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ORIGINAL RESEARCH ARTICLE

Characterization and utilization of trichoderma sp. for efficient management of oil palm empty fruit bunch waste in plantations

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ABSTRACT

BACKGROUND AND OBJECTIVES: *Trichoderma* species (*Trichoderma* sp.) is commonly found in nature, particularly in soil and roots, often thriving in plants rich in cellulose such as oil palm. Therefore, this study aimed to characterize *Trichoderma* sp. in each substrate as well as to assess cellulolytic and ligninolytic potential in vitro using a specific medium. Characterization and utilization of the plant were examined to efficiently manage empty fruit bunch (EFB) waste in Indonesian oil palm plantations. By exploring the biological, ecological, and biochemical attributes of *Trichoderma* sp., this study examined the mechanisms associated with efficacy in bioconversion processes and waste remediation.
METHODS: A survey method was used to determine sampling locations, and purposive sampling was utilized in the field. Furthermore, several stages were undertaken including isolation, identification, as well as testing of morphology and potential in vitro.
FINDINGS: The results showed that the growth characteristics of *Trichoderma* sp. in filling a petri dish spanned approximately five days, forming colonies with a dark green hue. Microscopically, the isolates consisted of conidiophores, phialides, and conidia. Meanwhile, in vitro potential was assessed through cellulolytic and lignocellulolytic assays, with each isolate demonstrating varying capabilities in breaking down cellulose and lignocellulose. The highest cellulase activity (3.55 units per gram) was observed in enzyme starter granules treated with air drying. The highest viability per gram was found in spore inoculum (17.0 x 107) with air drying treatment. The greatest reduction in weight of oil palm EFB waste (65.3 percent) was achieved through the application of *Trichoderma* sp. enzyme starter granules with air drying treatment. Furthermore, eight isolates demonstrated cellulolytic and ligninolytic potential. Isolates sourced from soil had rapid growth on starter and baglog mediums, indicating potential for subsequent field applications as a biodegradation agent for organic waste.
CONCLUSION: Based on the macroscopic (shape and color of mycelium) and microscopic characteristics (mycelium form), a total of eight *Trichoderma* sp. isolates were obtained. During the potential test, it was observed each isolate had different cellulolytic and ligninolytic activities. This study provided valuable insights into the diversity and enzymatic potential of *Trichoderma* sp. fungi, underscoring the importance of selecting suitable strains and optimizing cultivation conditions for various biotechnological applications. By exploring cellulolytic and ligninolytic capabilities, the results contributed to the development of more efficient and sustainable strategies for organic waste management and bioconversion. In general, this study represented a significant milestone in the quest for sustainable waste management solutions in agriculture, offering a promising pathway towards mitigating environmental impact and promoting the long-term sustainability of oil palm cultivation.

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INTRODUCTION

The rise in global demand for oil palm is propelling Indonesia towards becoming the leading producer and exporter worldwide (Schouten *et al*., 2023). Although the significant economic growth contributes to national development, it has also raised a pressing environmental concern, namely the management of oil palm empty fruit bunch (EFB) waste (Obada *et al*., 2022). Oil palm industry generates vast quantities of waste, including EFB, which presents significant challenges in disposal and environmental impact (Kamyab *et al*., 2018). Conventional methods such as burning or landfilling contribute to air pollution, soil degradation, and greenhouse gas emissions, necessitating sustainable alternatives (Asadpour *et al*., 2021). The use of *Trichoderma* sp. formulations in the field not only increases the treatment of existing EFB waste, which traditionally decomposes in plantations but also accelerates the decomposition process. Considering the rise in annual production of oil palm reaching unprecedented levels, the accumulation of EFB waste poses significant challenges to sustainable waste management practices and environmental conservation efforts in Indonesian plantations. In agricultural sustainability and waste management, the utilization of microbial organisms has been discovered as a promising avenue, offering environmentally friendly and economically viable strategies for tackling agricultural waste. Recent years have witnessed a shift towards biological waste management strategies, leveraging the capabilities of microorganisms to degrade organic waste efficiently. In this context, *Trichoderma* species (*Trichoderma* sp.), a genus of fungi known for cellulolytic and ligninolytic activities, has been proposed as a promising candidate for bioconversion of lignocellulosic biomass, including oil palm EFB (Kamyab *et al*., 2017). Using *Trichoderma* sp. in oil palm plantations offers several practical applications and strategies to enhance waste management efficiency, composting, bioremediation, bioconversion to value-added products, soil amendment, integrated pest management, inoculant production, and distribution. By implementing these practical applications and strategies, oil palm plantations can effectively harness the potential to improve waste management efficiency, reduce environmental impact, and enhance overall sustainability. Advanced molecular and biochemical techniques have enabled detailed characterization of *Trichoderma* sp. strains, elucidating enzymatic profiles, genetic diversity, and metabolic pathways. This knowledge provides insights into the mechanisms underlying the ability to degrade complex organic compounds found in EFB. Biotechnological advancements, including genetic engineering and strain improvement techniques, are being explored to enhance the efficacy of *Trichoderma* sp. in EFB degradation. Strategies such as overexpression of cellulolytic enzymes and optimization of fermentation conditions hold promise for maximizing bioconversion efficiency. However, successful integration into oil palm waste management practices requires careful consideration of factors such as application methods, substrate composition, and environmental conditions. Studies have demonstrated the effectiveness of *Trichoderma* sp. inoculants in composting, bioremediation, and biofuel production from EFB. The adoption of *Trichoderma*-based waste management solutions offers multiple environmental and economic benefits, including reduced greenhouse gas emissions, improved soil fertility, and potential revenue generation from value-added products derived from EFB. Cost-benefit analyses indicate favorable returns on investment compared to traditional waste disposal methods. Despite the promising potential, several challenges remain, including scale-up issues, regulatory considerations, and public acceptance. Future study directions include optimization of fermentation processes, exploration of novel *Trichoderma* strains, and evaluation of synergistic microbial consortia for enhanced waste degradation. In this domain, *Trichoderma* sp., a group of ubiquitous filamentous fungi, has garnered significant attention for the multifaceted roles in plant growth promotion, disease suppression, and organic matter decomposition (Woo *et al*., 2023; Salazar *et al*., 2023). These fungi contribute to the decomposition and nutrient cycling of oil palm EFB waste due to the crucial enzymes including cellulase and lignocellulose (Kuthiala *et al*., 2022). Furthermore, the role of Indonesia in the global oil palm industry underscores the need for the management of EFB waste. As the global largest producer of oil palm, the country faces the dual imperative of maximizing productivity while mitigating the environmental impacts associated with waste disposal. In this context, harnessing the potential of *Trichoderma* sp. holds particular promise

for revolutionizing waste management practices (Ibrahim *et al*., 2023; Ramli *et al*., 2020). This study delves into the characterization of *Trichoderma* sp. to efficiently manage EFB waste in Indonesian oil palm plantations. By exploring the biological, ecological, and biochemical attributes of the fungi, the results offer insights into the mechanisms associated with efficacy in bioconversion processes and waste remediation. A comprehensive exploration of interactions with EFB waste substrates was also conducted to uncover the potential for *Trichoderma*-mediated decomposition and nutrient recycling, thereby transforming EFB waste into valuable resources. The implications of harnessing *Trichoderma* sp. for sustainable bioconversion and waste management extend beyond the confines of agricultural practice (Iqbal *et al*., 2023; Blasi *et al*., 2023; Srivastava *et al*., 2023). By promoting the circular economy model in which waste is repurposed as a resource, *Trichoderma*-based strategies have the potential to alleviate the environmental burden associated with conventional waste disposal methods (Archana *et al*., 2022; Organo *et al*., 2022). Moreover, by enhancing soil health and fertility through organic matter decomposition, *Trichoderma* sp. can contribute to the long-term sustainability of oil palm plantations, fostering resilience against environmental stressors and promoting ecosystem integrity (Aslam *et al*., 2022; Sofo *et al*., 2022). A synthesis of microbiological, agronomic, and environmental perspectives provided a holistic understanding of transforming EFB waste management practices in Indonesian plantations (Bolan *et al*., 2023; Rather *et al*., 2023; Anand *et al*., 2022). This study offers actionable insights that empower stakeholders in oil palm industry to adopt sustainable and ecologically sound waste management strategies by bridging the gap between fundamental investigations and practical applications. Furthermore, the characterization and utilization of *Trichoderma* sp. represent a paradigm shift toward a greener, more resilient, and economically viable future for Indonesian oil palm plantations. The biological and ecological attributes of the fungi facilitate sustainable bioconversion processes and enhance waste management practices. This study not only intends to advance current understanding of microbial-mediated waste management but also offers practical solutions that promote sustainable practices in the Indonesian oil palm industry. The potential of *Trichoderma* sp. can foster a paradigm shift towards more efficient, eco-friendly, and economically viable methods for EFB waste utilization, thereby paving the way for a greener and more sustainable future (Fig. 1). Using fungi for efficient management of oil palm EFB waste represents a cutting-edge approach to addressing the environmental challenges associated with oil palm production. By harnessing the biotechnological potential, transforming waste into a valuable resource becomes easy, contributing to the sustainability of oil palm industry and mitigating the environmental footprint. The experiment in this study was conducted in the Microbiology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Andalas University, Indonesia, from 2023 to 2024.

MATERIALS AND METHODS

Sample collection and preparation

Samples of palm oil mill effluent (POME) were collected from *Tidar Kerinci Agung* (TKA) Ltd, a

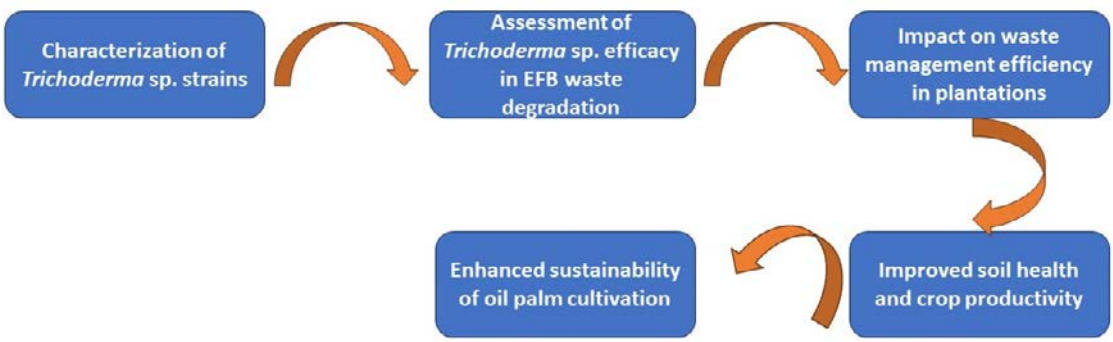


Fig. 1: Characterization and utilization hypothesis of *Trichoderma* sp. for efficient management of oil palm EFB waste in plantations



Fig. 2: Geographical location of the study area in West Sumatra Province, Indonesia

Table 1: Nutrients in oil palm EFB (Uke *et al*., 2023)

Nutritional content Percent (%)						Nutritional content milligram per liter (mg/L)			
N	P	K	Mg	Ca	Cl	B	Cu	Zn	Mn
0.80	0.07	2.15	0.14	0.21	0.33	13	44	33	15

private limited company located in Dhamasraya Regency, Indonesia, and *Rimbo Panjang Sumber Makmur* (RSPM) Ltd, located in West Pasaman Regency (Fig. 2). Processing was carried out in the Microbiology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Andalas University, Padang, Indonesia.

Oil palm EFB represents a significant portion of the solid waste generated by the industry (Osman *et al*., 2019). The nutritional content of oil palm EFB (Uke *et al*., 2023) is presented in Table 1.

Isolation of Trichoderma sp. mold on potato dextrose agar (PDA) medium

Oil palm substrate collected comprised EFB, midribs, stems, and surrounding soil, totaling 10 grams (g), which had been crushed and placed into a bottle sanitized with 70% alcohol. Subsequently, 90 milliliter (mL) of sterile water was added, followed by shaking for 1 minute to extract hyphae and spores. This process was then carried out using a multilevel dilution method. Fungi colonies growing separately or individually were observed and promptly transferred under aseptic conditions to another petri dish containing PDA medium (Matas-Baca *et al*., 2022).

Purification of Trichoderma sp. isolate

Each growing colony was promptly purified by isolating on PDA medium in a petri dish, followed by an incubation period at 28 degrees Celsius (°C) for 2-7 days (Elsayed *et al*., 2023). Purified colonies were transferred to test tubes containing slanted PDA medium and stored as culture stocks in readiness for further testing.

Characterization of mold Trichoderma sp.

Characterization of *Trichoderma* sp. mold was conducted using PDA medium. Macroscopic characteristics such as colony color and surface appearance were observed, while microscopic

examination comprised mycelium, spore morphology, and spore arrangement (Senayake *et al*., 2020).

Propagation of Trichoderma sp. isolates

Isolates of the mold *Trichoderma* sp. for degrading EFB waste were obtained through the isolation of oil palm EFB, fronds, stems, and the surrounding soil. Subsequently, propagation was carried out on PDA medium, and the culture was stored in a dry location at room temperature (Campos *et al*., 2020).

Production of spore-based granules and enzyme root granules

The sterilized and cooled baglog was inoculated with spores from two parent seeds and placed onto the surface of the sterile baglog medium. Incubation was then carried out at room temperature until the mycelium of *Trichoderma* sp. filled the contents. After the baglog medium was fully colonized by *Trichoderma* sp. mycelium, the entire plastic surface was pierced with a fine needle. Baglog was then placed in a standing position and stored in a clean room away from direct sunlight, at a temperature of 22-28°C. Following this, the baglog was left for 7 days until the entire surface of the medium turned greenish blue. Once the medium had fully become a starter, it was removed from the plastic bag, air-dried, and prepared for product manufacturing. For the filler material, 5% cassava flour was added to the spore source and stirred until a smooth (homogeneous) consistency was reached. Molding into granules measuring 4-5 millimeters (mm) was then carried out using a meat grinder (Spore-Based Granules), and subsequently pressed into tablet-shaped granules measuring 2-3 centimeters (cm) using a pipe (Enzyme Root Granules). The formed granules were dried using oven drying, sun drying, and aeration. Finally, the spore source was ready for testing (Saldaña-Mendoza *et al*., 2020).

Characteristics and in vitro potential of Trichoderma sp.

In vitro characteristics and potency observations were carried out using a specific medium (cellulolytic and lignocellulolytic). These observations were performed macroscopically (Leiva *et al*., 2020).

Cellulase activity assay

Cellulase activity was assessed using dried spores and enzyme starter granules. A 10 g sample was taken and placed into a glass vessel, then supplemented with 0.05 molars acetate buffer at potential of hydrogen 5, with a volume up to 50 mL. Subsequently, the sample was centrifuged at 1000 revolutions per minute (rpm) for 5 minutes, and the resulting supernatant was collected (Wei *et al*., 2021).

Cellulase activity of spore-based granules and enzyme sources

Cellulase activity of spore and enzyme-forming agents was measured by calculating the sugar content of the product in each type of drying technique using the Somogy-Nelson method with carboxy methyl cellulose (CMC) agar as a substrate. The absorbance was measured using a spectrophotometer with a wavelength of 540 nanometers (nm) (Rodrigues *et al*., 2023).

Potential of hydrogen (pH)

pH value was determined by weighing 1 g of spore-bearing and 1 g of enzyme-bearing granules separately and adjusting the volume to 10 mL by adding distilled water. Measurement was carried out using a Corning Pinnacle 530 digital pH meter previously calibrated with pH 4 and 7 buffer solutions. The electrode was rinsed with sterile distilled water, cleaned with a tissue, and then immersed into the sample. The numerical reading on the digital pH meter represents pH value of the sample used (Kubeneck *et al*., 2023).

Growth rate of Trichoderma sp.

The growth rate of *Trichoderma* sp. on baglog medium was observed from the time required for the mold mycelium to grow evenly in the medium down to the bottom. Measurements were made using a ruler vertically on the side of baglog once every day (Matas-Baca *et al*., 2022).

Reducing the weight of oil palm EFB waste

To determine the weight reduction of EFB waste, the initial weight of waste was measured and then subtracted from the final weight after treatment with spore and enzyme starter, followed by composting for 2 weeks (Suhartini *et al*., 2023).

RESULTS AND DISCUSSION

Characteristics and in vitro potential of Trichoderma sp.

The mold used for degrading EFB waste was

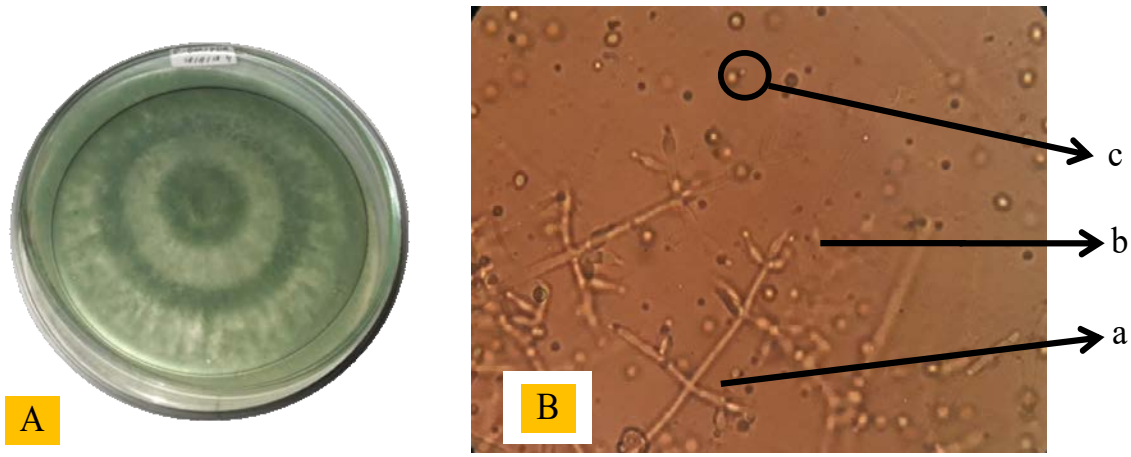


Fig. 3: *Trichoderma* sp.. (A) Macroscopic; (B) Microscopic (10 x 100 magnification). Description: (a) Conidiophores; (b) Fialid; (c) Conidia

isolated from various sources including oil palm EFB, fronds, stems, and the surrounding soil at two locations namely TKA Ltd, and RSPM Ltd. From TKA, four isolates were obtained namely T-DM (soil around Dhamasraya oil palm trees), B-DM (Dhamasraya oil palm trunk), P-DM (Dhamasraya oil palm fronds), and TK-DM (empty coconut bunches from Dhamasraya oil palm). Meanwhile, from RSPM, four isolates were obtained namely T-P (soil around Pasaman oil palm trees), B-P (Pasaman oil palm stems), P-P (Pasaman oil palm fronds), and TK-P (Pasaman oil palm EFB). Eight isolates of *Trichoderma* sp. were observed on PDA medium, both macroscopically (mycelium color) and microscopically (colony shape), as depicted in Fig. 3.

Based on Fig. 3A, the color of *Trichoderma* sp. mycelium on PDA medium initially appeared white, then light green, and finally transitioned to dark green. Additionally, on full growth, white and dark green fruiting bodies were formed, resembling encircled rings. Colonies grown on PDA medium took 3 to 4 days to completely cover a petri dish (90 mm). According to previous reports, achieving a 90 mm diameter may take up to 5 days. Growth rate of *Trichoderma* sp.. mold is influenced by carbon (C) source present in growth medium (Abuhena *et al*., 2022). Glucose is one of the C sources most supportive of growth (López *et al*., 2022). As shown in Fig. 3B, microscopic observations showed that *Trichoderma* sp. mold had branched conidiophores. The conidia possess phialides, and the apex has slightly shorter dimensions. *Trichoderma* sp. typically has 2-4 short-sized phialides but others may also have longer dimensions (Kubiak *et al*., 2022). Fungi features a single, elongated phialide, with a wide dimension in the middle. Phialides commonly appear mostly in conidiophore clusters (Jambhulkar *et al*., 2022) with a smooth, round shape and are scattered in the growth medium. Furthermore, the conidia are typically round to oval-shaped, with thin walls. In vitro test was conducted using specific medium to observe cellulase and lignocellulase produced by *Trichoderma* sp. mold. The potential lignocellulase activity was assessed using PDA medium supplemented with 0.1% tannic acid. Lignocellulase potential was confirmed by the formation of brown zones beneath and around the mold colonies. Meanwhile, cellulolytic test was conducted on a specific medium, CMC agar, to determine the ability of *Trichoderma* sp. isolates to produce cellulase. This was indicated by the formation of clear zones around the colonies, which became visible when stained with 0.1% congo red. Cellulolytic and lignocellulolytic strength of *Trichoderma* sp. mold is presented in Fig. 4.

The mold showed capability in expressing lignocellulolytic enzymes crucial for degrading lignocellulosic waste. The specific medium for lignocellulolytic activity is PDA medium modified with the addition of 0.1% tannic acid (Peña-Lucio *et al*., 2022) which has a molecular structure similar to lignin. Characteristics of molds capable of degrading lignin include the formation of brown zones,

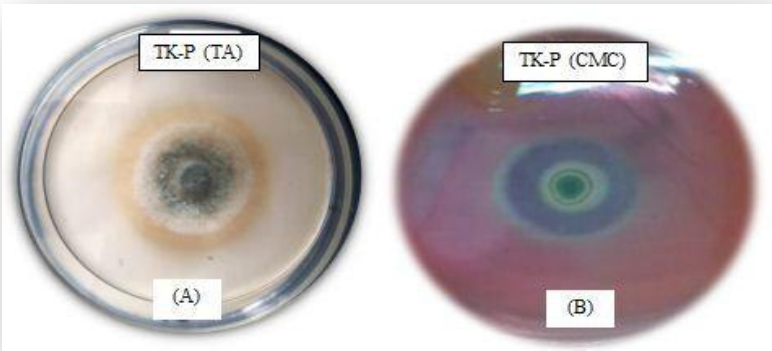


Fig. 4: *Trichoderma* (TK-P Isolate) Potential in vitro (A) PDA Medium plus Tanat Acid 0.1% (B) CMC Medium and Congo Red 0.1%

indicating the presence of phenol oxidase activity (Daly *et al*., 2021). Isolates of *Trichoderma* sp. mold obtained were further subjected to index calculation to assess lignin-degrading ability in vitro. The index calculation was performed by determining the ratio of lignocellulase activity of the mold. This refers to the ratio between the diameter of the brown zone formed and the mold colony (Sharapova, 2023). Meanwhile, to assess the effectiveness of using cellulose in medium containing lignocellulose, the strong bond between hemicellulose and cellulose poses a barrier in the hydrolysis process. As shown in Fig. 3, *Trichoderma* sp. mold produced cellulase enzymes and effectively degraded cellulose. Cellulase enzymes produced break down complex molecules into simpler ones. Cellulase enzyme activity can be observed using specific medium such as CMC medium, cellulose derivative that readily dissolves in water. This compound provides a carbon source for mold growth and also supports the detection of cellulase activity (Hadimani *et al*., 2023). Fig. 4 shows the lignocellulolytic and cellulolytic indexes obtained based on the ratio of clear or brown zones to colony diameter. Cellulolytic and ligninolytic activity ratios varied among the eight isolates, indicating potential differences in the origin of the inoculum (Fig. 5). Fungi mycelium forming the largest clear zone indicates higher cellulase enzyme activity (Naher *et al*., 2021). The clear zone serves as the initial indicator of enzyme effectiveness in fungi. The larger the potential of cellulase produced by these microbes, the greater the clear zone produced (Asghar, & Kataoka, 2021). Additionally, *Trichoderma* also demonstrates ligninolytic activity, indicating the potential to degrade lignin-containing waste. The isolation of lignin-degrading fungi, including species from the genera *Aspergillus, Penicillium, Trichoderma, Scopulariopsis, Fusarium,* and *Aureobasidium* has been previously reported (Musa *et al*., 2018). The differences in degradation ratios are attributed to the specific abilities of each mold isolate in the given growth medium.

Factors influencing cellulolytic and ligninolytic activity produced by *Trichoderma sp.* include substrate composition (nutrition) and environmental parameters such as temperature, humidity, and pH. Microbial abilities, including enzyme production, are influenced by the nutrients present in the medium (Zhang *et al*., 2022). Water content and pH are significant factors affecting microbial potential. Lower water levels lead to decreased enzyme activity, while higher water content culminates in increased enzyme activity (Cui *et al*., 2020). The enzymatic remodeling process requires cellulase, which plays a crucial role in restructuring cellulose by hydrolyzing the β-1,4-glycosidic bonds in cellulose chains and the derivatives. Cellulolytic enzymes comprise three main groups, namely endo-β-1,4-glucanase, exo-β-1,4-glucanase, and β-glucosidase. These enzymes work together to randomly hydrolyze amorphous portions of cellulose fibers, yielding oligosaccharides of varying lengths and forming new cellulose chains (Li *et al*., 2024).

Growth of Trichoderma sp. *on baglog medium*

Growth of *Trichoderma* sp. occurs through the

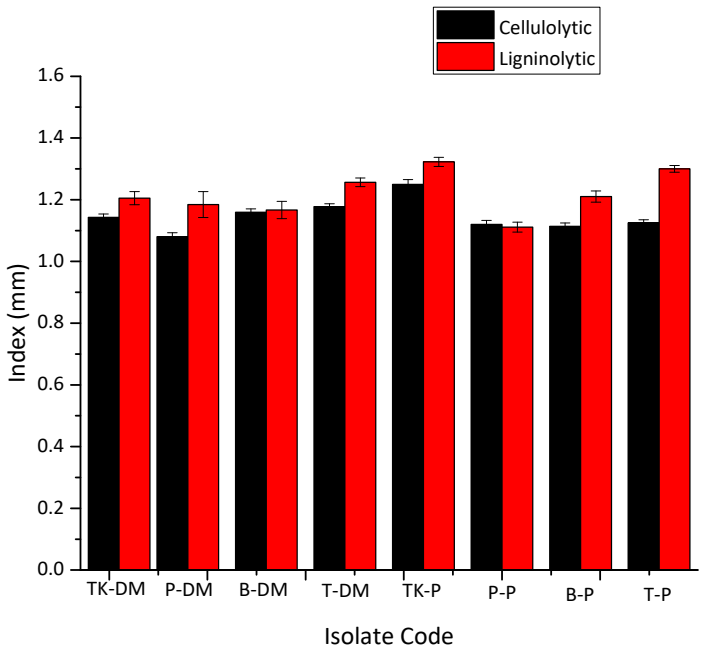


Fig. 5: Cellulolytic and Ligninolytic Index of 4 *Trichoderma* sp. isolates in a specific medium.

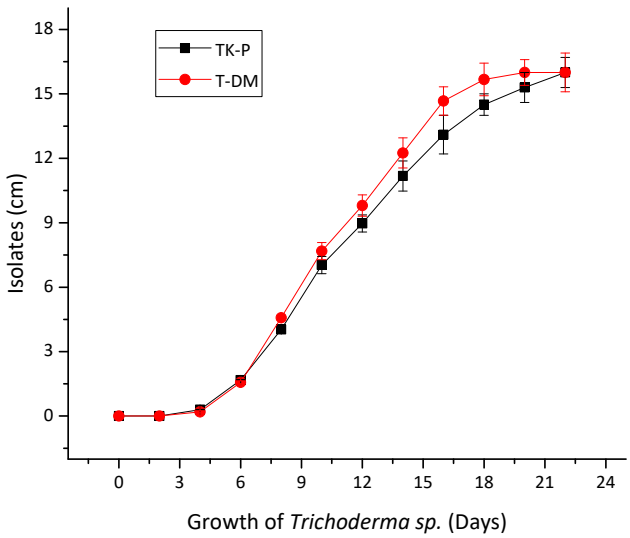


Fig. 6: The growth *Trichoderma* sp. isolate TK-P and T-DM on baglog medium

development of mycelium, which absorbs the necessary nutrients by using cellulase to break down cellulose into simple sugars present in baglog medium comprising sawdust and bran. The breakdown of cellulose into simple sugars serves as a source of growth. Observations to assess mycelium growth entail measuring the rate of mycelium expansion until it fills the vertical side of baglog (Fig. 6).

The growth of *Trichoderma* sp. mold mycelium initiates on day 5 post-inoculation. During the first week, growth was slow, attributed to the mold's adaptation to baglog medium. Furthermore, the composition and nutrients present in sawdust and bran provided favorable conditions for stimulating

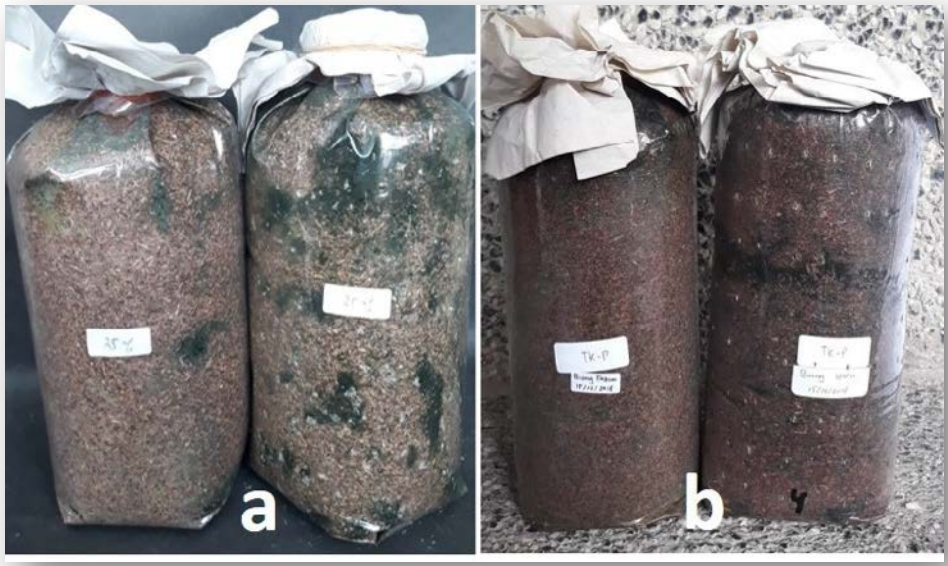


Fig. 7: Mycelium growth of *Trichoderma* sp. isolates T-DM (a) and isolates TK-P (b) on baglog medium

mycelium growth. In the second week, mycelium growth of T-DM isolates demonstrated a rapid increase compared to TK-P isolates. This surge was driven by the ample nutrients in the medium, enabling mycelium to grow at maximum speed. The second week also witnessed optimal mold mycelium growth compared to the initial observation week. By the third week, the mycelium has colonized baglog medium in depth. T-DM isolates took a total of 18 days post-inoculation to fill baglog, with mycelium reaching a length of 160 mm, while TK-P isolates achieved this 19 days after inoculation. Factors influencing the growth of *Trichoderma* sp. mold include substrate nutrients, temperature, pH, aeration, and humidity. Based on the observation, the combination of substrates including bran and sawdust medium can stimulate the growth and activity of *Trichoderma* sp. mold mycelium. The substrate in the medium plays a crucial role in supporting growth, leading to more optimal rates. Before using the medium for fungi growth, fermentation must first be carried out. The process simplifies complex compounds, making it easier for fungi to absorb nutrients present in the medium (Cheng *et al*., 2023). Moreover, moisture and aeration are additional factors significantly influencing the growth of *Trichoderma* sp. mold. This is evident in the even distribution of mycelium in baglog, both on the sides and at the bottom (Fig. 7).

The composition of baglog medium, namely bran, and sawdust, significantly influenced the growth of mold mycelium, with these materials serving as nutrients for *Trichoderma* sp. mold. The nutrient content provided by the substrate or medium is a critical factor affecting mold growth (Ali *et al*., 2023). Sawdust contains essential C elements that play a vital role in mold mycelium growth. Additionally, sawdust is rich in cellulose and hemicellulose, making it an ideal substrate for mushroom growth. Fungi use cellulose and hemicellulose as sources of nutrition. The process entails decomposing these compounds into simpler components, namely glucose and water, used by fungi as a source of nutrition (Nag *et al*., 2024). *Trichoderma* sp. mycelium growth is also influenced by the addition of bran, which contains essential nutrients such as carbohydrates (27.01%), phosphorus (P) (0.69%), potassium (K) (1.92%), and nitrogen (N) (0.65%) (Elsayed *et al*., 2023). Bran further contributes to reducing pH value of the substrate. pH decrease is attributed to fermentation, where starch is rapidly broken down into sugar absorbed by fungal mycelium. However, not all sugar is absorbed by mycelium, leading to the conversion of some into acid. The rich nutritional content and cost-effectiveness of bran make it an ideal medium (Amara

Table 2: Recapitulation of enzyme and spore starter granules of *Trichoderma* sp. (T-DM) with 3 drying methods

Granules	Drying Treatment	Spore Viability/g ($x10^7$)	pH	Cellulase Activity (u/g)	Reducing Waste Weight (%)
Spore Source	Wind Dry	17.0	4.8	2.53	63.8
	Sun Dry	15.0	5.2	2.33	62
	Oven Dry	11.7	5.2	1.40	61.5
Enzyme Factors	Wind Dry	10.7	4.7	3.55	65.3
	Sun Dry	10.7	5.5	3.43	62.5
	Oven Dry	7.3	5.9	2.75	59.9

& El-Baky, 2024). Water content also significantly influences the growth of *Trichoderma* sp. mold, with the optimal water value in baglog typically ranging from 50% to 75%. In general, water levels exceeding 75% can lead to a decrease in enzyme activity (Elsayed *et al*., 2023). This is supported by Elsayed *et al*., (2023), suggesting that the ideal water content falls in the range of 50% to 70%. Both high and low water content can have substantial effects on the growth of *Trichoderma* sp. mold. Based on the viability test, the highest viability was observed in the spore starter granules compared to the enzyme. This is because the spore starter granules contain a higher concentration of spores, while the enzyme starter granules contain fewer spores due to the reliance on mycelium for sporulation. Both spore and enzyme starter granules of *Trichoderma* sp. isolate T-DM were subjected to three drying treatments namely air, sun, and oven drying. The most effective method for spore starter granule viability was air drying, yielding the highest spore count at 17.0 x 10^7 spores per gram (spores/g), compared to sun drying and oven drying. As for enzyme starter granules, the best methods were air and sun drying, with a spore count of 10.7 x 10^7 spores/g, surpassing the oven drying method (Table 2). *Trichoderma* sp. molds can produce cellulase that effectively degrades cellulose into simple sugars in large quantities. Based on Table 2, the enzyme starter granules had higher cellulase activity compared to spore. Cellulase activity obtained from both granules was higher in the air drying treatment, with values of 3.55 unite per gram (u/g) and 2.53 u/g for spore and enzyme starter granules, respectively. Meanwhile, for spore starter granules, sun and oven drying produced 2.33 u/g and 1.40 u/g, respectively. For enzyme starter granules, sun and oven drying treatment produced cellulase activity values of 3.43 u/g and 2.75 u/g. Drying methods can influence the enzyme activity produced, with the most effective being air and sun drying. This is because the temperature during drying is optimal for the enzyme activity produced. The ideal temperature for enzyme activity is between 27°C and 35°C, as indicated by Islam *et al*., (2023). Sun drying has drawbacks, attributable to neven drying and unpredictable temperature fluctuations above 35°C. Moreover, sunlight utilization is less effective due to unpredictable weather conditions, leading to sudden temperature changes. Improper drying processes, excessively long or short drying times, uneven drying, and sudden temperature changes can cause certain chemical changes, as stated by Nag *et al*., (2023). Oven drying method produces low cellulase activity due to the high temperature (40°C), which disrupts enzyme performance. Temperature plays a crucial role in enzyme activity, as high levels can alter protein conformation, hindering reactive groups (Li *et al*., 2023). pH values of spore and enzyme starter granule products under air, sun, and oven drying treatments ranged between 4.7 and 5.9 as shown in Table 2. Extremely high or low pH levels can inhibit the growth of *Trichoderma* sp. molds. According to Elsayed *et al*., (2023), the optimal pH for mold growth is typically between 4 and 7. Based on the results, the weight reduction of EFB waste using enzyme starter granules was higher compared to spore starter granules. Both granules with three drying treatments showed significant results. For the air drying treatment, both enzyme and spore starter granules had the highest weight reduction values, namely 65.3% and 63.8%, respectively. The weight reduction was closely related to the growth of *Trichoderma* sp. mycelium on the substrate.

The quality of compost produced from oil palm EFB waste can be determined by calculating carbon-to-nitrogen (C/N) ratio. Islam *et al*., (2023) also stated that C/N is one of the indicators of compost quality

Table 3: C/N ratio values for oil palm EFB waste with spore and enzyme root granules in the air-dry treatment

Granules	Parameter	Initial EFB (%)	Compost (%)	Indonesian National Standards Minimum	Maximum
Spore source	C	30.15	21.37	9.80	32
	N	0.99	1.34	0.40	-
	C/N	30.45	15.95	10	20
Enzyme factors	C	30.15	15.84	9.80	32
	N	0.99	1.43	0.40	-
	C/N	30.45	11.08	10	20

Table 4: Comparison of results on management of oil palm EFB waste

Microorganisms	Results	Sources
Cellulolytic fungi (*Trichoderma* sp.)	By harnessing the microbial decomposition process occurring during composting, nutrients trapped in oil palm fiber can be released and transformed into forms that are more readily available to plants, thereby improving soil structure, strengthening root growth, and optimizing nutrient uptake efficiency by plants.	Oktaviani *et al*., 2024
A consortium comprising cellulolytic bacteria and fungi.	The results underscore the potential of microbial inoculation to enhance the decomposition of organic materials and promote sustainable agricultural practices.	Setiawati *et al*., 2019
Bacillus subtilis strain Deutsche Sammlung von Microorganismen 10 (DSM 10)	The results demonstrate the potential of cellulolytic bacteria in optimizing EFB composting, consistent with compost quality standards and facilitating sustainable waste management practices.	Gusmawartati and Sari, 2023
Microbes that degrade cellulose	The study provides valuable insights for optimizing the utilization of solid waste from oil palm mills, enhancing compost quality, and minimizing fertilizer costs in agricultural practices.	Sakiah and Sembiring, 2016
Bacillus subtilis S11Y	The results underscore the potential of biological pretreatment to enhance the efficiency and quality of renewable energy sources derived from lignocellulosic biomass waste.	Koesoemadinata *et al*., 2021
Cellulolytic and lignocellulolytic fungus *(Trichoderma* sp.)	This study provides valuable insights into the diversity and enzymatic potential of *Trichoderma* sp. fungi, contributing to the development of more efficient and sustainable strategies for organic waste management and bioconversion processes.	This study

and maturity. The decomposition process entailed in composting requires organic C for energy and growth fulfillment, while N was used for protein synthesis as a building block for cell metabolism. The most effective C/N ratio for the composting process typically ranges from 30 to 40. Microorganisms break down C compounds as an energy source and use N for protein synthesis. Therefore, it is necessary to calculate C/N ratio in the initial substrate before application and after harvesting. Measurement was only conducted on samples showing the best results based on the weight reduction of EFB waste using spore and enzyme starter granules, with the best results obtained from the air drying treatment.

Table 3 shows C/N ratio values of the composted EFB waste with the application of spore and enzyme starter granules after 2 weeks. The best C/N ratio value was achieved with the application of enzyme starter granules at 11.08%, while spore starter granules yielded 15.95%. According to a previous study, the value typically ranges between 10% and 20% (Xu *et al*., 2020). A high ratio in compost raw materials can lead to a slower composting process. C/N ratio comprises the values of organic C and N,

with N playing a crucial role in the decomposition of compost materials and the development of microorganisms (Asgar *et al*., 2021). During the composting process, C/N ratio tends to decrease, which is caused by several factors including the maturity of fertilizers and compost materials used. The reduction in organic C values is due to mature compost that experiences continuous decomposition, leading to an increase in N content with the formation of ammonia released into the air (Islam *et al*., 2023). This decrease is caused by the activity of microorganisms that use C compounds as an energy source for the composting process. Additionally, the decrease in organic C compounds leads to an increase in N compounds during composting. After complete degradation, organic materials produce a certain amount of protein and amino acids that break down into ammonium (NH_4^+) or nitrate (NO_3^-), leading to significant protein synthesis (Asgar *et al*., 2021). A comparison of the results of managing palm oil EFB waste using various types of microorganisms is presented in Table 4.

CONCLUSION

In conclusion, the growth characteristics of *Trichoderma* sp. in filling a petri dish take approximately 5 days, showing colonies with a dark green hue. Microscopically, the isolates consist of conidiophores, phialides, and conidia. In vitro potential of *Trichoderma* sp. consists of cellulolytic and lignocellulolytic assays, with each isolate demonstrating varying capabilities in breaking down cellulose and lignocellulose. The highest cellulase activity (3.55 U/g) was observed in enzyme starter granules, while the highest viability per gram was found in spore inoculum (17.0×10^7) with air drying treatment. The greatest reduction in weight of EFB waste (65.3%) was achieved through the application of *Trichoderma* sp. enzyme starter granules with air drying treatment. Furthermore, eight isolates obtained demonstrated cellulolytic and ligninolytic potential. Isolates sourced from soil showed rapid growth on starter and baglog mediums, indicating potential for subsequent field applications as a biodegradation agent. Based on the macroscopic (shape and color of mycelium) and microscopic characteristics (mycelium form), a total of eight isolates were obtained. This initial categorization underscores the diversity in *Trichoderma* sp., suggesting potential differences in biochemical capabilities. Subsequent in vitro testing using a specialized medium was carried out to evaluate cellulolytic and ligninolytic activities. The results showed significant variations in enzymatic activity across the isolates, indicating diverse capabilities in breaking down cellulose and lignin. This diversity underscores the importance of selecting appropriate *Trichoderma* strains for specific biotechnological applications, depending on the desired enzymatic activities and target substrates. The results suggest that certain *Trichoderma* sp. isolates may show superior cellulolytic or ligninolytic potential compared to others, potentially due to genetic variations or environmental factors influencing enzymatic machinery. Variability in enzymatic activity suggests the need for thorough screening and selection processes when harnessing *Trichoderma* sp. for industrial or environmental purposes, ensuring optimal performance and efficiency in biodegradation processes. Moreover, this study emphasizes the importance of tailored cultivation and treatment methods to enhance the enzymatic potential of isolates. For instance, the isolate demonstrating the highest cellulase activity when subjected to air drying treatment indicates the potential for optimizing cultivation conditions to maximize enzyme production. These insights into cultivation and treatment strategies could significantly enhance the efficacy of *Trichoderma*-based biodegradation processes, particularly in the management of organic waste materials such as EFB. The variability in enzymatic activity underscores the need for thorough screening and selection processes when using *Trichoderma* sp. for industrial or environmental purposes. Valuable insights were also provided into the diversity and enzymatic potential of *Trichoderma* sp. fungi, emphasizing the importance of selecting suitable strains and optimizing cultivation conditions for various biotechnological applications. By elucidating cellulolytic and ligninolytic capabilities of different *Trichoderma* sp. isolates, the results contribute to the development of more efficient and sustainable strategies for organic waste management and bioconversion processes. This study provides valuable insights into the diversity and enzymatic potential of *Trichoderma* sp. fungi, contributing to the development of more efficient and sustainable strategies for organic waste management and bioconversion processes.

AUTHOR CONTRIBUTIONS

N. Nurmiati, the corresponding author, contributed to supervising the first author in collecting data, analyzing data, and interpreting the results. P. Periadnadi drafted or wrote the manuscript, study design, execution, acquisition of data, analysis, and interpretation. K. Kartiwan prepared test data and images and interpreted the results. T.W. Edelwis participated in the interpretation of the results and manuscript preparation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this manuscript. In addition, ethical issues, including plagiarism, informed consent, misconduct, data fabrication or falsification, double publication or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS	DEFINITION
%	Percent
°C	Degree Celsius
NH_4^+	Ammonium
C	Carbon
C/N	Carbon-to-nitrogen
CMC	Carboxy methyl cellulose
cm	Centimeter
DSM10	Microorganismen 10
EFB	Empty fruit bunch
et al.	And others
Fig.	Figure
g	Gram
Ltd	Private limited company
mg/L	Milligram per liter
mL	Milliliter
mm	millimeter
M	molars
N	Nitrogen
NO_3^-	Nitrate
nm	Nanometer
PDA	Potato dextrose agar
pH	Potential of hydrogen
rpm	Revolution per minute
RSPM	Rimbo Panjang Sumber Makmur
sp.	Species
spores/g	spores per gram
TKA	*Tidar kerinci agung*
U/g	Units per gram

REFERENCES

Abuhena, M.; Kabir, M.G.; Azim, M.F.; Al-Rashid, J.; Rasul, N.M.; Huq, M.A., (2022). A stressing method for producing high-density *Trichoderma* spores in a dual-layer by utilizing a starch-based medium in a reconditioning approach. Bioresour. Technol. Rep., 19: 101165 **(13 pages).**

Ali, U.; Anwar, Z.; Hasan, S.; Zafar, M.; Ain, N.U.; Afzal, F.; Eljeam, H.A.R.A., (2023). Bioprocessing and screening of indigenous wastes for hyper production of fungal lipase. Catalysts. 13(5): 853-863 **(11 pages).**

Amara, A.A.; El-Baky, N.A., (2023). Fungi as a source of edible proteins and animal feed. J. Fungi. 9(1): 73-82 **(10 pages).**

Anand, U.; Pal, T.; Yadav, N.; Singh, V.K.; Tripathi, V.; Choudhary, K.K.; Singh, A.K., (2023). Current scenario and future prospects of endophytic microbes: promising candidates for abiotic and biotic stress management for agricultural and environmental sustainability. Microbiol. Ecol., 86(3): 1455-1486 **(32pages).**

Archana, H.R.; Darshan, K.; Lakshmi, M.A.; Ghoshal, T.; Bashayal, B.M.; Aggarwal, R., (2022). Biopesticides: A key player in agro-environmental sustainability. Trends Appl. Microbiol. Sustainable Econ., 613-653 **(41 pages).**

Asadpour, R.; Yavari, S.; Kamyab, H.; Ashokkumar, V. Chelliapan, S.; Yuzir, A. (2021). Study of oil sorption behaviour of esterified oil palm empty fruit bunch (OPEFB) fibre and its kinetics and isotherm studies. Environ. Technol. Innov., 22: 101397 (**8 pages**).

Asghar, W.; Kataoka, R., (2021). Effect of co-application of *Trichoderma* spp. with organic composts on plant growth enhancement, soil enzymes and fungal community in soil. Arch. Microbiol., 203(7): 4281-4291 (**11 pages**).

Aslam, A.A.; Shamim, M.; Nazir, M.S.; Ishtaiq, M.; Akhtar, M.N.; Ali, Z.; Abdullah, M.A., (2022). Applications of microbes in soil health maintenance for agricultural applications. Appl. Microbes Environ. Microbiol. Biotechnol., 365-399 (**35 pages**).

Bolan, S.; Hou, D.; Wang, L.; Hale, L.; Egamberdieva, D.; Tammeorg, P; Bolan, N., (2023). The potential of biochar as a microbial carrier for agricultural and environmental applications. Sci. Total Environ., 163968 (**12 pages**).

Blasi, A.; Verardi, A.; Lopresto, C.G.; Siciliano, S.; Sangiorgio, P., (2023). Lignocellulosic agricultural waste valorization to obtain valuable products: An overview. Recycling. 8(4): 61-69 (**9 pages**).

Campos, B.F.; Araújo, A.J.C.; Felsemburgh, C.A.; Vieira, T.A.; Lustosa, D.C., (2020). *Trichoderma* contributes to the germination and seedling development of açaí palm. Agriculture. 10(10): 456-468 (**13 pages**).

Cheng, Y.; Ang, B.; Xue, C.; Wang, Z.; Yin, L.; Wang, T.; He, Z., (2023). Insights into the fermentation potential of pollen: manufacturing, composition, health benefits, and applications in food production. Trends Food Sci. Technol., xx: 104245 (**16 pages**).

Cui, Y.; Zhang, Y.; Duan, C.; Wang, X.; Zhang, X.; Ju, W.; Fang, L., (2020). Ecoenzymatic stoichiometry reveals microbial phosphorus limitation decreases the nitrogen cycling potential of soils in semi-arid agricultural ecosystems. Soil Tillage Res., 197: 104463 **(14 pages).**

Daly, P.; Cai, F.; Kubicek, C.P.; Jiang, S.; Grujic, M.; Rahimi, M.J.; Druzhinina, I.S., (2021). From lignocellulose to plastics: Knowledge transfer on the degradation approaches by fungi. Biotechnol. Adv., 50: 107770 (**11 pages**).

Elsayed, A.M.; Mahmoud, M.; Abdel Karim, G.S.; Abdelraof, M.; Othman, A.M, (2023). Purification and biochemical characterization of two laccase isoenzymes isolated from *Trichoderma* harzianum S7113 and its application for bisphenol A degradation. Microbial. Cell Fact., 22(1): 1-10 **(11 pages).**

Hadimani, S.; Supriya, D.; Roopa, K.; Soujanya, S.K.; Rakshata, V.; Netravati, A.; Jogaiah, S., (2023). Biodegradable hybrid biopolymer film based on carboxy methyl cellulose and selenium nanoparticles with antifungal properties to enhance grapes shelf life. Int. J. Biol. Macromol., 237: 124076 **(14 pages).**

Ibrahim, L.A.; Shaghaleh, H.; El-Kassar, G.M.; Abu-Hashim, M.; Elsadek, E.A.; & Alhaj Hamoud, Y., (2023). Aquaponics: A Sustainable Path to Food Sovereignty and Enhanced Water Use Efficiency. Water. 15(24): 4310-4321 **(12 pages).**

Islam, M.R.; Kamal, M.M.; Kabir, M.R.; Hasan, M.M.; Haque, A.R.; Hasan, S.K., (2023). Phenolic compounds and antioxidants activity of banana peel extracts: Testing and optimization of enzyme-assisted conditions. Measurement: Food. 10: 100085 **(10 pages)**.

Iqbal, B.; Li, G., Alabbosh, K.F.; Hussain, H.; Khan, I.; Tariq, M.; Ahmad, N., (2023). Advancing environmental sustainability through microbial reprogramming in growth improvement, stress alleviation, and phytoremediation. Plant Stress. 100283 **(9 pages)**.

Jambhulkar, P.P.; Singh, B.; Raja, M.; Ismaiel, A.; Lakshman, D.K.; Tomar, M.; Sharma, P.; (2024). Genetic diversity and antagonistic properties of *Trichoderma* strains from the crop rhizospheres in southern Rajasthan, India. Sci. Rep., 14(1): 8610-8621 **(12 pages)**.

Kamyab, H.; Chelliapan, S.; Din, M.F.M.; Shahbazian-Yassar, R.; Rezania, S.; Khademi, T.; Azimi, M. (2017). Evaluation of Lemna minor and Chlamydomonas to treat palm oil mill effluent and fertilizer production. J. Water Process Eng., 17: 229-236 (**8 pages**).

Kamyab, H.; Friedler, F.; Klemes, J.J.; Chelliapan, S.; Rezania, S. (2018). Bioenergy production and nutrients removal by green microalgae with cultivation from agro-wastewater palm oil mill effluent (POME)-a review. Chem. Eng. Transactions. 70: 2197-2202 (**6 pages**).

Koesoemadinata, V.C.; Chou, K.; Baharin, N.S.K.; Yahya, W.J.; Yuzir, M.A.M.; Akhir, F.N.M.; Hara, H. (2021). The effectiveness of biological pretreatment of oil palm empty fruit bunch on its conversion into Bio-Coke. Bio. Technol. Reports. 15: 100765 (**15 pages**).

Kubeneck, S.; Bonatto, C.; Diering, N.L.; Camargo, A.F.; Dos Santos, L.H.; Warken, A.J.; Treichel, H., (2024). Evaluation of the Disposition Of Swine Hair Pre-treated with *Trichoderma* sp. Soil. Water, Air, Soil Pollut., 235(2): 1-12 **(13 pages)**.

Kubiak, A.; Pilarska, A.A.; Wolna-Maruwka, A.; Niewiadomska, A.; Panasiewicz, K., (2023). The Use of Fungi of the *Trichoderma* Genus in Anaerobic Digestion: A Review. Int. J. Mol. Sci., 24(24): 17576 **(10 pages).**

Kuthiala, T.; Thakur, K.; Sharma, D.; Singh, G.; Khatri, M.; Arya, S. K. (2022). The eco-friendly approach of cocktail enzyme in agricultural waste treatment: A comprehensive review. Int. J. Bio. Macro., 209: 1956-1974 (**19 pages**).

Leiva, S.; Oliva, M.; Hernández, E.; Chuquibala, B.; Rubio, K.; García, F.; Torres de la Cruz, M., (2020). Assessment of the potential of *Trichoderma* spp. strains native to Bagua (Amazonas, Peru) in the biocontrol of frosty pod rot (Moniliophthora roreri). Agronomy. 10(9): 1376-1388 **(13 pages).**

Li, R.; Li, X.; Tian, D.; Liu, X.; Wu, Z., (2023). Amino-functionalized MOF immobilized laccase for enhancing enzyme activity stability and degrading Congo red. J. Taiwan Institute Chem. Eng., 143: 104647 **(13 pages).**

Li, X.; Xiang, Z.; Dang, W.; Lin, Z.; Wang, H.; Wang, H.; Yao, R., (2024). High-yield and scalable cellulose nanomesh preparation via dilute acid vapor and enzymatic hydrolysis-mediated nanofabrication. Carbohydr. Polym., 323: 121370 **(11 Pages).**

López, A.C.; Giorgio, E.M.; Vereschuk, M.L.; Zapata, P.D.; Luna, M.F.; Alvarenga, A.E., (2023). Ilex paraguariensis Hosts Root-*Trichoderma* spp. with Plant-Growth-Promoting

Traits: Characterization as Biological Control Agents and Biofertilizers. Curr. Microbiol., 80(4): 120-132 **(13 pages).**

Matas-Baca, M.Á.; García, C.U.; Pérez-Álvarez, S.; Flores-Córdova, M.A.; Escobedo-Bonilla, C.M.; Magallanes-Tapia, M.A.; Chávez, E.S., (2022). Morphological and molecular characterization of a new autochthonous *Trichoderma* sp. isolate and its biocontrol efficacy against Alternaria sp. Saudi J. Biol. Sci., 29(4): 2620-2625 **(26 pages).**

Musa, H.; Kasim, F.H.; Gunny, A.A.N.; Gopinath, S.C., (2018). Salt-adapted moulds and yeasts: Potentials in industrial and environmental biotechnology. Process Biochem., 69: 33-44 **(12 pages).**

Nag, M.; Lahiri, D.; Ghosh, S.; Sarkar, T.; Pati, S.; Das, A.P.; Ray, R.R., (2024). Application of microorganisms in biotransformation and bioremediation of environmental contaminant: A review. Geomicrobiol. J., 41(4): 374-391 **(18 pages).**

Naher, L.; Fatin, S.N.; Sheikh, M.A.H.; Azeez, L.A.; Siddiquee, S.; Zain, N.M.; Karim, S.M.R., (2021). Cellulase enzyme production from filamentous fungi *Trichoderma* reesei and Aspergillus awamori in submerged fermentation with rice straw. J. Fungi. 7(10): 868-878 **(11 pages).**

Obada, D.O.; Kekung, M.O.; Levonyan, T.; Norval, G.W., (2023). Palm oil mill derived empty palm fruit bunches as a feed stock for renewable energy applications in Nigeria: A review. Bioresour. Technol. Rep., xx: 101666 **(16 pages)**.

Oktaviani, M.; Kamaluddin, N.N.; Simarmata, T. (2024). A Enhancing the Composting Process and Quality of Oil Palm Empty Fruit Bunches (EFB) Using Indigenous Cellulolytic Microbes: A Review. Int. J. Life Sci.Agri. R., 3(4): 274-283 (**10 pages**).

Organo, N.D.; Granada, S.M.J.M.; Pineda, H.G.S.; Sandro, J.M.; Nguyen, V.H.; Gummert, M., (2022). Assessing the potential of a *Trichoderma*-based compost activator to hasten the decomposition of incorporated rice straw. Sci. Rep., 12(1): 448-459 **(12 pages).**

Osman, S.; Ibrahim, Z.; Alias, A.H.; Wahab, N.A.; Ramli, R.; Hamid, F. A.; Ahmad, M., (2022). Basic properties of oil palm biomass (OPB). Oil Palm Biomass Compos. Panels: 39-56 **(18 pages).**

Peña-Lucio, E. M.; Chávez-González, M. L.; Londoño-Hernandez, L.; Ruiz, H. A.; Martínez-Hernandez, J. L.; Govea-Salas, M.; Aguilar, C. N., (2023). Solid-state fermentation of green tea residues as substrates for tannase production by Aspergillus niger TBG 28A: Optimization of the culture conditions. Fermentation. 9(9): 781-793 **(13 pages).**

Ramli, U.S.; Othman, A.; Tahir, N.I.M.; Lau, B.Y.C.;Shahwan, S.; Hassan, H.; Kushairi, A., (2020). Omics—A potential tool for oil palm improvement and productivity. Oil Palm Genome. 141-157 **(17 pages).**

Rather, L.J.; Mir, S.S.; Ganie, S.A.; Li, Q., (2023). Research progress, challenges, and perspectives in microbial pigment production for industrial applications-A review. Dyes Pigments. 210: 110989 **(12 pages)**.

Rodrigues, A.O.; May De Mio, L.L.; Soccol, C.R., (2023). *Trichoderma* as a powerful fungal disease control agent for a more sustainable and healthy agriculture: recent studies and molecular insights. Planta. 257(2): 31-43 **(13 pages)**.

Sakiah, S.; Sembiring, M. (2016). Effectiveness of Some Nitrogen Dose and Cellulolytic Microorganism (MOS) toward Decomposition Rate of Tan and Empty Aerobic Palm. Agrotech. J., 1(1): 33-36 (**4 pages**).

Salazar, B.; Ortiz, A.; Keswani, C.; Minkina, T.; Mandzhieva, S.; Pratap Singh, S.; Sansinenea, E., (2023). Bacillus spp. as bio-factories for antifungal secondary metabolites: Innovation beyond whole organism formulations. Microbial. Ecol., 86(1): 129-139 **(11 pages)**.

Saldaña-Mendoza, S.A.; Pacios-Michelena, S.; Palacios-Ponce, A.S.; Chávez-González, M.L.; Aguilar, C.N., (2023). *Trichoderma* as a biological control agent: mechanisms of action, benefits for crops and development of formulations. World J. Microbiol. Biotechnol., 39(10): 269-280 **(12 pages)**.

Sari, P.R. (2023, June). Cellulolytic Bacteria as Decomposers in Dry Empty Fruit Bunches Composting. IOP Conference Series: Earth Environ. Sci., 1188(1): 012002 (**8 pages**).

Schouten, G.; Padfield, R.; Kraamwinkel, D., (2023). Contested representations: A comparative analysis of palm oil sustainability in Malaysian and Dutch media. World Development Sustainability. 3: 100075 **(12 pages)**.

Senanayake, I.C.; Rathnayaka, A.R.; Marasinghe, D.S.; Calabon, M.S.; Gentekaki, E.; Lee, H. B.; Xiang, M.M., (2020). Morphological approaches in studying fungi: Collection, examination, isolation, sporulation and preservation. Mycosphere. 11(1): 2678-2754 **(77 pages)**.

Setiawati, M.R.; Suryatmana, P.; Hindersah, R.; Kamaluddin, N.; Efendi, S. (2019, December). The effectiveness of various compositions lignolytic and cellulolytic microbes in composting empty fruit bunch palm oil and sugar cane biomass. IOP Conference Series: Earth Environ. Sci., 393(1): 012032 (1**0 pages**).

Sharapova, I., (2023). The Study of Potentially Lignocellulolytic Actinobacteria Pseudonocardia sp. AI2. Indian J. Microbiol., 63(2): 190-196 **(7 pages)**.

Sofo, A.; Mininni, A.N.; Ricciuti, P., (2020). Soil macrofauna: A key factor for increasing soil fertility and promoting sustainable soil use in fruit orchard agrosystems. Agronomy. 10(4): 456-465 **(10 pages)**.

Srivastava, R.K.; Nedungadi, S.V.; Akhtar, N.; Sarangi, P.K.; Subudhi, S.; Shadangi, K.P.; Govarthanan, M., (2023). Effective hydrolysis for waste plant biomass impacts sustainable fuel and reduced air pollution generation: A comprehensive review. Sci. Total Environ., 859: 160260 **(12 pages)**.

Suhartini, S.; Rohma, N.A.; Hidayat, N.; Sunyoto, N.M.S.; Mardawati, E.; Mascruhin, N.; Melville, L., (2023). Comparison of acid and alkaline pre-treatment on methane production from empty palm oil fruit bunches (OPEFB): Effect on characteristics, digester performance, and correlation of kinetic paramet Renewable Energy. 215: 119009 **(10 pages)**.

Uke, A.; Sornyotha, S.; Baramee, S.; Tachaapaikoon, C.; Pason, P.; Waeonukul, R.; Kosugi, A., (2023). Genomic analysis of Paenibacillus macerans strain I6, which can effectively saccharify oil palm empty fruit bunches under nutrient-free conditions. J. Biosci. Bioeng., 136(1): 1-6 **(7 pages)**.

Wei, T.; Xu, Q.; Zou, C.; He, Z.; Tang, Y.; Gao, T.; Dai, Z., (2021). A boronate-modified renewable nanointerface for ultrasensitive electrochemical assay of cellulase activity. Chinese Chem. Lett., 32(4): 1470-1474 **(5 pages)**.

Woo, S.L.; Hermosa, R., Lorito, M.; Monte, E., (2023). *Trichoderma*: A multipurpose, plant-beneficial microorganism for eco-sustainable agriculture. Nat. Rev. Microbiol., 21(5): 312-326 **(15 pages)**.

Xu, Z.; Zhang, T.; Wang, S.; Wang, Z., (2020). Soil pH and C/N ratio determines spatial variations in soil microbial communities and enzymatic activities of the agricultural ecosystems in Northeast China: Jilin Province case. Appl. Soil Ecol., 155: 103629 **(15 pages)**.

Zhang, S.; Zhang, L.; Xu, G.; Li, F.; Li, X., (2022). A review on biodiesel production from microalgae: Influencing parameters and recent advanced technologies. Front. Microbiol., 13: 970028 **(13 pages)**.

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