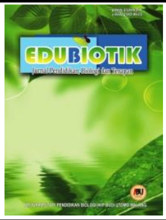
Edubiotik : Jurnal Pendidikan, Biologi dan Terapan
ISSN 2528-679X (print), ISSN 2597-9833 (online)
Vol. 8, No. 02, September 2023, pp. 89 – 105

Available online at:
http://ejurnal.budiutomomalang.ac.id/index.php/edubiotik



Research Article

OPEN ACCESS

Bacteria *Pseudomonas taiwanensis* as a decomposing agent of peat fiber

Elrich Gratiawan WD Gulo [1,a], Dewi Amalia [1,b,*], Lindung Zalbuin Mase [2,c], Faisal Estu Yulianto [3,d], Yusmiati Kusuma [1,e], Ery Radya Juarti [1,f], Agus Suyono [1,g]

[1] Department of Civil Engineering, Politeknik Negeri Bandung, Bandung Barat, Indonesia
[2] Department of Civil Engineering, Universitas Bengkulu, Bengkulu, Indonesia
[3] Department of Civil Engineering, Universitas Madura, Pamekasan, Indonesia
Email: elrich.gratiawan.mtri22@polban.ac.id [a], dewi.amalia@polban.ac.id [b,*], lmase@unib.ac.id [c], faisal.estu@unira.ac.id [d], metty@polban.ac.id [e], ery.radya.juarti@polban.ac.id [f], asuyono349@gmail.com [g]
* Corresponding author

Article Information
Submitted: 2023-08-30
Accepted: 2023-12-18
Published: 2023-12-31

ABSTRACT

Efforts are needed to accelerate the decomposition of peat fiber to reduce the fiber content through bioaugmentation using *Pseudomonas taiwanensis* bacteria so that it can reduce the high-water content of peat fiber. The research aimed to determine the effect of adding *Pseudomonas taiwanensis* bacteria on the decomposition of peat fiber. This research is a laboratory experimental research. The research sampling location was in Bereng Bengkel Village, Palangkaraya. The parameters observed included fiber content, fiber size distribution, and peat fiber decomposition speed following the Peat Testing Manual. The research instrument was an observation sheet for fiber content, size distribution, and peat fiber decomposition speed. Research data was analyzed using descriptive statistical analysis. The results showed that adding 15% *Pseudomonas taiwanensis* bacteria with a curing period of 28 days in fibrous peat resulted in the highest reduction in fiber content, from the initial condition of 61.14% to 12.33%. This variation also shows a decrease in coarse and medium fiber content and a significant increase in fine fiber content. The decomposition rate for this variation shows good consistency. The conclusion was that adding 15% *Pseudomonas taiwanensis* bacteria with a curing period of 28 days showed optimal results in accelerating the decomposition of peat fiber through the bioaugmentation method.

Keywords: Decomposition, fibrous peat, *Pseudomonas taiwanensis*

Publisher
Biology Education Department
IKIP Budi Utomo, Malang, Indonesia

How to Cite
Gulo, E. G. WD., Amalia, D., Mase, L. Z., Yulianto, F. E., Kusuma, Y., Juarti, E. R., & Suyono, A. (2023). Bacteria *Pseudomonas taiwanensis* as a decomposing agent of peat fiber. *Edubiotik : Jurnal Pendidikan, Biologi Dan Terapan, 8*(02), 89-105. https://doi.org/10.33503/ebio.v8i02.3539

INTRODUCTION

Indonesia has the largest peatland area in the tropics, especially on the islands of Sumatra, Kalimantan, and Papua (Palamba et al., 2018). Indonesia's peatland area is estimated at 21 million hectares, which covers 70% of the total peatland area in Southeast Asia and 50% of the total tropical peatland area in the world (Bay et al., 2021). Peat is formed from plant remains such as leaves, twigs, and roots that have not been completely decomposed in a flooded environment (Darma et al., 2022; Hu et al., 2011). This long decomposition process is caused by the high water content in peat which creates an anaerobic environment (without oxygen) so that the decomposition process by microbes is inhibited (Takada et al., 2016). Therefore, peat has a high organic content as a result of plant decomposition (Santi et al., 2022). Peat has a blackish-brown color in almost all soil layers as a result of organic matter decomposition (Devangsari et al., 2022; Hikmatullah & Sukarman, 2014). Peat in Indonesia tends to have a high fiber content (Mochtar & Yulianto, 2014). Therefore, peat in Indonesia is referred to as fibrous peat (Li et al., 2022).

Fibrous peat is a problematic soil in the civil construction sector because it has a very high water content that causes its compressibility index to be very high. A very high compressibility index harms buildings built on fibrous peat as it is very sensitive to settlement which can cause damage (Wahab et al., 2020; Zebua, 2022). Therefore, fibrous peat is considered disadvantageous in infrastructure construction because it is not capable of supporting the infrastructure building foundation (Pradana & Rohmah, 2018). Meanwhile, the need for residential land and transportation facilities is increasing with the times. However, the availability of suitable land for infrastructure development is limited (Ramdhan, 2018). This situation often occurs, especially on the islands of Sumatra, Kalimantan, and Papua, which have a significant distribution of peatlands (Palamba et al., 2018). Therefore, infrastructure development on peatlands is often unavoidable (Waruwu et al., 2020). In the past, construction work on peatlands was often done by replacing the subgrade with sand or better-quality soil (Saida et al., 2023). However, natural resources are limited to fulfill the replacement of subgrade in every infrastructure construction work on peatlands (Ismail et al., 2017). Therefore, in overcoming the problem of fibrous peat in infrastructure construction in Indonesia, an appropriate alternative is needed to improve the geotechnical properties of fibrous peat.

In general, fibrous peat has a very high water content (Kolay & Taib, 2018). The water content of peat soil can reach 600%, which means that fibrous peat can absorb water 5-6 times its dry weight (Stevani & Makarim, 2021). The high water content in fibrous peat is caused by the high fiber content in the peat. Peat fibers cause peat to have two types of pores, which are micropores and macropores (Mochtar & Yulianto, 2014). Macropores are the pores between the soil grains and peat fibers, while micropores are the pores inside the peat fibers (Rismantojo & Ningsih, 2021). Both types of pores can absorb and store large amounts of water so that fibrous peat is always in a saturated condition (Yulianto et al., 2022). In addition, the overall peat fiber affects most of the behavior of fibrous peat, such as high compressibility index and low shear strength values (Gofar & Sutejo, 2007; Johari et al., 2016). Therefore, to improve the geotechnical properties of fibrous peat, it is necessary to accelerate the peat fiber decomposition process to reduce the fiber content. Accelerating the peat fiber decomposition process is intended to reduce the peat fiber content, which is the main cause of the high water content in fibrous peat. Once the peat fibers are successfully decomposed, the fibrous peat will become denser and stiffer, resulting in improved geotechnical properties (Ma'ruf et al., 2022).

Efforts to accelerate the decomposition process of peat fibers in Indonesia are still very limited. Based on the results of the literature, it was found that there were only two related studies that accelerated peat fiber decomposition through the bioaugmentation method (Prativi et al., 2018; Yogyanta et al., 2019). Bioaugmentation is the process of adding microorganisms such as bacteria, fungi, or algae into an environment to increase the degradation or decomposition of certain pollutants (Medaura et al., 2021). However, in the research (Prativi et al., 2018; Yogyanta et al., 2019) there was a misconception that was thought to be the cause of the lack of maximum acceleration of the peat fiber decomposition process so that the geotechnical properties of fibrous peat did not experience a significant increase. The misconception is the addition of more than one species of microbial decomposer to the fibrous peat, resulting in competition between microbial species for nutrients (Bauer et al., 2018; Hibbing et al., 2010). This competition can lead to the death of certain microbial species, thus not optimizing expected biological processes such as decomposition (Kumar et al., 2022). Therefore, in the practice of accelerating peat fiber decomposition, it is better to use only one microbial species.

The bacteria that have the potential to decompose naturally can be isolated from the media itself (Fidiastuti & Susantini, 2017). Previous research reported that there are several species of indigenous lignocellulolytic bacteria found in fibrous peat that can decompose peat fibers (Zulaika et al., 2022). This group of bacteria is known as indigenous lignocellulolytic bacteria because, in the metabolic process, these bacteria produce cellulase enzymes that can break down cellulose compounds which are the main constituents of plant tissues such as peat fibers. Of the several types of bacteria that have been isolated, it is known that *Pseudomonas taiwanensis* has the highest decomposition ability compared to other bacterial isolates. *Pseudomonas taiwanensis* is a rod-shaped, gram-negative, motile bacterium, with one or three polar flagella, does not form spores, rounded rod ends, and has a size of about 2.7-2.2 μm (Wang et al., 2010). In addition, *Pseudomonas taiwanensis* bacteria can survive in very extreme environments such as peat environments that have very high acidity and low oxygen (He et al., 2018). Thus, the use of *Pseudomonas taiwanensis* bacteria as a bioaugmentation agent can optimize the acceleration of the peat fiber decomposition process to improve the quality of fibrous peat geotechnically.

As mentioned earlier in previous studies the results of peat fiber decomposition obtained were not too significant because it used more than one type of decomposer bacteria (Prativi et al., 2018; Yogyanta et al., 2019), so in the current study only one type of bacteria was used to accelerate the process of peat fiber decomposition through the bioaugmentation method, which is the bacterium *Pseudomonas taiwanensis* proposed by Zulaika et al. (2022). This bacterium was chosen as the bioaugmentation agent in this study because it has a very high decomposition ability (Zulaika et al., 2022), and can survive in a very extreme peat environment (He et al., 2018). This study aims to investigate the effect of the addition of *Pseudomonas taiwanensis* bacteria through the bioaugmentation method on the peat fiber decomposition process in terms of fiber content, fiber size distribution, and peat fiber decomposition velocity. The peat used in this study originated from Bereng Bengkel Village, Palangkaraya. This research is the first experimental study in the laboratory that utilizes the potential of *Pseudomonas taiwanensis* bacteria as a bioaugmentation agent to accelerate the peat fiber decomposition process. Thus, the research objective is to determine the effectiveness of *Pseudomonas taiwanensis* bacteria in accelerating the decomposition of peat fiber using the bioaugmentation method.

RESEARCH METHODS

This research is an experimental study in the laboratory that was conducted for 3 months from June to August 2023 at the Soil Mechanics Laboratory of Politeknik Negeri Bandung. In practice, this research consisted of 4 stages of implementation, namely; (1) fibrous peat sampling, (2) preliminary testing, (3) bacterial culture, (4) the process of mixing bacteria and peat soil, and (5) final testing. The research began with peat soil sampling in Bereng Bengkel Village, Palangkaraya, Central Kalimantan. The location of the soil sampling is shown in Figure 1, located at coordinates 2º21'26 "S and 114º01'12"E taken from Google Earth.

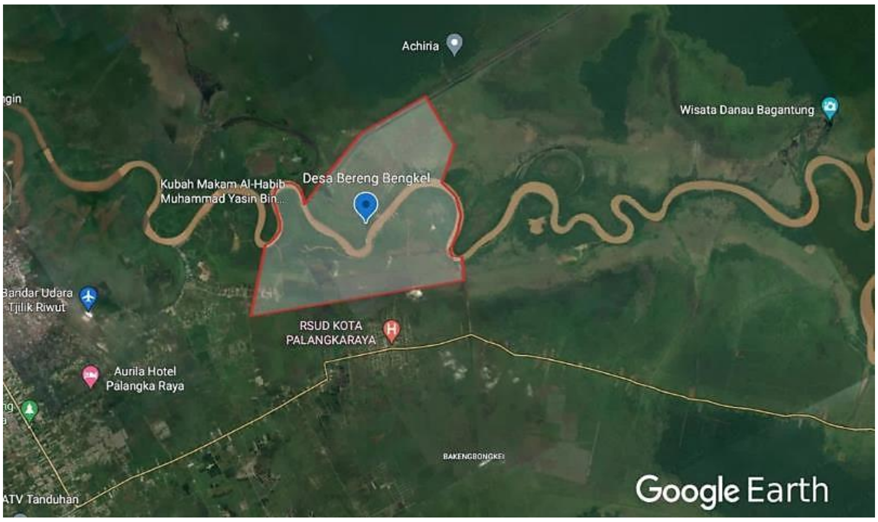


Figure 1. Fibrous Peat Sampling Location
(Source: Google Earth, Bereng Bengkel Village, Palangkaraya, Central Kalimantan, 2023)

Before taking soil samples, observations or visual observations of peat soil based on ASTM D2488-09a were carried out. Soil samples were taken by digging the soil at a depth of 0,5-1 meter, as shown in Figure 2. Practically, there are two types of peat soil samples taken: undisturbed samples and disturbed samples. Undisturbed samples refer to soil where the original structure is still preserved, while disturbed samples refer to soil where part or all of the structure has been modified or damaged. However, undisturbed sample collection for peat soils is very different than for other soil types. The reason is that undisturbed sample collection for peat soil is unable to be performed with a Shelby tube because the texture of peat soil is very soft, and also the acidity of peat soil can cause corrosiveness in the Shelby tube. Therefore, undisturbed samples were taken using PVC (polyvinyl chloride) tubes measuring 4 inches in diameter and 20 cm long, as shown in Figure 3a. Meanwhile, disturbed samples were taken using a 2-layer polybag which would then be put back into the sack, as shown in Figure 3b. This prevents the disturbed samples from losing their water content. The collected soil samples were then sent to Politeknik Negeri Bandung using cargo or expedition services. Once the peat soil samples were obtained, preliminary tests were carried out on the undisturbed samples. The preliminary tests were meant to test the fiber content, fiber size distribution, and decomposition velocity of the initial peat fibers.

Figure 2. Pre-digging of Soil Sampling Locations

Figure 3. Soil Samples: (a) Undisturbed Sample, (b) Disturbed Sample

The fiber content and fiber size distribution were tested based on the Peat Testing Manual 1979. Fiber content testing was carried out by soaking the peat sample in water in which sodium hexametaphosphate (SHMP) had been dissolved at 5% of the total weight of the water in the hydrometer tube for 24 hours, as shown in Figure 4.

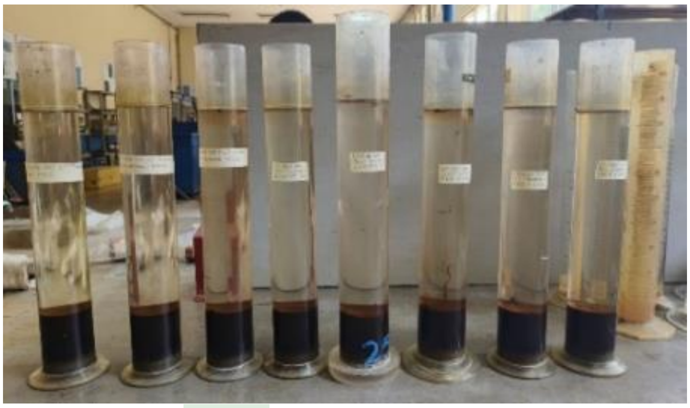


Figure 4. Fiber Content Testing

After 24 hours, the peat sample in the hydrometer tube was poured into a sieve number 100 and cleaned with water flowing from the tap. After cleaning, the peat samples were soaked in water to which HCL had been added at 2% of the total weight of the soaking water for 10 minutes. Then, the samples were dried in an oven for 24 hours. After 24 hours, the peat sample was weighed as the final result of fiber content in the sample. Based on the fiber content, the decomposition velocity can be calculated using using the following formula.

$$DV = \frac{IFC - FFC}{CP}$$

Information:
DV : Decomposition Velocity (%)
IFC : Initial Fiber Content (%)
FFC : Final Fiber Content (%)
CP : Curing Period (days)

Meanwhile, fiber size distribution testing was carried out by oven-drying a 100-gram sample for 24 hours. After 24 hours, the samples were then sieved using sieve number 8 and number 20 simultaneously.

Samples retained on sieve number 8 were identified as crude fiber content, and samples retained on sieve number 20 were identified as medium fiber content. Meanwhile, the sieving residue is identified as fine fiber content. To calculate the percentage of fiber content can be seen in using the formula below. The data obtained from the results of this test are then processed quantitatively and then the results of data processing are analyzed using descriptive statistical analysis and discussed with a relevant literature review approach (previous research). Descriptive statistical analysis is a type of statistics used to explain data and summarize it to make it easier to understand without losing or changing information.

$$\%\, CFC/MFC/FFC = \frac{SRW}{SW} \times 100\%$$

Information:
CFC : Crude Fiber Content (%)
MFC : Medium Fiber Content (%)
FFC : Fine Fiber Content (%)
SRW : Retained Sample Weight (gram)
SW : Sample Weight (gram)

Furthermore, the culture process of *Pseudomonas taiwanensis* bacteria was carried out at the Bioprocess Laboratory of Politeknik Negeri Bandung. The isolate of *Pseudomonas taiwanensis* bacteria was obtained from the agricultural agent seed of plant. The culture of bacteria carried out by conventional bacterial culture or liquid culture with nutrient broth media. In general, bacterial culture with nutrient broth media is carried out by planting 2-3 ose bacterial isolates in nutrient broth media that has been prepared in an erlenmeyer. This bacterial culture process must be carried out on a sterile table, specifically laminar air flow, as shown in Figure 5a. After bacterial cultivation is complete, the culture medium is then put into a shaker incubator for 24 hours. The result of this bacterial culture is a solution of *Pseudomonas taiwanensis* bacteria, as shown in Figure 5b.

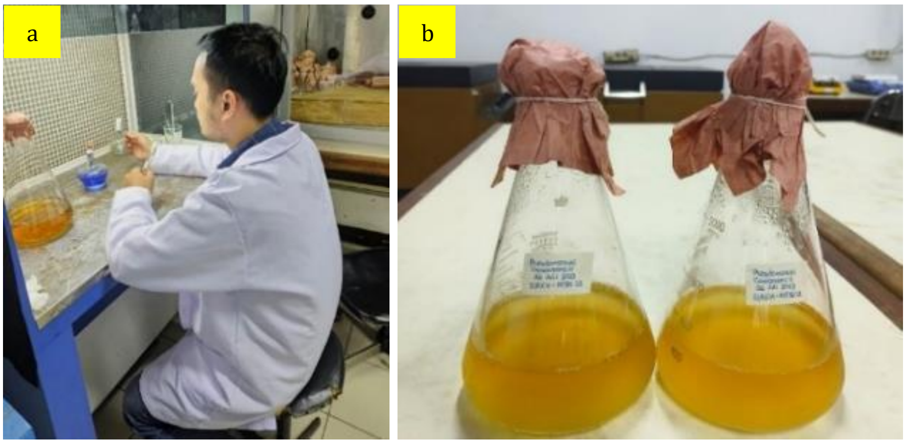


Figure 5. Bacteria Culture Process: (a) Laminar Air Flow, (b) *Pseudomonas taiwanensis* Bacteria Solution

After the bacterial solution has been obtained, the process of mixing bacteria with fibrous peat is carried out. In this study, 5 samples were made consisting of fibrous peat from disturbed samples with a weight of 4000 grams each, put into a plastic box. Following the accelerated decomposition method used, namely bioaugmentation, the samples that had been made were then added with a solution of *Pseudomonas taiwanensis* bacteria by hand stirring, as shown in Figure 6. The variation in the addition of bacteria to the samples can be seen in Table 1. The determination of the variation of bacteria addition is based on the results of a literature review in previous studies (Prativi et al., 2018; Yogyanta et al., 2019). The samples were then observed and tested every 7, 14, and 28 days to see the effect of the addition of *Pseudomonas taiwanensis* bacteria on the decomposition of peat fibers at various curing times. The final tests carried out included testing the fiber content and fiber size distribution based on the Peat Testing Manual 1979 whose test methods have been previously presented. The data obtained from these tests was then processed quantitatively. The results of the data processing were then analyzed using descriptive statistical analysis and discussed using a review approach based on relevant literature.

Figure 6. The Process of Mixing Bacteria with Peat

Table 1. Variation of Sample

Sample	Variation of Addition of Bacteria (by weight of peat sample)	Weight of Soil Sample	Curing Periods
1	Fibrous Peat + 5% *Pseudomonas taiwanensis*		
2	Fibrous Peat + 10% *PseudomonasTaiwanensis*		
3	Fibrous Peat + 15% *Pseudomonas taiwanensis*	4000 gram	7, 14 & 28 days
4	Fibrous Peat + 20% *Pseudomonas taiwanensis*		
5	Fibrous Peat + 25% *Pseudomonas taiwanensis*		

FINDING AND DISCUSSION

The test results of fiber content and fiber size distribution of the initial peat can be seen in Table 2. Based on the test results, it is known that the peat of Bereng Bengkel Village, Palangkaraya has a very high fiber content reaching 61,14%. According to ASTM D-4427-07, peat with a fiber content of 61,14% is classified as " moderate fibrous peat" or "hemic peat". This is in line with the results of previous studies which state that the peat of Bereng Bengkel Village, Palangkaraya is classified as moderate fiber peat or hemic peat (Ma'ruf et al., 2022; Prativi et al., 2018; Yogyanta et al., 2019; Yulianto et al., 2022). This can also be proven based on visual soil observations, where the soil has clearly visible fibers, a soft and moist texture, and a blackish brown color, as shown in Figure 7. According to ASTM D2488-09a, these are characteristics of fibrous peat.

The high fiber content in the peat of Bereng Bengkel Village, Palangkaraya is caused by the anaerobic or low oxygen condition of the peat environment (Chen et al., 2021). This condition inhibits the activity of decomposer microorganisms to break down organic materials such as leaves, twigs, and roots completely (Takada et al., 2016). As a result, the fiber content of peat becomes high because the continuous addition of organic matter surpasses its decomposition velocity (Masganti et al., 2017). In addition, in terms of the fiber size distribution of the initial peat, the crude fiber content is higher than the medium and fine fiber content. This is in line with the results of previous research, where crude fiber content tends to be higher than medium fiber content and fine fiber content (Mochtar & Yulianto, 2018). This indicates that the peat of Bereng Bengkel Village, Palangkaraya has not been fully decomposed. Therefore, the peat of Bereng Bengkel Village, Palangkaraya is qualified to be used as a sample in the experimental study of accelerating peat fiber decomposition using the bioaugmentation method by *Pseudomonas taiwanensis* bacteria.

Figure 7. Visual of Fibrous Peat in Bereng Bengkel Village, Palangkaraya

Table 2. Initial Fiber Content of Fibrous Peat

Parameters	Unit	Value	Value from Previous Studies
Fiber Content	%	61,14	39,5-61,33
Crude Fiber Content	%	45,08	35,35-49,69
Medium Fiber Content	%	31,69	31,94-35,84
Fine Fiber Content	%	23,23	18,37-29,00

In this study, samples that had been treated with the addition of *Pseudomonas taiwanensis* bacteria were observed and tested every 7, 14, and 28 days, as shown in Figure 8. This was done to examine the effect of the addition of *Pseudomonas taiwanensis* bacteria at various curing times (Prativi et al., 2018; Yogyanta et al., 2019). The observation results of the samples on days 7, 14, and 28 are described in Table 3. Based on the observations, it is known that the samples added with the *Pseudomonas taiwanensis* bacterial solution became very soft and watery after the 7-day curing period, as shown in Figure 9. This is due to the addition of bacteria in the form of a solution, causing an increase in the water content of the peat soil, which initially already had a very high water content. This phenomenon also occurred in research (Prativi et al., 2018) where in peat samples that had been added to a solution of anaerobic decomposer bacterial consortium, there was an increase in water content which made the samples increasingly soft-textured.

In addition, all samples added with *Pseudomonas taiwanensis* bacteria released a strong foul odor during the 7 and 14 days of curing. This indicates that the aeration process is inhibited during the decomposition process, producing foul-smelling compounds such as organic acids, ammonia, and H2S (Ngapiyatun et al., 2020). The aeration process or oxygen exchange process in peat samples is inhibited because the samples have anaerobic conditions due to increased water content (Prativi et al., 2018). This condition made the results in previous studies not optimal, because the anaerobic condition of the sample caused inhibition of activity and even death of the aerobic decomposer consortium bacteria used as bioaugmentation agents (Prativi et al., 2018; Yogyanta et al., 2019). However, after reaching the 14 and 28 day curing period, the condition of the samples in this study slowly became denser and had a dark brown color, as shown in Figure 9. This indicates that the aeration process has started properly and the decomposition process is ongoing. This is different from the results of research (Prativi et al., 2018), where in the results of their research the samples remained soft in texture even in the 56-day curing period due to the high water content so that the samples remained in a saturated condition. As a result, the samples in the study remained in a condition without oxygen, thus inhibiting the activity of the aerobic decomposer bacterial consortium that had been added.

Figure 8. Sample Observation

Although the condition of the sample became anaerobic at 7 days, in fact the decomposition process has been ongoing in samples that have been added with *Pseudomonas taiwanensis* bacteria. This can be seen in Figure 10, where a significant decrease in fiber content has been achieved at only 7 days of curing. In the 7 days, there was a significant decrease in fiber content in the variation of adding 10% *Pseudomonas taiwanensis* bacteria, from the initial condition of 61,14% to 35,18%. This can occur because even though the sample conditions become anaerobic during the 7-day curing period, *Pseudomonas taiwanensis* bacteria are still able to carry out the decomposition process. After all, these bacteria can survive in very extreme environments even in anaerobic or unoxic environments (He et al., 2018). This differs from the results of research (Prativi et al., 2018; Yogyanta et al., 2019), where in the study, the bioaugmentation agent used was a consortium of various types of aerobic decomposer bacteria. As a result, the decomposition process in the study was not maximized because the consortium of aerobic decomposer bacteria was unable to survive when the sample was in anaerobic conditions.

Based on Figure 10, it can be seen that the highest decrease in fiber content occurred in the variation of 15% addition of *Pseudomonas taiwanensis* bacteria in the 28-day curing period, from the initial condition of 61,14% to 12,33%. Meanwhile, the lowest decrease in fiber content occurred in the variation of 5% addition of *Pseudomonas taiwanensis* bacteria in the 7-day curing period, from the initial condition of 61,14% to 43,14%. This significant decrease in fiber content strengthens the statement (Zulaika et al., 2022), that *Pseudomonas taiwanensis* bacteria have the potential to accelerate the decomposition of peat fiber. This phenomenon is influenced by the curing period of the sample, where the longer the curing period, the more the biological process is expected to run optimally. This can occur because scientifically, bacteria need time in the metabolic process, so the longer the curing period, the more optimal the results obtained. This is following the results of previous studies (Prativi et al., 2018; Yogyanta et al., 2019), where fiber content decreases with the increase of the curing period.

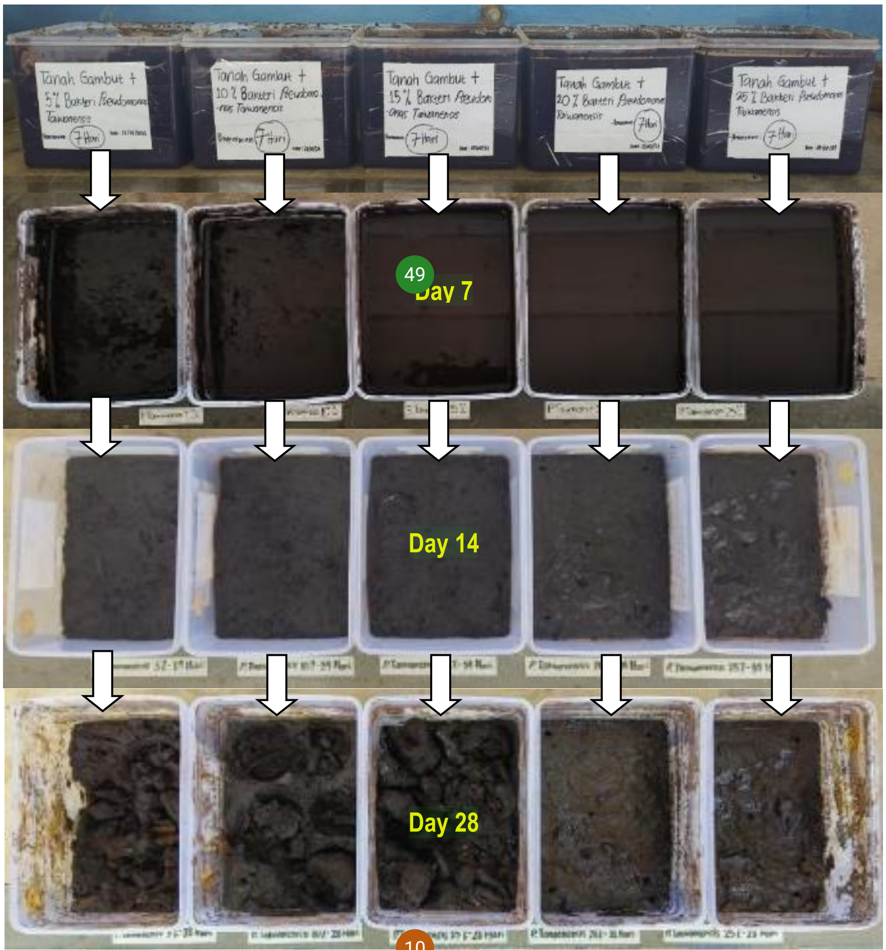


Figure 9. Condition of Samples after 7, 14 and 28 Days Curing Period

Table 3. Characteristics of Samples after 7, 14, and 28-Days Curing Period

Sample	Color Day-			Texture Day-			Smell Day-		
	7	14	28	7	14	28	7	14	28
Fibrous Peat + 5% *Pseudomonas taiwanensis*	Solid black	Dark brown	Dark brown	Slightly soft	Slightly dense	Dense	Very foul	Foul	No smell
Fibrous Peat + 10% *Pseudomonas taiwanensis*	Solid black	Dark brown	Dark brown	Soft	Slightly soft	Slightly dense	Very foul	Foul	No smell
Fibrous Peat + 15% *Pseudomonas taiwanensis*	Solid black	Dark brown	Dark brown	Very soft	Soft	Slightly soft	Very foul	Foul	No smell
Fibrous Peat + 20% *Pseudomonas taiwanensis*	Solid black	Dark brown	Dark brown	Very soft	Soft	Slightly soft	Very foul	Foul	No smell
Fibrous Peat + 25% *Pseudomonas taiwanensis*	Solid black	Dark brown	Dark brown	Very soft	Soft	Slightly soft	Very foul	Foul	No smell

In the study Yogyanta et al. (2019), the highest decrease in fiber content occurred in the variation of adding a 10% solution of aerobic decomposer bacterial consortium with a 28-day curing period. However, the decrease in fiber content obtained only reached 36,67% from the initial condition of 50%. When compared to the results in the current study, the decrease in fiber content obtained was 2 times greater than in the previous study (Yogyanta et al., 2019). This is because the bacteria used in the current study are indigenous bacteria from the fibrous peat of Bereng Bengkel Village, Palangkaraya which has a high level of decomposition and can survive in extreme environments such as anaerobic conditions and high acidity, so that the expected decomposition process can be maximized (Zulaika et al., 2022). In contrast to previous studies that used many types of aerobic decomposer bacteria, so that the decomposition process was less than optimal because the sample conditions would turn anaerobic due to the addition of bacteria in the solution (Prativi et al., 2018; Yogyanta et al., 2019).

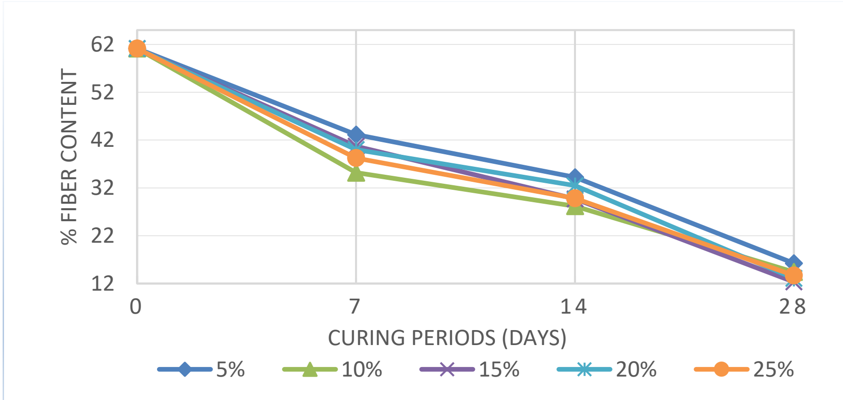


Figure 10. The Effect of Adding *Pseudomonas taiwanensis* Bacteria on Fiber Content

From the value of fiber content that has been obtained in each sample, the decomposition velocity of each sample can be determined using equation (1). The results of the calculation of the decomposition velocity are presented in the form of a graph which can be seen in Figure 11. Based on Figure 11, it can be seen that the highest decomposition velocity occurred in the variation of the addition of 10% *Pseudomonas taiwanensis* bacteria in the 7-day curing period, which amounted to 3,71% per day. Then it gradually decreased along with the increase in the curing period. This is due to the decreasing availability of the substrate which causes the activity of *Pseudomonas taiwanensis* bacteria to decrease (Sari et al., 2021). This substrate is a source of nutrients for *Pseudomonas taiwanensis* bacteria, which is cellulose, a component of plant tissue including fibers in peat. The reduction of this substrate is the result of the decomposition process that causes the fiber to decrease in peat. This is in line with the results of research (Prativi et al., 2018; Yogyanta et al., 2019), where the increasing period of curing, the velocity of decomposition in peat that has been added with a solution of aerobic decomposer bacteria consortium also decreases.

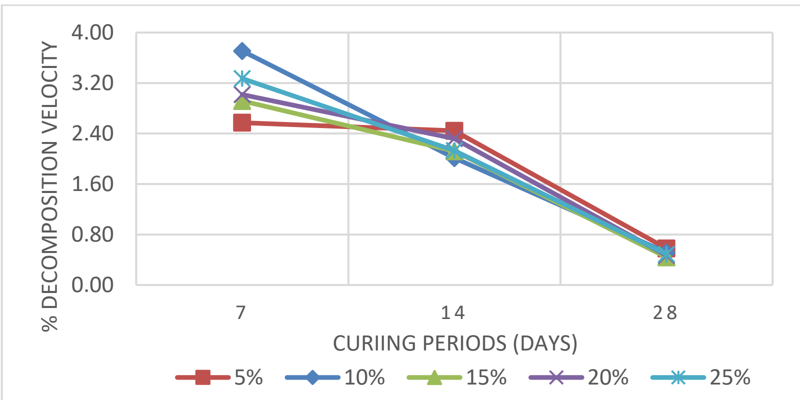


Figure 11. The Effect of Adding *Pseudomonas taiwanensis* Bacteria on Decomposition Velocity

In this study, fiber size distribution test was also conducted to determine the levels of crude fiber, medium fiber, and fine fiber in the samples. Figure 12 shows that there was a consistent decrease in crude fiber content and medium fiber content in the variation of the addition of *Pseudomonas taiwanensis* bacteria by 5% and 10% in the 7-day curing period. While in the variation of the addition of 15%, 20%, and 25% of *Pseudomonas taiwanensis* bacteria in the 7-day curing period, there was a tendency to decrease the crude fiber content and decrease the medium fiber content which was less when compared to the variation of the addition of *Pseudomonas taiwanensis* bacteria by 10% and 5% in the 7-day curing period. This occurs because the variation of the addition of 5% and 10% of *Pseudomonas taiwanensis* bacteria in the 7-day curing period contributes less water to the sample so that the aeration process takes place earlier than in samples with variations of the addition of 15%, 20%, and 25% of *Pseudomonas taiwanensis* bacteria in the 7-day curing period (Ngapiyatun et al., 2020).

This is different from the results of research (Prativi et al., 2018), where the crude fiber content increased. This happened because, in practice, the aerobic decomposer bacteria consortium solution was combined with the addition of CaCO3 to increase peat stiffness. In fact, the addition of CaCO3 at the same time as the aerobic decomposer bacteria consortium solution will only make the CaCO3 harden first without binding the soil particles in the peat so it becomes chunks that are stuck on sieve number 8 during the fiber size distribution test (Prativi et al., 2018). Therefore, in the practice of accelerating the decomposition process of peat fibers with bacterial solution, other materials should not be added to the combination. In addition, it is also known that there was an increase in the highest fine fiber content in the variation of adding 10% *Pseudomonas taiwanensis* bacteria in the 7-day curing period, from the initial condition of 23,23% to 68,64%. This indicates that there has been a significant process of peat fiber decomposition. Meanwhile, the lowest increase in fine fiber content in the 7-day curing period occurred in the variation of 5% addition of *Pseudomonas taiwanensis* bacteria, from the initial condition of 23,23% to 58,94%. This occurred due to the addition of less bacteria than in other samples. Although the aeration process took place earlier in this sample, the amount of bacteria added still affected the expected decomposition process (Sari et al., 2021).

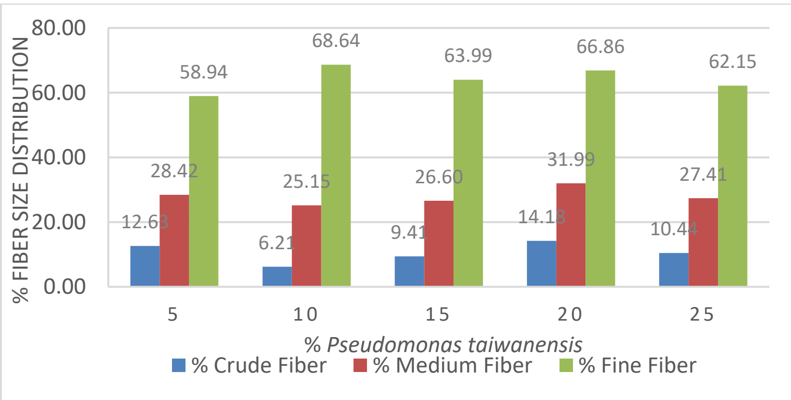


Figure 12. Fiber Size Distribution in the 7-Days Curing Period

Figure 13 shows the fiber size distribution in samples that have been added with *Pseudomonas taiwanensis* bacteria in the 14-day curing period. Based on Figure 13, it is known that the fine fiber content is increasing when compared to the 7-day curing period (Figure 12). Especially in the variation of adding 25% *Pseudomonas taiwanensis* bacteria in the 14-day curing period, the highest increase in fine fiber content occurred, from the initial condition of 23,23% to 68%. This indicates that the samples with the addition of significant amounts of *Pseudomonas taiwanensis* bacteria (15%, 20% and 25%) only experienced the maximum decomposition process during the 14-day curing period. This phenomenon is associated with the sustainability of the aeration process described earlier. In addition, at 14-day curing period, the crude fiber content gradually decreased significantly compared to the crude fiber content at 7-day curing period (Figure 12). This is in line with the results of research (Yogyanta et al., 2019), where in the 14-day curing period, crude fiber content decreased significantly.

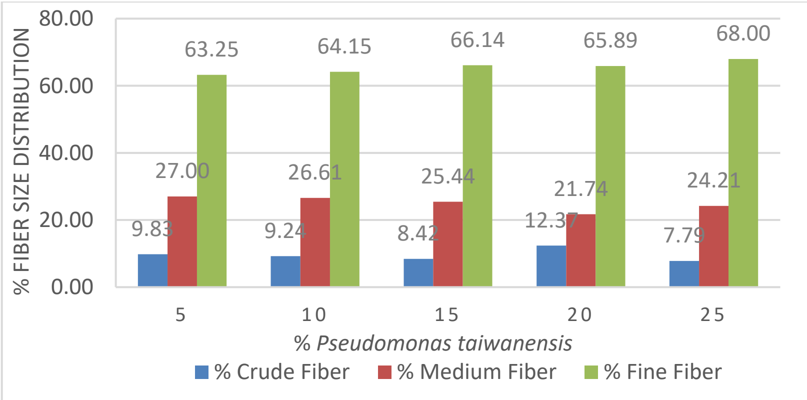


Figure 13. Fiber Size Distribution in the 14-Days Curing Period

The fiber size distribution during the 28-day curing period can be seen in Figure 14. Based on Figure 14, it can be seen that the increase in fine fiber content has decreased when compared to the 14-day curing period in Figure 13. This is influenced by the decreasing availability of substrates in peat so that the activity of *Pseudomonas taiwanensis* bacteria has decreased (Sari et al., 2021). At 28-day curing period, the highest increase in fine fiber content occurred in the variation of adding 15% *Pseudomonas taiwanensis* bacteria, from the initial condition of 23,23% to 62,30%. This makes the variation of 15% *Pseudomonas taiwanensis* bacteria the most consistent variation in increasing the fine fiber content, indicating that the decomposition process is going optimally in this variation. Meanwhile, the lowest increase in fine fiber content was found in the variation of 25% addition of *Pseudomonas taiwanensis* bacteria in the 28-day curing period, from the initial condition of 23,23% to 55,68%. This indicates that in the variation of 5% addition of *Pseudomonas taiwanensis* bacteria, the level of decomposition is smaller when compared to other samples. This can be seen in the results of fiber content in Figure 10, where at the end of the 28-day curing period, the lowest decrease in fiber content was found in the variation of adding 5% *Pseudomonas taiwanensis* bacteria when compared to other variations.

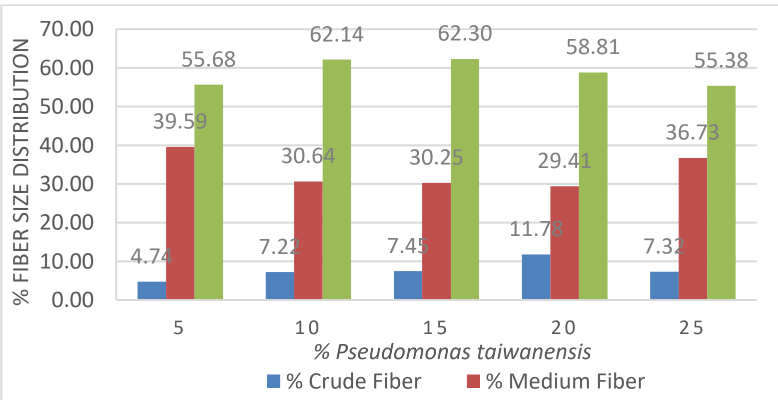


Figure 14. Fiber Size Distribution in the 28-Days Curing Period

Based on the description of the research results above, it can be concluded that the optimum percentage of addition of *Pseudomonas taiwanensis* bacteria to accelerate the decomposition process of peat fiber is in the variation of adding 15% *Pseudomonas taiwanensis* bacteria with a 28-day curing period because it experiences the highest decrease in fiber content, the highest increase in fine fiber content, and has a consistent decomposition velocity. In research (Prativi et al., 2018), the optimum percentage of the addition of aerobic decomposer bacterial consortium solution was at a percentage of 10% with a 14-day curing period. However, in that study, the decrease in fiber content was not so significant, from the initial condition of 33% to 28%. When compared to the findings of the current study, the decrease in fiber content was very significant, which was in the variation of adding 15% *Pseudomonas taiwanensis* bacteria with a 28-day curing period, there was a decrease in fiber content from the initial condition of 61,14% to 12,33%. Therefore, *Pseudomonas taiwanensis* bacteria can be used as an advanced bioaugmentation agent in optimizing the acceleration of the peat fiber decomposition process.

This finding suggests that *Pseudomonas taiwanensis* bacteria can be used as an alternative to improve the properties of fibrous peat through the bioaugmentation method for the benefit of the infrastructure construction sector. This is based on the results of research previously presented, where the addition of 15% *Pseudomonas taiwanensis* bacteria with a 28-day curing period can accelerate the decomposition process of peat fibers. Based on the literature, decomposed peat tends to have better geotechnical properties than undecomposed peat. After fibrous peat is decomposed, the void ratio becomes smaller, the bulk density value increases, the water content gets lower, the shear strength value increases, and the compressibility index gets smaller (Hikmatullah & Sukarman, 2014; Prativi et al., 2018; Yogyanta et al., 2019; Zulaika et al., 2022). Therefore, efforts to improve fibrous peat for the benefit of future infrastructure construction can take advantage of the potential of the bacterium *Pseudomonas taiwanensis* in decomposing peat fibers to improve its geotechnical properties.

CONCLUSION

The addition of 15% *Pseudomonas taiwanensis* bacteria to the fibrous peat resulted in the highest fiber content reduction of 12,33%. In this variation, there was also a decrease in crude fiber content and medium fiber content, and a very significant increase in fine fiber content. The velocity of decomposition in the 15% addition of *Pseudomonas taiwanensis* was also very consistent. Meanwhile, the variation of 5% addition of *Pseudomonas taiwanensis* bacteria with a 7-day curing period showed the lowest decrease in fiber content among other samples, from the initial condition of 61,14% to 43,14%. Therefore, the variation of adding 15% *Pseudomonas taiwanensis* bacteria with a 28-day curing period is the most optimal percentage to accelerate the decomposition of peat fiber through the bioaugmentation method. In future research, it is recommended to continue research on the effect of the addition of *Pseudomonas taiwanensis* bacteria on changes in the geotechnical properties of fibrous peat. Further research could involve variables such as water content, pH value, ash content, organic content, shear strength, and consolidation.

ACKNOWLEDGMENT

We would like to thank the P3M of Politeknik Negeri Bandung for funding this research with the Applied Research scheme with contract number B/92.26/PL1.R7/PG.00.03/2023.

REFERENCES

Bauer, M. A., Kainz, K., Carmona-Gutierrez, D., & Madeo, F. (2018). Microbial wars: Competition in ecological niches and within the microbiome. *Microbial Cell, 5*(5), 215–219. https://doi.org/10.15698/mic2018.05.628

Bay, Y. P., Yulianti, N., Suparno, S., Adji, F. F., Damanik, Z., & Sustiyah, S. (2021). Sifat fisik gambut pedalaman pada laboratorium alam hutan gambut Sebangau, Kalimantan Tengah. *Jurnal Ilmu Lingkungan, 15*(2), 216-233. https://doi.org/10.31258/jil.15.2.p.216-233

Chen, M., Gowthaman, S., Nakashima, K., Komatsu, S., & Kawasaki, S. (2021). High water content peat soil improved by MICP technique with fiber-reinforcement. *International Conference on GEOMATE*, Kyoto, Japan 16–21. http://repo.lib.jfn.ac.lk/ujrr/handle/123456789/4351

Darma, A. T., Walida, H., Saragih, S. H. Y., & Rizal, K. (2022). The analysis of peat soil biological characteristics after being incubated using vermicompost from a mixture of chicken dung, banana hump, and tofu waste. *JURNAL AGRONOMI TANAMAN TROPIKA (JUATIKA), 4*(2), 207–215. https://doi.org/10.36378/juatika.v4i2.2233

Devangsari, I. M., Nurudin, M., Sartohadi, J., & Karmila, Y. A. (2022). Characteristics of peat functional group in Padang Island, Indonesia. *IOP Conference Series: Earth and Environmental Science, 1005*(2022) 012022, 1-9. https://doi.org/10.1088/1755-1315/1005/1/012022

Fidiastuti, H. R., & Suarsini, E. (2017). Potensi bakteri indigen dalam mendegradasi limbah cair pabrik kulit secara in vitro. *Bioeksperimen, 3*(1), 1-10. https://doi.org/10.23917/bioeksperimen.v3i1.3665

Gofar, N., & Sutejo, Y. (2007). Long term compression behavior of fibrous peat. *Malaysian Journal of Civil Engineering, 19*(2), 104–116. https://journals.utm.my/mjce/article/view/15751

He, T., Ye, Q., Sun, Q., Cai, X., Ni, J., Li, Z., & Xie, D. (2018). Removal of nitrate in simulated water at low temperature by a novel psychrotrophic and aerobic bacterium, *Pseudomonas taiwanensis* strain j. *BioMed Research International*, 4984087, 1-9. https://doi.org/10.1155/2018/4984087

Hibbing, M. E., Fuqua, C., Parsek, M. R., & Peterson, S. B. (2010). Bacterial competition: Surviving and thriving in the microbial jungle. *Nature Reviews Microbiology*, 8, 15–25 (2010). https://doi.org/10.1038/nrmicro2259

Hikmatullah, & Sukarman. (2014). Physical and chemical properties of cultivated peat soils in four trial sites of ICCTF in Kalimantan and Sumatra, Indonesia. *Journal of Tropical Soils, 19*(3), 131–141. http://dx.doi.org/10.5400/jts.2014.v19i3.131-141

Hu, B. L., Rush, D., Biezen, E. Van Der, Zheng, P., Mullekom, M. Van, Schouten, S., Sinninghe Damsté, J. S., Smolders, A. J. P., Jetten, M. S. M., & Kartal, B. (2011). New anaerobic, ammonium-oxidizing community enriched from peat soil. *Applied and Environmental Microbiology, 77*(3), 966–971. https://doi.org/10.1128/AEM.02402-10

Ismail, A. G., Mustofa, A., Dwicahyani, A., Ridlo, M. M., & Sambowo, A. (2017). Pengaruh beton daur ulang dan bahan tambah fly ash terhadap kuat tekan dan kuat lentur beton struktural ramah lingkungan. *Jurnal Riset Rekayasa Sipil, 1*(1), 59–63. https://doi.org/10.20961/jrrs.v1i1.14722

Johari, N. N., Bakar, I., Razali, S. N. M., & Wahab, N. (2016). Fiber effects on compressibility of peat. *IOP Conference Series: Materials Science and Engineering, 136*(1), 1–9. https://doi.org/10.1088/1757-899X/136/1/012036

Kolay, P. K., & Taib, S. N. L. (2018). Physical and geotechnical properties of tropical peat and its stabilization. In Peat, 93–105. https://doi.org/10.5772/intechopen.74173

Kumar, N., Chaturvedi, S., & Khurana, S. M. P. (2022). Survival and thriving behavior of bacteria in microbial jungle. *Microbial Resource Technologies for Sustainable Development*, 1–21. https://doi.org/10.1016/B978-0-323-90590-9.00011-0

Li, Z. S., Rahayu, W., Souli, H., Soepandji., B. S., & Fleureau, J. M. (2022). Compressibility and shear strength of a tropical fibrous peat. *Géotechnique Letters, 12*(2), 139-147. https://doi.org/10.1680/jgele.21.00154

Ma'ruf, M. A., Yulianto, F. E., Wardani, M. K., Iswinarti, & Firmansyah, Y. K. (2022). Utilization of lime and rice husk ash for peat soil stabilization in different water content condition. *IOP Conference Series:*

Earth and Environmental Science, 999(012028), 1-6. https://doi.org/10.1088/1755-1315/999/1/012028

Masganti, Anwar, K., & Susanti, M. A. (2017). Potensi dan pemanfaatan lahan gambut dangkal untuk pertanian. *Jurnal Sumberdaya Lahan, 11*(1), 43–52. https://www.neliti.com/publications/223343/

Medaura, M. C., Guivernau, M., Moreno-Ventas, X., Prenafeta-Boldú, F. X., & Viñas, M. (2021). Bioaugmentation of native fungi, an efficient strategy for the bioremediation of an aged industrially polluted soil with heavy hydrocarbons. *Frontiers in Microbiology, 12*(626436). https://doi.org/10.3389/fmicb.2021.626436

Mochtar, N. E., & Yulianto, F. E. (2014). Pengaruh usia stabilisasi pada tanah gambut berserat yang distabilisasi dengan campuran CaCO3 dan pozolan. *Jurnal Teknik Sipil, 21*(1), 57–64. https://doi.org/10.5614/jts.2014.21.1.6

Ngapiyatun, S., Rahman, A., Aziza, H., & Winarni, B. (2020). Pemanfaatan limbah sampah kota sebagai kompos. *Buletin Loupe , 16*(02), 1–6. https://doi.org/10.51967/buletinloupe.v16i02.222

Palamba, P., Ramadhan, M. L., Pamitran, A. S., Prayogo, G., Kosasih, E. A., & Nugroho, Y. S. (2018). Drying kinetics of Indonesian peat. *International Journal of Technology, 9*(5), 1006–1014. https://doi.org/10.14716/ijtech.v9i5.805

Prativi, A., Mochtar, N. E., & Zulaika, D. E. (2018). Peat soil stabilization by adding solution of endogenous aerobic decomposer bacteria consortium. *Proceeding 12th International Conference on Building Design, Materials, Civil and Transportation Engineering (BDMCTE-18), Bali, Indonesia*, 78–83. https://www.dirpub.org/images/proceedings_pdf/DIR0118404.pdf

Ramdhan, M. (2018). Analisis persepsi masyarakat terhadap kebijakan restorasi lahan gambut di Kalimantan Tengah. *Jurnal Risalah Kebijakan Pertanian Dan Lingkungan, 4*(1), 60-72. https://journal.ipb.ac.id/index.php/jkebijakan/article/view/20066

Rismantojo, E., & Ningsih, N. N. (2021). Pengaruh penambahan mikroorganisme terhadap sifat fisik dan kuat geser tanah gambut Palembang. *Jurnal Teknik Sipil, 28*(3), 269–280. https://doi.org/10.5614/jts.2021.28.3.4

Saida, N. A., George, A. D., & Mohamad, H. M. (2023). A review on experimental investigations and geotechnical characteristic of peat soil stabilization. *International Journal of Advanced Research in Engineering Innovation, 5*(1), 1–19. https://doi.org/10.55057/ijarei.2023.5.1.1

Santi, I. N., Hayata, H., & Bangun, B. (2022). Characteristics of peat with different depths in supporting growth and productivity of oil palm. *Journal of Tropical Soils, 28*(1), 17. https://doi.org/10.5400/jts.2023.v28i1.17-22

Sari, N. P., Rinaldi, & Rodhiyah, Z. (2021). Pengaruh perbedaan tinggi tumpukan kompos terhadap jumlah bakteri *Escherichia coli* dan *Salmonella* sp. pada kompos sampah organik pasar dan limbah padat rumah potong hewan. *Jurnal Engineering Universitas Jambi, 3*(1), 44–55. https://doi.org/10.22437/jurnalengineering.v3i1.12206

Stevani, A., & Makarim, C. A. (2021). Analisis perbandingan penurunan fondasi dangkal di tanah gambut dengan stabilisas kapur dan abu sekam padi. *JMTS: Jurnal Mitra Teknik Sipil, 4*(1), 233–248. https://doi.org/10.24912/jmts.v0i0.11099

Pradana, M. S, & Rohmah, A. M. (2018). Pemodelan kadar air pada sifat fisik stabilisasi tanah gambut. *Journal of Mathematics and Mathematics Education (JMME), 8*(1), 56–67. https://doi.org/10.20961/jmme.v8i1.25826

Takada, M., Shimada, S., & Takahashi, H. (2016). Tropical peat formation. *Tropical Peatland Ecosystems* (pp. 127–135). Springer Japan. https://doi.org/10.1007/978-4-431-55681-7_8

Wahab, A., Embong, Z., Hasan, M., Musa, H., Zaman, Q. U. Z., & Ullah, H. (2020). Peat soil engineering and mechanical properties improvement under the effect of eks technique at parit kuari, Batu Pahat, Johor, West Malaysia. *Bulletin of the Geological Society of Malaysia*, 70, 133–138. https://doi.org/10.7186/bgsm70202011

Wang, L. T., Tai, C. J., Wu, Y. C., Chen, Y. B., Lee, F. L., & Wang, S. L. (2010). *Pseudomonas taiwanensis* Sp. Nov., isolated from soil. *International Journal of Systematic and Evolutionary Microbiology, 60*(9), 2094–2098. https://doi.org/10.1099/ijs.0.014779-0

Waruwu, A., Deni Susanti, R., Sanjaya Sihombing, H., Yogi Purba, T., Kunci, K.-K., Bambu, G., Beton, T., & Sistem Perkuatan, S. (2020). Pengaruh susunan tiang dengan grid bambu pada tanah gambut terhadap lendutan. *Prosiding Seminar Nasioanl Teknik (SEMNASTEK) Universitas Islam Sumatera Utara*, 9–15. https://jurnal.uisu.ac.id/index.php/semnastek/article/view/2983

Yogyanta, D. A., Mochtar, N. E., & Zulaika, E. (2019). Acceleration of decomposition process by lignocellulolytic bacteria and its effect on the physical and engineering properties of Kalimantan fibrous peat. *Proceedings of the Third International Conference on Sustainable Innovation 2019-Technology and Engineering (IcoSITE 2019), 187,* 35-39. https://doi.org/10.2991/icosite-19.2019.7

Yulianto, F. E., Mochtar, N. E., & Ma'ruf Afif, M. (2022). Physical and engineering properties of peat soil stabilized with the admixture of CaCO3+rice husk ash due to water infiltration from surrounding ares. *Journal of Applied Engineering Science, 20*(1), 276–284. https://doi.org/10.5937/jaes0-32003

Zebua, H. F. (2022). Analisa penurunan akibat beban timbunan pada tanah gambut dengan perkuatan. *Jurnal Ilmiah Desain & Konstruksi, 21*(1), 50–64. https://doi.org/10.35760/dk.2022.v21i1.5188

Zulaika, E., Solikhah, F., Utomo, M. A. P., Endah, N., & Assavalapsakul, W. (2022). Cellulose degrading bacteria isolated from Palangkaraya, Central Kalimantan, Indonesia as peat fiber decomposer to accelerate peat soil compression. *Biodiversitas: Journal of Biologycal Diversity, 23*(3), 1648–1654. https://doi.org/10.13057/biodiv/d230356

15% Overall Similarity

Top sources found in the following databases:

- 9% Internet database
- 8% Publications database
- Crossref database
- Crossref Posted Content database
- 9% Submitted Works database

TOP SOURCES

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	Universitas Tidar on 2023-04-07 Submitted works	2%
2	ejurnal.budiutomomalang.ac.id Internet	1%
3	Christophe Noll, Margaret Kunach, Frédérique Frisch, Lucie Bouffard et... Crossref	<1%
4	repository.umy.ac.id Internet	<1%
5	rjoas.com Internet	<1%
6	Anna Dewi, Dewi Amalia, Lindung Zalbuin Mase. "Experimental Study o... Crossref	<1%
7	scilit.net Internet	<1%
8	Cork Institute of Technology on 2011-05-06 Submitted works	<1%

9	Yullianty Noorlaelasari, Ery Radya Juarti, Ari Rahman, Anita Juraida. "A... Crossref	<1%
10	"Proceedings of the 5th International Conference on Sustainable Civil E... Crossref	<1%
11	jurnal.unimed.ac.id Internet	<1%
12	media.neliti.com Internet	<1%
13	University College Technology Sarawak on 2017-12-26 Submitted works	<1%
14	Universiti Tenaga Nasional on 2013-01-28 Submitted works	<1%
15	jtam.ulm.ac.id Internet	<1%
16	University of Wollongong on 2023-05-30 Submitted works	<1%
17	scindeks-clanci.ceon.rs Internet	<1%
18	researchgate.net Internet	<1%
19	University Tun Hussein Onn Malaysia on 2022-10-20 Submitted works	<1%
20	UC, Irvine on 2023-06-04 Submitted works	<1%

21	ejournal.unwaha.ac.id Internet	<1%
22	N N Johari, I Bakar, S N M Razali, N Wahab. "Fiber Effects on Compress... Crossref	<1%
23	Sam Houston State University on 2023-11-21 Submitted works	<1%
24	Yulindasari Sutejo, Anis Saggaff, Wiwik Rahayu, Hanafiah. "Hydraulic c... Crossref	<1%
25	buletinsdg.geologi.esdm.go.id Internet	<1%
26	KARUNA, Dasari Subramaniyam, UDHUMANSKA, Ubaidulla, RATHNAM... Publication	<1%
27	Norhaliza Wahab, Kasbi Basri, Mohd Khaidir Abu Talib, Munzilah Md R... Crossref	<1%
28	East Tennessee State University on 2021-04-13 Submitted works	<1%
29	Universitas Warmadewa on 2017-08-21 Submitted works	<1%
30	bioresources.cnr.ncsu.edu Internet	<1%
31	Ahmed, Mahmoud Nasr Mahmoud. "Development of Structural Lightwe... Publication	<1%
32	Muhammad Afief Ma'ruf, Faisal Estu Yulianto, Mila Kusuma Wardani, I... Crossref	<1%

33	smujo.id	Internet	<1%
34	Curtin University of Technology on 2012-10-07	Submitted works	<1%
35	Deha Agus Umarhadi, Ram Avtar, Wirastuti Widyatmanti, Brian Alan Jo...	Crossref	<1%
36	Flinders University on 2018-10-11	Submitted works	<1%
37	The Robert Gordon University on 2010-10-25	Submitted works	<1%
38	University Tun Hussein Onn Malaysia on 2018-08-16	Submitted works	<1%
39	University of Brighton on 2012-05-04	Submitted works	<1%
40	ejournal.forda-mof.org	Internet	<1%
41	etda.libraries.psu.edu	Internet	<1%
42	harvest.usask.ca	Internet	<1%
43	ijtech.eng.ui.ac.id	Internet	<1%
44	repository.i3l.ac.id	Internet	<1%

45	frontiersin.org Internet	<1%
46	A. B. Salahudeen, A. O. Eberemu, K. J. Osinubi. "Assessment of Cemen... Crossref	<1%
47	George, Scott Fillerup. "Restricted Microbial Presence, Activity, and Co... Publication	<1%
48	Kingston University on 2011-02-24 Submitted works	<1%
49	Mahidol University on 2009-04-30 Submitted works	<1%
50	Politeknik Negeri Bandung on 2023-04-18 Submitted works	<1%
51	Y Lestari, E Maftu'ah. "Amelioration and variety selection to increase s... Crossref	<1%
52	Zhiliang Wang, Miao Li, Linfang Shen, Jingyu Wang. "Incorporating clay... Crossref	<1%
53	civilejournal.org Internet	<1%
54	dergipark.org.tr Internet	<1%
55	ejournal.uniks.ac.id Internet	<1%
56	eprints.lancs.ac.uk Internet	<1%

57	kayseri.edu.tr Internet	<1%
58	Nazile Ural. "Effects of additives on the microstructure of clay", Road ... Crossref	<1%
59	University of Bradford on 2019-12-13 Submitted works	<1%
60	Ali Hauashdh, Radin Maya Saphira Radin Mohamed, Junaidah Jailani, J... Crossref	<1%
61	University College Technology Sarawak on 2023-09-07 Submitted works	<1%
62	University of Hong Kong on 2011-06-20 Submitted works	<1%
63	Yulianto Estu, Mochtar Endah, Afif Ma'ruf. "Physical and engineering pr... Crossref	<1%