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Article

Optimizing Briquette Performance of Mushroom Cultivation Waste Omah Jamur Ungaran Used the Taguchi Method: Circular Economy Approach

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Abstract Indonesia ranks 75th of 166 countries receiving an achievement from the Sustainable Development Goals (SDGs). The main factor in the success is the appropriate sustainable waste management, which utilizes alternative energy sources to support a circular economy. One potential use for biomass waste generated from oyster mushroom cultivation is wood powder briquettes. The main ingredient of powder briquettes is the waste oyster mushroom cultivation of wood powder. Omah Jamur Ungaran is a Small Medium Enterprise (SME) that specializes in cultivating white oyster mushrooms. However, the cultivation process generates considerable waste. This study focused on two essential variables: moisture content and ash content. The research employs the Taguchi method as a parameter. The method considers five factors: water volume, baglog charcoal, tapioca, blending time, and drying oven temperature. The results indicate a ranking order of the factors: the first is drying oven temperature (in Celsius); second is water volume (in ml); third is baglog charcoal (in grams); fourth is tapioca (in grams); and fifth is blending time (in minutes). The optimal conditions demonstrated 50 ml of water volume, 66 grams of baglog charcoal, 20 grams of tapioca, a blending time of 3 minutes, and a drying oven temperature of 140°C. Under these conditions, the best ash content results were observed by values ranging from 11.7% to a maximum of 30%.

Keywords: Baglog oyster mushroom waste, briquettes, circular economy, waste management,Taguchi method.

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1. Introduction

Small and Medium Enterprises (SMEs) play a crucial role in Indonesia's economy, with their numbers varying significantly across provinces. Since Indonesia has many SMEs, the focus should be on improving labour quality rather than quantity [1]. SME performance requires critical innovative with marketing capabilities since it is significantly influencing outcomes. Strategic entrepreneurship mindset and leadership contribute to create an entrepreneurial value in Indonesian SMEs. The benefit is not only for the individuals and organizations involved but also for society [2]. The digitization efforts of Indonesia comparing to Malaysia's SME reveals the differences in agile leadership, organizational ambidexterity, and workforce transformation levels. Both countries' SMEs may benefit from focusing on these factors to optimize performance and ensure business sustainability [3]. A multifaceted approach is required to enhance SME performance in Indonesia by emphasizing innovation, strategic leadership, and workforce development. They perform as key pillars for improvement. Indonesia's Sustainable Development Goals (SDGs) received an achievement with the score of 70.16 out of a scale of 100 or ranking 75th out of 166 countries. Indonesia's SDGs achievement in 2023 has been increased, with the score of 69.16 on a scale of 100, compared to 2022. One of the supporting factors for the success of the Sustainable Development Goals (SDGs) is an appropriate sustainable waste processing as alternative energy. It also supports a circular economy in Indonesia [4].

The circular economy was introduced in 1990. It aims to be a sustainable development strategy and proposes to overcome environmental degradation by managing industrial waste and saving resources, thereby it can increase the economic growth [5]. Indonesia is a tropical country because the location is close to the equator, which means sunlight and temperatures are the same throughout the year. Indonesia enables many plants to grow well due to fertile soil; one example is the white oyster mushroom (Pleurotus Ostreatus) [6]. However, cultivating white oyster mushrooms impacts the large amount of waste produced from the cultivation process. One use of biomass wastes produced from cultivating oyster mushrooms, which can be used as alternative energy, is briquettes [7], [8], [9]. Briquettes are fuels made from solid organic materials. There are two types of briquettes: coconut shell briquettes and sawdust briquettes.

This research will focus on wood dust briquettes since the main ingredient of these briquettes was oyster mushroom baglog waste, which contains wood powder. Biomass briquettes offer a promising alternative fuel source, particularly in developing countries, addressing waste management and energy demand challenges [10]. These briquettes can be produced from various materials, including agricultural waste, wood, and plastics, with calorific values ranging from 16.22 to 24.64 MJ/kg [10]. The production process typically involves drying, mixing, carbonization, and compaction of raw materials. Binders, such as starch, are often added to improve cohesive strength [11]. Quality parameters for briquettes include density, ash content, and calorific value, with low moisture and ash content (below 10%) and high calorific values being desirable [12]. Using natural materials like wood powder as fillers in composite materials has also gained attention in other applications, such as eco-friendly brake pads [13].

One of the SMEs with waste management problems is Omah Jamur Ungaran, located on Jl. Sumbawa IX Street No. 155 Gedang Asri Baru Housing, Watububan, Gedanganak, East Ungaran, Central Java. SMEs Omah Mushroom Ungaran has been run the business since 2006. Initially, their business focused only on selling the results of oyster mushroom cultivation. White oyster mushrooms (Pleurotus Ostreatus) are a food mushroom well-known in Indonesia for their deliciousness. They also can be used as medicine because they are rich in carbohydrates, protein, vitamins, and minerals. Mushrooms are widely cultivated worldwide for their delicious taste [14]. Since 2012, Omah Jamur Ungaran have succeeded in expanding their business by selling baglogs or oyster mushroom planting media and oyster mushroom seeds to farmers around Semarang. From several aspects of the company involved, Omah Jamur Ungaran has problems related to the production capacity of growing media for oyster mushrooms or baglog.

Baglog, which can grow mushrooms, has an active period of 3 until 4 months, so there are accumulations of waste produced after the oyster mushroom process. The characteristics of baglog that has become waste are that it is blackened, has a bland texture, and seems light. Once the oyster mushrooms no longer grow in the planting medium, it must be resolved and utilized because baglog waste is increasingly accumulating and filling the production space. It is considered an ecological bioconversion system; namely, agricultural residues or what is usually called waste that have no value. However, the waste can be processed into products [14].

An over-the-top increment in vitality adjusts the expanding increment in human life savings. Non-renewable vitality sources such as coal, rough oil, and characteristic gas, over time, will run out, and the cost will increase [15]. Burning coal can lead to global warming and poisonous toxins that can diminish quality and pose dangers to posture and well-being. Suspense concerning vitality and quality related to burning coal has become the most inspiration for creating renewable and ecologically environment vitality [16]. Renewable energy sources such as wind, water, solar, and biomass are more popular. Biomass is an organic mass from agriculture obtained by two methods: biomass explicitly grown from plants or short rotation woody plants and biomass waste from primary agricultural production, logging, and wood processing [15]. Renewable energy from biomass can replace fossil energy sources. It has been identified as an alternative biological resource to overcome this challenge due to its abundance, renewable nature, clean nature, and reduction of greenhouse gases [17]. Fig 1 shows the oyster mushroom baglog waste.

Fig. 1. Oyster Mushroom Baglog Waste.

According to AK Sunnu et al., using the pyrolysis strategy inquiries about manufacturing briquettes from rural squanders such as rice husks, corn cobs, palm shells, and sawdust. Palm shell briquettes recorded the most elevated calorific esteem of 20,836.32 kJ/kg, with fiery remains of 2.7 % And 3.95% water substance compared to other briquettes. Palm shell and sawdust briquette fuel appear to a bubbling point of 100 in as small as 10 minutes [18]. Alexander Nikiforov et al. 2023 show that this research manages biomass waste (husks and leaves of sunflowers). Industrial waste (coal and coke dust) and biochar briquettes were combined using a hydraulic press with a compression pressure of 25 MPa without binder. The results show that the composition of coal dust increases, leading to an increase in combustion time, while the combustion rate decreases. The best quality, calorific value, and combustion parameters are the following briquettes: pieces of 70% sunflower shells and 30% clean coal from Karajila warehouse, 60% sunflower shells and 40% clean coal from Shwarkul camp. Briquettes made from 70% sunflower husks and 30% clean coke. Briquettes made from 80% waste and 20% clean coal from Karajira warehouse. Briquettes made from 70% waste and 30% pure coal from Šwarkul camp [19].

This research aims to manage biomass waste sustainably, specifically agricultural waste, and support the circular economy into solid fuel for environmentally friendly tickets. Thus, it can be relevant in finding sustainable energy solutions, reducing environmental impacts, and creating an economic value-added through processing and utilizing waste products using the Taguchi approach.

In several cases, the circular economy of agricultural waste has been used to develop or reduce existing agrarian waste. Teresa Rodríguez-Espinosa et al. 2023 show in research which addresses the use of nitrogen as well as reducing excessive consumption of natural resources and environmental damage, that the current called "take-make-use-dispose" should be replaced with the "prevention-reuse-remake-recycle." The circular economy model promises to preserve natural resources and provide sustainable agriculture in this process. Through these results, it is recommended to reduce harvest waste and search for realistic and practical methods to handle large amounts of organic residue in the context of a circular economy [20]. Compressed biomass in briquettes can be various shapes and sizes, such as cylindrical, cubic, or rectangular, with or without a hole in the centre [17]. Recently, many researchers conducted a detailed review of the biomass briquette manufacturing process and the various briquette machinery [21]. Most of the research on briquettes focuses on the properties of briquettes made from agricultural waste. Chapol Chungcharoen et al. 2020 show that ordinary agricultural wastes include wood waste, corn waste, and other agricultural wastes. The research shows that abundant agricultural waste resources can be utilized as economical and sustainable raw materials for developing solid fuels in China. The results indicate that combustion is the method most widely used and developed among various conversion technologies to convert biomass fuel into energy [22], [23]. Several researches about agricultural waste processes have been carried out, such as turning them into biochar and biomass. Many studies have extensively investigated various aspects of compression technology, such as production processes, briquette machines, and equipment for measuring different properties of solid fuels [24], [25]. The study relates to biomass raw materials, processing characteristics, and economics of biomass compaction [26], [27] process variables for making briquettes, combustion and emissions [28] making biomass briquettes economically, [29]. Based on Samsudin Anis et al. 2023 research on briquettes and their effects on the environment and briquette attached as a binder [30]. However, a recent review of current research on biomass briquettes and parameters regarding the quality of briquettes is not yet described in the literature.

In previous research, many studies related to the utilization of agricultural waste were in high-value products, including briquettes. However, several existing studies show that briquettes are made from first-generation waste. The use of second— generation agricultural waste derivatives - even third is still rare. Therefore, further studies are needed to ensure the quality of the waste processing. The main objective of this study is to review current research on the use of binders in biomass briquette production and briquette quality parameters, focused on ash and moisture properties.

This research only focused on the quality of briquettes, including water content, ash content, and handling resulting from the briquette-making process. This review concluded that no comprehensive investigation can determine the influence of ash content and water content parameters on briquette quality. Therefore, it is proposed to use and implement an experimental design, in which the results and analysis can be understood as the main factors in determining the biomass and its processes, influencing the response parameters. We will analyze the quality of briquettes made from oyster mushroom baglog waste by connecting its composition and how it is made with ash and water content. We attempt to answer these critical questions by testing oyster mushroom baglog waste briquettes by burning them. If there is a relationship between the composition (measurement of mushroom baglog waste, tapioca flour, water, drying/oven temperature, and ash and water content results to the quality of oyster mushroom baglog waste briquettes, then this data will be worthy for policy makers, producers, and consumers so that they can better understand the quality of solid fuel briquettes.

2. Methods

2.1. Framework Circular Economy(CE) for Oyster Mushroom Production

Researchers created an adaptation framework to explain CE measurements at each level and ensure the impact of CE on economic, social, and environmental aspects. Fig 2 illustrates the Micro-level Framework for oyster mushroom production. CE implementation measurements are made at the micro level to improve the circularity of the manufacturing company's systems and cooperation with other businesses through an effective supply chain. Oyster mushroom SMEs produce baglog waste that can be used as fuel. Baglog waste is processed into fuel briquettes that can be used as a source of energy and economic resources. Oyster mushroom baglog waste briquettes can be sold to consumers and used as a source of heating energy in the baglog-making process. Oyster mushroom waste that has become briquettes can be used as fuel energy for the baglog steaming process, which is a mushroom growing media.

2.2. Experimental Procedure

This research requires an experimental process in several stages, from material preparation to analysis and conclusions. Fig 3 illustrates the experimental procedure for making oyster mushroom briquettes.

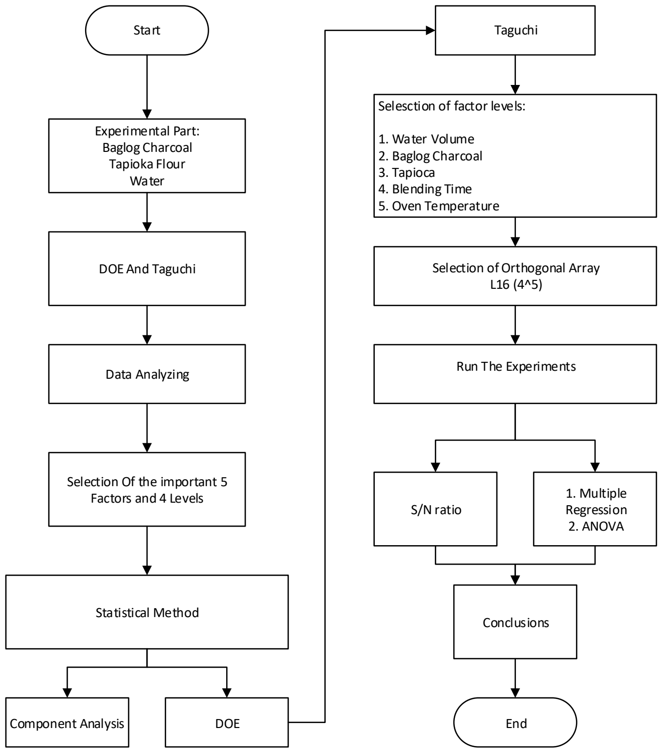

Fig. 3. Experimental procedure flowchart.

2.2.1. Experimental part

Prepare tools and materials for the process of making briquettes from oyster mushroom baglog waste. The materials used were burnt oyster mushroom baglog waste and tapioca mixture. The biomass waste material was obtained from Omah Jamur Ungaran. The equipment used in the briquette making process includes a bio briquette press machine, oven, scales, stopwatch, tub, stirrer, and lighter. The equipment is used to tests the water content values by weighing the wet content and weight after drying and the ash content by burning. How to make briquettes:

- Baglog waste is converted into charcoal powder by burning it.

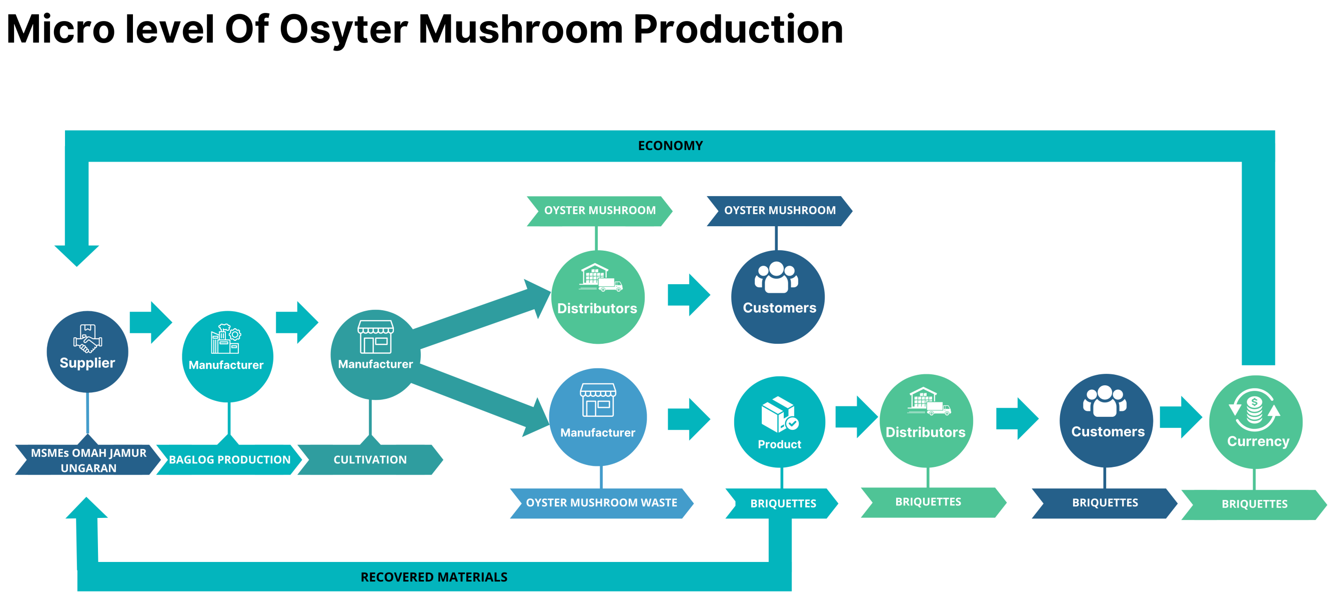

Fig. 2. Framework of micro level of oyster mushroom production.

- Mix oyster mushroom baglog waste, tapioca flour, and water according to the measurements for experimental design.
- Stir the dough until it is smooth and shaped like clay, then the dough is ready to be moulded as shown in the picture below.
- Prepare a briquette maker with a square mould, then insert the briquette mixture and make sure the plug is plugged to the electric current.

The flow of the briquette-making process can be seen in Fig 4 below:

2.2.2. Design of experiments (DoE)

1. Taguchi Experimental Method
   Inspection, screening, and assistance processes cannot eliminate poor product quality. No total inspection can determine the quality that is returned to the product. Taguchi pays serious attention to the symptoms that affect product quality. Furthermore, the concept of quality and its development are based on the philosophy of prevention [31], [32]. Taguchi's method uses a specific matrix known as an Orthogonal Array. This standard matrix is necessary for determining the minimum number of tests that can provide as much data as possible for almost all variables affecting the parameters. The most important part of the orthogonal array method is selecting the combination of input variable levels for each experiment [33]. Fractional factorial designs have been widely used in industrial research process improvement. The main example is Taguchi's robust design. Genichi Taguchi developed a highly efficient variant of the fractional factorial design to improve quality control [34]. Taguchi's approach is essential modification design of experiments (DOE) methodology used to design and conduct an experiments [35]. One of the critical aspects defined in this method is the "quality loss function." This function refers to the loss when performance deviates from the determined specification limits. The loss function indicates that deviation from the goal results in loss, and success refers to minimal deviation from the goal [31], [36]. The quality Loss functions can be categorized into three types: Nominal – Best, Smaller is better, and Larger is better.

2. Orthogonal Array Matrix
   We select five factors controlled at four levels. They are water measure (ml), baglog waste measure (g), tapioca flour measure (g), blending time (minutes), drying oven temperature (°C). Orthogonal array L 16 (4^5) consists of 5 factors and 16 trials with repetitions of 2 sessions. This run is selected as a suitable layout to determine the optimal combination of the levels. A schematic diagram of the main steps in studying briquette quality using the Taguchi approach is presented in the image. Taguchi's approach can select the factors and their levels, choose an appropriate orthogonal arrangement, and perform the experiments randomly to avoid systematic errors. Ex-

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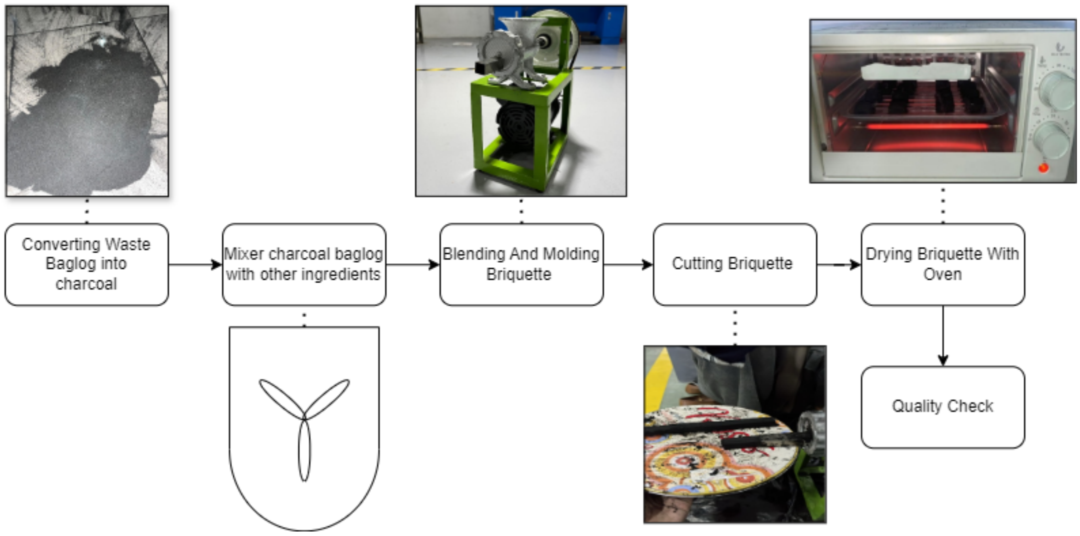

Fig. 4. Briquette making process.

Table 1. Level settings

Independent Variable	Level 1	Level 2	Level 3	Level 4
Water Volume (ml)	50	60	72	86
Baglog Charcoal (gr)	66	66	73	80
Tapioca (gr)	20	22	24	27
Blending Time (minutes)	1	2	3	4
Drying Oven Temperature (Celsius)	120	140	160	180

periments were performed in both solid and liquid conditions. Then the results were subjected to statistical analysis. Table 1 describes the level settings of the independent variable

In this study, we used four levels with a total of 5 factors, so the degrees of freedom (dof) for each factor can be obtained using the following formula [37]:

$$dof(f) = \sum l - 1 \qquad (1)$$

Where,

dof = degree of freedom

f = factor

l = level each factor

By using the formula above, the calculation of the dof value for each factor can be determined as follows:
$dof(A) = 4 - 1 = 3$
$dof(B) = 4 - 1 = 3$
$dof(C) = 4 - 1 = 3$
$dof(D) = 4 - 1 = 3$
$dof(E) = 4 - 1 = 3$

Based on the degree of freedom calculation results, the number of dof for all factors is 15. If you look at the selector array table [38], the orthogonal array chosen is L16 with some experimenters of 16. Meanwhile, the Orthogonal Array Matrix Parameter Classification can be seen in Table 2.

3. Parameter Quality
This research uses two parameters to determine the quality of briquettes made from baglog waste: the moisture content and the ash content.
Moisture content (MC) is the evaporation of free water within the briquettes until moisture matches the surrounding air. Moisture content affects the quality of briquettes. The lower the moisture content, the higher the calorific value and the higher the combustion efficiency is [39].

$$MC = \frac{DBW}{WBW} x100\% \qquad (2)$$

where,

MC = Moisture content
DBW = Dry Briquette Weight
WBW = Wet Briquette Weight

Ash is the leftover part of the combustion process that no longer contains the element carbon. The

Table 2. Orthogonal Array Matrix Parameter Classification

No. Experiment	Water volume(ml)	Baglog Charcoal(gr)	Tapioca (gr)	Blending Time(minutes)	Drying Oven Temperature(Celsius)
1	50	60	20	1	120
2	50	66	22	2	140
3	50	73	24	3	160
4	50	80	27	4	180
5	60	60	22	3	180
6	60	66	20	4	160
7	60	73	27	1	140
8	60	80	24	2	120
9	72	60	24	4	140
10	72	66	27	3	120
11	72	73	20	2	180
12	72	80	22	1	160
13	86	60	27	2	160
14	86	66	24	1	180
15	86	73	22	4	120
16	86	80	20	3	140

content of ash, silica, powder raw materials, and the amount of adhesive used influences the ash content of briquettes. The impact on the value of the charcoal's main component is unfavourable. As the ash content increases, the calorific value of the briquettes decreases, so the quality of the briquettes decreases. Ash content (Ac) can be calculated using the following formula

$$AC = \frac{AW}{DBW} x100\% \quad (3)$$

AC = Ash content

AW = Ash Weight

DBW = Dry Briquette Weight

4. S/N Ratio (Signal To Noise Ratio)
Aims to select the contribution of any component in reducing response variations. The S/N ratio can be designed for changes in the intersection of information into prices, which is the level of variation that appears. In this research, the Smaller, the Better-quality characteristics are used. The SN ratio calculation can use the formula:

- Smaller the better

$$SNR_{stb} = -\ 10\ log[\frac{1}{n}\sum_{i}^{n} y_i^2] \quad (4)$$

SNR_{stb} = S/N Smaller the better
n = Amount of Data
y_i = i-th data

- Nominal the better

$$SNR_{ntb} = 10log[\frac{\mu^2}{\sigma^2}] \quad (5)$$

SNR_{ntb} = S/N Nominal to better
μ = Average of Data
σ = Variation of Data

- Larger the better

$$SNR_{ltb} = -\ 10\ log[\frac{1}{n}\sum_{i}^{n} \frac{1}{y_i^2}] \quad (6)$$

SNR_{ltb} = S/N Larger the better
n = Amount of Data
y_i = i-th data

2.2.3. Multiple regression analysis and analysis of variance (ANOVA)

Multiple regression analysis is used to analyze the influence of two independent variables, namely water volume (x_1), baglog charcoal (x_2), tapioca (x_3), blending time (x_4) and drying oven temperature (x_5) on moisture content (y_1) and ash content (y_2). The mathematical formula is written as follows:

Moisture Content ((y_1)

$$y_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \varepsilon \quad (7)$$

Ash Content (y2)

$$y_2 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \varepsilon \quad (8)$$

Where,

y_1 = respone variable (moisture content)

y_2 = respone variable (ash content)

x_1, x_2, x_3, x_4, x_5 = Independen Variable

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ = Coefficient Regression

We assume that the value of E (ε) = 0, β_1 and β_2 are partial regression coefficients. β_1 measures the expected change in Y per unit change in x_1 when x_2 is held constant, and β_2 measures the expected change in Y per unit change in x_2 when x_1 is held constant. Stages in working on multiple regression:

1. Find the values of β_0, β_1, β_2, β_3, β_4, β_5
2. Looking for simultaneous correlation values (R) and coefficient of determination (R2) The simultaneous correlation formula (R) is as follows:

$$R = \sqrt{\frac{\beta_1 . \sum x_1 y + \ \beta_2 . \ \sum x_2 y + ...\beta_n . \ \sum x_n y}{\sum y^2}} \quad (9)$$

3. Perform an F test

$$F = \frac{(R^2)/(k-1)}{(1-R^2)/(n-k)} \quad (10)$$

where :

K = number of independent variables, including intercept or constant (β0)

n = number of data

The F test conditions are:
H0: Independent variables: water volume (x_1), baglog charcoal (x_2), tapioca (x_3), blending time (x_4) and drying oven temperature (x_5) have no effect significant for the dependent variables' moisture content (y_1) and ash content (y_2)

Ha: Independent Variable: Water volume (x_1), baglog charcoal (x_2), tapioca (x_3), blending time (x_4) and drying oven temperature (x_5) significantly affect the dependent variables moisture content (y_1) and ash content (y_2).

3. Results

After carrying out the stages of testing the quality of the briquettes for moisture and ash content, the results are obtained. The following table is the result of y_1 and y_2.

Table 3. Result of y_1 and y_2.

No.	Y1	Y2	Y1 (Repetition)	Y2 (Repetition)
1	0.31	0.28	0.34	0.28
2	0.13	0.16	0.13	0.16
3	0.34	0.18	0.45	0.15
4	0.35	0.22	0.44	0.20
5	0.37	0.15	0.39	0.19
6	0.38	0.24	0.41	0.16
7	0.19	0.12	0.38	0.19
8	0.31	0.17	0.47	0.20
9	0.35	0.12	0.32	0.30
10	0.42	0.21	0.54	0.24
11	0.53	0.26	0.42	0.25
12	0.40	0.20	0.42	0.23
13	0.43	0.20	0.41	0.21
14	0.36	0.16	0.39	0.16
15	0.32	0.18	0.43	0.20
16	0.22	0.16	0.21	0.09

3.1. Taguchi Analysis

Researchers use the Smaller the better characteristic, namely the S/N Ratio characteristic, which shows the smaller value is the better. It aims to achieve minimum moisture content. Response optimization can minimize moisture and ash content, validated by repeated experiments. Therefore, each factor level influences the response variable. The following is the process of moisture content data: • Moisture Content
Taguchi Analysis: Moisture Content versus Water Volume (ml); Baglog Charcoal (gr); Tapioca (gr); Blending Time (minutes); Drying Oven Temperature (°C). Figure 5 shows the S/N Ratio Moisture Content. Figure 6 shows the plot of the main effects of the S/N ratio chart for moisture content. In the Main Effects Plot SN Ratio graph of moisture content, there is a ranking order, the first order is the drying oven temperature in Celsius, the second order is the water volume in ml, the third order is the baglog charcoal in gr, the fourth order is the tapioca in grams and the last order is the blending time in minutes. The optimal conditions for setting moisture content parameters are a water volume of 50 ml, a baglog charcoal of 66 gr, a tapioca of 22 g, a blending time of 1 minute and a drying oven temperature of 140^oC.

• Moisture Content Repetition
Taguchi Analysis: Moisture Content (Repeats) versus Water Volume (ml); Baglog Charcoal (gr); Tapioca (gr); Blending Time (minutes); Drying Oven Temperature (°C). Figure 7 shows the S/N ratio of moisture content

(repetition). Figure 8 shows the main effects plot S/N ratio chart for moisture content (repetition).

- Ash Content

Taguchi Analysis: Ash Content versus Water Volume (ml); Baglog Charcoal (gr); Tapioca (gr); Blending Time (minutes); Drying Oven Temperature (°C). Figure 9 shows the S/N ratio of ash content. Figure 10 shows the plot of the main effects of the S/N ratio chart for ash content. In the Main Effects Plot SN Ratio chart for ash content, there is a ranking order, the first order is the tapioca in gr, the second sequence is the water volume in ml, the third sequence is the drying oven temperature in Celsius, the fourth sequence is the baglog charcoal in gr, and the last sequence is the blending time in minutes. The optimal conditions for setting the ash content parameters are a water volume of 72 ml, a baglog charcoal of 60 gr, a tapioca of 24 grams, a blending time of 3 minutes and a drying oven temperature of 140^oC.

- Ash Content Repetition

Taguchi Analysis: Ash Content (Repeats) versus Water Volume (ml); Baglog Charcoal (gr); Tapioca (gr); Blending Time (minutes); Drying Oven Temperature (°C). Figure 11 shows the S/N ratio ash content (repetition). Figure 12 shows the plot of the main effects of the S/N ratio chart for ash content (repetition). In the Main Effects Plot SN Ratio ash content (Repetition) graph, there is a ranking order, the first order, namely the baglog charcoal in gr; the second order, namely the blending time in minutes; the third order, namely the water volume in ml, the fourth order, namely the temperature of the drying oven in Celsius and the last order is the tapioca in gr. The optimal conditions for setting ash content parameters are a water volume of 86 gr, a baglog charcoal of 66 g, a tapioca of 20 gr, a blending time of 3 minutes and a drying oven temperature of 160^oC.

Response Table for Signal to Noise Ratios

Smaller is better

Level	Water Content	Baglog Charcoal	Tapioka Content	Blending Time	Drying Oven Temperature
1	11,049	8,871	9,352	10,222	9,972
2	10,254	10,086	10,460	9,871	12,282
3	8,080	9,815	9,426	9,561	8,506
4	9,431	10,042	9,576	9,159	8,053
Delta	2,969	1,215	1,108	1,063	4,229
Rank	2	3	4	5	1

Fig. 5. S/N Ratio Moisture Content.

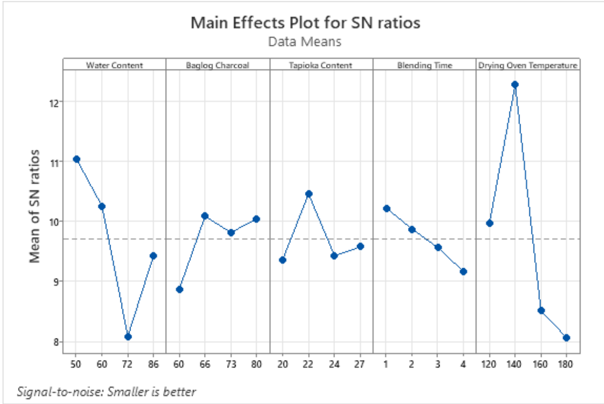

Fig. 6. Main Effects Plot S/N Ratio Chart For Moisture Content.

Response Table for Signal to Noise Ratios

Smaller is better

Level	Water Content	Baglog Charcoal	Tapioka Content	Blending Time	Drying Oven Temperature
1	9,766	8,942	9,643	8,369	7,600
2	7,678	9,151	9,603	9,587	11,161
3	8,149	7,705	7,888	8,342	7,745
4	8,780	8,576	7,239	8,076	7,867
Delta	2,088	1,446	2,404	1,511	3,561
Rank	3	5	2	4	1

Fig. 7. S/N Ratio Moisture Content Repetition.

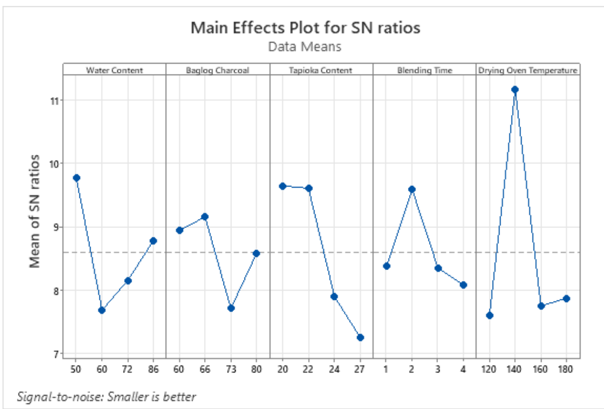

Fig. 8. Main Effects Plot S/N Ratio Chart For Moisture Content Repetition.

Response Table for Signal to Noise Ratios

Smaller is better

Level	Water Volume	Baglog Charcoal	Tapioca	Blending Time	Drying Oven Temperature
1	13,33	15,17	13,00	14,57	14,54
2	15,47	14,11	14,85	14,41	15,66
3	15,57	15,05	16,30	15,08	14,41
4	14,57	14,61	14,79	14,88	14,34
Delta	2,24	1,06	3,31	0,67	1,32
Rank	2	4	1	5	3

Fig. 9. S/N Ratio Ash Content.

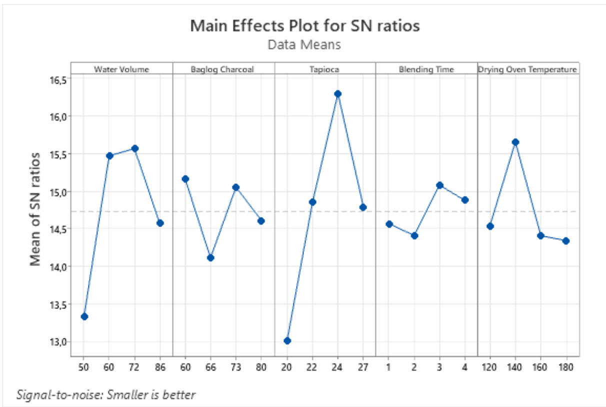

Fig. 10. Main Effects Plot S/N Ratio Chart For Ash Content.

Response Table for Signal to Noise Ratios

Smaller is better

Level	Water Volume	Baglog Charcoal	Tapioca	Blending Time	Drying Oven Temperature
1	13,97	12,59	14,91	13,26	13,63
2	14,57	14,68	13,80	14,14	13,74
3	12,99	14,43	14,29	15,71	15,16
4	15,26	15,09	13,78	13,68	14,25
Delta	2,27	2,49	1,13	2,46	1,53
Rank	3	1	5	2	4

Fig. 11. S/N Ratio Ash Content Repetition.

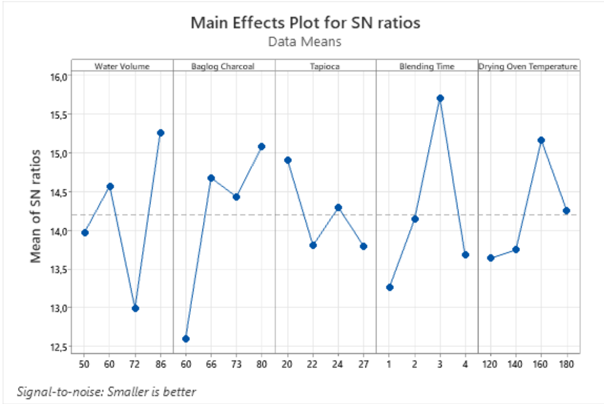

Fig. 12. Main Effects Plot S/N Ratio Chart For Moisture Content.

3.2. Multiple Regression Analysis (MRA)

Moisture Content (y_1)

Figure 13 shows the model summary of regression moisture content. Figure 14 shows the ANOVA results for moisture content. Figure 15 shows the model multiple regression moisture content. The figure above shows that the correlation (R-squared) is 0.999, with a total sig value for ANOVA of 0.000 and a sig value for coefficients of 0.000. Hence the decision for the moisture content variable is significantly related to variables x_1 (water volume), x_2 (baglog charcoal), x_3 (tapioca) because the Sig ANOVA value is smaller than Alpha is 0.05 or 5.%

Model MRA Moisture Content:

$$y_1 = 0.228 + 0,00x_1 + 0,001x_2 + 0,001x_3 + \epsilon$$

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.999	.00188

a. Predictors: (Constant), X3New, X1New, X2New

Fig. 13. Model Summary Moisture Content.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.085	3	.028	8025.048	.000[b]
	Residual	.000	12	.000		
	Total	.085	15			

a. Dependent Variable: Y1

b. Predictors: (Constant), X3New, X1New, X2New

Fig. 14. Anova Result Moisture Content.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.228	.002		142.770	.000
	X1New	.001	.000	.775	120.296	.000
	X2New	.001	.000	.628	97.453	.000
	X3New	.001	.000	.064	9.911	.000

a. Dependent Variable: Y1

Fig. 15. Model Multiple Regression Moisture Content.

Ash Content (y_2)

Fig. 10 shows the model summary ash content. Fig. 11 shows the ANOVA result ash content. Fig. 12 shows the model multiple regression ash content. The figure above shows that the correlation (R-squared) is 0.389, with a total sig value for ANOVA is 0.105 and a Sig value for coefficients is 0.000 Therefore, the decision for the ash content variable is not significantly related to the variables x_1 (water Volume), x_2 (baglog charcoal), x_3 (tapioca) because the Sig. ANOVA value is greater than the Alpha value that is 0.05 or 5%

 Model MRA Ash Content:

$$y_2 = 0.178 + 0,00x_1 + 0,00004423x_2 + 0,001x_3 + \epsilon$$

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.624[a]	.389	.236	.04011

a. Predictors: (Constant), X3New, X1New, X2New

Fig. 16. Model Summary Ash Content.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.012	3	.004	2.547	.105[b]
	Residual	.019	12	.002		
	Total	.032	15			

a. Dependent Variable: Y2

b. Predictors: (Constant), X3New, X1New, X2New

Fig. 17. Anova Result Ash Content.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.178	.034		5.233	.000
	X1New	.000	.000	.614	2.720	.019
	X2New	-4.423E-5	.000	-.067	-.298	.771
	X3New	-.001	.001	-.088	-.391	.702

a. Dependent Variable: Y2

Fig. 18. Model Multiple Regression Ash Content.

The experiment results show the best parameter settings for the briquette-making process used baglog waste. The briquette production will be used for the sterilization combustion process of the baglog output so that SME Omah Jamur Ungaran can reduce the cost of using Liquified Petroleum Gas (LPG). SME Omah jamur ungaran produce 23,000 baglogs in each year. The active period of baglogs for mushroom-growing media is 3 months. After that, the baglogs become waste. The waste generated for 3 months is 2.9 tons. The owner of Omah Jamur Ungaran MSME, Muhamad Rahardi Irvan, said that he did not have a method for processing oyster mushroom baglog waste generated from mushroom cultivation processing. The baglog waste had no use, even if used as fertilizer ssince the main composition of the baglog is sawdust. The wood powder can be utilized as ideal for briquettes. Omah Jamur Ungaran found a solution to using oyster mushroom waste as an alternative biomass energy for making solid fuels, such as briquettes. The briquettes can be used during the cultivation process of making baglogs. There is a baglog sterilization process in which 160 baglogs are steamed for 8 hours using LPG gas. The impact is that the use of LPG gas increases and incurs more costs. Meanwhile, the waste produced by Omah Jamur Ungaran is very supportive of being used as an alternative fuel. Briquettes made from baglog waste are stated to be able to support the circular economy in Omah Jamur Ungaran because they can replace the LPG gas used in the sterilization process. There is an integration system in waste management that wastes generated in the cultivation process will be reused in the cultivation process again. The inference demonstrates that there is a circular economy that minimizes production costs. In addition, the briquettes produced become new business opportunities for partners. The briquettes sold can supports the development of product innovation and growth in briquettes by implementing food standards (food grade). The Indonesian National Briquettes Standard can increase consumer confidence in Briquettes , and expand the partner cooperation market to support business sustainability in the future.

4. Discussion

This study demonstrates the moisture content was the optimal condition for setting parameters: a water volume is 86 g, a baglog charcoal is 66 g, a tapioca is 20 g, a time when blending is 3 minutes and a drying oven temperature is 160^oC. They informed the moisture content, fiber length and compaction time values used [21]. In tapioca biomass, the percentage of lignin, cellulose and hemicellulose were 40% 41% and 5.8% respectively. Then, the ash content is in optimal conditions for setting the moisture. The content parameter: water volume is 50 ml, baglog charcoal is 66 g, tapioca is 20 g, blending time is 2 minutes and drying oven tem-

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perature is $140^{o}C$ [40].

The regression model of relapse mainly clarifies the reaction to briquette thickness, strength record, and compressive quality, agreeing with the required exploratory components. The balanced correlation coefficients reflect the variety within the reaction factors that cannot be clarified by the three exploratory components utilized in this consideration. In addition, although the remaining standard deviation (σR) of the three relapse models is slight, the relative measure is very expansive. It can occur when the relative amount (in percent) of the residual standard deviation of the contrast between the most and least is significant. The values of the reaction obtained by the recurrence indicated or related to the apparent free coefficient. The Relapse shows the regression model values. Table 9 demonstrates the first order is the drying oven temperature in Celsius, the second order is the water volume in ml, the third order is the baglog charcoal in grams, the fourth order is the tapioca in grams, and the last order is the time when blending in minutes. While the ranking order of the S/N ratio on moisture content (Repeatability): the first order is the drying oven temperature in Celsius, the second order is the tapioca in grams, the third order is water volume in ml, the fourth order is the time when blending in minutes, and the last order is the baglog charcoal in grams [40]. The ANOVA analysis showed three variables. Each was significantly influenced by water content. Furthermore, there is an interaction effect between baglog charcoal, water volume and tapioca. Moisture content and fiber have a length of ($p < 0.05$). The results are the effect on the water volume, baglog charcoal, and tapioca. Variables measured by the ANOVA analysis are moisture content and particle size. The difference univariate is commonly utilized to get the most effects. The past behaviour appeared in preparatory tests conducted on briquettes with a moisture substance of 4% in which the useless reaction factors was found when utilizing lower levels of dampness substance. On the other hand, Mursito et al. (2020) reported little relevance of water volume, baglog charcoal, and tapioca to moisture and ash content. The scope is to understand the behaviour found within the preparatory tests when changing the dampness substance influencing the quality of the briquettes [41]. On the other hand, from the preparatory tests, it was found that expanding the dampness substance drove an increase briquette quality; this is often in line with what was seen by other analysts, in which the ideal dampness substance for tapioca biomass is 9.4% close to the value found for moisture content, which is 8.4% by weight. Furthermore, according to Sova et al. (2022), moisture content has an inversely proportional effect on the variation of the durability index [42]. It is because the indicated behaviour observed is that an increase in moisture content results, a decrease in the moisture content index and ash content. In another work, the researchers established that the effect of iteration between water rate, baglog waste, and tapioca rate based on iteration between moisture content and compression time is irrelevant, as shown in the ANOVA analysis results [11]. The results of this study indicated that the ash content of the briquettes reaches 11%, which is still below the ISO 17225 standard for high-quality solid biofuels, which require lower ash content for residential and commercial use. Although the ash content is higher than expected for the ISO standard, this study offers an innovative approach to utilizing mushroom baglog waste as a raw material for briquettes, which aligns with circular economy efforts. The briquettes standard emphasizes the importance of the origin of biomass, which is the feedstock of solid biofuels. It codifies into a classification based on a four-digit system that recognizes many biofuels, including aquatic feedstocks. ISO 17225 is divided into nine parts, and the topic is the origin of biomass feedstocks. Regarding biofuels, the reference standard distinguishes between Part 2 and Part 3 for solid wood biofuels (briquettes). Sections 4 and 5 are low-process biofuels (wood chips and firewood). Although ISO 17225 specifies certain quality classes for each group of biofuels (classes A1, A2, and B for wood pellets), some of the biomass included in ISO 17225-1 Italy does not meet the relative limits of biofuels for quality to medium quality. As a part of the second derivative of the baglog waste utilization from mushroom cultivation, this study shows the improving quality of biomass briquettes by paying attention to moisture and ash content parameters. The ash content is higher than the ISO standard, so it is still challenge itself. However, it does not reduce the contribution of this study to efforts reducing waste and developing sustainable energy solutions. The ash content of 11% still shows potential for further development to comply with stricter standards, especially to create more competitive products in the biofuel market. It is important to note that this study supports the goal of a circular economy by utilizing agricultural waste, especially baglog waste, which has not been optimally utilised previously. This process also contributes to achieve the Sustainable Development Goals (SDGs), especially those related to sustainable waste management and the use of renewable energy. Although this study describes the essential quality parameters of biomass briquettes, future quality requirements may differ. The requirements, processes and routes for biomass briquette production are increasing and changing as new options are discovered. Research to this direction must continue to evolve in line with the industry's new requirements. Ultimately, the needs of enterprises and consumers who use briquettes for various bioenergy purposes will determine future quality requirements.

5. Conclusion

This study examines a new approach using Taguchi statistical analysis to optimize the process and post-process parameters and to maximize the quality of baglog waste-based briquettes. Among the various parameters of the baglog waste briquette-making process, this research focuses on the analysis of important variables, namely moisture content and ash content. Through the identification of these main parameters and the development of quality analysis, the following conclusions are obtained:

- S/N ratio of moisture content, there is a ranking order, namely the first sequence is the drying oven temperature in Celsius, the second sequence is the water volume in ml, the third sequence is the baglog charcoal in gr, the fourth sequence is the tapioca in grams, and the last sequence is the time when blending in minutes. The optimal conditions for setting moisture content parameters are water volume of 50 ml, baglog charcoal of 66 gr, tapioca of 22 g, blending time of 1 minute and drying oven temperature of 140^oC.
- S/N ratio of moisture content (Repetition), there is a ranking order, namely the first order is the drying oven temperature in Celsius, the second order is the tapioca in grams, the third order is the water volume in ml, the fourth order is the blending time in minutes and the last order is baglog charcoal in gr. The optimal conditions for setting moisture content parameters are water volume of 50 ml, baglog charcoal of 66 gr, tapioca of 20 gr, blending time of 2 minutes and drying oven temperature of 140^oC.
- S/N ratio of ash content, there is a ranking order, namely the first order is the tapioca in gr, the second sequence is the water volume in ml, the third sequence is the drying oven temperature in celsius, the fourth sequence is the baglog charcoal in gr, and the last sequence is the time when blending in minutes. The optimal conditions for setting the ash content parameters are water volume of 72 ml, baglog charcoal of 60 gr, tapioca of 24 grams, blending time of 3 minutes and drying oven temperature of 140^oC.
- S/N Ratio of ash content (Repetition), there is a ranking order, namely the first order is the baglog charcoal in gr, the second sequence is the blending time in minutes, the third sequence is the water volume in ml, the fourth sequence is the drying oven temperature in Celsius, and the final order is the tapioca in gr. The optimal conditions for setting ash content (repetition) parameters are water volume of 86 gr, baglog charcoal of 66 gr, tapioca of 20 gr, blending time of 3 minutes and drying oven temperature of 140^oC.
- The optimal moisture content and ash content variables for the volume are 50 ml, the baglog charcoal is 66 grams, the tapioca is 20 grams, the blending time is 3 minutes, and the drying oven temperature is 140^oC.

The study concludes that utilizing baglog waste to produce briquettes effectively supports a circular economy at the Omah Jamur Ungaran SME. By transforming the 2.9 tons of baglog waste generated every three months into briquettes, the SME can reduce its reliance on LPG in sterilization and lower production costs. This innovation offers new business opportunities by producing food-grade briquettes, which enhance consumer confidence and expand collaborative market prospects. The briquettes can replace LPG gas in the baglog sterilization process, demonstrating a sustainable integration of waste management within mushroom cultivation. The circular use of resources fosters cost efficiency and resource conservation. Moreover, adopting the Indonesian National Standard for Briquettes strengthens product competitiveness in the market. The standardization enhances product quality and marketability, promoting business resilience and sustainability. This approach exemplifies how local SMEs can leverage waste as a resource, encouraging growth in the biomass energy sector. Ultimately, Omah Jamur Ungaran's initiative aligns with broader economic and environmental goals for sustainable development.

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