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Original Research Article

Evaluation of Bio-Drying Cow Dung with Inoculation of *Bacillus* sp. as Refuse Derived Fuel (RDF) Material

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Abstract
Global warming, driven in part by livestock manure emissions, poses a major environmental challenge. Refuse Derived Fuel (RDF) offers a waste-to-energy solution by converting solid cow manure into an energy source. This study investigates the impact of *Bacillus* sp. inoculation on the bio-drying process of cow dung. The main challenge in processing cow manure into RDF is ensuring the moisture content and calorific value meet the minimum RDF standards. Therefore, a bio-drying process is carried out on cow manure to achieve these required standards. Bio-drying performance was assessed based on drying time, moisture content, pH, and calorific value. The results show that inoculation with *Bacillus* sp.. at 10^6 log cfu ml^{-1} kg^{-1} yielded the most efficient outcome, achieving the fastest drying time (12 days), lowest moisture content (9.64%), optimal pH (7.8), and highest calorific value (2,656.5 kcal/kg). The findings confirm a direct link between moisture reduction and calorific improvement. Hence, bio-dried cow dung treated with inoculation of *Bacillus* sp. 10^6 log cfu ml^{-1} Kg^{-1} is recommended as a viable RDF material.

Keywords: *Bacillus* sp.; bio-drying; cow dung biomass; RDF; thermophilic bacteria; waste to energy

1. Introduction

Climate change and global warming pose serious challenges to the world. Human driven greenhouse gas emissions, especially from fossil fuels, have increased global temperatures. Global data on energy use that generates CO2 emissions in 2022 reached more than 36,800 MT, an increase of 0.9% compared to 2021 (IEA, 2023). Reflecting on that condition, effective measures are urgently needed to reduce greenhouse gas emissions, especially from sources that produce greenhouse gas emissions. One of the sources of greenhouse gas emissions is organic waste, such as animal manure. Livestock manure is a significant source of methane, contributing primerly to greenhouse gas emissions in agriculture (Cardenas et al., 2021). Livestock waste can be defined as a byproduct of the livestock industry that becomes waste or refuse, which in its nature and concentration contains toxic and hazardous substances, thereby directly or indirectly damaging the environment, disrupting health, and threatening the survival of humans and other organisms (Ning et al., 2021). So far, the management of livestock waste, with a cattle population in Indonesia reaching 18.61 million heads in 2022, still lacks proper and effective governance, leading to frequent environmental pollution, including soil, water, and air pollution

(Ministry of Agriculture of Indonesia, 2022). Dairy cows are the biggest emitter in livestock management, with 4,919.61 tons of CO2-eq/year (Heriyanti et al., 2022).

A method for processing livestock waste, such as that from dairy cows, involves the production of Refuse Derived Fuel (RDF), which utilizes the waste-to-energy (WtE) concept. RDF represents a method of converting waste into energy by treating the waste to achieve a specific calorific value, followed by combustion to harness the resultant heat as an energy source (Chaerul & Wardhani, 2020). The calorific value of dried cow dung at moisture content of 10.98% (dry basis) are 3,434.5 Kcal/Kg (Fajobi et al., 2022). Projections suggest that by 2040, renewable energy sources will account for 8% of the total global energy demand (Rachmawatie, 2024).

The biggest challenge in obtaining RDF from animal manure is achieving the moisture content that meets RDF standards as required by SNI 8966:2021 (Indonesian standard of RDF) regarding solid RDF for power plants, which states that moisture content < 15% for RDF class 1, moisture content < 20% for RDF class 2, and moisture content < 25% for RDF class 3 (Ismawati et al., 2022). Previous research shows that the calorific value of solid fuel produced from cow dung will decrease linearly with the increase in moisture content of the solid fuel (Szymajda & Laska, 2019). The drying technology in the process of producing fuel from animal manure will determine the cost of the RDF. One of the drying technologies is using bio-drying technology. Bio-drying is a vaporization process that uses biological heat obtained from microbial reactions during the decomposition of organic components. The bio-drying process has various benefits, including the ability to reduce the required moisture content, decrease volume, and increase material density through the peffective utilization of biological heat (Bilgin & Tulun, 2015; Cai et al., 2016; Tom et al., 2016). This research focuses on the effects of inoculating thermophilic bacteria (*Bacillus* sp.) at various dosages on the bio-drying of cow dung, particularly in relation to calorific value, moisture content, and drying time.

2. Methods

2.1. Characteristics of Livestock Manure

The sample was obtained via simple random sampling to guarantee representativeness. Simple random sampling is a prevalent technique in quantitative research, renowned for its capacity to yield representative and unbiased samples. This strategy guarantees that each unit in the population has an equal probability of selection, hence ensuring that the findings are statistically valid and generalizable. It reduces selection bias and offers a dependable basis for making inferences about the larger population (Noor et al., 2022). The Fresh cow dung samples were randomly collected from cows in three different pens at RPH Bubulak Bogor, Indonesia, for the initial testing of the characteristics of the cattle manure. The samples collected on 9 october 2024. Three fresh cow dung samples were taken in their pure form without any additives and send to Nature Chemlab Laboratory for checking moisture content, ash content, and organic carbon content. Fresh cow dung was found to have an average moisture content of 68. 84%, an ash content of 6. 39%, and an organic carbon content of 46.09% (dry weight). From various research stated that fresh cattle manure containing moisture content between 60% until 80% (Hossen et al., 2022; Lima & Victor, 2022).

2.2. Experimental

The bio-drying of cow manure is tested using a bioreactor. A bioreactor is a device or system engineered to facilitate biochemical processes that involve biological catalysts, including substrates, enzymes, or living cells. The system offers a regulated environment that allows biocatalysts to perform their designated functions efficiently (Raganati & Procentese, 2022). The bio-reactor used is a reactor tank equipped with stirring blades and a compressor that supplies air into the reactor tank (Xu et al., 2022). The bio-drying reactor employs a combination of physical and biochemical process techniques. The reactor may be constructed as a container that incorporates an aeration system. Bioreactors can be classified as closed containers, open tunnel-hall systems, or rotating drums, based on operational requirements and process design (Velis et al., 2009). The bioreactor used in this study is an open tunnel-hall type, with a height of 46 cm and a diameter of 21 cm, equipped with a 1-phase electric dynamo with a gearbox that constantly rotates the stirring blades at 50 rotation per minute and a 1-phase electric air pump capable of blowing air at 1.5 liters per minute with a pressure of more than 0.02 mpa as shown in Figure 1.

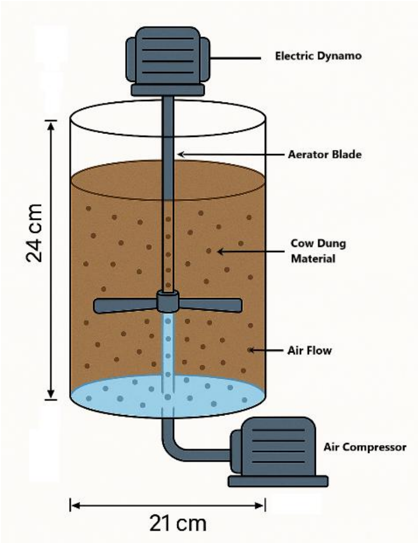


Figure 1. Bio reactor for bio-drying process of livestock manure

2.3. Sample Laboratory Test

Sample results of the cow dung bio-drying process were tested for the moisture content, gross calorific value, and acidity level. The testing of acidity level and moisture content was conducted at the Nature Chemlab laboratory, Bogor, Indonesia. The acidity level was measured using a pH meter. To ascertain moisture content, weigh 20-gram samples as "wet samples" and dry them to a consistent weight using suitable drying apparatus at a temperature that does not exceed 239°F (115°C). Allow the sample to cool after it has dried. Record the "dry weight of the sample" by reweighing the sample after it has chilled. The moisture content is calculated using the subsequent equation (1):

$$W = \frac{A-B}{B} \; x \; 100\% \qquad (1)$$

Where, A denotes the weight of the wet sample in grams, B indicates the weight of the dry sample in grams, and W represents the percentage of moisture in the sample.

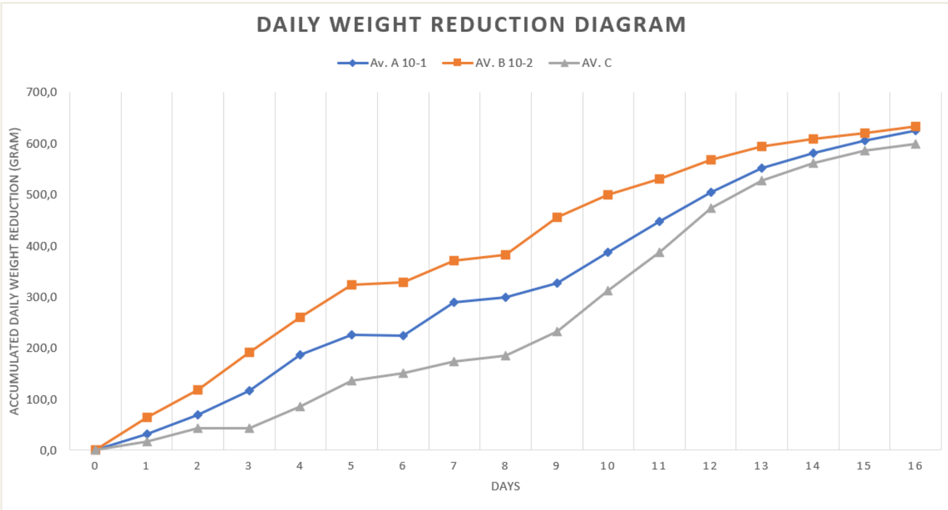
The gross calorific testing was conducted at the Laboratory of Nutrition Science and Feed Technology, IPB University, Indonesia. A digital balance is used to weigh one gram of cow dung. The "Start Pre-Weight" button is used to transmit the reading to the bomb calorimeter, where it is stored alongside the sample name. A small crucible is used to contain the cow dung sample, which is then secured in the designated location under the bomb's cover. Direct contact with the cow dung is guaranteed by cutting a segment of nichrome wire and connecting it to the two ignition rods concealed beneath the cover. The oxygen line is connected to the valve on the bomb's cover, and the entire assembly is meticulously sealed. The "Oxygen Fill" button is pressed, which fills the bomb with oxygen to the specified pressure. The bomb is then precisely positioned within the calorimeter's water jacket, ensuring that it does not contact the stirrer. The "Start" button is pressed, the machine's lid is closed, and electrical leads are attached to the terminals on the bomb cover. The Gross Calorific Value (GCV) is subsequently displayed on the screen after the cow dung sample is ignited by the system.

2.4. Descriptive and Statistical Analysis

The data from the bio-drying process measurements will be statistically tested using one way Analysis of Variance (One-Way ANOVA) by Minitab version 21 software to observe the relationship between the treatment effects on the gross calories produced, the treatment effects on the weight reduction of the cow dung test samples, and the treatment effects on the rate of weight reduction of the test samples. A statistical technique used to compare the means of three or more independent groups based on a single component or independent variable is called One-Way Analysis of Variance (ANOVA). By looking at variance within and across groups, this technique determines if statistically significant variations exist among group means. Additionally, we are examining the link between the dry matter and the gross calories produced utilizing regression analysis using Minitab version 21 software. A statistical technique for modelling and examining relationships between one or more independent variables and one or more dependent variables is regression analysis. This method is mainly utilized for quantitative data to discern patterns, forecast outcomes, and assess the strength of correlations. In addition to conducting statistical analysis on the test data, we also perform descriptive analysis to better understand the effects of treatment on the resulting test parameters. Furthermore, descriptive analysis is used to assess the suitability of cow dung as RDF material by comparing the calorific value and moisture content produced with the minimum RDF quality standards (SNI 8966:2021). The results of the descriptive analysis can be hpresented in the form of cross tabulations, frequency distribution tables, bar charts, line graphs, and pie charts (Sugiyono, 2013).

3. Result and Discussion

3.1. The Relationship Between Treatment and The Weight Reduction of Test Samples



Av. A 10-1 : sample with inoculation *Bacillus* sp. at concentration 10⁷ log cfu ml⁻¹ Kg⁻¹,
Av. B 10-2 : sample with inoculation *Bacillus* sp. at concentration 10⁶ log cfu ml⁻¹ Kg⁻¹,
AV. C : sample control without inoculation *Bacillus* sp.

Figure 2. Accumulated daily weigh reduction of test samples during the process of bio-drying.

From the observation of the daily weight measurements of the samples, the results are presented in Figure 2. As shown in Figure 2, we can see that each treatment shows a tendency for the weight reduction of the test samples to decrease linearly. The average accumulated weight reduction of the samples, in descending order, is as follows: the highest reduction is observed in the treatment with the addition of *Bacillus* sp. at a dilution of 10^{-2} (633.3 gram), followed by the treatment with the addition of *Bacillus* sp. at a dilution of 10^{-1} (625.0 gram), and finally the control treatment without any bacterial addition (598.0 gram). This indicates the metabolic activity of thermophilic bacteria, which generates heat, resulting in the evaporation of moisture from the bioreactor (Sadaka & Ahn, 2012; Yang et al., 2024). The experimental group inoculated with thermophilic bacteria demonstrated a markedly higher moisture removal rate than the non-inoculated group. Additionally, the breakdown of organic matter was significantly accelerated by the presence of thermophilic bacteria (Yang et al., 2024). Once the thermophilic phase (temperature exceeding 50 ◦C) was reached, the degradation of organic matter reached its maximum and the annihilation of pathogens was at its most intense (Zhang et al., 2021). High temperature can increase evaporation rate and can kill pathogens. Zhang et al (2021) also found that the temperature of initial mesophilic phase of compost pile is increasing quickly and lasting some days. Then, compost pile step into thermophilic phase when its temperature more than 50 ◦C, during this phase the maximum degradation of the organic matter occurs together with the destruction of pathogens.

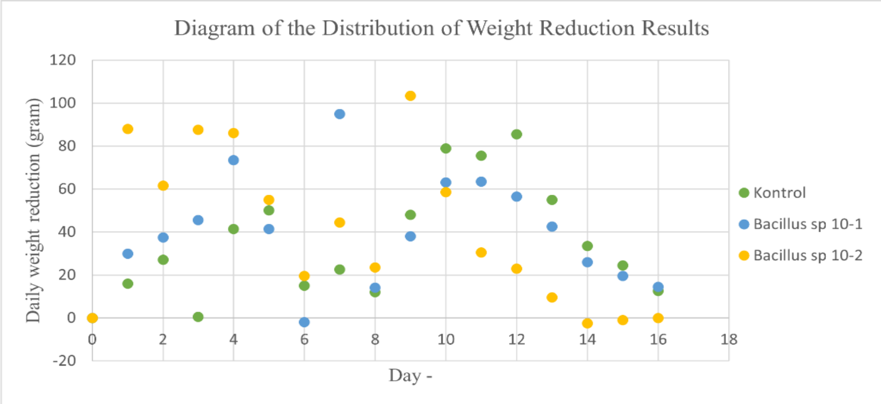


Figure 3. Diagram of the distribution weight reduction of test sample in the bio-drying process.

From Figure 3, we can see the distribution of the daily weight reduction of the samples. Figure 3 shows that the weight reduction of the samples ranges between 0 grams and 120 grams. The weight reduction of test sample shows a significant difference between the first 8 days and the following 8 days of the process of bio-drying. treatment group inoculated with *Bacillus* sp. at a 10^{-2} dilution exhibited the highest average daily weight reduction during the first 8 days, with an average reduction of 58 grams per day. The treatment with *Bacillus* sp. at a 10^{-1} dilution exhibited an average reduction of 42 grams per day, while the control group experienced an average reduction of 23 grams per day. Figure 2 also indicates that inoculating *Bacillus* sp. during the first 8 days of the bio-drying process led to a significantly greater average weight reduction compared to the control. The inclusion of *Bacillus* sp. can enhance the thermophilic phase in the bio-drying process, thus facilitating the weight reduction of the test samples (Cai et al., 2016). The results were reversed during the second 8 days of the bio-drying process, with the control exhibiting a greater average weight reduction than the *Bacillus* sp. inoculated treatment. The highest average daily weight reduction was observed in the control sample, with an average reduction of 52 grams per day, followed by the treatment with *Bacillus* sp. at a dilution of 10^{-1}, with an average reduction of 40 grams per day, and finally the treatment with *Bacillus* sp. at a dilution of 10^{-2}, with an average reduction of 28 grams per day. This is happen because of control sample starting in thermophilic phase for the second 8 days and the other sample with adding *Bacillus* sp. already pass thermophilic phase. This condition make the weight reduction of control sample increasing rapidly in the second 8 days and weight reduction rate on sample with inoculation *Bacillus* sp. become slower than the first 8 days.

From Figure 3, it can be seen that the test sample with the addition of *Bacillus* sp. at a concentration of 10^6 log cfu/ml per Kg cow manure (sample *Bacillus* sp. 10^{-1}) already reached stagnation in weight reduction by day 14 (0 grams weight reduction). This contrasts with the other two treatments, which still showed potential for weight reduction. It can be concluded that the treatment with *Bacillus* sp. at a concentration of 10^6 log cfu/ml per Kg cow manure (sample *Bacillus* sp. 10^{-2}) achieved harvest readiness for the bio-drying process 2 days faster. This treatment offers the added value of faster drying times and a better average daily reduction rate, reaching 39.6 grams per day. This aligns with Xu et al (2022) which found that microorganisms play the most significant role in reducing the moisture content of biogas residue compared to mechanical treatments, with thermophilic bacteria contributing to 78.7% of the total drying of biogas residue. Additionally, the addition of thermophilic bacterial inoculant can quickly reduce moisture content to 9.4% within 12 days in the bio-drying of biogas residue. The inoculation of thermopilic bacterial make the thermophilic phase start faster in bio-drying process. It's make the weight reduction of the sample will be faster than other treatments. Thermophilic bacteria significantly increased the amount of organic matter degradation (Yang et al., 2024). Upon entering the thermophilic phase (temperature above 50 °C), the degradation of organic matter was the greatest and pathogens destruction peaked (Zang et al., 2021). Other research also stated that for normal composting with increasing temperature, the average moisture content decreased rapidly from 59.5% at 0 day to 33.7% at 37 days (Ning et al., 2021). It's mean with the inoculation of *Bacillus* sp. in the bio-drying process make the drying process faster than normal composting.

Table 1. Daily percentage of weight reduction of test samples.

Treatment Code	Days										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Bacillus sp. 10^{-1}	0%	5%	6%	8%	11%	6%	0%	10%	2%	4%	10%
Accumulation	0%	5%	11%	19%	30%	36%	36%	46%	48%	52%	62%
Bacillus sp. 10^{-2}	0%	10%	8%	12%	11%	10%	1%	7%	2%	11%	7%
Accumulation	0%	10%	19%	30%	41%	51%	52%	58%	60%	72%	79%
Control	0%	3%	5%	0%	7%	8%	3%	4%	2%	8%	13%
Accumulation	0%	3%	7%	7%	14%	23%	25%	29%	31%	39%	52%

As shown in Table 1, the total weight reduction of the samples was 50% by the fifth day after the addition of *Bacillus* sp. at a dilution of 10^{-2} to the bio-drying process. This was followed by the treatment with *Bacillus* sp. at a dilution of 10^{-1} by day 9, and finally the control variable by day 10. This indicates that the addition of thermophilic bacteria, specifically *Bacillus* sp. at a concentration of 10^6 log cfu/Kg of fresh cow manure, is able to achieve a significantly higher percentage of weight reduction in the same number of days compared to the control. Xu et al. (2022) demonstrated that incorporating thermophilic bacteria during the drying of biogas residue achieved the greatest moisture reduction relative to the control and alternative treatments. The inoculation of thermophilic bacteria accelerates the thermophilic phase, thus enhancing substrate degradation. During the thermophilic phase, Actinobacteria and Bacillus exhibit dominance, resulting in elevated levels of volatile substrate degradation, water production, and water evaporation. The substantial bio-heat produced by thermophilic microorganisms, in conjunction with the convective circulation generated by mechanical aeration, may be responsible for the high evaporation rate (Cai et al., 2016). Thermophilic inoculation improved quorum sensing and glyoxylate and dicarboxylate metabolism, allowing microorganisms to more effectively adapt to high-temperature environments and release additional energy that aids in water evaporation, as demonstrated by additional metabolic pathway analysis (Yang et al., 2024).

3.1. Feasibility Study of Cow Manure as RDF Material

The gross calorific value, final moisture content, and acidity level of the final test samples from each bio-drying treatment were determined through laboratory testing in this study. Table 2 presents the laboratory test outcomes for each treatment.

Table 2. Lab test results of bio-drying samples for each treatment

Treatment code	pH	Moisture content (%)	Caloric Value (Kkal/Kg)
Bacillus sp. 10^{-1}	6,1	50,01	1.170,0
Bacillus sp. 10^{-2}	7,8	9,64	2.656,5
Control	7,5	20,21	2.189,0

The bio-drying test results on the samples showed that the lowest average moisture content was obtained with he addition of *Bacillus* sp. at concentration of 10^6 log cfu/ml, reaching 9.64%, and the resulting calorific value was 2,656.5 Kcal/Kg. From these bio-drying test results, it can be concluded that pure cow manure is suitable for RDF material. The cow manure bio-drying process result can meet the minimum standard of SNI 8966:2021 for RDF type 3. The minimum standard of SNI 8966:2021 for RDF type 3 is minimum calorific value of 2,388 Kcal per kg, maximum moisture content of 25%, and maximum ash content of 25% Ismawati et al., 2022). Additionally based on the results of the cow manure fuel analysis (Liu et al., 2019; Anwar et al., 2024), it is believed that the fuel that is dried for about 6% is likely to be used as fuel by reaching the legal quality standard of 3,000 Kcal/kg for livestock excretion solid fuel. Bio-drying has proven to be an eco-friendly and efficient technology for reducing moisture content, utilizing metabolic heat generated from the degradation of organic matter in sludge without the need for additional external energy to enhance the drying process (Yang et al., 2024). Livestock manure, such as cow dung, is a promising renewable energy source due to its fuel characteristics, potential ignition difficulties, availability for operation, and viable ash disposal methods (Maj, 2022).

3.2. The Effect of *Bacillus* sp. Addition Treatment on The Moisture Content Produced in The Bio-Drying Process

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
PERLAKUAN	2	2311066	1155533	66.66	0.003
Error	3	52000	17333		
Total	5	2363067			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
131.657	97.80%	96.33%	91.20%

Figure 4. Statistical comparation of moisture content across treatments in bio-drying process.

Based on the statistical analysis results as shown on Figure 4, the effect of the treatment involving the addition of thermophilic bacteria (*Bacillus* sp.) on the resulting moisture content showed a p-value of 0.003, being lower than the significance level (α), indicates that the observed differences are statistically significant. Therefore, it can be concluded that the treatment exerts a statistically significant influence on the resulting moisture content in the bio-drying process. The statistical test data showed an R-sq of 97.80%, meaning that the treatment variable can explain 97.80% of the variability in the moisture content due to the treatment. R-sq represents the proportion of the variance in the dependent variable that is predictable from the independent variables. This statistical analysis also strenghten the previous data in the research which is there's a significant different final moisture content result on each treatment. We can conclude that inoculation of *Bacillus* sp. on bio-drying process can give significant impact on water evaporation of the cow dung. Inoculation of *Bacillus* sp. give better moisture content result in the same time bio-drying process than without inoculation of *Bacillus* sp. This finding aligns with previous studies (Cai et al., 2016; Xu et al., 2022), which indicate that the thermophilic phase is the most intensive water evaporation stage in the bio-drying process. The inoculation of thermophilic bacteria in the bio-drying process enhances moisture evaporation efficiency. Inoculation thermophilic bacteria to sludge can shorten the bio-drying process (Quan et al., 2023; Anwar et al., 2024).

3.3. The Effect of *Bacillus* sp. Addition Treatment on The Final Calorific Value Produced in The Bio-Drying Process

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
PERLAKUAN	2	1753.5	876.73	17.80	0.022
Error	3	147.7	49.24		
Total	5	1901.2			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7.01726	92.23%	87.05%	68.92%

Figure 5. Statistical analysis results of the effect of treatment on the final calorific value produced in the bio- drying process.

The statistical significance of the observed differences is indicated by the p-value of 0.022, which is less than the significance level (α) in Figure 5. The calorific value of the bio-dried material is statistically significantly affected by the treatment, as is evidenced by these results. The data also showed an R-sq of 92.23%, meaning that the treatment variable can explain 92.23% of the variability in the calorific value produced, while only 7.77% of the results cannot be explained by the treatment variable. Our research shows that the highest gross calorific value produced is from the bio-drying of cow manure with the addition of *Bacillus* sp. at a concentration of 10^6 log cfu/ml per kg of cow manure, reaching a calorific value of 2,656 kcal/kg, as shown in Table 2. Bacterial inoculation is responsible for the accelerated temperature rise and extended thermophilic phase, which in turn enhances moisture evaporation during the bio-drying process (Zhou et al., 2023). The calorific value of dried cow manure exhibits a linear decrease with increasing moisture content (Szyamajda & Laska, 2019).

3.4. The Effect of Moisture Content of Cow Manure From The Bio-Drying Process on The Calorific Value Produced

Regression Equation

GROSS KALORI = 2931.8 - 34.81 KADAR AIR

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2931.8	89.8	32.67	0.000	
KADAR AIR	-34.81	2.80	-12.42	0.000	1.00

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2931.8	89.8	32.67	0.000	
KADAR AIR	-34.81	2.80	-12.42	0.000	1.00

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	2303336	2303336	154.25	0.000
KADAR AIR	1	2303336	2303336	154.25	0.000
Error	4	59731	14933		
Total	5	2363067			

Figure 6. Regression analysis results of the effect of moisture content of cow manure from the bio-drying process on the calorific value produced.

The regression analysis was employed by the researchers to investigate the impact of the moisture content of cow dung from the bio-drying test on the calorific value produced. The analysis assesses the correlation between the calorific values derived and the moisture content of treated bio-drying samples. Figure 6 displays the findings of the regression analysis. From the results of the correlation regression analysis of calorific value with the moisture content of cow manure test samples statistically processed using Minitab, shows a p-value of 0.000, being lower than the significance level (α), indicates that the observed differences are statistically significant. Therefore, it can be concluded that the moisture content of cow manure resulting from the bio-drying process significantly affects the calorific value produced. The statistical data indicated that the calorific value is inversely proportional to the moisture content. The calorific value of bio-dried cow dung decreases as the moisture content increases. The regression equation indicated that a 1% increase in the moisture content of bio-dried cow dung results in a decrease of 34.81 kcal per kg in calorific value (Szymajda & Laska, 2019).

4. Conclusions

(1) The research results indicate that inoculating the bio-drying process with thermophilic bacteria (*Bacillus* sp.) significantly influences both the moisture content and the calorific value of the final product. The inoculation of thermophilic bacteria *Bacillus* sp. at a concentration of 10^6 log cfu/ml per kg of pure cow manure resulted in higher moisture reduction and calorific value compared to the control (without bacterial addition). (2) The addition of *Bacillus* sp. at a concentration of 10^6 log cfu/ml per kg of pure cow manure in the bio-drying process produced dried cow manure that meets the standards of SNI 8966:2021 for RDF type 3 material. The dried cow manure from the bio-drying process is suitable as RDF material, providing a new and renewable energy source. (3) The treatment with *Bacillus* sp. at a concentration of 10^6 log cfu/ml per kg of cow manure significantly accelerated the drying process compared to no bacterial addition (12 day drying process). Increased moisture content in cow manure leads to a reduced calorific value. Further research may focus on identifying the optimal dosage of *Bacillus* sp. inoculation get the best bio-drying performance. Additionally, studies could explore the effects of other thermophilic bacterial strains or combinations thereof to enhance the efficiency of the bio-drying process.

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