducted experiments, it has been determined that the ideal values for each water resistance parameter are at 135 C for level 3-barrel temperature, 30 rpm for level 1 screw rotation speed, and 0/100 for level 1 composition. The temperature of 95 degrees Celsius is the ideal level for biodegradation. Level 3 composition is 85/15, and the level 3 screw rotates at 50 rpm. Temperature and the composition of the material are characteristics that significantly affect water resistance, whereas temperature and the composition of the material significantly affect biodegradation.

Keywords: biodegradable plastic, low-destiny polyethylene, taguchi method

1 Introduction

Plastic is an organic polymer compound made of petroleum produced by polymerizing, polycondensing, and polyadding monomer to make the necessary shape

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[1]. Most of the essential products are plastic, so it was chosen. Polyethylene (PE) is one form of plastic. Polyethylene is classified into two categories based on its density: Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE). According to Billmeyer [2], LDPE has the advantages of being flexible, recyclable, and having an easy manufacturing process.

Nevertheless, plastic also has a drawback: it is not readily broken down (non-biodegradable) by harmful microorganisms in the soil [3]. A degradable polymer is required to solve non-biodegradable issues. Adding natural polymers, like starch, is one substitute [4]. Materials from renewable biomass sources linked to naturally occurring biopolymers, such as proteins, carbohydrates, wood chips, natural rubber, recovered food waste, etc., are known as bioplastics [5]. According to Ismail et al. [6], bioplastics can be recycled, sustained, biodegraded, and sometimes composted.

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Vegetable protein can be found in soybeans, from which it is frequently isolated or extracted. Aside from flour and soy protein concentration, protein isolate is one outcome of soybean protein isolation. According to the dry weight percentage, the minimum protein level is 90% [7]. In addition to being biodegradable, soy protein isolate can lower the rate at which water vapor diffuses, making it a good choice for packing goods subjected to high humidity [8].

Previous research on "The Effect of Varying Composition of LDPE and Banana Weevil Starch" [9] suggests that the percentage value of the water (swelling) power of the biodegradable plastic produced might be increased by combining LDPE and banana weevil starch. It is envisaged that using starch as a mixture with LDPE will compensate for the drawbacks of LDPE synthetic plastic by facilitating its easy degradation by soil microorganisms. Starch waste decomposes readily in the environment.

An extruder is used to carry out the extrusion process used to create mixed bioplastics. Pellets made of biodegradable plastic are produced by extrusion and then dried and pelleted. Plastic bags can then be delivered by processing bioplastic pellets using a plastic converter machine that blows films into different plastic forms. Injection molding and thermoforming will create items like phones and keyboards. Plastic bottle products are made by blow molding, while laminated films for snack packaging are made by extrusion coating [10].

A machine that can perform a mixing operation to guarantee that the material is uniform and evenly distributed is called an extruder [11]. A range of standard-sized products can be produced by the extruder machine, depending on several factors, including barrel temperature, screw rotation speed, roller speed, and material composition. Given the rising need, there are still opportunities to develop bioplastic pellets for environmental conservation initiatives. Thus, it is vital to examine how screw rotation speed, barrel temperature, and material composition affect the extrusion process of LDPE-based bioplastic pellets in this experiment. Additionally, the impact of soybeans on plastic water resistance and plastic biodegradation tests must be considered. The Taguchi method design approach was employed in this experiment to combine an experimental method and experimental design.

Based on the experience of researchers, they have researched bioplastic composition studies. This time, we continued to study making semi-finished products as bioplastic pellets. Pellet products (this semi-finished product) are essential in providing raw materials for making final products made from bioplastic in the industry.

However, the quality of the resulting bioplastic pellets is susceptible, influenced by many factors in the final process, such as temperature, pressure, and speed in the extrusion process [12][13]. The author tried to investigate the impact of barrel temperature, material composition, and screw rotation speed on the water resistance test and biodegradation of the resultant bioplastic pellets based on the above description. Additionally, this study looks for parameter values that maximize water resistance and conduct biodegradation experiments on bioplastic pellets made of high-quality mixtures [14][15][16].

2 Method

Experimental techniques are used in this study. This study aimed to ascertain how parameter modifications affected the production of bioplastic pellets composed of a blend of LDPE and biodegradable plastic derived from soy.

2.1 Material and Equipment

Among the instruments employed in this study are:

1) The electric motor that powers the extruder machine has the following specifications:

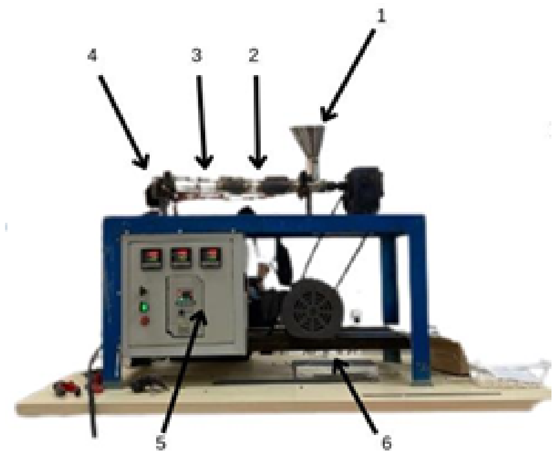

Fig. 1. The plastic pellet extruder machine; 1) Hopper, 2) Band Heaters, 3) Screw, 4) Dies, 5) Thermocontrol and Speed controls, 6) Electric Motor Powertrain.

Machine Model	: The extrusion machine uses an electric motor
Heater	: 3 band heaters
Dimensions	: 775 x 390 x 650 mm
Power	: 220 Volts
Motor Specifications	: 1/3 hp (1450 rpm)
Screw Rotation Speed	: 0 – 50 rpm
Heater Temperature	: 0 – 250℃

Materials

This study's primary materials are Low-Density Polyethylene (LDPE) and biodegradable plastic made of tapioca, protein-rich soybeans, and glycerol.

2.2 Procedures

The research procedures are as follows:

Stage of preparation. Getting supplies and tools ready is the first step. Next, weigh the biodegradable plastic and LDPE pellet's input by the composition test results. The hopper needs to be cleaned to remove any remaining dust.

Phases of extrusion. Turning on the plastic pellet extruder machine is the first step in this process. Next, adjust the screw rotation speed and temperature of the Band Heater to match the test settings. Then came the use of a thermogun to measure the temperature and a tachometer to measure the speed of the screw movement. Place the biodegradable plastic and LDPE pellets into the hopper after it has reached the appropriate temperature and speed.

Phases of evaluating bioplastic pellets for water resistance (ASTM D570). The first step is to use compression molding to print the specimen, which has the following dimensions: 20 mm in length, 20 mm in width, and less than 1 mm in thickness. The specimen must then be immersed for 24 hours in a jar with 30 mL of distilled water. The specimen is taken out after a full day, cleaned with a dry cloth, and then weighed with a wet weight before being placed in

2.3 Parameters

Independent variables.

The following study is referenced in the level selection of this research parameter:

1) Barrel temperature: 5℃, 115℃, 135℃ was the variation employed in the re-search Jiménez-Rosado et al [12] according to which soybeans would not mature at a temperature below 95℃ and will be harmed at a temperature above 135℃.
2) Composition: The purpose of this study is to compare how the Composition of LDPE added to biodegradable plastic differs, thereby significantly reducing or ap-proaching the qualities of
3) Rotational speed: 30, 50, and 70 rpm are the speeds employed, according to re-search [13]. Nevertheless, the researchers' extruder could only operate at 50 rpm.

In this research, there are three variations of the variables used, which are explained in Table 1

Table 1. Three variations of the variables used.

Control Factors	Parameter	Level 1	Level 2	Level 3
A	Barrel Temperatures	95℃	115℃	135℃
B	Plastic Composition *biodegradable*/ LDPE	0:100	5:95	15:85
C	Screw Speed	30 rpm	40 rpm	50 rpm

Dependent variables. The dependent variables in this study are the water resistance test results and the irreversible bioplastic pellets' biodegradation values

Controls Variables. Room temperature (28℃ – 30℃) is the control variable in this study.

3 Result and Discussion

Extrusion process water resistance and biodegradation are studied in multiple tests on bioplastic pellet production from a blend of soybean bioplastic pellets and Low-Density Polyethylene (LDPE) pellets.

Result

The material used in the extrusion machine research was a blend of LDPE pellets and biodegradable soybean plastic. The mixture composition, barrel temperature, and screw rotation speed were the key variables that produced the pellet products, which are bioplastics. Before extruding bioplastic pellets, the material must be weighed, the temperature must be measured, and the screw rotation speed must be measured to maximize outcomes. Its goal is to validate the barrel temperature using a thermocontrol to determine whether or not it is at the proper temperature.

The Taguchi method with an L9(3) orthogonal matrix design was used to achieve the data processing findings and three replications were performed. It is assumed that the existence of independent variables in this study impacts the dependent variable.

Water resistance test

The data collection results on water resistance are displayed in Table 2 and are as follows.

Table 2. The data collection results on water resistance.

No	Parameter			Results (%)			
	Temperatures (°C)	Speed (rpm)	Composition (gr)	1	2	3	Average
1	95	30	0 / 100	99.30	99.30	99.24	99.35
2	95	40	5 / 95	97.06	96.20	97.27	97.70
3	95	50	15 / 85	96.55	94.60	96.50	98.55
4	115	30	5 / 95	98.24	97.60	98.52	98.59
5	115	40	15 / 85	97.88	97.60	97.35	98.68
6	115	50	0 / 100	99.53	99.50	99.45	99.65
7	135	30	15 / 85	98.24	97.88	98.57	98.27
8	135	40	0 / 100	99.88	99.85	99.94	99.86
9	135	50	5 / 95	97.91	97.93	97.61	98.20

Table 2 lists the control factors or parameters that are used: barrel temperature, material mixture composition, and screw rotation speed. Each of these parameters has three levels: 0 g/100 g, 5 g/95 g, and 15 g/85 g for the barrel temperature, and 30 rpm, 40 rpm, and 50 rpm for the screw rotation speed. Digital scales that use the ASTM D570 reference are used to measure the difference between dry and wet weights for testing the water resistance of plastic from extruded items.

Biodegradation test

The biodegradation test findings for bioplastic pellets are shown in Table 3 and are as follows.

Table 3. The biodegradation test findings for bioplastic pellets.

No	Parameter			Results (%)			
	Temperatures (°C)	Speed (rpm)	Composition (gr)	1	2	3	Average
1	95	30	0 / 100	0.21	0.18	0.12	0.17
2	95	40	5 / 95	2.59	3.14	2.64	2.79
3	95	50	15 / 85	3.88	3.42	3.39	3.56
4	115	30	5 / 95	2.34	2.26	2.31	2.30
5	115	40	15 / 85	3.26	3.24	3.02	3.17
6	115	50	0 / 100	0.14	0.17	0.12	0.14
7	135	30	15 / 85	2.62	2.41	3.32	2.79
8	135	40	0 / 100	0.19	0.09	0.11	0.13
9	135	50	5 / 95	2.60	2.00	1.90	2.17

The sheet used for the biodegradation test is 20 mm long by 20 mm wide and less than 1 mm thick. Because soil contains a variety of microorganisms, including bacteria, fungi, and algae, it is utilized as a medium. After 15 days of burial in soil, the sample's mass loss percentage in biodegradable plastic was calculated to determine the biodegradation test results. Use a 3-way soil meter with ASTM D6003-96 requirements to measure the physical characteristics of the soil.

S/N ratio calculation

Results of the S/N ratio calculation about the water resistance of pellets made of bioplastic The information is displayed as follows in Table 4 using Minitab 19 software.

Table 4. The biodegradation test findings for bioplastic pellets.

No	Temperatures (C)	Screw Speed *(rpm)*	Composition (gr)	(S/N) Ratio
1	95	30	0 / 100	39.94
2	95	40	5 / 95	39.74
3	95	50	15 / 85	39.69
4	115	30	5 / 95	39.85
5	115	40	15 / 85	39.81
6	115	50	0 / 100	39.96
7	135	30	15 / 85	39.85
8	135	40	0 / 100	39.99
9	135	50	5 / 95	39.82

Results of the S/N ratio calculation for the biodegradation of pellets made of bioplastic The information is displayed as follows in Table 5 using Minitab 19 software.

Table 5. The S/N ratio calculation for the biodegradation of pellets made of bioplastic.

No	Temperatures (C)	Screw Speed *(rpm)*	Composition (gr)	(S/N) Ratio
1	95	30	0 / 100	-16.08
2	95	40	5 / 95	8.82
3	95	50	15 / 85	10.99
4	115	30	5 / 95	7.24
5	115	40	15 / 85	10.02
6	115	50	0 / 100	-17.12
7	135	30	15 / 85	8.67
8	135	40	0 / 100	-18.64
9	135	50	5 / 95	6.48

Results of the S/N ratio calculation for water resistance at each level The control factors are shown in Table 6.

Table 6. Results of the S/N ratio calculation for water resistance at each level the control factors

Control Factor	S/N Average			Difference
	Level 1	Level 2	Level 3	
Temperature	39.79	39.87	39.88	0.09
Screw Speed	39.88	39.85	39.82	0.05
Composition	39.96	39.80	39.78	0.18

Figure 2 displays a plot of the average S/N ratio results for the study utilizing the parameters of temperature, material composition, and screw rotation speed. Two are described below.

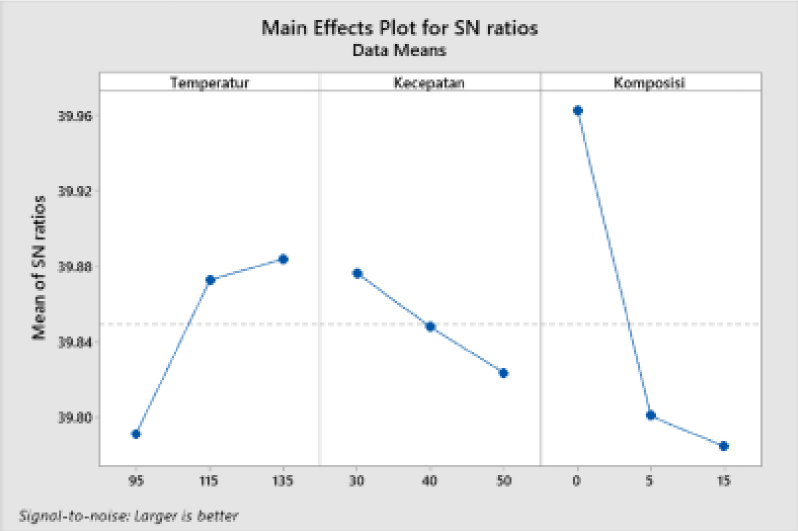

Fig. 2. A plot of the average S/N ratio results for the study utilizing the parameters of temperature, material composition, and screw rotation speed.

The data from each factor influenced is the optimal data level, as shown in plot Figure 2 above. Consequently, the most combination The average S/N ratio plot's results, which are shown in Table 7 below, indicate the optimal temperature, screw rotation speed, and Composition, which is 135C at 30 rpm. The S/N ratio of biodegradation calculation results for each level of control factor is shown in Table 8.

Table 7. The average S/N ratio plot's results

Control Factor	Level	Value
Temperature	3	135 °C
Screw Speed	1	30 rpm
Composition	1	0 / 100

Table 8. The diference S/N ratio plot's results

Control Factor	S/N Average			Difference
	Level 1	Level 2	Level 3	
Temperature	1.24	0.05	-1.16	2.41
Screw Speed	-0.06	0.07	0.12	0.18
Composition	-17.28	7.51	9.89	27.17

Figure 3 displays a plot of the average S/N ratio results for the study utilizing the following parameters: temperature, material composition, and screw rotation speed.

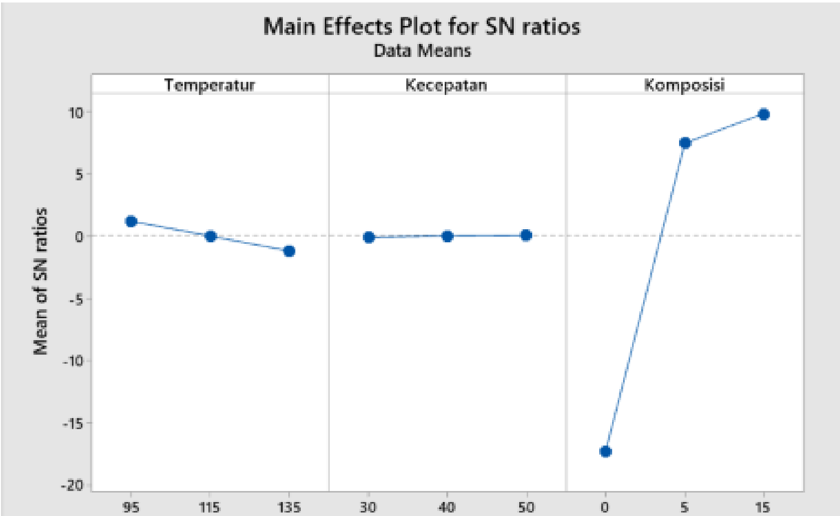

Fig. 3. A plot of the average S/N ratio results for the study utilizing the following parameters.

Tables 9 and 10 display the percentage contributions of each parameter produced using ANOVA computations. Significant and minor parameter impacts were found in the research results for the data analysis of water resistance and biodegradation tests. The error from biodegradation was 4.19%, and the error from water resistance was 27.21%, according to an analysis of ANOVA data processed using the Taguchi method.

Table 9. The percentage contributions of each parameter produced using ANOVA.

Control Factor	Contributio Percentage
Temperature	14.24 %
Screw Speed	3.86%
Composition	54.68 %
Error	27.21 %
Total	100 %

Table 10. The percentage contributions of each parameter produced using ANOVA.

Control Factor	Contributio Percentage
Temperature	2.23%
Screw Speed	0.80%
Composition	94.35%
Error	2.62%
Total	100 %

Discussion

The following is a presentation of the data analysis findings about the impact of various parameters on water resistance and biodegradation tests.

1) The temperature

The percentage contribution of temperature has been calculated using the data from the ANOVA test. With an F value of 5.23, water resistance is 14.24%. The results demonstrate the relationship between temperature and extrusion bioplastic pellets, with the greater the barrel temperature leading to the melting or fusing of the LDPE-soya biodegradable plastic combination into a new material.

The results are consistent with studies by Jiménez-Rosado et al. from 2022 [12], which found that raising the temperature can increase plastic's water resistance and decrease its water absorption. A higher barrel temperature can result in more uniform and smaller particles, reducing contact area and impeding water absorption.

Based on the temperature contribution percentage data, it was determined by doing an ANOVA calculation on the biodegradation test, yielding a result of 2.23% and an F value of 8.52. The result is the same as the water resistance test, in which the temperature at which bioplastic pellets with a mixed composition are extruded has an effect. Ardiatma and Kurniareja (2022) [15] report that rising temperatures cause many plastic particles to undergo physicochemical changes, making the plastic more homogeneous and denser in structure. Naturally, these properties make it more difficult for microorganisms to break down the constituent particles of plastic.

2) Screw rotation speed

ANOVA water resistance test data on the percentage contribution of the rotational speed screw was 3.86% with an F value of 1.41, the smallest percentage of the other parameters, and an insufficient F value from the F table, meaning that this parameter with the extrusion of pellets at 30, 40, and 50 rpm has no bearing on the outcome mixed bioplastic made of LDPE and biodegradable soybeans.

The ANOVA test calculation yielded a biodegradation of 0.80% with an F value of 3.06, less than the F table, indicating no effect on the extrusion results of the LDPE-soya biodegradable plastic mixture. The same is true for the water resistance contribution to the rotational speed of the biodegradation screw.

3) Composition

Data from the ANOVA test computation has been derived from the percent composition contribution. The parameter influencing the water resistance test results is 54.68%, with an F value of 20.09. The more LDPE in the plastic biodegradable soybeans, the more bioplastic pellets there are.

The finished product is very resistant to water. Research by Marfu'ah [9], which implies that a molecule's resistance is tied to its preparation's fundamental features, supports this. Glycerol's hydrophilic quality results from the structure of its hydrogen-OH bonds can create intramolecular connections with water molecules, among other things. Biodegradation of 94.35% with an F value of 360.65 is the percent composition contribution data acquired from the ANOVA test calculation. The result is comparable to the endurance test water, in which the composition factors affect the results of biodegradation experiments. Nguyen et al. [16] found that the biodegradation of plastic increases with a more significant content of biodegradable plastic relative to LDPE. This phenomenon is because microorganisms devour and attack starch, causing plastic structures to fracture and the LDPE chain to push the biodegradation process forward.

4 Conclusion

It is possible to draw the following conclusions from the conducted research:

1) Temperature and material composition are two variables related to water resistance and biodegradation that significantly affect the outcomes of pellet extrusion for bioplastics, according to data analyzed using the Taguchi method with assistance from Microsoft Excel and Minitab 19. The rotation speed parameter screw, meanwhile, is not essential.
2) The best results from the extrusion of bioplastic pellets on the water resistance value of bioplastic pellets are found on the temperature parameter 135oC, the screw rotation speed of 30 rpm, and material composition of 0/100 in this study, according to data processing with Minitab 19. When bioplastic pellets are tested for biodegradation, the ideal conditions are found at 95 °C, 50 rpm screw rotation speed, and 15 % material composition.

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