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Modelling Bioconversion Processes in Hospital Food Waste Management Using Black Soldier Fly Larvae

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ABSTRACT

Food waste is a social problem as it reduces safe, nutritious food, increases contamination risks through improper disposal, attracts pests, promotes harmful bacteria growth, and heightens environmental issues that threaten agricultural productivity. The study's goals are to look into how hospital food waste can be turned into nutrient-rich animal feed and fertiliser by setting standards based on the amount of food waste from inpatients, seeing how different waste treatment methods affect the growth and uptake of nutrients by larvae, and and assess the optimization of bioconversion processes through Structural Equation Modeling (SEM). The data analysis employed Analysis of Variance (ANOVA) and WarpPLS (Warp Partial Least Squares) Path Analysis, using Black Soldier Fly (BSF) as the bioreactor medium. Although the C/N ratio does not meet the standards set by the Indonesian Minister of Agriculture, results show that BSF larvae consuming rice and non-rice waste can serve as alternative raw materials for animal feed and fertilizer. Implementing *Hermetia illucens* or BSF for organic waste management is a creative solution that can reduce methane emissions and contribute to sustainable waste management. Using SEM to convert hospital waste into high-value products and minimize disposal supports sustainable waste management and a circular economy.

1. INTRODUCTION

Hospitals are healthcare institutions that provide comprehensive individual health services, including inpatient, outpatient, and emergency services. The services provided include medical and medical support services, nursing and/or midwifery, as well as non-medical services [1]. In an effort to make hospitals environmentally friendly, waste management is a key aspect that needs to be considered. This corresponds to the sustainable design concepts of eco-friendly hospitals, which emphasise the need to reduce, reuse, recycle, and compost waste [2]. Hospitals, as one of the significant producers of organic waste, have the potential to utilise food scraps or waste produced every day. Food waste not only causes negative impacts on the economy but also has detrimental consequences for the environment and society [3], which is serious if not managed well. Hospitals produce around 20%-30% of food waste, which is estimated to be wasted and not utilized [4, 5]. Nutritional installations are a source of food waste in hospitals [6]. According to research [7], inpatient rice waste generation in hospitals is 36.25%, and it is clear that food waste management in hospitals requires further attention for sustainable development.

Food waste management in hospitals also has significant public health implications. Wasted food generates up to 10% of annual global greenhouse gas emissions, highlighting the environmental impact of food waste [8]. Therefore, implementing prevention models and sustainability systems in hospital waste management, especially food waste, is considered an important step to achieve sustainability goals and support more sustainable food security. Various methods have been explored to recycle this waste, for example, thermophilic anaerobic fermentation is an efficient method for managing organic waste and producing beneficial by-products that are also safe for the environment [9].

Food waste is used in hospitals through a bioconversion process, which involves the use of living organisms such as insects to process waste. The use of insect larvae in this method not only helps with waste management but also allows for simultaneous energy production, making it an effective alternative solution. The use of *Hermetia illucens* (*H. Illucens*) or Black Soldier Fly (BSF) larvae offers a sustainable solution for converting organic waste into high-value products such as animal feed and organic fertiliser [10]. These larvae are effective in reducing waste volumes and converting them into protein-rich biomass, providing significant added nutritional value. The research stands out as it delves into the application of BSF as a bioconversion agent in a hospital setting, a relatively unexplored approach that holds promise for producing high-quality biomass for animal feed and organic fertilizer, thereby significantly enhancing hospital food waste management.

Given the importance of sustainable waste management, research on modelling the bioconversion potential of food waste in hospitals becomes very relevant. An effective model will help optimise the bioconversion process, thereby increasing efficiency and effectiveness in processing food waste. We aim to identify critical factors that influence the bioconversion process and estimate the resulting output, which could be either larval biomass or the quality of the produced fertiliser. Many hospitals face serious problems regarding food waste, highlighting the importance of this research.

This research also addresses the research gap on "Food Lost and Food Waste", addressing the reasons behind food waste, identifying the type of food discarded, quantifying its amount, and devising strategies to prevent, reduce, or avoid it [11]. Therefore, this research can enhance our understanding of food waste management in hospitals, particularly in previously unexplored areas. Within the framework of environmental regulations, the use of BSF as a bioconversion agent is also in accordance with hospital waste management guidelines by the National Environmental Agency (BLH). Combining these aspects, this research has the potential to have a significant positive impact on addressing the problem of food waste in hospitals and contributing to global efforts to achieve sustainable development, especially in the field of environmental science.

2. LITERATURE REVIEW

2.1 Food waste

According to the study [12, 13], waste contributes significantly to environmental impacts globally, representing up to 10% of emissions. Food waste is an increasingly pressing global problem, with the Food and Agriculture Organisation (FAO) estimating it at 1.3 billion metric tonnes, or about a third of the food consumed by humans each year. FAO defines food waste as food that is fit for human consumption and is thrown away, regardless of whether it is stored beyond its expiration date or left to spoil [12]. Any food, including inedible parts, that is removed from the food supply chain, picked up, or thrown away is considered food waste. Every year, according to FAO, Indonesia produces an average of 13 tonnes of food waste [14]. Food loss and waste, commonly known as "food waste", is acknowledged as a global issue because of its significant effects on the environment, society, and economy [11].

Food waste is a social problem because it can impact food security. This relates to the waste of natural resources [15, 16], as well as financial resources [17]. A variety of factors, including social, technological, product-related, legislative, and behavioral factors, influence the production of food waste. According to research conducted by [15, 18], it highlights how context-specific and unpredictable the relevance of these factors is.

The food services sector experiences the highest level of food waste in hospitals, and numerous studies have examined the financial and environmental consequences of this excessive waste. Food waste, which is defined as food that is served to patients but not ingested, accounts for a substantial proportion of approximately 30% and can account for up to 65% of all meals served [19].

2.2 Food waste recovery

The waste hierarchy has become the main framework for waste management and is adopted globally [20]. Finding the solution most likely to produce the best overall environmental impact is the goal of the waste hierarchy. As seen in Figure 1, "prevention" is the most profitable option, and "disposal" is the least profitable option at the base of the inverted pyramid.

This pyramid delineates the optimal approach, commencing with preventive measures and progressing to the reuse of excess food suitable for human consumption, followed by the recovery of food no longer intended for human consumption as animal feed, the recycling or recovery of high-value food molecules (like natural dyes), the recovery of nutrients and energy, and ultimately, the removal of food waste [21]. In that hierarchy, the recovery option is probably the most important before food scraps are thrown away.

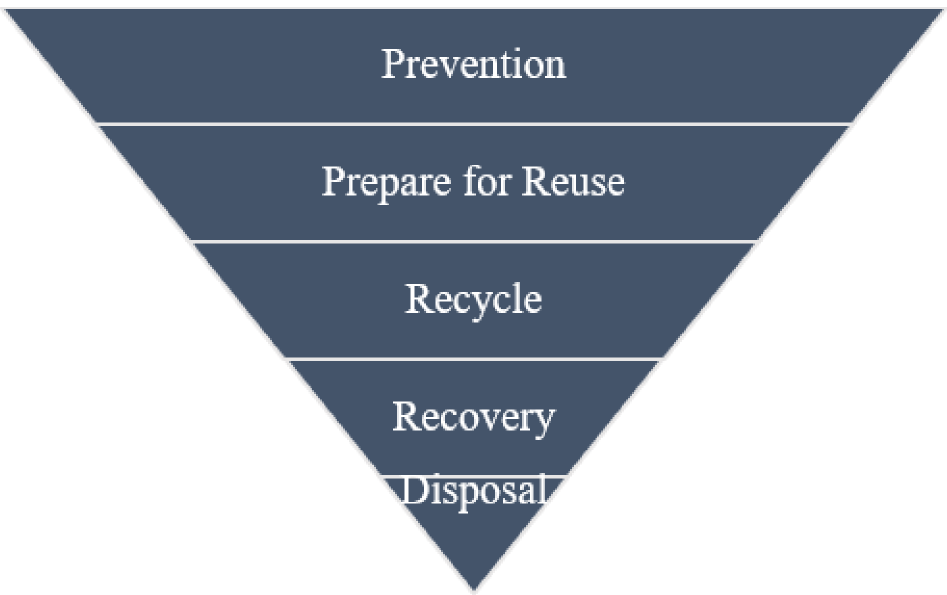

Figure 1. Waste hierarchy

In 2012, the ISEKI Food Association's (FA) Special Interest Group 5 proposed and coined the term "food waste recovery." The phrase refers to the process of recovering valuable compounds from waste by-products and reusing them in the food chain in a concise way. Separation of compounds in food waste-that is, moving from macroscopic to macromolecules and then to micromolecules-is the most significant challenge in food waste utilization. Further clarification is necessary to produce the desired compound or product [22]. Recovery of rice waste through fermentation and distillation produces onggok and bioethanol levels of 80%.

2.3 Hermetia illucens (Black Soldier Fly)

Hermetia illucens (*Black Soldier Fly*/BSF) is believed to originate from the South American savanna. BSF is a diptera that is characterised by a very high growth index and is rich in fat and protein [23]. BSF is often found in tropical, subtropical, and temperate climates [24]. Although H. illucens prevents flies from breeding, it does not damage plants, pollute the environment, infiltrate human residences, or spread disease [25]. Black Soldier Fly (BSF) larvae are saprophages that are efficient at consuming various types of organic waste, such as kitchen scraps and manure. The saprophytic nature of BSF larvae, which has been documented in the fields of entomology and waste management, plays an important role in the waste management process. In the process of decomposing organic waste, larvae can break down dangerous and harmful bacteria, such as Salmonella spp. and *Escherichia coli*, thereby minimizing the negative impact of this waste on the environment [26].

The life cycle consists of the following five stages: egg, larva, pupa, prepupa, and adult. Although the adult and egg-hatching stages are relatively short, the larval and pupal stages contribute maximally to the overall life cycle. A female BSF can produce large numbers of eggs, which hatch into neonate larvae very quickly due to their short lifespan. The fact that they produce eggs near abundant food sources may contribute to their prolific egg production [27].

After the BSF eggs hatch into larvae, these larvae move to the nearest food source that is easy to reach. The larvae will turn into prepupae, the final immature instar, and the feeding process will stop. BSF larvae are a well-known bioconversion agent capable of producing high protein content in their body mass [28]. Their high protein content makes them a valuable protein source that has the potential to replace traditional protein sources in animal feed and fertilizer formulations. Then they become pupae, and they move from food sources to dry crevices. Insects basically contain large amounts of protein and fat. During the pupal phase, the species reaches its maximum size, consisting of 36–48% protein and 33% fat. After 14 days, adult development completes metamorphosis, and then fat content returns to normal, reaching 30.6% in females and 32.2% in males [29].

Humans are able to utilise insect bodies (for food, medicine, or decoration), products (secretions, faeces), behaviour (pollination, parasitism, preying on other organisms), cells, and intracellular activity, structure, and function [24]. *H. illucens* has the ability to convert organic waste into protein and fat. The salivary and intestinal glands of *H. illucens* secrete digestive enzymes, which are much more effective than those secreted by houseflies [30]. Organic waste conversion is strongly influenced by the larval gut microbiome.

3. MATERIAL AND METHODS

3.1 Types of research

This experimental research aims to determine the relationship between food waste from hospital admissions and the use of *H. illucens* as a bioreactor in converting food waste into raw materials for animal feed and fertilizer. All research implementation steps were fully implemented [31]. The following are the stages carried out during the research:

1. A literature study to understand the flow and characteristics of food waste (rice and non-rice) in hospitals. Next, observations were made by counting food waste for eight days, starting with sorting, containerization, and collection by the assistant nurse under the supervision of the head nurse, as well as with the help of cleaning staff in sorting and collecting waste.
2. Food waste collected in the morning and evening is mixed and homogenized based on its characteristics (rice and non-rice waste), followed by several treatments before being used as a food source for *H. illucens*. This treatment includes:
   a. Onggok (OGK) is the leftover fermentation of rice waste
   b. Unfermented rice waste (LNS)
   c. Non-Rice Waste Without Fermentation (LNNS)
   d. Non-Rice Waste Probiotic Fermentation (LNNSF)
   e. Non-Rice Waste and Rice Without Probiotic Fermentation (LM0)
   f. Probiotic Fermentation of Non-Rice Waste and Rice Waste (LM1)
   g. Probiotic Fermentation of Non-Rice and Onggok Waste (LM2)
   h. Non-Rice Waste and Onggok Without Probiotic Fermentation (LM3)

Table 1. Calculation of food waste feed in a box (⅛ g eggs) per 1770 g/12 days

D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12	Unit
30	40	50	60	70	80	100	200	300	310	320	330	gr
1.59	2.12	2.65	3.17	3.7	4.23	5.29	10.58	15.87	16.4	16.93	17.46	%

Note: D: Day; gr: gram
Based on Primary Data (2023)

Table 2. Calculation of food waste feed in a box (⅛ g eggs) per 1890 g/12 days

D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12	Unit
40	50	60	70	80	90	110	210	310	320	330	340	gr
1.99	2.49	2.99	3.48	3.98	4.48	5.47	10.45	15.42	15.92	16.42	16.92	%

Note: D: Day; gr: gram
Based on Primary Data (2023)

Table 3. Calculation of food waste feed in a box (⅛ g eggs) per 2010 g/12 days

D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12	Unit
50	60	70	80	90	100	120	220	320	330	340	350	gr
2.35	2.82	3.29	3.76	4.23	4.69	5.63	10.33	15.02	15.49	15.96	16.43	%

Note: D: Day; gr: gram
Based on Primary Data (2023)

The eight treatments are consumption of *H. illucens* larvae, which are given in three size variants: 1770 g/12 days, 1890 g/12 days, and 2010 g/12 days, as in Table 1, Table 2, and Table 3. Recovery of rice waste through fermentation and distillation produces onggok and bioethanol with a content of 80%. This entire process produces larvae as raw material for animal feed and raw material for fertilizer from the decomposition of food waste.

Modelling the bioconversion potential of food waste in hospitals using path analysis, which involves several latent variables. These variables include food waste with indicators of treatment size, physical H. illucens larvae with indicators of number and weight, animal feed raw materials with indicators of protein, fat, and carbohydrates, and residues used as raw materials for fertiliser with indicators of C/N ratio and weight.

3.2 Data analysis

3.2.1 Homogeneity test

The homogeneity test is conducted in a multivariate manner due to the simultaneous involvement of the dependent variable. The homogeneity test uses Box's M test with a significance level of $\alpha = 0.05$. The decision criteria are defined as follows: if the resulting significance value is greater than 0.05, the variance-covariance matrix in both classes is homogeneous or identical. The homogeneity of variance test is used to ascertain the homogeneity of the samples that have been collected. The dependent variable was subjected to a homogeneous test. Levene SPSS 26 for Windows is employed for conducting this univariate homogeneity test of the treatment group. The decision-making criterion indicates that the variance of the data group is homogeneous if the significance is greater than 0.05.

3.2.2 Normality test

The purpose of this normality test is to ascertain whether the data distribution is a normal distribution. The Kolmogorov-Smirnov test is employed to determine the normality of data, and a significance value (p) of 0.05 or higher is deemed to demonstrate normal distribution (Field, 2009). Furthermore, data will be considered normally distributed if the skewness and kurtosis values fall within the range of -2 to +2 (George & Mallery, 2010). Field (2009) offers an alternative that asserts, “Data can be considered to be nearly normally distributed if the research sample exceeds 30.” In other terms, the population in research can be represented by normally distributed data (Field, 2009). The Kolmogorov-Smirnov test is employed to determine the normality of this data, with the assumption that the data is normally distributed if the Asymp. Sig is greater than 0.05.

3.3.3 Analysis of Variance Test (ANOVA)

We used ANOVA to determine the simultaneous influence of independent variables on the dependent variable. Developing a significant relationship implies that it is applicable to the entire population. Depending on the researcher's preference, we used various significance levels, including 0.01 (1%), 0.05 (5%), and 0.10 (10%). This test evaluated each treatment's impact on black soldier fly larvae's protein, fat, carbohydrate content, and the C/N ratio of manure or leftover feed.

3.3.4 Path Analysis

We use path analysis to examine the relationship between food waste, animal feed raw materials, fertilizer raw materials, and their physical properties. Path analysis uses WarpPLS to generate a structural equation model. The use of WarpPLS involves entering or importing data (for example, from Microsoft Excel), drawing a flow diagram according to the structural model, and analyzing it. In principle, the WarpPLS program package describes a model using pre-existing data from the WarpPLS worksheet and the designed structural model. Typically, the conceptual framework section articulates this structural model.

4. RESULTS

4.1 Animal feed raw materials

4.1.1 Normality test results

Food waste consumed by H. illucens undergoes treatment to become OGK, LNS, LNNS, LNNSF, LM0, LM1, LM2, and LM3. We conducted a distribution of weight measurements of the decomposition and physical residues of H. illucens aged 12 days after consuming the eight food waste treatments. We then carried out a data normality test using the One Sample Kolmogorov-Smirnov Test, the results of which are displayed in the following table:

According to Table 4, the number of live larvae in Asympia is high. Sig 0.076>0.05 indicates a normal data distribution, followed by the weight of one asymp larva. Sig 0.130>0.05 means normal data distribution, and then the weight of all maggots is the asymptote. Sig. 0.200>0.05 means normal data distribution and the Total Residue Weight Asymptote. Sig. 0.200>0.05 means normal data distribution. So that the three data have a normal distribution.

4.1.2 Homogeneity test results

This is done as a precondition for hypothesis testing. Table 5 below displays the results of the homogeneity test.

All data tested showed homogeneous results and the ANOVA test could be continued.

4.1.3 Hypothesis test results

A one-way ANOVA test was carried out to determine whether there is potential for the number of live larvae, the weight of one larva, and the weight of all larvae as an alternative source of raw materials for animal feed. The results of the one-way ANOVA test are presented in Table 6 below.

Table 4. Normality test

	Kolmogorov-Smirnov Test Statistic	Asymp. Sig. (2-tailed)	Keterangan
Number of Live Larvae	0.168	0.076[c]	Normal
Weight of 1 Larva	0.157	0.130[c]	Normal
Weight of All Larvae	0.133	0.200[c,d]	Normal
Total Residue Weight	0.090	0.200[c,d]	Normal

Note: Based on researcher process (2024)

Table 5. Homogeneity test

	Levene Statistic	Sig.	Keterangan
Number of Live Larvae	0.321	0.933	Homogen
Weight of 1 Larva	1.464	0.249	Homogen
Weight of All Larvae	2.211	0.090	Homogen
Total Residue Weight	0.063	0.999	Homogen

Note: Based on researcher process (2024)

Table 6. ANOVA test

	F – value	p - value
Number of Live Larvae	35.738	<0.001
Average Weight of 1 Larva	90.903	<0.001
Weight of All Larvae	45.048	<0.001

Note: Based on researcher process (2024)

Table 7. Results of protein, fat and carbohydrate content tests

	Proteins Assay		General Free Fatty Acid Assay Kit		Carbohydrate Assay	
Sample ID	Average	Stdev	Average	Stdev	Average	Stdev
OGK	0.714	0.01	0.644	0.03	1.009	0.02
LNS	0.775	0.02	0.645	0.02	1.052	0.07
LNNS	0.555	0.02	0.723	0.02	1.082	0.15
LNNSF	0.746	0.02	0.686	0.03	0.533	0.01
LM0	0.694	0.02	0.789	0.01	0.286	0.02
LM1	0.701	0.03	0.731	0.02	0.266	0.03
LM2	0.701	0.02	0.705	0.02	0.321	0.02
LM3	0.591	0.02	0.704	0.01	0.302	0.02

Note: Onggok (OGK); Unfermented rice waste (LNS); Non-Rice Waste
Based on Researcher Process (2024)

Table 8. Normality test

	Protein Level	Fat Level	CarbohydRate Levels
Kolmogorov-Smirnov Test Statistic	0.177	0.105	0.267
Asymp. Sig. (2-Tailed)	0.050[c]	0.200[cd]	0.108[c]
Category	Normal	Normal	Normal

Note: Based on researcher process (2024)

Table 9. Homogeneity test

	Protein Level	Fat Level	Carbohydrate Levels
Levene Statistic	0.310	0.664	5.315
Sig.	0.939	0.699	0.113
Category	Homogen	Homogen	Homogen

Note: Based on researcher process (2024)

Table 10. Protein content test results

	Sum of Squares	df	Mean Square	F - value	p - value
Between Groups	0.117	7	0.017	36.277	<0.001
Within Groups	0.007	16	0.000		
Total	0.124	23			

Based on Table 6 above, it was found that the one-way ANOVA test value of the number of live larvae, the average weight of 1 larva, and the weight of all larvae had a p-value of <0.001, so this parameter was significant. This means that there is potential for larvae to be an alternative source of raw materials for animal feed.

4.2 Test protein, fat, and carbohydrate levels

4.2.1 Average protein, fat and carbohydrate contents

The results of the larval nutritional content test in each treatment can be seen in Table 7 below (levels in terms of absorbance).

Without Fermentation (LNNS); Non-Rice Waste Probiotic Fermentation (LNNSF); Non-Rice Waste and Rice Without Probiotic Fermentation (LM0); Probiotic Fermentation of Non-Rice Waste and Rice Waste (LM1); Probiotic Fermentation of Non-Rice and Onggok Waste (LM2); and Non-Rice Waste and Onggok Without Probiotic Fermentation (LM3).

The Bradford method produces absorbance values, and based on this absorbance, the protein content can be calculated using a linear line from the standard curve for protein content [32]. The LNS treatment had the highest average protein, namely 0.775 with a standard deviation of 0.02. Meanwhile, larvae treated with LNNS had the lowest average protein, 0.555 with Stdev 0.02.

Using the General Free Fatty Acid Assay Kit to measure fat showed that larvae treated with LM0 had the highest average fat content, at 0.789 with a standard deviation of 0.01. Meanwhile, the lowest average fat was for larvae treated with OGK, namely 0.644 with Stdev 0.03.

The results of carbohydrate measurements using the Carbohydrate Assay method showed that larvae treated with LNNS had the highest average fat content, namely 1,082 with a standard deviation of 0.15. Meanwhile, larvae with LM1 treatment had the lowest average fat, 0.266 with Stdev 0.03.

4.2.2 Normality test results

We used the One Sample Kolmogorov-Smirnov Test to test the normality of the data and determine the distribution of protein levels based on the obtained protein levels. Table 8 below presents the results of the data normality test.

According to Table 8, the distribution of data for protein, fat, and carbohydrate levels has asymptote values. The statistical significance values for protein (0.050), fat (0.200), and carbohydrates (0.108) are all greater than 0.05, indicating a normal distribution of the data.

4.2.3 Homogeneity test results

This is done as a precondition for hypothesis testing Table 9 below displays the results of the homogeneity test.

Based on Table 9's analysis, it was determined that the data for protein and carbohydrate levels showed homogeneous group variance. This is based on a significance value (Sig) > 0.05, with the Sig for protein content being 0.939, the Sig for fat content being 0.699, and the Sig for carbohydrate content being 0.113. This condition shows that the variability in each group is consistent for all variables tested.

4.2.4 Hypothesis test results

One-way ANOVA test was carried out to determine whether there is potential for protein levels as an alternative source of raw materials for animal feed. One-way ANOVA test results in Table 10 - Table 12 below.

Based on the three tables above, it was found that the One-way ANOVA test value with a p - value of <0.001 (p<0.05) means that there is potential for protein, fat and carbohydrate levels to serve as alternative raw materials for animal feed. Because the results obtained show meaningful or significant potential.

4.3 Alternative sources of fertilizer raw materials

4.3.1 Average testing C/N ratio

The C/N ratio is the ratio of carbon mass to nitrogen mass in cash. A high C/N (>25) indicates that the decomposition process is slow. A good fertilizer that meets the requirements should have a low C/N ratio. The analytical methods used are redox titration and specttrophotometry with NaOH and Khjeldal Nessler reagents. The following are the results of the C/N ratio test for giving food waste to inpatients.

Table 11. Fat content test results

	Sum of Squares	df	Mean Square	F - value	p - value
Between Groups	0.047	7	0.007	16.929	<0.001
Within Groups	0.006	16	0.000		
Total	0.054	23			

Table 12. Carbohydrate content test results

	Sum of Squares	df	Mean Square	F - value	p - value
Between Groups	2.956	7	0.422	104.922	<0.001
Within Groups	0.064	16	0.004		
Total	3.020	23			

Table 13. C/N Ratio test results

Code	C/N Ratio	
	Average	Stdev
OGK (Onggok)	110.51	2.85
LNS (Unfermented rice waste)	84.33	1.85
LNNS (Non-Rice Waste Without Fermentation)	50.51	0.80
LNNSF (Non-Rice Waste Probiotic Fermentation)	54.80	0.50
LM0 (Non-Rice Waste and Rice Without Probiotic Fermentation)	59.21	1.61
LM1 (Probiotic Fermentation of Non-Rice Waste and Rice Waste)	127.09	2.47
LM2 (Probiotic Fermentation of Non-Rice and Onggok Waste)	108.81	1.95
LM3 (Non-Rice Waste and Onggok Without Probiotic Fermentation)	52.66	0.88

Note: Based on researcher process (2024)

Table 14. Normality test

	C/N Ratio
Kolmogorov-Smirnov Test Statistic	0.251
Asymp. Sig. (2-tailed)	0.375 c
Category	Normal

Noted: Based on Researcher Process (2024)

Table 15. Homogeneity test

	C/N Ratio
Levene Statistic	1.549
Sig.	0.211
Category	Homogen

Noted: Based on researcher process (2024)

Table 16. C/N ratio test

	Sum of Squares	df	Mean Square	F - value	p - value
Between Groups	20020.741	7	2860.106	890.243	<0.001
Within Groups	51.404	16	3.213		
Total	20072.144	23			

Noted: Based on Researcher Process (2024)

According to the measurements using the C/N ratio in Table 13, the best decomposition residues as an alternative source of fertilizer raw materials were those that received LNNS treatment because they had the lowest average C/N ratio value, namely 50.51. while the LM1 treatment had the lowest average C/N ratio value, namely 127.09.

4.3.2 Normality test results

Based on the obtained C/N ratio results, we conducted a data normality test using the One Sample Kolmogorov-Smirnov Test to determine the distribution of carbon mass to nitrogen mass ratio levels. The results of the data normality test can be seen in Table 14 below.

This table shows that the Asymp. Sig. 0.375 is greater than 0.05 at the ratio of carbon mass to nitrogen mass. which means that data is distributed normally.

4.3.3 Homogeneity test results

This is done as a precondition for hypothesis testing. Table 15 below displays the results of the homogeneity test.

According to this table, the ratio of carbon mass to nitrogen mass is Sig 0.211>0.05. This indicates that the group variance of the data is either the same or homogeneous.

4.3.4 Hypothesis test results

A one-way ANOVA test was conducted to determine whether the C/N ratio has potential as an alternative source of fertilizer raw materials. One-way ANOVA test results are as follows.

The one-way ANOVA test value in Table 16 with a p-vvalue of <0.001 (p<0.05) shows that the C/N ratio could be used as an alternative source of fertiliser raw materials. The obtained results indicate a significant and meaningful potential.

4.4 Path analysis

A structural equation model of the connection between food waste, animal feed raw materials, fertiliser raw materials, and the physical traits of *H. illucens* larvae is shown below in Figure 2.

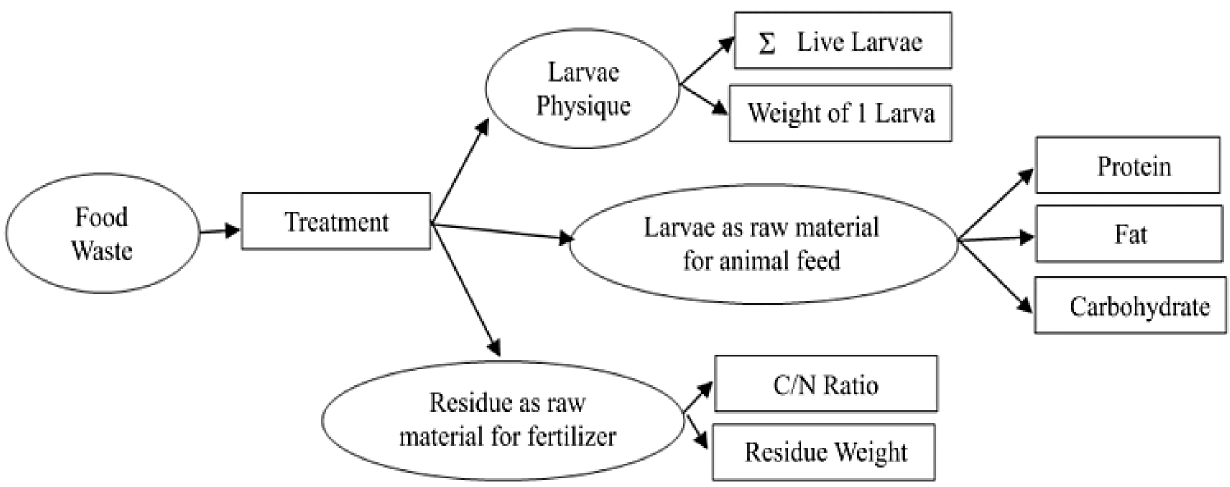

Figure 2. Structural equation model

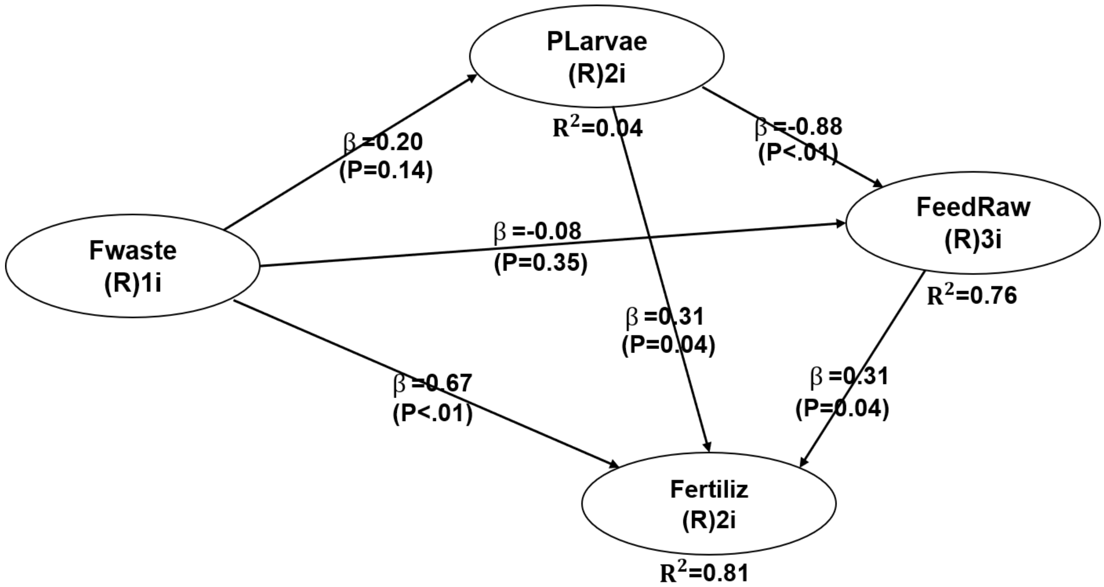

Figure 3. Path analysis model

Next, the model is created using path analysis, which produces the following (Figure 3).

The general results of the PLS Path Warp analysis are as follows:

a. Average path coefficient (APC)=0.408, P=0.005;

b. Average R-squared (ARS)=0.538, P<0.001;

c. Average adjusted R-squared (AARS)=0.507, P<0.001;

d. Average block VIF (AVIF)=1.127, acceptable if <= 5, ideally <= 3.3;

e. Average full collinearity VIF (AFVIF)=2.486, acceptable if <= 5, ideally <= 3.3;

f. Tenenhaus GoF (GoF)=0.610, small >= 0.1, medium >= 0.25, large >= 0.36;

g. Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1;

h. R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1;

i. Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7;

j. Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7.

A detailed explanation of each matrix is as follows:

a. Average Path Coefficient (APC)

It is the average of the model's path coefficients. The strength and direction of the relationship between the variables in the model are indicated by the path coefficients. The APC value of 0.408 indicates that the model's average path coefficient is around 0.408. A P value of 0.005 indicates that the APC is statistically significant (a low P value indicates statistical significance).

b. Average R-squared (ARS)

The model calculates the average of the coefficient of determination (R-squared). R-squared shows how well the independent variable explains the variation in the dependent variable. The ARS value of 0.538 indicates that the dependent variable's average percentage of variation is explained by the independent variables in the model. A P value < 0.001 indicates that the ARS is statistically significant.

c. Average Adjusted R-squared (AARS)

The model calculates the average of the adjusted coefficient of determination, also known as adjusted R-squared. AARS takes into account the number of independent variables in the model and provides a more conservative estimate of how well the model fits the data. The AARS value of 0.507 indicates the average percentage of variation in the dependent variable that is explained by the independent variables in the model after taking into account the number of independent variables in the model. A P value < 0.001 indicates that the AARS is statistically significant.

d. Average Block VIF (AVIF)

We calculate the average of the Variance Inflation Factor (VIF) in blocks of independent variables. VIF is used to detect multicollinearity between independent variables. An AVIF value of 1.127 indicates that the average VIF in the independent variable block is around 1.127. Values lower than 3.3 indicate ideality and no significant multicollinearity.

e. Average Full Collinearity VIF (AFVIF)

The model calculates the average of the VIFs. An AFVIF value of 2.486 indicates that the model's average VIF is approximately 2.486. Values less than 3.3 indicate ideality and no significant multicollinearity in the model.

f. Tenenhaus GoF (Goodness of Fit) (GoF)

This is a measure that indicates how well the model fits the data. A GoF value of 0.610 indicates that the model is very good at predicting or explaining the data.

g. Sympson's Paradox Ratio (SPR)

The ratio is used to measure the degree of Simpson's paradox effect. An SPR value of 1,000 indicates that the model is ideal and acceptable, and there is no Simpson's paradox effect.

h. R-squared Contribution Ratio (RSCR)

This is a ratio that quantifies the contribution of each independent variable's coefficient of determination (R-squared) to the dependent variable. An RSCR value of 1,000 indicates ideal or acceptable, and each independent variable makes a significant contribution to the variability in the dependent variable.

i. Statistical Suppression Ratio (SSR)

The SSR value is a ratio that quantifies the impact of statistical suppression within the model. An SSR value of 1.000 indicates that there is no statistically significant suppression effect in the model.

j. The Nonlinear Bivariate Causality Direction Ratio (NLBCDR)

This is a ratio that measures how well the model can determine the direction of nonlinear bivariate causality. An NLBCDR value of 1,000 indicates that it is acceptable and that the model is able to determine the direction of nonlinear bivariate causality well.

5. DISCUSSION

The utilization of Black Soldier Fly (BSF) larvae, *Hermetia illucens*, in the bioconversion of hospital food waste into valuable byproducts such as animal feed and organic fertilizer illustrates an innovative approach to managing organic waste in a sustainable manner. The effectiveness of BSF larvae in converting waste while ensuring that the output materials are of high nutritional quality makes this method particularly appealing for both waste reduction and resource recovery.

5.1 Bioconversion efficiency and waste management in hospitals: Utilizing black soldier fly larvae

The integration of Black Soldier Fly (BSF) larvae, *Hermetia illucens*, into the waste management systems of hospitals marks a significant advancement in handling organic waste efficiently and sustainably. BSF larvae can very quickly convert fresh organic matter into compost and biomass rich in protein and fat [33]. Hospitals, significant producers of organic waste, traditionally rely on methods like incineration or landfilling, which are not only environmentally detrimental due to emissions of greenhouse gases such as methane but also costly in terms of waste processing and disposal. The utilization of BSF larvae offers a sustainable alternative by bioconverting organic waste into valuable byproducts, thereby reducing the volume and environmental impact of waste significantly [34].

BSF larvae are exceptionally proficient at consuming various organic substrates, including the diverse array of food scraps generated in hospital settings. Their capability to reduce waste volume by up to 70% in a matter of days not only decreases the physical footprint required for waste storage but also reduces the frequency and cost associated with traditional waste disposal methods [35]. Additionally, optimizing the environmental parameters such as temperature, humidity, and the carbon-to-nitrogen ratio in the waste feed is crucial. These parameters directly influence the larvae’s growth and waste processing efficiency, thereby ensuring the process’s effectiveness and the consistency of the output quality.

The byproducts of the larval bioconversion process, specifically the larval biomass and the frass (excreta), present further sustainable opportunities. The high protein and fat content of the larval biomass make it a viable substitute for traditional animal feed, whereas the nutrient-rich frass serves as an excellent organic fertilizer. Both byproducts can be utilized to support on-site hospital green spaces or sold externally to generate revenue, thus supporting the economic sustainability of the waste management system and promoting a circular economy approach [36].

The application of BSF larvae in hospital waste management systems not only mitigates the challenges associated with organic waste but also aligns with global sustainability objectives. The innovative approach mentioned transforms waste management within the healthcare industry from being a logistical and financial burden into an environmentally and economically beneficial model. This transformation offers a scalable and effective solution that can be widely adopted across the healthcare sector. By implementing sustainable waste management practices, healthcare facilities can not only reduce the negative environmental impact of waste but also create economic value from waste streams, contributing to a circular economy approach [37].

5.2 Nutritional analysis of larval biomass in bioconversion processes

The use of Black Soldier Fly (BSF) larvae, *Hermetia illucens*, for bioconversion of organic waste in hospitals presents a sustainable avenue for producing high-value nutritional outputs. Significant in this context is the larval biomass, which has been identified as a rich source of proteins, fats, and carbohydrates. The protein content of BSF larvae, particularly, has garnered attention for its potential to substitute traditional feed ingredients in animal nutrition. According to a study by Barragan-Fonseca et al. [38], BSF larvae can contain protein levels ranging from 35% to 50% of dry weight, depending on the diet they are fed. This high protein content is essential for the nutrition of various livestock species and can significantly reduce reliance on conventional sources such as soybean meal and fishmeal, which are environmentally intensive in production.

The lipid profile of BSF larvae is also noteworthy. These larvae accumulate fats ranging from 15% to 25% of their dry weight, with a composition rich in lauric acid, a medium-chain fatty acid known for its antimicrobial properties [39]. This characteristic makes BSF-derived lipids particularly valuable for enhancing the health and growth rates of poultry and swine, which benefit from lauric acid’s health-promoting effects. Furthermore, the carbohydrates present in BSF larvae, although in smaller quantities compared to proteins and fats, provide a necessary energy source that can be utilized in feed formulations, adding to the overall caloric content of the feed.

The ability of BSF larvae to convert hospital waste into such nutrient-rich biomass not only underscores their role in sustainable waste management but also highlights their contribution to creating a circular economy. This aligns with global sustainability targets by reducing waste, lowering greenhouse gas emissions from traditional waste disposal methods, and providing an eco-friendly alternative to feed production [40]. As the pressures on conventional feed resources continue to rise, BSF larvae offer a promising solution that supports environmental sustainability while providing economic benefits

5.3 Advanced modeling and optimization of bioconversion processes in hospital waste management

The integration of Structural Equation Modeling (SEM) in hospital waste management exemplifies the effectiveness of modeling and optimization in enhancing waste conversion processes, particularly using Black Soldier Fly (BSF) larvae. This innovative approach focuses on transforming hospital waste into valuable raw materials for animal feed and organic fertilizers [41], industrial insect rearing that efficiently converts food waste into valuable products, including animal feed and fertilizers. It emphasizes the circular economy concept and the transformation of waste into valuable resources, which aligns with the innovative approach of utilizing hospital waste for animal feed and organic fertilizers. Emphasizing the crucial role of SEM in analyzing the effects of various waste treatment conditions on larval growth and nutrient profiles.

Employing SEM, the study meticulously models the interaction between pre-treatment conditions and their subsequent impacts on larval metrics, such as protein, lipid, and carbohydrate levels. Initial stages involve rigorous validation of the measurement model to ensure accurate representation of variables related to waste treatment and larval growth, followed by structural analysis using SmartPLS. This software is noted for its capability to manage complex models effectively, particularly beneficial in settings with smaller sample sizes, providing reliable and detailed path analysis [42]. The path analysis reveals significant coefficients linking waste treatment types to improved larval growth and nutrient absorption, indicating that certain pre-treatment methods markedly enhance larval development and nutrient uptake.

The results of the SEM demonstrate robust goodness-of-fit indices, such as the Comparative Fit Index (CFI) exceeding 0.95 and the Root Mean Square Error of Approximation (RMSEA) below 0.07. These metrics confirm the model's capability to accurately capture the observed data's variance, substantiating the hypothesis that specific waste treatment protocols can significantly boost the bioconversion efficiency of hospital waste into viable byproducts [43]. Beyond technical modeling, the research aligns with broader environmental sustainability goals, advocating for the reduction of waste volumes and the conversion of organic waste into useful byproducts [44]. This not only supports the circular economy in healthcare facilities but also promotes the sustainable management of resources.

Moreover, the selection and optimization of animal feed raw materials are pivotal for ensuring the nutritional quality and safety of feed within hospital settings. Studies like those by Ye et al. [45], emphasize the molecular adaptability of Bacillus species, which significantly enhance feed production through their physiological characteristics. This aligns with the observations of De Smet et al. [46], who note the adaptability of Black Soldier Fly larvae to different food substrates, enhancing nutrient absorption vital for effective feeding strategies that bolster animal health.

The utilization of homogeneity tests, as discussed by Pantelić et al. [47], ensures that data across different treatment groups remains consistent, facilitating reliable conclusions from statistical analyses like one-way ANOVA. It aligns with the utilization of homogeneity tests to ensure data consistency, which is crucial for drawing reliable conclusions from statistical analyses like one-way ANOVA. These tests are crucial in validating that enhancements in feed formulations are genuinely effective in promoting animal growth and productivity.

This comprehensive approach not only highlights the utility of advanced statistical models in waste management but also underscores the critical nature of sustainable practices within healthcare settings. By exploring the relationships between waste treatment and larval growth through SEM, this research offers a methodologically sound framework for future studies aiming to optimize resource utilization and transform waste into economically valuable products. Such endeavors are instrumental in advancing ecological engineering, particularly in the context of optimizing animal feed production and enhancing the sustainability of hospital operations.

5.4 The potential for bioconversion of food waste into fertiliser raw materials is significant

The potential for bioconversion of inpatient food waste as an alternative source of fertiliser raw materials is an interesting research topic in the context of waste management and sustainability. This research includes a description of food waste, bioconversion processes, nutritional analysis, environmental benefits, process efficiency, and impacts on the environment. Over the course of 12 days, testing the C/N ratio on different decomposing residues of *H. illucens* larvae showed different results depending on the type of feed used. Non-rice waste that had been fermented with probiotics had the highest C/N ratio. A high C/N ratio tends to slow down the decomposition process, impacting nutrient release and the overall decomposition rate [48, 49]. The conclusion from laboratory tests shows that the overall decomposition residue does not meet the requirements because the C/N ratio value is above the standard of the Regulation of the Minister of Agriculture of the Republic of Indonesia.

6. CONCLUSION

- Researchers explored the use of Black Soldier Fly (BSF) larvae to convert hospital food waste into valuable animal feed and organic fertilizer.
- A systematic approach using Structural Equation Modeling (SEM) was found to enhance the bioconversion process.
- Different waste treatment methods significantly affect the growth and nutrient uptake of larvae, with pre-treatment methods improving bioconversion efficiency.
- Rigorous statistical tests, including ANOVA and path analysis, helped identify the best protocols for waste reduction and nutrient recovery.
- Strong model fit indices (CFI > 0.95 and RMSEA < 0.07) confirm the effectiveness of the protocols.
- Integrating BSF larvae into hospital waste management aligns with ecological and operational standards and promotes sustainable waste management and a circular economy.
- Hospital cleaning services and room heads play crucial roles in maintaining standards and meeting legal requirements for Eco Hospital establishment.
- The use of BSF larvae, *Hermetia illucens*, presents a sustainable opportunity to produce high-value food products through bioconversion.
- Techniques like fermentation and distillation to produce onggok (OGK) and 80% bioethanol enhance the nutritional value and utility of waste.
- Fermenting a mixture of OGK and non-rice food waste using probiotics (LM2) is optimal for producing high-value protein.
- The bioconversion process produces residue suitable for fertilizer, though adjustments are needed to meet the C/N ratio standards set by the Indonesian Minister of Agriculture.
- SEM application in this context highlights the effectiveness of modeling and optimization techniques in waste management.

This research supports sustainable waste management in healthcare facilities, contributes to eco-hospital development, and promotes environmental and economic sustainability.

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NOMENCLATURE

D	Carbon to Nitrogen Ratio
α	Day
Sig	Significance Level
gr	Significance Level (g)
p	Gram
β	Probability value
LM0	Coefficient
LM1	Non-Rice Waste and Rice Without Probiotic Fermentation
LM2	Probiotic Fermentation of Non-Rice Waste and Rice Waste
LM3	Probiotic Fermentation of Non-Rice and Onggok Waste
LNNS	Non-Rice Waste and Onggok Without Probiotic Fermentation
LNNSF	Non-Rice Waste Without Fermentation
LNS	Non-Rice Waste Probiotic Fermentation
OGK	Unfermented Rice Waste