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Optimization of aerobic fermentation of solid fertilizer from goat manure using response surface methodology (RSM)

Rizna Aini Mandriana*, Muhammad Tajul Mafachir, Mu'tasim Billah, Ni Ketut Sari, Ely Kurnianti, Suprihatin

Department of Chemical Engineering, Veteran State Development University of East Java, Surabaya 60294, Indonesia

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ABSTRACT

The increase in goat population has led to a significant increase in the volume of goat manure, which has the potential to cause environmental pollution if not managed properly. Goat manure has a good enough nutritional content to be used as organic fertilizer, but the high initial C/N ratio indicates that the material is not yet stable and requires a fermentation process to improve its quality. Therefore, this study aims to optimize aerobic fermentation conditions using the Response Surface Methodology (RSM) method by analyzing the effect of air flow rate and oxidation time on the C/N ratio and air content. The fermentation process was carried out in a reactor in a vessel with an active aeration system at various air flow rates of 5–25 L/min and oxidation times of 16–24 days. The results showed that increasing the air flow rate and oxidation time significantly reduced the C/N ratio from 30.47 to 11.52–17.62. The optimum conditions were obtained at an air flow rate of 20 L/min and an oxidation time of 22 days, with a C/N ratio of 12.4769 and an air content of 23.3309%, and a desirability value of 1. These results indicate that the optimized process is capable of producing organic fertilizer that meets national quality standards (SNI 7763:2004). In addition, this study provides an effective approach in managing livestock waste into value-added products and supports the development of sustainable agricultural systems.

1. Introduction

The development of the livestock sector in Indonesia has shown significant growth in recent years, including goat commodities. The increase in livestock population has a direct impact on the increase in the volume of solid waste in the form of livestock manure [1]. In Panceng District, which is one of the goat farming centers in East Java, the goat population is reported to increase by around 15% annually based on data from the Central Statistics Agency of East Java Province. This condition causes the production of solid livestock waste to increase and has the potential to cause environmental problems if not managed optimally.

The accumulation of goat manure that is not managed properly can have a negative impact on the environment and public health [2]. Livestock waste that is left for a long time has the potential to produce ammonia gas (NH_3) due to the decomposition process of organic materials, which can cause air pollution and health problems such as eye and skin irritation and respiratory system disorders [3]. In addition, the disposal of livestock waste into water bodies can reduce water quality and trigger the growth of pathogenic microorganisms [2]. Therefore, an effective and sustainable livestock waste processing system is needed.

On the other hand, goat manure has great potential to be used as organic fertilizer because it contains macro nutrients such as nitrogen (N), phosphorus (P), and potassium (K) which play a role in increasing soil fertility [4]. However, fresh goat manure generally has a high C/N ratio (>30), with a carbon content of 47.34% and nitrogen of 1.34% [5]. A high C/N ratio indicates that the material is not yet stable and has not met the compost maturity standards according to Indonesian National Standards (SNI), so it requires a fermentation or composting process to reduce the carbon content and increase the stability of the organic material.

Several previous studies have examined the composting process using the in-vessel non-flow reactor method with variations in the aeration system. [6] reported that the use of forced aeration was able to reduce the C/N ratio by up to 72.01%, from an initial ratio of 56.60 to 15.84 within 20 days. Aeration plays an important role in providing oxygen for aerobic microorganisms which accelerate the decomposition process of organic materials, thus influencing the rate of decrease in the C/N ratio and the level of compost maturity [7].

Another study showed that composting process optimization can be done using the Response Surface Methodology (RSM) approach by considering various operational parameters and responses such as C/N ratio and air content simultaneously [8]. In addition, parameters such as air content and C/N ratio are also reported to play an important role in determining the final quality of compost [5]. Research related to aeration generally only emits the effect of one air flow rate without examining its interaction with process time simultaneously [9]. On the other hand, the multi-response optimization approach using the desire function for compost quality parameters is still limited in its application to controlled aerobic fermentation systems [10].

However, research on the effect of variations in air flow rate

* Corresponding author. Tel.: +6285746854372
Email: riznamandriana@gmail.com
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and oxidation time on the C/N ratio in aerobic fermentation of goat manure, especially under livestock conditions in Panceng District, is still limited. Most studies still focus on general composting systems and have not specifically examined the simultaneous interaction between air flow rate and oxidation time in controlled aerobic fermentation systems. In addition, studies that integrate these two variables with a multi-response optimization approach C/N ratio and water content) simultaneously are also still very limited.

Therefore, this study aims to analyze the effect of variations in air flow rate and oxidation time on the C/N ratio in the aerobic fermentation process of goat manure using the in-vessel non-flow reactor method with active aeration. This study offers novelty by integrating variables of air flow rate and oxidation time in a controlled aerobic fermentation system and applying multi-response optimization using a desire function to obtain optimal and comprehensive operating conditions. The results of this study are expected to provide an alternative technology for processing livestock waste that is more effective and supports the use of goat manure as an organic fertilizer that meets quality standards.

2. Method

2.1. Materials

Goat manure obtained from Panceng sub-district, Gresik Regency, East Java, Indonesia, Water (H_2O), EM4 (Effective Microorganism-4). Additional ingredients in the form of brown sugar solution are used as a nutrient source for activating microorganisms in EM4 before being used in the fermentation process.

2.2. Goat manure fermentation process

Effective microorganisms 4 (EM4) were activated by adding brown sugar and water in a ratio of 1:1:1 (v/v). The mixture is placed in a closed container for 1 week for the activation process. Wet goat manure solid waste was first dried using an oven at 60°C for 52 hours until the water content was reduced, the sample was crushed and sieved to 30 mesh to obtain uniform particles. A total of 1 kg of sifted goat manure sample was put into a non-flow reactor in-vessel type reactor. Next, the activated EM4 solution was added to the reactor and the mixture was homogenized using a stirring rod. The reactor used is a non-flow in-vessel type with a closed system equipped with active aeration using a compressor and flowmeter to regulate the air flow rate constantly during the fermentation process. The reactor is then tightly closed to ensure that the incoming air supply comes from the active aeration system connected to the compressor. The fermentation process was carried out with varying oxidation times of 16, 18, 20, 22, and 24 days. And the air is continuously circulated using a compressor with flow rate variations of 5, 10, 15, 20, and 25 L/min.

During the aerobic fermentation process, the organic matter in goat manure undergoes biological degradation by microorganisms, breaking down complex compounds such as cellulose and hemicellulose into simpler compounds. This process reduces the organic carbon content and gradually lowers the C/N ratio, an indicator of compost maturity [11]. After the fermentation process is complete, the samples are analyzed to determine the C/N ratio and water content. Carbon content analysis used the Walkley–Black Modified Spectrophotometric method and nitrogen content analysis used the Kjeldahl method, while water content was determined using the gravimetric method.

2.3. Experimental design

The experimental design in this study was designed using the Response Surface Methodology (RSM) with the Central Composite Design (CCD) approach. The independent variables used were air flow rate (A) and oxidation time (B), while the observed responses included the C/N ratio and water content. The Response Surface Methodology (RSM) method was chosen because it is able to optimize several process and response variables simultaneously and is efficient in determining optimal conditions [12].

In this study, air flow rate and oxidation time were selected as the primary variables due to their dominant role in controlling oxygen transfer and microbial activity during aerobic fermentation. Air flow rate directly influences oxygen availability within the system, which is essential for aerobic microbial metabolism and the degradation of organic matter [13] Insufficient aeration may limit diffusion and slow down the decomposition process, while excessive aeration can increase moisture loss and reduce process efficiency [14].

Oxidation time is another critical parameters that determines thee duration of microbial activity and the extent of organic matter stabilization. Longer oxidation periods allow microorganism to degrade more complex compounds such as cellulose and lignin, resulting in a more stable compost with lower C/N ratio [15].

Other operational parameters, such as temperature, pH, and initial substrate characteristics, were maintained relativity constant to minimize external variability. This approach enables a more focused evaluation of the interaction between selected variables, which is consistent with RSM principles where limiting the number of variables improves model accuracy and interpretability [16].

Optimization was carried out using a desirability function approach with the aim of minimizing the C/N ratio and water content simultaneously to obtain optimum conditions that meet organic fertilizer quality standards. Each parameter was varied at five levels ($-\alpha$, -1, 0, $+1$, $+\alpha$), as shown in Table 1. The air flow rate (L/min) was varied at 5, 10, 15, 20, and 25, while the oxidation time (days) was varied at 16, 18, 20, 22, and 24. In the CCD experimental design, the number of trials (Y) is determined using the following Eq. (1):

$$Y = 2^k + 2k + C_0 \quad (1)$$

where Y is the number of trials, k is the number of variables, and C0 is the number of repetitions of the center point. In this study, the number of variables is 2, and the number of center points is .

Table 1. Experimental parameters and their levels

Sample	Parameter	-α	-1	0	+1	+α
A	Air flow rate (L/min)	5	10	15	20	25
B	Oxidation time (days)	16	18	20	22	24

The experimental design in this study was developed using the Response Surface Method (RSM) with the Central Composite Design (CCD) approach to evaluate the effect of air flow rate and

oxidation time on the C/N ratio and water content during aerobic fermentation of goat manure. Two independent variables were used, namely air flow rate (A) and oxidation time (B). The experiments were generated using Design Expert software, resulting in a total of 25 experiments consisting of factorial points, axial points, and center points.

In this design, the alpha (α) value is set to 2 as the star or axial point for an orthogonal CCD design with two independent variables. The levels of each variable were defined within the experimental range of 5–25 L/min for air flow rate and 16–24 days for oxidation time. Parameter values at each level of variation are rounded to simplify the experimental conditions. The mathematical relationship between the independent and response variables is modeled using a second-degree polynomial equation as shown in Equation (2):

$$y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum b_{ij} x_i x_j \quad (2)$$

Where b_0 is a constant term, b_i represents the linear coefficient, b_{ii} is the quadratic coefficient and b_{ij} is the interaction coefficient between variables x_i and x_j [8]. These coefficients describe the influence of air flow rate and oxidation time on the observed responses in the fermentation process.

The developed model was then validated using analysis of variance (ANOVA) to determine the statistical significance of each factor and to evaluate the adequacy of the model [17]. The optimum condition is obtained by minimizing the C/N ratio and water content through a desire function approach. The optimal combination of variables is determined based on the highest desired value, which indicates the best fit between the prediction model and the desired response.

3. Result and Discussion

3.1. C/N ratio analysis

The C/N ratio is one of the key indicators used to evaluate the maturity and stability of compost or organic fertilizer. In this study, the initial C/N ratio of goat manure was relatively high, indicating that the material required a fermentation process to reduce the carbon content and achieve a more stable organic composition. After aerobic fermentation, the C/N ratio decreased significantly, with values ranging from 11.52 to 17.62. The decrease in the C/N ratio occurs because microorganisms use carbon as an energy source during metabolic processes. Through aerobic respiration, some of the carbon is converted to carbon dioxide (CO_2) and released into the atmosphere, while nitrogen tends to remain in the system. As a result, the relative nitrogen concentration increases, resulting in a lower C/N ratio.

The experimental data were then analyzed using the Response Surface Method (RSM) to statistically evaluate the effect of air flow rate and oxidation time on the C/N ratio. This analytical method allows the identification of the most influential parameters in controlling the degradation of organic matter during fermentation. The RSM model also provides insight into the interaction between aeration and fermentation time in accelerating microbial decomposition. Optimization results show that higher air flow rates combined with longer oxidation times significantly increase organic carbon degradation, resulting in lower C/N ratios. The optimal conditions predicted by the model resulted in a C/N ratio close to 11.486, which meets the maturity standards for organic fertilizer according to national compost quality guidelines.

3.2. Water content analysis

Moisture content is a critical parameter in determining the stability and quality of organic fertilizer produced from aerobic fermentation. The moisture content obtained from the fermentation process ranges from approximately 4.89% to 38.3%, depending on the air flow rate and oxidation time applied during the process. The reduction in moisture content during fermentation is primarily influenced by the continuous air flow supplied to the reactor. Higher air flow rates increase water evaporation due to increased air circulation within the reactor system. Furthermore, microbial metabolic activity during aerobic fermentation generates heat, which contributes to water evaporation and subsequently reduces the moisture content of the material.

The experimental results were then analyzed using Response Surface Methodology (RSM) to evaluate the effect of air flow rate and oxidation time on the moisture content of the fermented product. This statistical approach allows identification of the most significant variables affecting water removal during fermentation and provides insight into the interactions between operational parameters. Through this analysis, the model can predict the optimal operating conditions required to produce organic fertilizer with stable moisture content and improved storage characteristics. Furthermore, RSM allows for a quantitative understanding of how aeration intensity and fermentation duration affect moisture reduction through mechanisms such as heat generation, evaporation dynamics, and mass transfer within the reactor system. Optimization results indicate that higher air flow rates combined with longer oxidation times generally result in lower moisture content, resulting in a more stable organic fertilizer product.

3.3. Evaluation of RSM analysis

The experimental data obtained were then analyzed using the Response Surface Methodology to determine the relationship between process variables and the observed responses. This analysis was conducted using Design-Expert software with a Central Composite Design experimental design that allows for the evaluation of linear, quadratic, and interaction effects between process variables on the response. In this study, the independent variables used were air flow rate (A) and oxidation time (B), while the observed responses included water content and C/N ratio.

The validity of the model obtained was then evaluated using analysis of variance (ANOVA). This analysis aims to determine the significance of the influence of each variable on the observed response and to ensure that the model obtained is able to represent the experimental data well. A p-value less than 0.05 indicates that the tested variable has a significant influence on the response, while a coefficient of determination (R^2) value close to 1 indicates that the model has a good level of fit with the experimental data [7].

The results of the analysis of variance for the C/N ratio response are shown in Table 2. Based on the table, it can be seen that the variables of air flow rate (A) and oxidation time (B) have a significant effect on changes in the C/N ratio with a p-value less than 0.05. In addition, the interaction between the two variables also shows an influence on the observed response.

Table 2. Analysis of variance (ANOVA) for C/N response ratio

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	87,17	5	17,43	380,47	< 0,0001	significant
A-Air Flow Rate	82,77	1	82,77	1806,19	< 0,0001	
B-Oxidation Time	3,06	1	3,06	66,78	< 0,0001	
AB	0,1840	1	0,1840	4,02	0,0595	
A^2	1,15	1	1,15	25,2	< 0,0001	
B^2	0,0064	1	0,0064	0,1399	0,7125	
Residual	0,8707	19	0,0458			
Cor Total	88,04	24				

Table 3. Analysis of variance (ANOVA) for water content response

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2203,4	14	157,39	325,03	< 0.0001	significant
A-Air flow rate	89,48	1	89,48	184,8	< 0.0001	
B-Oxidation Time	4,26	1	4,26	8,8	0,0141	
AB	0,4199	1	0,4199	0,8671	0,3737	
A^2	32,46	1	32,46	67,04	< 0,0001	
B^2	0,0000	1	0,0000	0,0001	0,9926	
A^2B	7,39	1	7,39	16,37	0,0023	
AB^2	0,0138	1	0,0138	0,0285	0,8693	
A^3	15,9	1	15,9	32,85	0,0002	
B^3	1,05	1	1,05	2,17	0,1719	
A^2B^2	2,27	1	2,27	4,69	0,0557	
A^3B	0,6053	1	0,6053	1,25	0,2897	
AB^3	4,89	1	4,89	10,10	0,0098	
A^4	9,7	1	9,7	20,03	0,0012	
B^4	0,0099	1	0,0099	0,0204	0,8892	
Residual	4,84	10	0,4842			
Cor Total	2208,24	24				

Based on Table 2 and Table 3, the F-value shows the magnitude of the influence of a factor on the response compared to the model error, while the P-value is used to assess the level of significance of each factor. In general, a P-value ≤ 0.05 indicates that a factor has a significant effect on the response. On the other hand, if the P-value ≥ 0.1, then the factor is considered not to have a significant influence. In Table IV.4, the analysis results show that factor A-Air Flow Rate has a P-value <0.0001 (<0.05%), as does B-Oxidation Time which also has a P-value of 0.0141 (<0.05%). This confirms that both factors have a very significant effect on changes in water content. In addition, the interaction between Air Flow Rate and Oxidation Time (AB) with a P-value of 0.3737. This shows that both factors work independently in determining the final water content in the goat manure oxidation process. In Table IV.5, the analysis results show that factor A-Air Flow Rate has a P-value <0.0001 (<0.05%), as does B-Oxidation Time which also has a P-value of 0.0141 (<0.05%). This confirms that both factors have a very significant effect on changes in water content. In addition, the interaction between Air Flow Rate and Oxidation Time (AB) with a P-value of 0.0595. This shows that both factors have a significant influence in determining the final C/N ratio in the goat manure oxidation process.

Table 4. Comparison of equation models suggested by software on response 1 c/n ratio

Source	Sequential p-value	Adjusted R^2	Predicted R^2	
Linear	< 0.0001	0.9725	0.9668	
2FI	0,1823	0.9736	0.9652	
Quadratic	**0,0003**	**0.9875**	**0.9844**	**Suggested**
Cubic	0,0560	0.9911	0.9826	
Quartic	0,9555	0.9879	0.9349	
Fifth	0,1321	0.9928	0.8790	Aliased

Table 5. Comparison of equation models suggested by software on response 2 water content

Source	Sequential p-value	Adjusted R^2	Predicted R^2	
Linear	< 0.0001	0,7953	0.7463	
2FI	0.1229	0,8090	0.7323	
Quadratic	**< 0.0001**	**0,9730**	**0.9611**	**Suggested**
Cubic	0.0180	0,9838	0.9693	
Quartic	0.0042	0,9947	0.9768	
Fifth	0.1825	0,9965	0.9180	Aliased

Based on Table 4 and Table 5, the recommended equation model is obtained to predict the response of water content and C/N ratio based on the two factors studied, namely Air Flow Rate and Oxidation Time. The selected models were the quadratic model for the water content response and the quadratic model for the C/N ratio response, because they showed good agreement between the Adjusted R^2 and Predicted R^2 values. In table IV.7, the Adjusted R^2 value is 0.9947 and the Predicted R^2 value is 0.9768, with a difference of 0.0179. Meanwhile, in table IV.8, the Adjusted R^2 value is 0.9875 and the Predicted R^2 value is 0.9844, with a difference of 0.0031. which is still within acceptable limits (not exceeding 0.2). This shows that the model has good capabilities in explaining data variations as well as in predicting responses. In addition, the R^2 value obtained is within a tolerable range, namely between 0.8 and 1, so the model is considered quite representative, which indicates that the model is statistically significant and suitable for use to describe the relationship between independent variables and the response of water content and C/N ratio.

Based on the evaluation of several models and ANOVA, it was found that the quadratic polynomial model provided the best fit in explaining the relationship between the two variables and the C/N ratio response, as shown in Equation (3), where A represents the air flow rate (L/min) and B represents the oxidation time (days).

$$Y = 23.5638 + (-0.497234*A) + (-0.283764*B) + (0.00429*AB) + (0.00513714*A^2) + (0.00239286*B^2) \quad (3)$$

This equation serves as a predictive model for estimating water content based on variations in air flow rate and oxidation time. The resulting optimization equation can be expressed as follows:

$$Y = -516.1224 + (35.15572*A) + (77.9686*B) + (-6.55003*AB) + (0.953071*A^2) + (-2.97588*B^2) + (0.0266122*A^2B) + (0.309277*AB^2) + (-0.0555547*A^3) + (0.00670833*B^3) + (-0.00107602*A^2B^2) + \quad (4)$$

$(0.000259333*A^3B) + (-0.00460833*AB^3) + (0.0007768*A^4) + (0.00096875*B^4)$

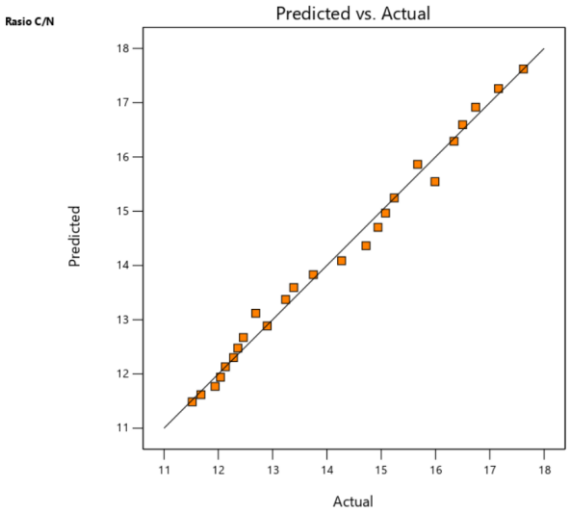

Fig. 1. Comparison of C/N ratio responses in predicted vs actual form

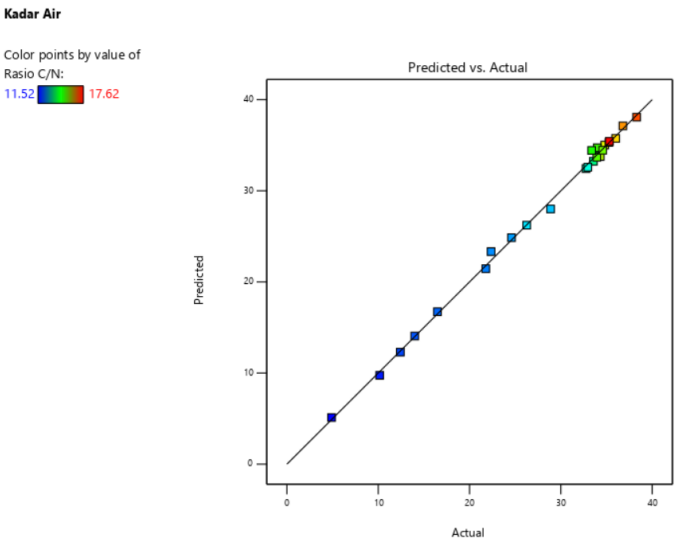

Fig. 2. Comparison of water content responses in predicted vs actual form

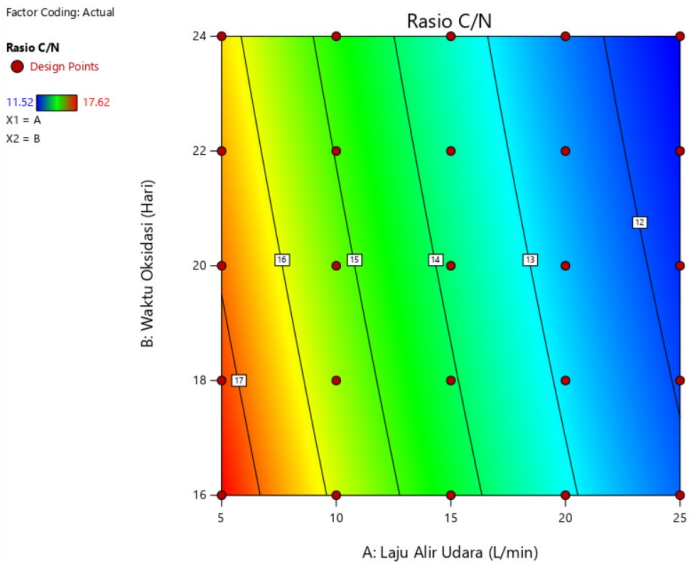

Fig. 3. Contour plot of air flow rate against oxidation time and against C/N ratio

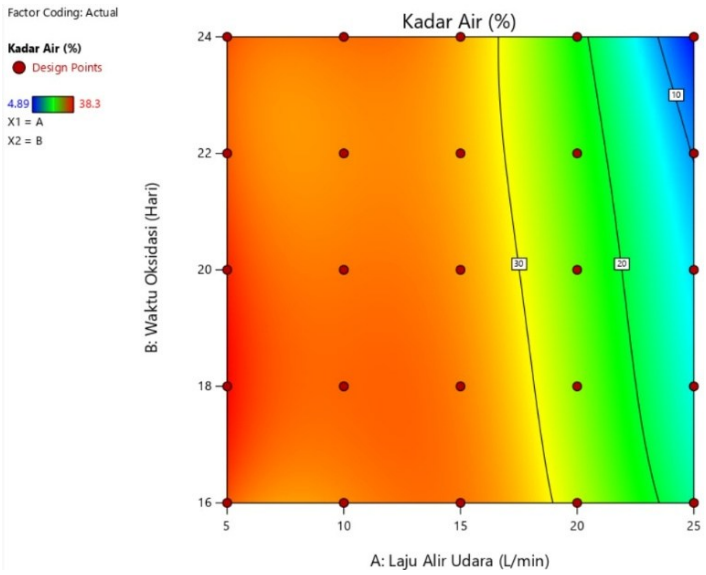

Fig. 4. Contour plot of air flow rate against oxidation time and water content

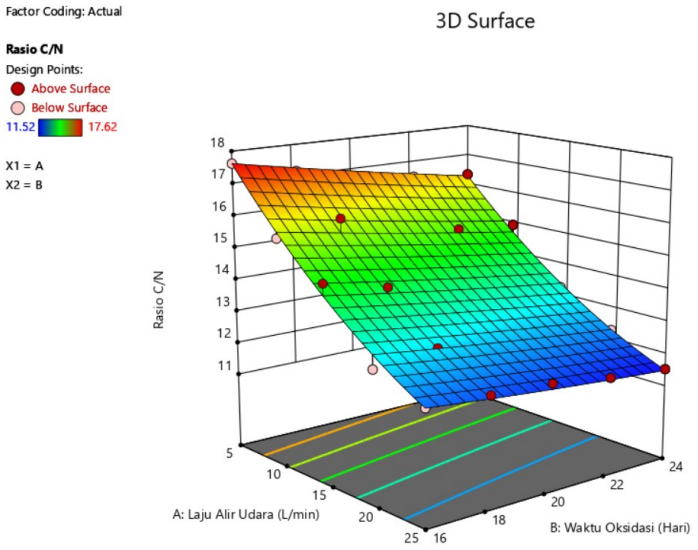

Fig. 5. 3D surface air flow rate against oxidation time and against C/N ratio

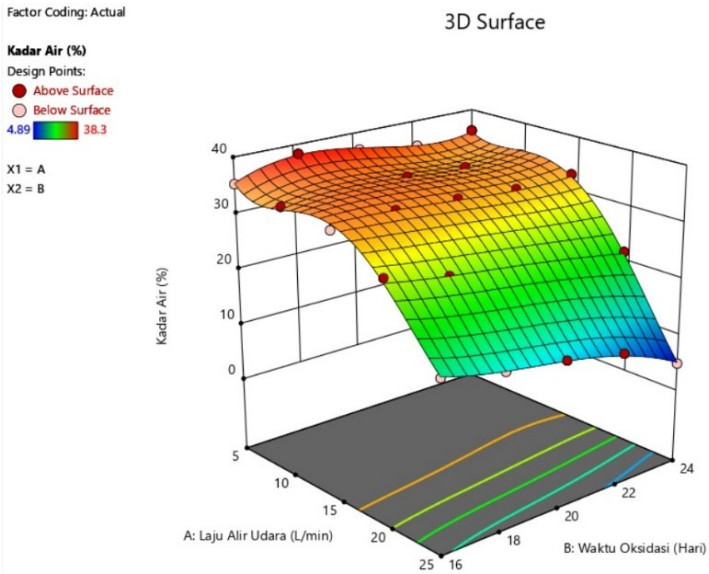

Fig. 6. 3D surface air flow rate against oxidation time and against water content

Table 6. Factor and response data for analysis with RSM

Run	Factor 1 A: Air flow rate (L/min)	Factor 2 B: Oxidation Time (days)	Response 1 C/N Ratio	Response 2 Water content
1	5	16	17,62	35,31
2	5	18	17,16	38,3
3	5	20	16,74	36,8
4	5	22	16,5	35,27
5	5	24	16,34	36,01
6	10	16	15,67	34,31
7	10	18	15,99	34,81
8	10	20	15,24	34,59
9	10	22	15,08	33,94
10	10	24	14,94	33,99
11	15	16	14,72	33,38
12	15	18	14,27	34,12
13	15	20	13,75	33,56
14	15	22	13,39	32,76
15	15	24	12,24	32,96
16	20	16	12,69	28,88
17	20	18	12,9	26,26
18	20	20	12,46	24,6
19	20	22	12,36	22,36
20	20	24	12,28	21,78
21	25	16	12,13	16,49
22	25	18	12,04	14
23	25	20	11,94	12,42
24	25	22	11,68	10,17
25	25	24	11,52	4,89

Fig. 1 and Fig. 2 Predicted vs Actual illustrates the relationship between the response value predicted by the model and the actual value of the experimental results. The points on the graph represent actual data compared against the model's predicted values. The closer the position of the point to the diagonal line (line of fit), the better the level of fit between the actual results and the predicted results. In the graph there are 25 points that come from the actual response data that has been analyzed. The closeness of the points to the diagonal line indicates that the coefficient of determination (R^2) value is close to 1, which indicates that the model has a high level of accuracy and predictive ability.

The relationship between the two factors, namely, Air Flow Rate and Oxidation Time and response (water content & C/N Ratio) is visualized in the form of a contour plot and a 3D surface plot which can be seen in Fig. 3 and Fig. 4. The contour plot in Fig. 3 and Fig. 4 shows the two-dimensional relationship between air flow rate (A) and oxidation time (B) against the C/N ratio and water content, while the 3D surface graph depicts the relationship in three dimensions so that the response change pattern can be clearer. Based on the contour plot, it can be seen that changes in water content and C/N ratio are more dominantly influenced by air flow rate than oxidation time. This can be observed from the color gradation which changes significantly along the x-axis, while the changes along the y-axis are relatively smaller. In Fig. 3, the red to orange areas indicate high C/N ratios, which occur at low air flow rates (around 5-10 L/min). Conversely, the green to blue areas indicate lower C/N ratios, which are obtained at high air water rates (around 15-25 L/min). While in Fig. 4, the red to orange areas indicate high water content, which occurs at low air flow rates (around 5-15 L/min). Conversely, the green to blue areas indicate lower water content, which is obtained at high air water rates (close to 25 L/min).

The 3D surface graphs shown in Fig. 5 and Fig. 6 are graphs that illustrate the relationship between air flow rate and oxidation time and the response (C/N ratio and water content)..The 3D surface graph shows that the response surface decreases sharply with increasing air flow rate. This shows that the greater the air flow rate, the lower the C/N ratio and water content produced.. Physically, this condition is logical because increased air flow accelerates the carbon oxidation process in the system. Meanwhile, the effect of oxidation time appears to be more gradual compared to air flow rate, which indicates that this variable has a smaller contribution to changes in the C/N ratio. Thus, it can be concluded that the air flow rate is the most dominant factor in reducing the C/N ratio and water content, and the optimum conditions for obtaining the lowest C/N ratio and water content are at a high air flow rate with a relatively longer oxidation time [18].

3.4. Optimazation results of the C/N response using RSM

Response optimization was carried out to evaluate the effect of air flow rate and oxidation time in obtaining the closest water content to the value of 23.3309% and C/N ratio of 12.4769. This optimization process is carried out by considering the lower limit and upper limit that have been previously determined as the operational range of the parameters. Determining the best conditions focused on achieving the appropriate water content and C/N ratio, as these values indicate that the fermentation process is proceeding optimally and approaching ideal conditions. The optimization limits for these responses are presented in Tables 7 and 8.

Table 7. Factor limitations and c/n ratio response for optimization

Name	Goal	Lower Limit	Upper Limit
Air flow rate (L/min)	is Range	5	25
Oxidation time (days)	*is Range*	16	24
C/N Ratio	*minimize*	11,52	17,62

Table 8. Factor limitations and water content response for optimization

Name	Goal	Lower Limit	Upper Limit
Air flow rate (L/min)	is Range	5	25
Oxidation time (days)	*is Range*	16	24
Water content (%)	minimize	4,89	38,3

Once the optimization constraints are established, the next step in using Design Expert 13 software is to generate a solution that represents the best process conditions. This process is carried out by combining the air flow rate and oxidation time factors to obtain the response value of Water content and C/N ratio that is close to the predetermined target. The software then calculates a combination of variables that can optimize the response and determines the desirability value as an indicator of the level of conformity of the results to the desired criteria. Based on the

results of data processing using Design Expert 13, the optimum solution was obtained which is presented in Table 9 and Table 10.

Table 9. Response 1 optimization results C/N ratio

Number	Air flow rate (L/min)	Oxidation time (days)	C/N Ratio	*Desirability*	
1	20	22	12.4769	1	*Selected*

Table 10. Response 1 optimization results water content

Number	Air flow rate (L/min)	Oxidation time (days)	Water Content	*Desirability*	
1	20	22	23.3309	1	*Selected*

Based on the optimization results using Design Expert software, one best solution (selected) was obtained with a combination of air flow rate of 20 L/min and oxidation time of 22 days. Under these conditions, the water content value predicted by the model is 23.3309% and the C/N ratio value predicted by the model is 12.4769. The desirability value obtained of 1 indicates that the combination of parameters fully meets the predetermined optimization criteria. In the desirability function method, the value is in the range of 0 to 1, where the value predicted by the model is the desired target. Thus, the combination of air flow rate and oxidation time can be considered as the optimum condition to obtain water content according to the limits or targets determined in the oxidation process.These results indicate that increasing the air flow rate to around 25 L/min with an oxidation time of more than 24 days provides the most effective conditions in achieving the targeted water content and C/N ratio [19].

3.5. Verification of optimum results

Verification of the optimization results was carried out by comparing the predicted values generated by the model with the actual values of water content and C/N ratio obtained from the experiment. Evaluation of model accuracy is carried out through Confidence Interval (CI), Tolerance Interval (TI), and Prediction Interval (PI) analysis, each of which has a lower limit and an upper limit at a 95% confidence level. This analysis aims to ensure that the actual values are still within a statistically acceptable range, so that the model used can be declared valid and reliable. The results of the verification of the optimum conditions are presented in Table 11 and Table 12 below.

Table 11. Confidence Interval Verification Results

Analysis	Predicted Mean	Predicted Median	Std Dev	SE Mean	95% CI low for Mean	95% CI high for Mean	95% TI low for 99% Pop	95% TI high for 99% Pop
C/N Ratio	13.83	13.83	0.214	0.084	13.654	14.006	12.929	14.731
Water content	33.2412	33.2412	0.695	0.462	32.2108	34.2716	29.5476	36.9348

Based on the analysis results in table 11, the predicted mean water content value was 33.2412% and the C/N ratio was 13.83, with the same predicted median value of 33.2412% and the C/N ratio of 13.83. The similarity of the average and median values shows that the distribution of the predicted data is relatively symmetrical and does not experience significant deviations. The standard deviation value of Water content is 0.695855 and the C/N ratio is 0.214066, indicating that the variation of the data to the average value is relatively small, so the model has good stability in predicting Water content. Meanwhile, the standard error of mean (SE Mean) value of Water content is 0.462434 and the C/N ratio is 0.084083 which describes the level of accuracy of the average estimate produced by the model, the smaller the SE Mean value, the higher the level of precision of the model. At a 95% confidence level, a confidence interval (CI) was obtained for the average Water content with a lower limit of 32.2108% and an upper limit of 34.2716%, as well as a C/N ratio with a lower limit of 13.654% and an upper limit of 14.006%. This means that with a 95% confidence level, the actual average Water content value is within that range. In addition, a 95% tolerance interval (TI) was obtained for 99% of the population at Water content with a lower limit of 29.5476% and an upper limit of 36.9348%, at a C/N ratio with a lower limit of 12.929% and an upper limit of 14.731%. This interval indicates that approximately 99% of the population of Water content and C/N ratio values are estimated to be within this range with a 95% confidence level. Overall, these results indicate that the prediction model used has a good level of accuracy and precision in estimating water content, and is able to adequately represent population variations [16] [20].

Table 12. Prediction interval verification results

Analysis	Predicted Mean	Predicted Median	Std Dev	n	SE Pred	95% PI low	95% PI high
C/N Ratio	13.83	13.83	0.214066	1	0.229987	13.3486	14.3114
Water content	33.2412	33.2412	0.695855	1	0.8355	31.3796	35.1028

Based on Table 12, the verification results using prediction Interval (PI) show that the predicted Mean Water content value is 33.2412%, with the same predicted median value of 33.2412% and the C/N ratio of 13.83%, with the same predicted median value of 13.83%. The similarity of these two values indicates that the predicted distribution is symmetrical. The standard deviation value of Water content is 0.695855 and the C/N ratio is 0.214066, indicating a relatively small level of data variation from the average. The number of observations (n) of 1 indicates that the prediction is made for one point of optimum conditions. The standard error of prediction (SE pred) value for water content is 0.8355 and the C/N ratio is 0.229987, which describes the level of uncertainty in predicting a new observation under certain conditions. This value is generally greater than the SE Mean, because it includes both the average variation and individual variation. At a 95% confidence level, the prediction interval (PI) for water content was obtained with a lower limit of 31.3796% and an upper limit of 35.1028% and a C/N ratio with a lower limit of 13.3486% and an upper limit of 14.3114%. This means that if the experiment is repeated under the same optimum conditions, the actual water content value is estimated to be within this range with a 95% confidence level. A relatively narrow prediction interval indicates that the model has fairly good predictive ability for individual observation values [16] [20].

The optimum conditions were achieved at an air flow rate of 20 L/min and an oxidation time of 22 days, with a moisture

content of 23.33%. Although the RSM model was able to predict these optimum conditions, specific experimental validation at the resulting optimum conditions has not been conducted. Therefore, these optimization results are still predictive and require further verification through additional experiments.

3.6. Experiment-based c/n ratio analysis

3.6.1. The effect of air flow rate on fermentation on the C/N ratio based on research

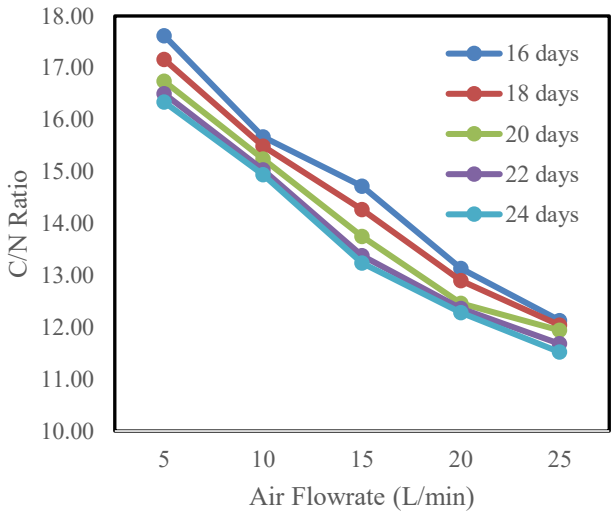

Fig. 7. Relationship between air flow rate and C/N ratio based on research

Based on Fig. 7, it shows that at an air flow rate of 6 to 10 L/min, there is a significant decrease in the C/N ratio. At a flow rate of 5 L/min, oxygen supply is still limited, so aerobic microorganism activity is not optimal, and the organic material decomposition process is relatively slow. When the flow rate is increased to 10 L/min, oxygen availability becomes more adequate to support microorganism respiration, so that carbon oxidation increases and the C/N ratio decreases. This is in line with research stating that aeration plays a crucial role in providing oxygen to aerobic microorganisms, thereby increasing biological activity and accelerating the organic material decomposition process [21]. However, at a flow rate of 15 L/min, there is a fluctuation in the C/N ratio before returning to a more stable trend at higher flow rates. This condition is thought to be caused by uneven oxygen distribution within the material. Although the amount of oxygen entering is greater, the air flow can form certain pathways (channeling) so that some parts of the material receive excess oxygen while others remain oxygen-deficient. This imbalance in oxygen distribution causes microbial activity to be uneven and the rate of carbon degradation to become unstable. Previous research has also shown that inappropriate variations in aeration rates can affect oxygen distribution and composting performance [22]. When the flow rate is increased to 20-25 L/min, oxygen distribution becomes more even, resulting in a more consistent oxidation process, and the C/N ratio declines steadily. In general, the variations in air flow rates used are in accordance with the principles of aerobic composting, where aeration serves as the primary controlling factor in oxygen availability. At low rates, oxygen limitations occur, at medium rates, transition conditions occur, and at high rates, more optimal conditions are achieved. This indicates that aeration rate is an important parameter in improving compost quality, especially in accelerating the reduction of the C/N ratio [13]. Furthermore, the resulting C/N ratio can also be compared with quality standards according to the National Standardization Agency, which states that a good C/N ratio is in the range of 10-20. The decrease in the C/N ratio that occurs during the fermentation process indicates that the goat manure has undergone good decomposition, marked by a reduction in the carbon content as an energy source for microorganisms and a relative increase in the nitrogen content [23].

3.6.2. The effect of oxidation time on fermentation on the C/N ratio based on research

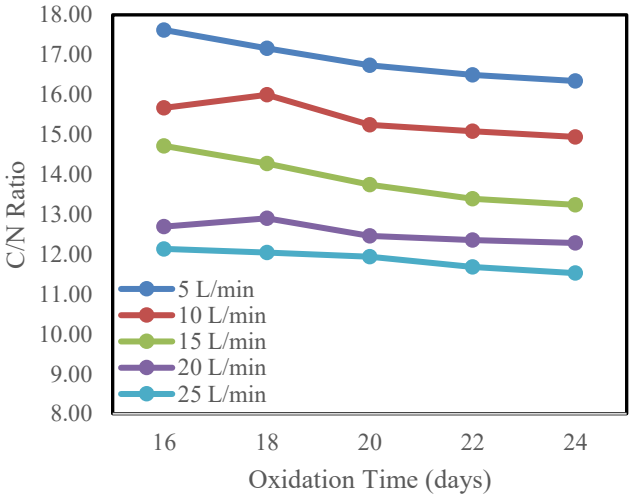

Fig. 8. Relationship between oxidation time and C/N ratio of goats based on research

Fig. 8 shows that, in general, increasing the oxidation time from 16 to 24 days causes a decrease in the C/N ratio across all air flow rate variations. At 16 days, the C/N ratio is still relatively high because the organic matter decomposition process has not yet fully occurred, so carbon is still stored in the form of complex compounds. At this stage, microbial activity is still in its early phase, so the degradation rate is not optimal. As the time increases to around 20 days, the C/N ratio begins to decrease more consistently, indicating that the microorganisms have adapted and the carbon oxidation process is more effective. This is in line with research stating that composting time significantly influences the decrease in the C/N ratio as an indicator of compost maturity [24]. However, at 18 days, fluctuations in the C/N ratio were observed across several air flow rate variations. This condition is thought to occur because microbial activity is in the active phase or transition to the thermophilic phase, where the rate of organic matter degradation increases but is not yet stable. At this stage, an imbalance between carbon degradation and nitrogen transformation can occur, such as a temporary accumulation of nitrogen in microbial biomass. As a result, the C/N ratio may experience a temporary increase before decreasing again. This phenomenon has also been reported in studies showing that process parameters such as aeration and time significantly influence C/N dynamics and fermentation stability [22]. At 22 to 24 days of oxidation, the C/N ratio continued to decline and tended to stabilize. This indicates that the fermentation process has entered the maturation stage, where most of the organic matter has degraded into more stable compounds. Microorganism activity begins to decline as the availability of readily biodegradable substrates decreases, so

changes in the C/N ratio are no longer significant [25]. Furthermore, the resulting C/N ratio can also be compared with quality standards according to the National Standardization Agency, which states that a good C/N ratio is in the range of 10-20. The decrease in the C/N ratio that occurs during the fermentation process indicates that the goat manure has undergone good decomposition, marked by a reduction in the carbon content as an energy source for microorganisms and a relative increase in the nitrogen content [23].

3.7. *Experiment-based water content analysis*

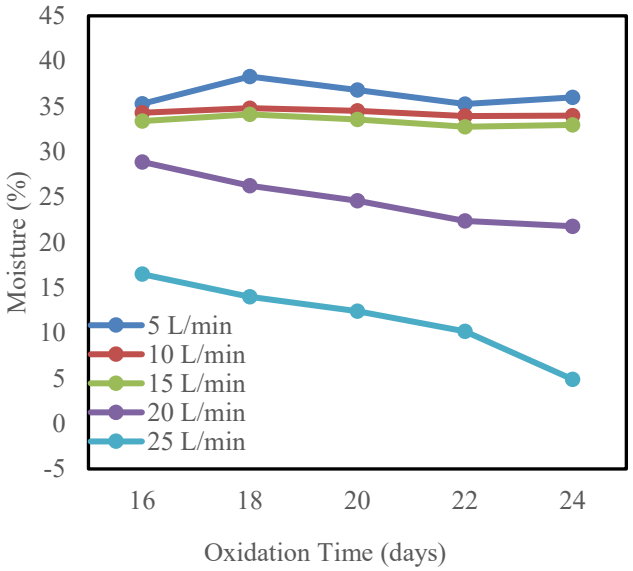

Fig. 9. Relationship between water content and oxidation time based on research

Fig.9 shows that moisture content tends to decrease with increasing oxidation time and air flow rate. At the beginning of the process, on day 16, the moisture content is still relatively high because the water in the material has not evaporated much. Over time, up to around day 20, the moisture content begins to decrease. This occurs because increased microbial activity generates heat, thus accelerating the water evaporation process. Furthermore, aeration also helps remove water vapor from the system. Research shows that moisture content does decrease during the composting process due to a combination of microbial activity and increased temperature, which encourages water evaporation [26]. However, in some conditions, fluctuations in moisture content are still observed, especially at low to medium air flow rates (5–15 L/min), for example on day 18. This may be caused by an imbalance between water production from microbial metabolism and the evaporation rate. During the active phase, microorganisms produce water as a byproduct of decomposition, causing the moisture content to temporarily increase. Furthermore, the uneven distribution of air and heat also causes the evaporation process to occur unevenly. Another study explains that moisture content is greatly influenced by the interaction between aeration, temperature, and biological activity during the fermentation process [27]. At higher air flow rates (20–25 L/min) and longer oxidation times (22–24 days), moisture content decreased more significantly and tended to be stable. This indicates that the evaporation process is more effective because the contact between the air and the material is better and the heat distribution is more even [28]. According to the national standardization agency, the resulting moisture content, which ranges from 4.89% to 38.3%, still meets the specified requirements of a maximum moisture content of 50% [23], but for better quality, the recommended maximum moisture content is 25% [29].

4. Conclusion

Based on the research that has been done, variations in air flow rate and oxidation time have a significant effect on the decrease in C/N ratio and water content in aerobic fermentation of goat manure. The optimum condition was obtained at an air flow rate of 20 L/min and an oxidation time of 22 days with a C/N ratio of 12.4769 and a water content of 23.3309%, which indicates a desirability value of 1. The interaction of the two variables plays an important role in improving the biodegradation process through increasing oxygen transfer and microorganism activity. In addition, the application of Response Surface Methodology (RSM) with a desirability function has been proven effective in determining the optimum conditions simultaneously. This study shows novelty in the integration of air flow rate and oxidation time variables in a controlled aerobic fermentation system.

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