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Enhancing the Composting Process and Quality of Oil Palm Empty Fruit Bunches (EFB) Using Indigenous Cellulolytic Microbes: A Review

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ABSTRACT: Palm oil production in Indonesia is projected to reach approximately 54.84 million tons by 2023, maintaining a consistent trend. This production volume is closely linked to the amount of Empty Fruit Bunches (EFB) generated as a by-product. If EFB is not managed effectively, it could have adverse effects on the environment. To address this issue, composting EFB is essential. However, the high cellulose content in EFB poses challenges for decomposition. The application of cellulolytic microorganisms presents a promising solution to enhance the composting process. This study aims to explore the benefits of incorporating cellulolytic microorganisms in accelerating EFB compost quality. The research methodology follows the Systematic Literature Review (SLR) approach based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review focuses on scientific literature from 2014 to 2024 available on the ScienceDirect and Google Scholar databases. Findings indicate that using a consortium of cellulolytic microorganisms can reduce cellulose content, decrease the C/N ratio, expedite composting, enhance compost quality by regulating temperature, reducing volume, increasing pH, macronutrients, and biological activity during EFB composting.

KEYWORDS: Cellulolytic Microbes, EFB Composting, Soil Quality, Systematic Review

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1. INTRODUCTION

Over the years, there has been a notable rise in productivity and land expansion for oil palm plantations, positioning Indonesia to potentially become the world's leading producer of crude palm oil (CPO). The expansion of oil palm plantation areas significantly contributes to the overall palm oil production volume. According to data released by the Directorate General of Plantations, Ministry of Agriculture of the Republic of Indonesia, the oil palm plantation area is projected to reach 15.380.981 hectares in 2022, marking an increase from the previous year's 14.663.416 hectares. Similarly, in 2023, there is expected to be a considerable surge, with the oil palm plantation area estimated to reach approximately 16.83 million hectares.

The primary output derived from palm oil is crude palm oil, commonly referred to as CPO (Crude Palm Oil), which constitutes approximately 21% of the yield from one ton of fresh fruit bunches (Kaniapan *et al.*, 2021; Awoh *et al.*, 2023). This percentage is influenced by the prevalence of by-products from oil palm cultivation, consisting of 23% empty fruit bunches (EFB), 14-15% palm fiber (PPF), and approximately 6-7% palm kernel shells (PKS) (Foong & Denny, 2022).

Empty fruit bunches (EFB) represent a by-product in the solid waste form generated during the processing of fresh palm oil fruit bunches into palm oil and kernels. EFB constitutes the most significant proportion of waste in palm oil production, comprising 44.21% cellulose, 16.68% hemicellulose, 35.51% lignin, and approximately 0.26% silica (Foong & Denny, 2022). This composition renders EFB resistant to decomposition. Notably, Indonesia's palm oil production is projected to reach approximately 45.58 million tons by 2022, directly correlating with the volume of EFB produced as a by-product of these activities.

Based on the increasing abundance of Empty Fruit Bunches (EFB), there is significant potential for optimal utilization. Initially, EFB was underutilized, leading to wastage and the potential for environmental pollution. However, over time, EFB can be repurposed as mulch to reduce soil evaporation and enhance organic material availability (Rudolf *et al.*, 2021). Nevertheless, the decomposition process when converted into mulch is time-consuming. Neglecting this could result in EFB accumulating, providing a breeding ground for plant pests. Moreover, burning EFB can have adverse effects on environmental health, contributing to air pollution through CH_4, H_2S, and NH_3 emissions that can harm the atmosphere (Ejaz *et al.*, 2020).

To prevent a recurrence of such incidents, utilizing Empty Fruit Bunches (EFB) as compost can prove highly effective due to its substantial nutrient content essential for plant development. EFB serves as an organic source rich in vital nutrients such as N, P, K, and Mg. Research indicates that every ton of EFB typically comprises N at 1.5%, P at 0.5%, K at 7.3%, and Mg at 0.9% (Tao *et al.*, 2018). However, employing EFB as the primary component for composting presents challenges, notably in the duration required for composting due to its organic composition and elevated C/N ratio, typically ranging between 35 and 55. These factors contribute to the inherent difficulty in decomposing EFB effectively.

When confronted with a contentious situation like this, a strategic approach is essential to reduce the C/N ratio, thereby expediting the composting process. The current scientific trend favors biological treatment, achieved by introducing microorganism inoculants with a robust capacity to decompose agricultural waste. It's crucial to note that only select microorganisms possess the ability to initiate the cellulolytic polymer degradation process; specifically, those capable of producing cellulose enzymes are classified as cellulolytic microorganisms (Bautista-Cruz *et al.*, 2024). Cellulose enzymes play a pivotal role in breaking down cellulose molecules by hydrolyzing β-1.4-glycosidic bonds into simpler forms known as oligosaccharides, which are further metabolized into glucose (Kaur *et al.*, 2020). Various cellulolytic microorganisms, including fungi like Trichoderma, Aspergillus, and Penicillium, alongside bacteria such as Cellulomonas, Cytophaga, Pseudomonas, Bacilli, and certain actinomycetes, are capable of producing cellulose enzymes for this purpose (Ejaz *et al.*, 2021).

Several studies have highlighted the beneficial impact of utilizing cellulolytic microorganisms in enhancing EFB composting, as outlined in this review journal. The primary aim of this article is to offer in-depth scientific insights into the effective utilization of cellulolytic microorganisms to lessen the C/N ratio, accelerate the EFB composting process, and ultimately enhance the quality of compost.

2. MATERIAL AND METHODS

The research methodology employed in composing this article involves a Systematic Literature Review (SLR) utilizing a journal search system adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow guidelines. PRISMA serves as a framework for assessing the outcomes of systematic reviews and meta-analyses, emphasizing transparent and thorough reporting in research of this nature (Moher *et al.*, 2015).

The research utilized data derived from databases and indexes accessible through ScienceDirect and Google Scholar. The search, conducted on March 5, 2024, employed specific keywords within ScienceDirect "Cellulolytic microbes AND compost quality" and in Google Scholar "Cellulolytic microbes AND empty fruit bunches AND compost quality". This process is succinctly illustrated in the algorithm flow diagram depicted in ***Figure 1.*** The selection criteria encompassed publications from 2014 to 2024, focusing on scientific research articles chosen based on their titles and abstracts. The publications meeting the established criteria revolved around cellulolytic microbes, compost quality, and the composting of empty fruit bunches.

At the beginning of the manual search process, a journal search was conducted using Google Scholar, which initially retrieved 1.680 journals. These were then filtered based on relevance to the desired theme, resulting in 78 selected journal titles. Subsequently, a search on ScienceDirect yielded 765 journals, which were filtered based on publication time period, article type (research articles), subject area (including environmental sciences and agricultural and biological sciences), and access type (open access), resulting in 36 research articles. After removing 22 duplicate journal titles, a total of 92 titles remained. By searching for titles related to plants, 57 journal titles were identified, and by focusing on EFB composting, 15 relevant journal titles were found. Further filtering based on the full text led to the selection of 8 journal titles that met the specified criteria.

3. Cellulolytic Microbes

Cellulolytic microorganisms are a category of microbes capable of hydrolyzing cellulose and breaking down cellulose-containing materials (Grata, 2020). The decomposition of cellulose occurs through the hydrolysis of β-1.4 glycosidic bonds. These microorganisms encompass aerobic bacteria, anaerobic bacteria, fungi, and actinomycetes, each employing distinct approaches to cellulose hydrolysis.

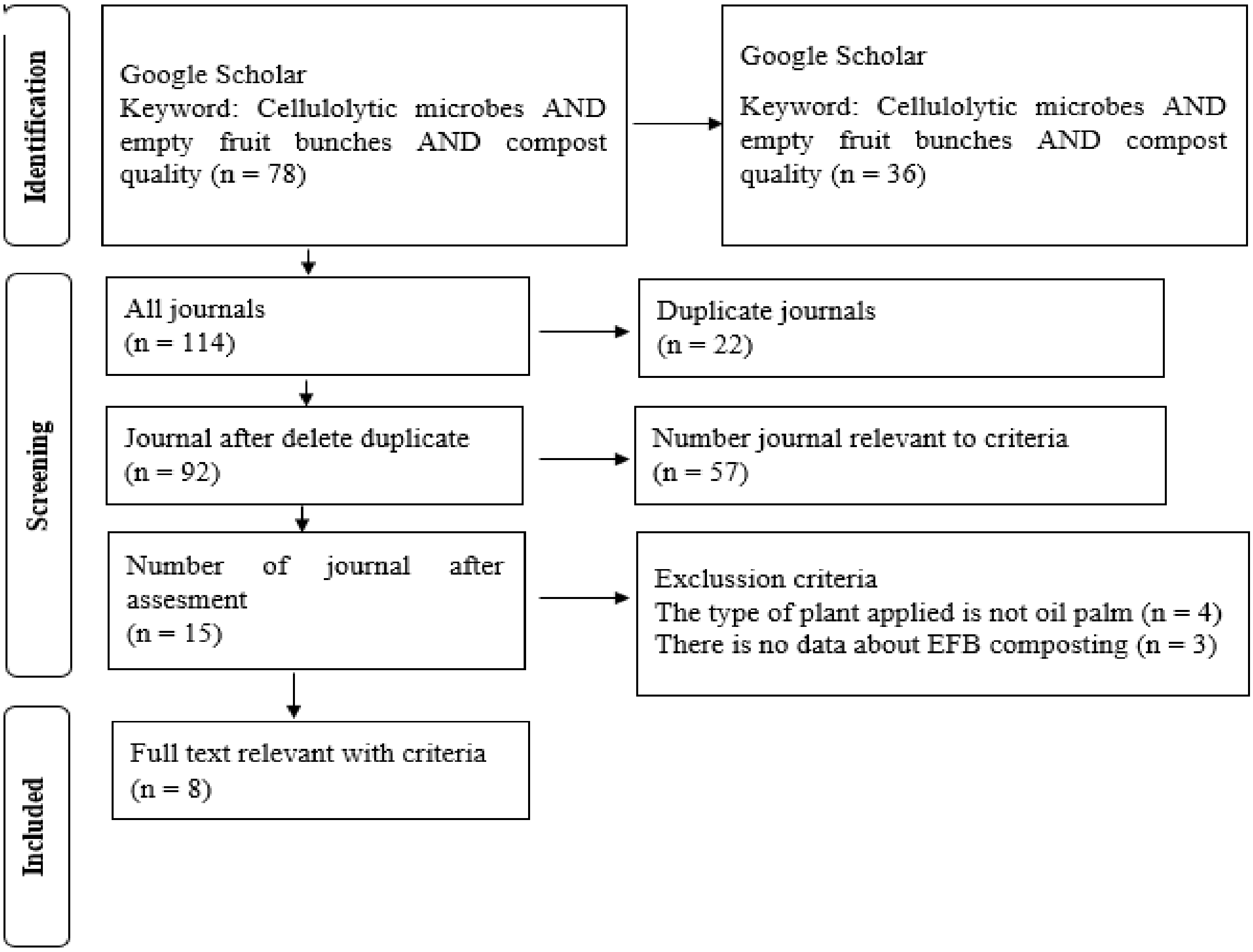

Figure 1. Flow chart Systematic Literature Review: Enhancing the Composting Process and Quality of Oil Palm Empty Fruit Bunches (EFB) Using Indigenous Cellulolytic Microbes

Fungi have the capacity to develop mycelium hyphae, enabling them to penetrate the capillary tubes and pores within the cellulose structure, thus facilitating direct cellulose production. Among the fungal species recognized for their cellulose production are *Aspergillus fumigatus* MS16, *Aspergillus terreus* MS105, *Trichoderma citrinoviride* AUKAR04, *Humicola insolens* MTCC 1433, *Phaffomycetaceae*, and *Dipodascaceae* (Singla *et al.*, 2017; Ejaz *et al.*, 2021).

Aerobic cellulolytic bacteria essentially release extracellular cellulolytic enzymes that can enhance hydrolysis efficiency (Grata, 2020). Meanwhile, anaerobic cellulolytic bacteria hydrolyze cellulose using a complex enzyme system occurring in the form of cellulosomes. Commonly known aerobic and anaerobic cellulolytic bacteria include *Acetivibrio cellulolyticus, Bacillus sp., Cellulomonas sp., Erwinia chrysanthemi, Streptomyces sp., Ruminococcus albus, Thermobispora bispora, Thermobifida fusca, Thermomonospora sp., and Clostridium sp.* (Sadhu *et al.*, 2013; Ejaz *et al.*, 2021). Additionally, Kaur *et al.*, (2020) mentioned several types of *Actinomycetes* including *Cellulomonas, Streptomyces, Micromonospora, Actinoplanes, Nocardia, Microbispora, Thermobifida, Saccharopolyspora, Streptoverticillium, Pseudonocardia, Actinopolyspora, Streptosporangium, Intrasporangium*, and *Thermoactinomycetes*.

Gusmawartati *et al.*, (2023) have highlighted that the cellulolytic microbial isolates identified exhibit significant potential in decomposing EFB waste. This potential is evidenced by the size of the clear zone, reduction in sugars, and outcomes of crude extraction of cellulose enzymes. Cellulolytic microorganisms have the capacity to produce cellulose enzymes, crucial for breaking down cellulose into soluble sugars. These sugars serve as essential carbon and nutrient sources for their own sustenance and that of other heterotrophic organisms. Cellulose enzymes act as decomposers with distinct characteristics, facilitating the hydrolysis of β-1.4-glycosidic bonds present in cellulose chains and their derivatives (Grata, 2020).

Cellulose enzyme complexes typically comprise three enzymes, each with distinct structures, enzymatic activities, specificities, and active centers. These enzymes include β-glucosidase, endo-1.4-β-D-glucanase (endoglucanase), and exo-1.4-β-D-glucanase (exoglucanase) (Ejaz *et al.*, 2021). Working synergistically, these three enzymes play vital roles in the cellulose hydrolysis process. β-glucosidase targets cellobiose and cellodextrin, crucial for converting cellobiose into glucose. Endo-1.4-β-D-glucanase acts on internal sites of oligosaccharides like carboxymethyl cellulose and amorphous cellulose, breaking β-1.4 bonds in macromolecules and producing large fragments. On the other hand, exo-1.4-β-D-glucanase is responsible for degrading the crystalline portion of the cellulose chain (Patel *et al.*, 2019).

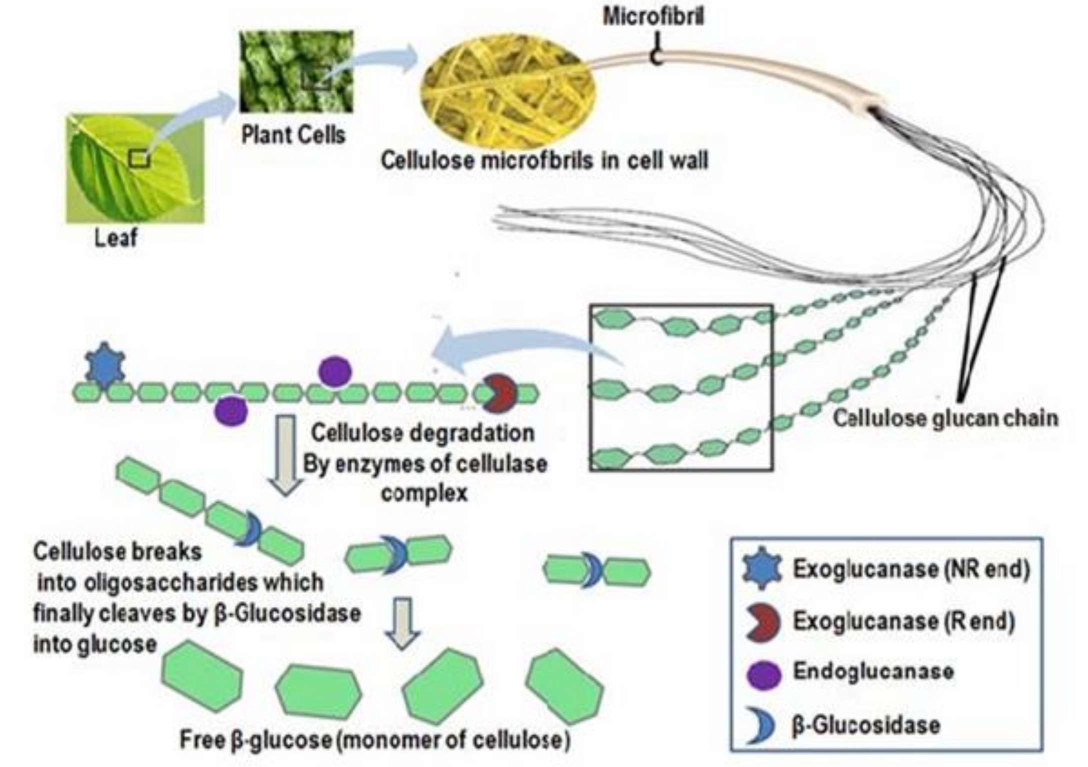

Figure 2. A diagrammatic representation of the Cellulose Enzyme Complex Metabolism (Singh *et al.*, 2015).

Endo-β-1.4-glucanase functions by randomly hydrolyzing the middle of the chain. Subsequently, exo-β-1.4-glucanase, also known as cellobiohydrolase, breaks down the disaccharide units (cellobiose) from the chain's end. Finally, β-glucosidase further breaks down cellobiose into glucose.

4. COMPOSTING PARAMETERS

4.1 Monitoring Parameters

Temperature

Temperature plays a crucial role in the composting process as it is interconnected with other factors. While high temperatures are necessary for compost sanitation, excessively high temperatures can hinder biological activity and lead to chemical alterations in the organic matter within the compost. Conversely, if the composting temperature is too low, it can impede the microbial degradation process of organic material. Therefore, maintaining an optimal temperature is key to fostering an efficient composting process, accelerating it, and enhancing the compost quality.

The temperature parameter serves as an indicator of compost maturity success. According to the standards outlined in SNI 19-7030-2004, the ideal temperature at the end of composting should not exceed 30°C or match the groundwater temperature. To ensure a stable final product, continuous monitoring is essential. This involves measuring temperature, confirming pathogen absence, and sustaining microbial activity for optimal conditions. Research conducted by Gusmawartati & Sari (2023) revealed that EFB compost temperature ranged from 28-30°C after 30 days of composting, indicating the compost had reached the maturation phase. The initial temperature rise during composting is attributed to the activity of thermophilic microbes breaking down organic matter.

Research conducted by Rahmadanti *et al.* (2019) indicates that the optimal temperature for composting Empty Fruit Bunches (EFB) using cellulolytic microorganisms is approximately 27.23°C. Discrepancies in the average composting temperatures may stem from variations in the compost materials' characteristics. Notably, materials like EFB and rice straw, due to their larger particle sizes, can enhance air circulation within the compost, leading to heightened temperatures generated by the heat released through this process.

Temperature fluctuations play an important role in microbial activity and oxygen availability. The rise in temperature stems from the heat produced by microorganisms engaged in decomposition, a process heavily reliant on oxygen consumption. The correlation between the rate of microbial oxygen absorption and temperature is direct; as oxygen consumption intensifies, temperature rises proportionally, and conversely, decreases as oxygen consumption diminishes.

pH

Essentially, the pH level interacts with the nitrogen conversion process during composting. Initially, the pH decreases as organic acids are released and ammonia evaporates in the early stages of decomposition. Subsequently, pH levels may rise due to organic material loss and mineralization. Towards the end of the composting process, the pH can become acidic due to the release of H+ ions during nitrification. The pH of compost is primarily influenced by the main ingredients and additives used. Additionally, temperature and humidity play crucial roles in determining the final pH of the compost.

The optimal pH level that complies with compost quality standards falls within the range of 6.70-7.49. A study by Gusmawartati & Sari (2023) demonstrates that the produced compost meets the quality criteria outlined in SNI: 19-7030-2004 with a pH level of 6.79. Additionally, Kurniawan & Gusmawartati (2021) observed a pH level of 8.06 in compost treated with a blend of cellulolytic microorganisms. This pH increase is attributed to the heightened microbial activity converting nitrogen organic compounds into ammonia and causing cations to neutralize the acids generated during composting.

Humidity

Humidity plays a crucial role in the activity of microorganisms as they rely on water for nutrient and energy transportation within cell membranes (Roman *et al.*, 2015). Additionally, optimal humidity levels are closely linked with temperature stabilization. Monitoring the temperature assists in determining the ideal time to aerate and dampen the compost pile. A humidity level below 30% can lead to compost dehydration, halting decomposition by microorganisms. Conversely, a humidity level exceeding 80% can create anaerobic conditions within the compost (Azim *et al.*, 2017). Therefore, maintaining optimal moisture levels is vital during composting. Razmjoo *et al.* (2015) discovered that the optimal humidity for the composting process ranges from 45% to 50%.

Organic Carbon

Organic carbon plays a vital role in the composting process by serving as an energy source for microorganisms, facilitating the breakdown of organic matter into simpler compounds. Total carbon comprises Total Organic Carbon (TOC) and inorganic carbon present in the form of carbonates and bicarbonates (Azim *et al.,* 2017). Throughout composting, the TOC content may decline as microorganisms metabolize organic materials to sustain their cellular functions, leading to the conversion of organic carbon into carbon dioxide (CO_2) through mineralization. This CO_2 is released through oxidation during composting, indicative of the microbial activity level in the process.

Research conducted by Gusmawartati & Sari (2023) revealed a 53% decrease in organic carbon during EFB composting when a consortium of cellulolytic bacteria was added, in comparison to the initial organic carbon levels. This decrease may be attributed to the addition of various cellulolytic bacteria types, which enable the production of complete enzyme complexes, enhancing the breakdown of cellulose by microbes. A study by Aini & Linda (2020) reported a 34.55% decrease in organic carbon after 30 days of composting following the introduction of a consortium of cellulolytic microorganisms. Additionally, Alfadlli *et al.* (2018) noted a reduction in organic carbon by up to 43.86% in their research. The organic carbon compost quality standard outlined in SNI: 19-7030-2004 specifies a range of 27% to 58%.

Nitrogen

Nitrogen in agricultural waste undergoes mineralization during composting, transforming into ammonium (NH^{4+}) and nitrate (NO^{3-}) through the process of nitrification. During this transformation:

- Some nitrogen is utilized in microbial metabolism to sustain organic material degradation.
- Some becomes part of the compost organic material in the humification process.
- Some is released as inorganic nitrogen.

In the final composting stage, nitrogen mineralization prevails, leading to an increase in NO^{3-} content, indicating maturity, and enhanced total nitrogen availability in the compost.

A study conducted by Gusmawartati & Sari (2023) indicated an increase in N-total during EFB composting by 1.96% with a consortium of cellulolytic bacteria, compared to 0.57% in the control over an 8-week composting period. This rise may be attributed to the heightened activity of cellulolytic bacteria breaking down organic matter, resulting in increased total N levels. Additionally, EFB composting with a consortium of local microorganisms yielded N-total levels of 1.27% after 60 days, in contrast to the control's 0.56% (Abdillah, 2021). Another study by Setiawati *et al.* (2019) demonstrated a 1.73% higher N-total production compared to the control in EFB composting.

4.2 Quality Parameters

Empirically, the quality of compost can be assessed by several key indicators related to its maturity. These include the absence of an ammonia odor, a temperature akin to that of groundwater, a dark color, lack of foul odors, and the ability to distinguish the various raw materials comprising the compost.

Physicochemical Characteristics

Research on compost quality primarily focuses on alterations in physicochemical parameters, including cation exchange capacity (CEC), C/N ratio, organic matter content, humification ratio, and pH (Albrecht, 2007; Azim *et al.*, 2017).

Cation Exchange Capacity

During the composting process, CEC typically rises alongside the development of humification in organic materials, resulting in the formation of carboxyl and phenolic functional groups (Wichuk & McCartney, 2013). Compost is deemed to have reached the maturation stage when its CEC content exceeds 60 meq.100 g^{-1} of organic material.

C/N Ratio

The C/N ratio serves as a fundamental parameter for evaluating compost maturity. Typically, this ratio decreases throughout the composting process, with a C/N ratio below 20 indicating well-matured compost. However, the final C/N ratio is contingent upon the initial material characteristics and the diverse microbial populations involved in composting. Research by Setiawati *et al.* (2019) demonstrated a 55.68% reduction in the C/N ratio of Empty Fruit Bunches (EFB) with the introduction of cellulolytic microorganisms, surpassing the reduction observed in sugarcane biomass. Furthermore, Gusmawartati & Sari (2023) noted a substantial decrease in the C/N ratio when employing a consortium of cellulolytic bacteria compared to individual strains. The average reduction in the C/N ratio over an 8-week composting period using a cellulolytic bacteria consortium was 86%, whereas it stood at 74% for single cellulolytic bacteria.

Humification Ratio

Humification is the breakdown and decomposition of organic matter and compost, leading to the creation of humus. Various studies indicate that the composting process results in an increase in the humic acid to fulvic acid ratio (HA/FA) (Huang *et al.*, 2006; Azim *et al.*, 2017). Literature findings show that the humification ratio remains consistently below 1 for immature compost and above 1-3 for compost in the ripening phase.

Biological Activity

Compost in its early stages, before maturation, demands substantial oxygen levels and produces notable amounts of carbon dioxide. The heightened microbial activity during this phase accelerates substrate biodegradation, resulting in a reduced requirement for oxygen compared to mature compost, which is more stable and less active (Azim *et al.*, 2017). This observation aligns with Siddiquee *et al.* (2016) research, indicating that the cellulolytic fungal activity peaked at 72.9% in the pre-maturation compost phase, gradually decreasing and stabilizing once the maturation phase commenced.

5. EFFECTIVENESS OF CELLULOLYTIC MICROORGANISMS

Soil functional microbes significantly contribute to the decomposition of organic matter derived from plant residues. This decomposition process, driven by microbes, occurs at varying rates dictated by the composition of the materials. Notably, materials like EFB, rich in cellulose compounds that are inherently resistant to decomposition, require the introduction of cellulolytic microorganisms to accelerate the breakdown process effectively (Zhang & Dong, 2022).

Cellulolytic microorganisms can either naturally grow or be intentionally introduced to accelerate the composting process. This is achieved by lowering the C/N ratio and cellulose content to enhance the compost's quality (Ejaz *et al.*, 2021). Numerous studies have investigated the use of cellulolytic microorganisms, particularly their ability to hasten the composting of organic materials rich in cellulose to enhance compost quality. Refer to ***Table 1*** for insights into the benefits and efficiency of incorporating cellulolytic microorganisms in EFB composting.

Table 1. Effectiveness of Cellulolytic Microorganisms

Cellulolytic Microorganisms	Effectiveness	References
Cellulolytic fungus (*Trichoderma* sp.)	• The adduction of cellulolytic fungi has the potential to decrease the C/N ratio by approximately 3.33% while elevating N-total by 0.91, P-total by 2.13, and K-total by 3.33 over a 28-day span. • The temperature at the completion of composting typically aligns closely with the groundwater temperature, hovering at approximately 24° C. • The anticipated total colony-forming units (CFU) of Trichoderma throughout the composting process are projected to reach 72.9%.	Siddiquee *et al.*, 2016
Consortium of Cellulolytic Bacteria and Fungi	• Application of a consortium comprising 4% cellulolytic bacteria and fungi has demonstrated the ability to decrease the cellulose content in Empty Fruit Bunches (EFB) to 64.92% from the initial 72.6% within a month. • Application of a consortium consisting of 2% cellulolytic bacteria and fungi has proven successful in reducing the Carbon-to-Nitrogen (C/N) ratio during EFB composting by 55.68%.	Setiawati *et al.*, 2019
Cellulolytic Bacteria Consortium (*Alcaligenes faecalis* strain KH-48, *Alcaligenes faecalis* strain ZJUTBX11, *Bacillus cereus* strain IARI-MB-6, *Bacillus cereus* strain TS11, *Bacillus cereus* strain Y22, *Bacillus sp.* S43, , *Bacillus sp.* 13847, and *Stenotrophomonas sp.* S169-III-5)	• The incorporation of a combination of cellulolytic bacteria and chicken manure has demonstrated the ability to diminish organic carbon levels by 34.5%, elevate total nitrogen content by 1.35%, and decrease the composting C/N ratio significantly to 25.56% from its initial value of 72.90% within a 30-day incubation period. • Following a germination assessment, the compost was deemed mature, devoid of phytotoxic effects, and found to be abundant in phytonutrients.	Aini & Linda, 2020
Cellulolytic Bacteria Consortium (*Bacillus subtilis* Strain C17, *Bacillus subtilis* Strain DSM 10, *Bacillus subtilis* Strain K43, *Bacillus subtilis* Strain SKUASIS, *Bacillus tequilensis* Strain RA 1402, and *Pseudomonas aeruginosa* Strain KUJM)	• The incorporation of a consortium of cellulolytic bacteria notably enhanced the compost quality, as evidenced by a C/N ratio of 17.28%, N-total content of 1.76%, P-total content of 0.32%, and K-total content meeting the SNI Compost Quality Standards (19-7030-2004). • Application of cellulolytic bacterial isolates led to a substantial increase in compost weight loss by 51.51% (a significant difference compared to the control, which experienced a weight loss of 15.55%), with the pH range of the compost measuring between 7.06 and 8.06.	Kurniawan & Gusmawartati, 2021

Cellulolytic Bacteria Consortium (*Bacillus subtilis* strain DSM 10, *Bacillus subtilis* strain K43, *Bacillus subtilis* strain C17, and *Pseudomonas aeruginosa* KUJM bacteria)	• Application of a consortium of cellulolytic bacteria into Empty Fruit Bunch (EFB) composting processes has shown the potential to enhance compost quality, aligning with the SNI Compost Quality Standard 19-7030-2004, while accelerating the maturation of the compost. • The effectiveness of this enhancement is evidenced by the compost temperature approaching the groundwater temperature of approximately 28°C, significant reduction in EFB volume by 70-80%, and the resulting compost displaying a dark brown hue resembling soil, accompanied by an earthy scent. • Application of a cellulolytic bacteria consortium can substantially lower the Carbon-to-Nitrogen (C/N) ratio to 12.44%, marking an impressive 85.83% reduction from the initial ratio over a 2-month period.	Gusmawartati & Sari, 2023
Consortium of Cellulolytic Bacteria and Fungi	Application a consortium comprising cellulolytic bacteria and fungi has the potential to decrease the C/N ratio by as much as 17.06% (from an initial ratio of 38.07%) and elevate the total nitrogen content by 1.73% within a month of composting.	Setiawati *et al.*, 2019
Cellulolytic Bacteria Consortium (*Bacillus subtilis* and *Bacillus cereus*)	The incorporation of a consortium of cellulolytic bacteria has the potential to decrease the C/N ratio of EFB composting by as much as 17% within a 25-day incubation period.	Zainal *et al*. 2018
Cellulolytic Microorganisms	• Capable of decreasing C/N levels by 74.6% from the original levels. • The combination between cellulolytic microorganisms and nitrogen successfully reduced the C/N ratio by up to 79.4%.	Sembiring, 2016

The efficacy of cellulolytic microorganisms can be assessed by their ability to reduce cellulose content and the C/N ratio in compost material. As noted by Richard (2008), one key metric for evaluating compost quality is the C/N ratio. This reduction is typically attributed to a decline in organic carbon levels resulting from microbial processes, while the proportion of total nitrogen remains relatively constant. During microbial consumption of organic carbon, a significant portion is converted to carbon dioxide, with the remainder being converted into nitrogen compounds. Organic carbon serves as the primary energy source for microorganisms during the decomposition of organic materials, facilitating the maintenance of protein as a fundamental component in cellular metabolism. An optimal C/N ratio for decomposition typically falls within the range of 30-40% (Azim *et al.*, 2017).

6. CHALLENGES AND FUTURE PROSPECTIVE

The potential of using cellulolytic microorganisms to enhance and expedite EFB composting is substantial. By incorporating these microorganisms, the C/N ratio of EFB can be decreased, accelerating decomposition and enhancing waste management efficiency in the palm oil industry (Shukor *et al.*, 2019). However, challenges may arise, such as the necessity to fine-tune composting conditions to ensure efficient cellulose degradation, especially when scaling up industrial operations. Factors like pH, temperature, substrate concentration, and cellulolytic microorganism composition require meticulous control to optimize compost production using EFB as a base material (Azim *et al.*, 2017). Further research is crucial to enhance the synergy between cellulolytic microorganisms and other elements in the EFB composting process, such as nutrients, moisture, and oxygen levels, which impact biological activity. Harnessing cellulolytic microorganisms in EFB composting could potentially steer agricultural practices towards environmental sustainability, mitigating adverse environmental effects.

CONCLUSION

The production of Empty Fruit Bunches (EFB) as a by-product of palm oil extraction is growing alongside the expansion of palm oil production. Inadequate EFB management can lead to harmful environmental consequences. It is crucial to investigate methods that utilize EFB for sustainable agricultural practices, such as composting. However, due to its high cellulose content, EFB poses challenges in breaking down. Hence, introducing cellulolytic microorganisms is needed to be able to accelerate decomposition, reduce the C/N ratio of EFB, and enhance the compost quality.

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